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TEXAS COMMISSION ON ENVIRONMENTAL QUALITY
2008 APR -7 PM 2:22
CHIEF CLERKS OFFICE

April 7, 2008

ACGB 47311

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VIA HAND DELIVERY

Ms. LaDonna Castañuela
Office of the Chief Clerk/MC-105
Texas Commission on Environmental Quality
12100 Park 35 Circle, Building F
Austin, Texas 78753

Re: Request for Contested Case Hearing on Draft Permit for Major Amendment
TPDES Permit No. WQ0003675000
Peter Henry Schouten and Nova Darlene Schouten, dba P&L Dairy

Dear Ms. Castañuela:

The City of Waco ("City"), the mailing address of which is P.O. Box 2570, Waco, Texas 76702-2570, phone number (254) 750-5640, fax number (254) 750-5880, **hereby requests a contested case hearing** on the Executive Director's decision to approve the application of Peter Henry Schouten and Nova Darlene Schouten, dba P&L Dairy, for a major amendment of TPDES Permit No. WQ0003675000, the draft permit that the Executive Director has issued to P&L Dairy based on his decision, and the application that P&L Dairy has filed for this permit amendment.

This request for contested case hearing is made by the City on its own behalf and as *parens patriae* on behalf of its citizens. The person who is responsible for receiving all official communications and documents for the City relating to this request is its undersigned retained legal counsel, Jackson Battle, Brown McCarroll, L.L.P., Suite 1400, 111 Congress Avenue, Austin, Texas 78701, phone number (512) 479-9757, fax number (512) 479-1101.

THE CITY OF WACO IS AN "AFFECTED PERSON."

The City is a "person affected" by the Executive Director's decision, as the term is defined in Texas Water Code § 5.115(a), and is an "affected person," as determined applying the factors listed in 30 T.A.C. § 55.203(c). Although it is approximately 50 miles (approximately 85 river miles downstream) from the P&L Dairy, the City is very significantly and directly adversely affected by the pollutants discharged by this dairy that flow downstream to Lake Waco.

All adjudicated and permitted rights to the water impounded in Lake Waco are owned by the City for recreation, irrigation, water supply, and other municipal use. The City is authorized

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to divert 78,970 acre-feet per year for municipal use, including meeting the public drinking water needs of over 160,000 of its citizens and the citizens of other smaller municipalities in the area. Tens of thousands of its citizens fish, swim, ski, and engage in other water recreation in Lake Waco every year.

The North Bosque River terminates in Lake Waco; therefore, Lake Waco is a "sink" for any pollutants dissolved or entrained in the waters of the North Bosque River. As stated in the Affidavit by Bruce Wiland, P.E., that is attached hereto as Exhibit A and incorporated herein for all purposes:

- The North Bosque River contributes approximately 64% of the total flow to Lake Waco.
- The North Bosque River contributes, on average, 72% of the total phosphorus (TP) loading to Lake Waco and 44% of the total nitrogen (TN) loading.
- Dairy operations in the watershed of the North Bosque River contribute at least 30% of the TP load and 10% of the TN 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 and sometimes just a matter of hours.
- Such rainstorm events carry phosphorus and bacteria from reaches of the North Bosque River watershed as distant from Lake Waco as is the P&L 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 North Bosque River watershed.
- Discharges from municipal wastewater treatment facilities into the North Bosque River account for less than 10% of the TP and less than 4% of the TN loadings to Lake Waco.
- Because other sources of TP and TN are largely uncontrollable, control of loadings from dairy CAFOs in the North Bosque River watershed is necessary to reduce the loadings to Lake Waco to a point that overgrowth of blue-green algae can be reduced.
- Discharges from dairy CAFOs in the North Bosque River watershed are the primary cause of the low N:P ratio in Lake Waco that results in the large growths of blue-green algae that impairs the quality of Waco's water supply.

- It is not possible to remedy the impairment of water quality in Lake Waco without substantially reducing the runoff and other discharges of total phosphorus from dairy CAFOs in the North Bosque River watershed.

- Source tracking studies indicate that dairy CAFO operations in the North Bosque River watershed are a probable source of Enterococcus and e-coli, which can possibly be accompanied by cryptosporidium, giardia, and other pathogens, entering Lake Waco.

This expert opinion by Mr. Wiland is corroborated by many studies performed by the Texas Institute for Applied Environmental Research ("TIAER"), by EPA Region 6, by "White Paper" subcommittees focused on the North Bosque River watershed as an aid to the TCEQ in its revision of Subchapter B three years ago, and by ENSR, Inc., in its performance of a recent "Lake Waco Comprehensive Lake Management Study," copies of which are attached to Mr. Wiland's Affidavit and also incorporated herein. Indeed, the TCEQ itself has determined that "Excessive Algal Growth" and Nitrogen in Lake Waco are "concerns" and that "Agriculture, Intensive Animal Feeding Operations, and Confined Animal Feeding Operations Nonpoint Sources" are the sources of these two identified water quality concerns. *See* the 2002 and 2004 Water Quality Inventories – Sources of Pollution for Water Bodies with Water Quality Concerns (October 1, 2002, and May 13, 2005), attached hereto as Exhibits B and C respectively and incorporated herein for all purposes. Even the Third Court of Appeals has found: "The water quality of Lake Waco, which is a 'sink' for any dissolved pollutants in the North Bosque River, has been affected [by upstream dairy CAFOs]" *City of Waco v. TNRCC*, 83 S.W.3d 169, 172 (Tex. App. – Austin 2002, pet. denied).

As concluded by Mr. Wiland, after his review of the P&L Dairy draft permit, "Fact Sheet," application, public comments, and the Executive Director's Response to Comments, the wastewater discharges and runoff of pollutants from the P&L Dairy's waste application fields (including "third party fields") that will be authorized by amended Permit No. WQ0003675000 will contribute to the taste, odor, and public health problems identified in Lake Waco:

- If the problems with the draft permit and incorporated application for P&L 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 P&L Dairy and its authorized increase in herd size from 580 to 990 cows, in that the amounts of phosphorus and pathogens transported from P&L 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 P&L 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 P&L 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 anywhere from a matter of hours to a few days.

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 P&L 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 P&L Dairy. With no more effective waste management methods than are required by this permit and application, P&L's addition of 410 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.

The phosphorus-laden runoff from the LMUs and third-party fields, to which this permit would allow P&L Dairy'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 P&L. This problem is compounded by the fact that the draft permit prepared for P&L Dairy allows P&L 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.

The Affidavit of Richard B. Garrett, P.E., that is attached hereto as Exhibit D and incorporated herein for all purposes, explains the adverse and extremely costly effects that the runoff and discharges of pollutants from dairies such as P&L in the North Bosque watershed are having on the City, its drinking water, and its citizens' health and quality of life:

- Lake Waco is the sole source of supply of the public water system of the City of Waco, exclusive of emergency water connections. It is the only surface water source of drinking water that the City treats and distributes to its 113,000 citizens and to approximately 45,000 residents of several small neighboring municipalities.

- Runoff from dairy-related waste application fields at CAFOs is the primary contributor of soluble phosphorus into Lake Waco. The amount of soluble phosphorus is the controlling factor ("the limiting nutrient") for the high algal growths that occur in Lake Waco. Therefore, the single greatest cause of algae growth in Lake Waco is the runoff from the waste application fields at dairy CAFOs in the watershed of the North Bosque River.

- The *geosmin* that is a product of the decay of the blue-green algae that occurs in Lake Waco, primarily in warm weather, is the source of objectionable taste and odors in the City's drinking water. The means that the City has employed thus far to address the offensive taste and odor caused by the algae-derived geosmin is increased use of powdered activated carbon in its water treatment process. The expense for this activated carbon has been over $250,000 per year in recent years (not counting equipment, labor, and service costs).

- Many times recently the City has reached the threshhold for the amount of activated carbon that it can use for water treatment, but has been forced to go ahead and deliver offensive tasting and smelling water to its customers. Not only does this cause concern for the diminishment of the quality of the lives of the City's customers who must drink, cook with, and bathe in this water, it threatens the economic development of the City. Waco is the home to several major industries that place a premium on the quality of the water that they use: Masterfoods, Minute Maid, and Allergan, to name a few. If these industrial customers or other industries that evaluate Waco as a site for their plants become dissatisfied enough with the taste, odor, and other qualities of the water that the City provides them, they may well look elsewhere.

- With the City at, and beyond, the limits of its capacity to address the algae-caused problems in its water with activated carbon, it has been forced to plan and budget for the installation of other, much more expensive, treatment systems. It will cost approximately $50 million for the dissolved air flotation (DAF), ozone addition, and other treatment combinations required to cope with the taste and odor problems caused by the excess algae in the Lake. These and other expensive treatment systems also may be necessary to meet future requirements to address problems with microbes and disinfectant byproducts associated with the algae and animal waste loads conveyed to the Lake from CAFOs in the North Bosque River watershed.

- Even if dairy CAFO waste-associated pathogens do not enter the City's treated drinking water supply, their presence in Lake Waco jeopardizes the enjoyment of the many aquatic recreational activities in which Waco citizens engage there. The pathogens conveyed to Lake Waco from the dairy CAFOs in the North Bosque watershed endanger the health of the City's many citizens who swim, fish, sail, ski and engage in other water recreation in Lake Waco.

Mr. Wiland's and Mr. Garrett's Affidavits support the conclusion that, if the problems with the draft permit and incorporated application for P&L Dairy that are identified in Waco's public comment letter are not addressed to any greater extent than described in the Executive Director's Response to Comments, Lake Waco, the City's drinking water, the City's financial resources, and the health and welfare of its citizens will be adversely affected by the issuance of the proposed permit and by the runoff and other discharges of pollutants from P&L Dairy, in all of the many serious ways described herein.

THE CITY DISPUTES THE EXECUTIVE DIRECTOR'S RESPONSES TO COMMENTS.

The City here identifies each of the Executive Director's Responses to Comments that it disputes and the basis of the dispute.

In all instances, unless stated to the contrary, the ***legal basis of the dispute*** concerns the City's contention that the federal Clean Water Act section 301(b)(1)(C), 33 U.S.C. § 1311(b)(1)(C); United States EPA rules at 40 C.F.R. §§ 122.4(a) & (d) and 122.44(d), as incorporated into TCEQ rules by 30 T.A.C. §§ 305.538 and 305.531(4), prohibit a discharge permit such as this from being issued unless the permit assures attainment of state water quality standards and that, in this case, the permit drafted for P&L Dairy does not achieve the water quality standards for phosphorus in the North Bosque River. The Executive Director, however, seems to contend in each instance that, as a matter of law, the Clean Water Act and these federal and state rules do not require a TPDES permit to assure attainment of the state water quality standards. The Executive Director does not appear to contend that the permit proposed for the P&L Dairy *will* assure attainment of the state water quality standards for phosphorus, but he does seem to contend that the contested elements of the draft permit will contribute to eventual attainment of the water quality standards – a contention with which the City disagrees, and which the City contends does not meet the requirements of the law.

Another legal basis for each disputed issue, unless stated to the contrary in the listing of disputed Responses to Comments that follows, is the City's contention that the federal Clean Water Act § 303(d), 33 U.S.C. § 1313(d), and EPA rules at 40 C.F.R. §§ 130.7 and 122.44(d) require all discharge permits such as the one proposed for P&L Dairy to comply with any approved TMDL applicable to any water body segment into which the discharge is authorized. The Executive Director does not seem to disagree with this general statement of the law regarding the effect of TMDLs on TPDES permitting, but he does disagree with the City's assertion that each of the contested portions of P&L's draft permit (and incorporated parts of its application), unless noted to the contrary herein, fails to comply with the approved TMDL for phosphorus in the North Bosque River. These identified disputes regarding compliance with the TMDL involve two basic legal issues: (1) the proper interpretation of the TMDL and its effects and (2) whether the draft permit prepared for P&L complies with the proper interpretation of the TMDL.

In view of the Executive Director's disagreement with most of the City's comments, **the City hereby adopts and reiterates all of the comments that it made in its November 9, 2007**

Public Comment letter, a copy of which is attached hereto, for convenience, as Exhibit E. (It should be noted that the numbers that the Executive Director assigned to the City's comments in his Response to Public Comment have no relation to the numbering of the comments in the City's comment submittal.)

Individual Disputed Executive Director Responses.

Response 1

The Executive Director's response is that the expansion of P&L Dairy does not make it a "new source" under state and federal rules and that, therefore, 40 C.F.R. § 122.4(i) is inapplicable.

Legal basis of dispute:

The City stands by and reiterates the legal arguments that it made in part I.1 of its comments in support of its contention that P&L Dairy is a "new source," as defined in 40 C.F.R. § 122.2.

The Executive Director failed to respond to the City's argument that, because construction of all sources at the site commenced after the first promulgation of the new source standards for CAFOs on February 14, 1974, P&L has been a "new source" ever since the initial construction and operation of a dairy at the site in 1993 (except that the Executive Director asserts that P&L Dairy was first constructed in 1988, an assertion with which the City will not quarrel).

Moreover, the City disputes the Executive Director's interpretation of the definition at 40 C.F.R. § 122.2 and the criteria in 40 C.F.R. § 122.29(b). The expansion of the retention control structures ("RCSs") from 17.35 acre-feet to at least 27.24 acre-feet creates a "new source" as the term is defined and explained in the cited regulations.

Even if P&L Dairy were not otherwise a "new source," the 70% expansion of its herd, from 580 to 990 cows, should make it a new source under the criteria for new source determination in 40 C.F.R. § 122.29(b) and 30 T.A.C. § 305.534(b), in that the resulting increase of the pollutant load is generated by processes that are "substantially independent" of existing sources – that is, the 410 additional cows. By adding 410 new cows to the dairy, P&L will be increasing the amount of wet manure produced daily by over 30 tons (approximately 11,225 tons per year). Moreover, the expansions of the cow pens, milk barn, free stalls, and/or other animal confinement areas to accommodate the 410 additional cows constitute "new sources" as the term is defined and explained in 40 C.F.R. §§ 122.2, 122.29(a), (b) and 30 T.A.C. §§ 305.2(24), 305.534(a), (b).

Response 2

The Executive Director responds to the City's contention, in part I.1 of its comments, that there has been no demonstration that there are sufficient remaining load allocations for phosphorus in the North Bosque River to allow for discharges from the expansion of this dairy and that existing dischargers into this river segment have not been subject to compliance schedules, as required by 40 C.F.R. § 122.4(i), by asserting (1) that it is "probable" that the TMDL-I Plan submitted by TCEQ included authorized and *unauthorized* (**?!**) discharges from RCSs in the loadings that it attributed to "WAFs," and (2) that CAFO loadings "are not amenable to simple total daily allocations."

Legal basis of dispute:

The problem with these two responses is that they both conflict with the interpretation of the phosphorus TMDLs for the North Bosque River that EPA Region 6 Administrator Cooke plainly described in his 12/03/2001 letter to Executive Director Saitas and with which Mr. Saitas expressly concurred in his responsive letter of 12/7/2001 (included in Exhibit F attached hereto). Table 1 included with Mr. Cooke's 12/03/2001 TMDL approval letter expressly contains "simple total daily allocations," and Footnote 2 to this Table expressly states that those allocations do not include discharges from "manure/wastewater holding lagoons" – that is, RCSs. If the Executive Director wants to attempt to revise its TMDLs for phosphorus in the North Bosque River, he may attempt to do so. However, until he does, the TCEQ must live with the EPA's interpretation of those TMDLs with which it agreed in December 2001. The Executive Director has offered no response to the City's contention that all existing dischargers into segments 1226 and 1255 of the North Bosque River have to be subject to compliance schedules before a permit can be issued to P&L Dairy allowing its discharges. The City adopts and reiterates the legal arguments made in part I.1. of its 11/9/2007 Comment letter.

Given the Executive Director's response, no factual dispute exists regarding (1) whether pollutant load allocations have been performed for wastewater discharges from CAFOs into the North Bosque River (*They have not.*), and (2) whether there were sufficient remaining pollutant load allocations to allow for P&L Dairy's phosphorus discharges (*There were not.*). Although the Executive Director has not actually responded to the City's contention that all existing discharges into Segment 1226 have not been made subject to compliance schedules, the City infers that the Executive Director does not challenge the City's assertion and that, therefore, no factual dispute on this issue exists.

Response 3A

As part of the Executive Director's response to the City's contention that the draft permit fails to attain state water quality standards by complying with the TMDLs for Phosphorus in the North Bosque River (*see* part I.2.(a) of the City's 11/9/2007 Comment letter), the Executive Director contends that the TMDL does not limit the number of dairy cows in the watershed to 40,450.

Legal and factual bases of dispute:

This response is not accurate. *See Two Total Maximum Daily Loads for Phosphorus in the North Bosque River for Segments 1226 and 1255* ("TMDL" or "TMDLs"), pp. 11-12. The modeling used to develop the TMDL and demonstrate compliance with the water quality standards was based on a certain number of cows in the watershed and is, therefore, directly tied to the number of cows. If the number of cows increase, the amount of manure produced and the amount of manure land-applied will increase. This will in turn increase the amount of phosphorus in the runoff. Therefore, the 40,450 cows used in the modeling is a de facto limit on the number of cows in the watershed. The fact that RCSs will increase in size has no significance with respect to the number of cows. The sizing of the RCS is based on the area of contaminated runoff from dairy production area, not on the number of cows. In any case, the TMDL and the modeling did not make any allowance for RCS overflows.

If one needs further proof of the relevance of the number of cows, one only need look at the TMDL-e and TMDL-f modeling results in Figure 6 on page 56 of the TMDL Implementation Plan adopted December 2002. The index station "Above Meridian" was the one used to establish the target phosphorus goal and a 50% reduction in phosphorus concentration. This station is just downstream of all of the CAFOs. Under the TMDL-e scenario with 40,450 dairy cows and the BMPs implemented, the long-term annual average soluble P concentration is 54.5 ppb, and the long-term annual average soluble P loading is 10,479 kg. Under the TMDL-f scenario with 66,930 dairy cows and the BMPs implemented, the long-term annual average soluble P concentration is 87 ppb, and the long-term average soluble P loading is 13,362 kg. Since the entire TMDL is predicated on meeting the water quality goal and since the TMDL-e is the only scenario that comes close to meeting this goal, there is in fact an implicit limitation on the number of cows whether the TCEQ explicitly states it or not.

The Executive Director makes the argument that "the model used in the TMDL demonstrated that water quality conditions would improve significantly even with many more dairy cattle in the watershed if management practices were improved." While the Executive Director's assertion may be factually correct, it is a misleading argument. It is akin to saying that safety conditions in a school zone where the speed limit is 20 mph would improve significantly even with increased traffic if cars slowed down from 70 mph to 35 mph. It may be an improvement over an extremely bad situation but it doesn't make it acceptable or get you to where you need to be. If one again looks at Figure 6 on page 56 of the TMDL Implementation Plan, one will find the long-term annual average soluble P concentrations: TMDL-Existing = 117 ppb, TMDL-f = 87 ppb, and TMDL-e = 54.5 pbb [Note: the TMDL-existing plot in the lower left-hand corner is incorrect and the one in the upper left-hand corner must be used]. The TMDL-f scenario (the one with 66,930 cows) shows better conditions than existed in the mid-1990s with no BMPs but it is significantly worse that the TMDL-e scenario (the one with 40,450 cows) which is the basis for the TMDL Implementation Plan. It is puzzling how the Executive Director can expect to achieve the water quality goals with existing authorizations of 59,807 dairy cows and applications for an additional 11,531 dairy cows (a total of 71,338 dairy cows) when the modeling clearly indicates that the goal cannot be achieved with 66,930 cows. Even the TMDL-e with 40,450 cows does not meet the original "preliminary target" of 30 ppm at the "Above Meridian" index station or the 50% reduction from the predicted "Existing" scenario.

Response 3B

The Executive Director contends that the TMDL does not require removal of 50% of the solid manure produced by the dairy cows from the North Bosque River watershed. He recites the five management options provided by Texas Water Code § 26.503(b)(2) and the Subchapter B rules.

Legal and factual bases of dispute:

While the Texas Water Code and the Subchapter B rules provide these general manure management options, other TCEQ and EPA rules require CAFO discharge permits to assure attainment of the state water quality standards for phosphorus in the North Bosque River. *See* 30 T.A.C. § 321.36(b); 40 C.F.R. §§ 122.4, 122.44 (as incorporated into TCEQ rules by 30 T.A.C. §§ 305.531(4), 305.538).

The modeling conducted for the TMDL established the requirements necessary to meet water quality standards in the North Bosque River. One of these requirements is removal of 50% of the solid manure from the North Bosque watershed. If this requirement is not met, the model predicts that water quality standards cannot be met. Simply changing waste application from fields with high soil phosphorus (i.e., LMUs) to fields with lower soil phosphorus (i.e., third-party fields) does nothing to reduce the *loading* to the North Bosque River. Allowing third-party fields that provide little control over the nutrient application works as a disincentive for a dairy to transport waste to a compost facility or out of the watershed and, therefore, violates the requirement that permits assure compliance with the TMDL and attainment of the state water quality standards.

Response 3C

The Executive Director contends that the TMDL does not require that the amount of Phosphorus in the dairy cattle's diet be reduced to 0.4%. Again, he says that no TCEQ rule requires this.

Legal and factual bases of dispute:

Again the City cites the TCEQ to the overriding state and federal rules that require that permits assure attainment of water quality standards. 40 C.F.R. §§ 122.4, 122.44; 30 T.A.C. §§ 305.531(4), 305.538; 30 T.A.C. § 321.36(b).

Three BMPs were assumed in the modeling supporting the TMDL: (1) removing 50% of the solid manure from the watershed, (2) reducing phosphorus application rates on WAFs to one times the phosphorus crop requirement rate, and (3) reducing phosphorus diets for dairy cows to 0.4%. Since the Executive Director has not even addressed phosphorus diet reduction in the permit for P&L Dairy, it is incumbent upon him to demonstrate how this BMP modeled for attainment of the water quality standards for phosphorus in the River was effectively replaced by another BMP. This he has not done.

Response 3E

The Executive Director contends that the TMDL does not require that a dairy's phosphorus application rate not exceed the *crop requirement rate* for phosphorus, but only that the phosphorus application rate not exceed the agronomic rate recommended by NRCS Code 590.

Legal and factual bases of dispute:

The Executive Director is not requiring limitation of the phosphorus application rates to *one* times the phosphorus crop requirement, as modeled in the TMDL, but is instead requiring only that P&L Dairy's NMP be based on NRCS Code 590, which allows application rates at *two* times the phosphorus crop requirement until fields exceed 200 ppm Phosphorus. The City maintains that this is contrary to the TMDL and fails to assure attainment of water quality standards for phosphorus in the North Bosque River.

Response 4

The Executive Director responds that the TCEQ's CAFO rules allow the use of third party fields.

Factual basis of dispute:

The Executive Director's response is non-responsive to the City's comment. The Executive Director seems to think that the only rules that apply to this facility are the CAFO Subchapter B rules. While the CAFO Subchapter B rules may allow the use of third party fields, there are other rules that do not allow a permit to be issued if attainment of water quality standards cannot be met. As an example, 30 T.A.C. § 307.4(e) states that "nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use." Clearly, the North Bosque River is not attaining the water quality standards as evidenced by its inclusion on the 303(d) list. The modeling conducted for the TMDL established the requirements necessary to meet water quality standards related to phoshorus in the North Bosque River. One of these requirements is removal of 50% of the solid manure from the North Bosque watershed. If this requirement is not met, the model predicts that water quality standards cannot be met. Simply changing waste application from fields with high soil phosphorus (i.e., LMUs) to fields with lower soil phosphorus (i.e., third party fields) does nothing to reduce the *loading* to the North Bosque River because in most cases the relationship between soil test phosphorus and phosphorus concentrations in runoff is linear. While the concentration of phosphorus leaving a field in runoff may be lower in a third party field with low soil test phosphorus than one in an LMU with high soil test phosphorus, the mass loading in the runoff from the applied waste will be essentially the same in either case. The City re-states its comment that allowing third party fields that provide little control over the nutrient application will work as a disincentive for a dairy to transport waste to a compost facility or out of the watershed. The Executive Director has provided no response to this specific concern nor explained how third party fields would not discourage removal of 50% of the solid manure from the North Bosque watershed.

The Executive Director has further responded to the City's comment by claiming that the application to third party fields will allow beneficial use of the nutrients for crop production and that the crops will take the phosphorus from the soil, binding it such that it is not available for runoff, assuming it is harvested. There is, of course, no requirement for harvesting the third party fields to which the nutrients are applied. The Executive Director is well aware that when soil phosphorus levels are in excess of about 60 ppm (no matter what the crop or yield is as a practical matter), not all of the phosphorus will be taken up by the crops. The Executive Director is allowing over three times the amount of phosphorus which would be taken up by a crop to be applied to the field (up to 200 ppm). The Executive Director implies that the application of nutrients to third party fields from CAFO wastes would reduce nutrients because less inorganic fertilizer would be used and because inorganic fertilizer rates are unregulated. These are not sound arguments. First, the cost of inorganic fertilizer is significant. A farmer is not going to buy more phosphorus fertilizer than necessary. He simply will not apply phosphorus fertilizer if the soil phosphorus is higher than 60 ppm. Economics will regulate application of inorganic fertilizer far better than any permit requirement could. Secondly, it is not reasonable to expect that nutrient runoff would be reduced by putting out three times as much available nutrients in the form of CAFO wastes than would be put out in the form of inorganic fertilizer. Basic arithmetic reveals the contrary.

Response 5

The Executive Director disagrees with the City's comment and states that the TCEQ rules and provisions in the draft permit contains control actions and management measures to address the goals of the TMDL. The Executive Director claims an adaptive management approach is an appropriate means to achieve phosphorus reductions. The Executive Director further indicates that monitoring will provide for additional protection.

Factual basis of dispute:

The Executive Director has still not provided any technical justification that the measures in the draft permit will meet the water quality standards and actually attain the reductions in phosphorus loading set forth in the TMDL. Contrary to what the Executive Director says, the TMDL is directly tied to the number of animals in the watershed. All of the water quality modeling done for the TMDL was based on a certain number of animals being present in the watershed and the amount of manure produced by these animals. As stated previously, if the Executive Director believes that the number of animals along with BMPs different than those used in the TMDL modeling runs will be protective of the water quality, then the Executive Director should rerun the TMDL model with the increased number of animals and the revised BMPs and demonstrate that water quality standards will be attained. Furthermore, the stream monitoring for 2007 indicates that the average orthophosphorus concentrations at Valley Mills, Clifton, and Above Meridian are higher than at any time since 1997. This is not a surprising result when one considers that, according to the inspected cow numbers for 2007, there were 46,478 dairy cows, almost 15% over what was modeled in the TMDL-e scenario. The TMDL Implementation Plan was adopted in December 2002, over *six* years ago. There is absolutely nothing, other than the dairies' unwillingness to do so, that would have prevented the dairies from voluntarily implementing the TMDL BMPs during the last six years. The current Subchapter B rules became effective in July 2004, almost four years ago. With the exception of the requirement to expand RCS capacity, there is nothing that has stood in the way of implementing the new rules or enforcing them, other than the dairies' unwillingness to abide by them and the TCEQ's unwillingness to enforce them. Clearly, the TCEQ's adaptive management policy has failed. The only adaptations that have occurred are in finding new ways to avoid implementing the TMDL and Subchapter B rules.

Response 6

The Executive Director responds to the City's contention that he has failed to make any "BPJ" determination that the "BCT" standards for control of pathogens have been met by contending (1) that the management measures for controlling phosphorus loading will also have some corollary effect on reducing pathogen and bacteria loading, (2) that states are allowed to use BMPs to control or abate discharges "when numeric effluent limitations are infeasible," and that it is infeasible to develop and apply numeric limitations to discharges from CAFOs.

Legal basis of dispute:

The Executive Director's response on this issue is completely *unresponsive* to the City's argument. He has offered no argument whatsoever that any of the factors specified in 40 C.F.R. § 125.3(d)(2) or Clean Water Act § 304(b)(4)(B) have been considered. See part II of the City's 11/9/2007 Comment letter. Therefore, the legal issue seems to be whether these requirements in EPA's rules and the Clean Water Act can be ignored for the reasons offered by the Executive Director.

The Executive Director does not refute the City's contention that none of the factors specified in 40 C.F.R. § 125.3(d)(2) and Clean Water Act § 304(b)(4)(B) have been considered. Therefore, no relevant and material factual issue exists.

Response 7

The Executive Director contends that application to third party fields is optional and that the CAFO operator does not control the third party fields. The Executive Director further indicates that the draft permit for P&L Dairy includes an additional six acre-feet of storage in RCS #2 which is the excess of what can be applied under the current NMP.

The Executive Director seems to contend that, as a matter of law, all of the indicia of control of third party fields that the City describes in its Comment III do not add up to sufficient "control" of the third party fields to be utilized by P&L to make them "land management units" ("LMUs") within the definition at 30 T.A.C. § 321.32(25) and the EPA definition of "land application area" at 40 C.F.R. § 412.2(e).

Factual basis of dispute:

If application to third party fields is optional, how does the CAFO operator intend to abide by the other terms of its permit which require it to maintain sufficient volume in the RCS to contain the 25-yr 10-day rainfall event? This is not an optional requirement. The Executive Director has indicated that the draft permit includes an additional six-feet of storage in RCS #2 for storage of what is the excess of what can be applied under the current NMP (24% of the wastewater). The problem with this is that the current NMP is only for one year. As pointed out in the City's comments, after two years, 68% of the wastewater will have to go offsite, not 24%. The draft permit has not accounted for this in the additional storage requirements. Another 11 acre-feet in addition to the six acre-feet would be needed to store all of this wastewater. The Executive Director has not responded to how application of wastewater to third party fields would not be under the control of the Applicant when the Applicant is the one that controls the pumps needed to deliver the wastewater to third party fields.

Legal basis of dispute:

The legal issue that remains is whether all of the controls that P&L Dairy is required to exert over third party fields, as provided in Part VII.A.8(e)(5)(i) of its permit, means that those third party fields must be treated as LMUs under 30 T.A.C. § 321.32(25) and "land application areas" under 40 C.F.R. § 412.2(e). *See* part III of the City's 11/9/2007 Comment letter for full explanation of the City's position.

Response 8

The Executive Director contends that Comprehensive Nutrient Management Plans ("CNMPs"), Nutrient Utilization Plans ("NUPs"), Pollution Prevention Plans ("PPPs"), and Retention Control Structure ("RCS") management plans are not required by the Second Circuit's 2005 decision in *Waterkeeper Alliance v. EPA* to be submitted with the application, reviewed by the TCEQ, made available to the public, and incorporated into the permit.

Legal basis of dispute:

The City disagrees with the Executive Director's analysis of the law as expressed in the *Waterkeeper* decision, and its application to the CNMPs, NUPs, PPPs, and RCS management plans, for the reasons explained in part IV of its 11/9/2007 Comment letter. The City stands by and reiterates the position on this point that is expressed in its comment letter. (There is no disputed factual issue related to this point.)

Response 11

The Executive Director states that the stage/storage table is not a requirement because TCEQ is evaluating the proposed construction and that a stage/storage curve will be part of the RCS management plan.

Factual basis of dispute:

Under the Executive Director's interpretation of the rules, the RCS management plan will become part of the PPP which is not reviewable by the public, even after it has been prepared. Once the permit is issued, the City will have no way to comment as to whether the calculations for sizing the RCS are appropriate and correct. The fact that the RCS has not yet been constructed is irrelevant. Proposed preliminary construction plans can and should be prepared prior to permit issuance from which a stage/storage curve can be derived. Otherwise, there is no way to accurately calculate the surface area of the RCS for purposes of determining the direct precipitation volumes or the evaporation rates which are integral parts of the water balance.

Response 12

The Executive Director states that forty percent is considered an attainable removal rate for settling basins and that specifics will be developed and kept in the PPP.

Factual basis of dispute:

While forty percent removal may be attainable, there is no evidence that the applicant has designed the settling basin to achieve this optimistic removal rate. Once again, under the Executive Director's interpretation of the rules, this information will only become part of the PPP which is not reviewable by the public. Once the permit is issued, the City will have no way to comment as to whether the calculations for sizing the settling basins are appropriate and correct. Proposed preliminary construction plans can and should be prepared prior to permit issuance from which an evaluation can be made.

Response 13

The Executive Director states that the sludge accumulation rate is the best estimate currently available and states that treatment volume is only required for facilities with over 1,000 head and that this facility will only be permitted for 990.

Factual basis of dispute:

The City agrees that this facility is not *required* by the rules to have treatment volume in its RCS. However, as the City pointed out, the design sludge accumulation rate of 0.0729 cu ft/lb of wet manure solids is based on these wet solids entering an RCS *with* treatment volume. With treatment volume, solids can be significantly reduced due to decomposition by bacterial activity during treatment. Without treatment, this level of decomposition does not occur. Since, as the Executive Director has pointed out, this facility will *not* have a treatment volume, the 0.0729 value for the accumulation rate is much too low and inappropriate for this facility. It should be much higher when no treatment volume is present. If the applicant wishes to voluntarily add a treatment volume, then the use of this 0.0729 value would be appropriate.

Response 14

The Executive Director states that the methodologies for estimating sludge volume requirements are limited and that the method used by the Applicant is one of a very limited number of methodologies.

Factual basis of dispute:

Estimating the sludge accumulation from runoff to be 25% of the 25-year 10-day event is not a methodology. It is picking a number at random. There is no scientific basis for this number. If the Executive Director really wanted to develop an estimate of sludge accumulation with a scientific basis, the Executive Director would require annual measurement of sludge accumulation as recommended by the City. This is a very simple solution and much preferable to picking a random number with no scientific basis.

Response 15

The Executive Director states that the draft permit requires an RCS management plan which provides the proposed storage at each level and a pond marker which shows the maximum sludge accumulation level. The Executive Director further states that certification of the sludge volume is not required prior to year three of the permit.

Factual basis of dispute:

The City responds that the RCS management plan is just a plan. It is not reality. If the plan is not enforced, it has very little meaning. The Executive Director will not require any certification for three years and therefore cannot know how much sludge is currently in the RCS. The RCS can easily contain accumulated sludge in excess of the sludge capacity at the initial issuance of this permit. The Executive Director cannot possibly know without a certification of the sludge accumulation level. A pond marker showing the maximum sludge capacity is of little use, since under virtually all circumstances, the actual water level will be higher than the sludge level. There will be no way for an inspector to see the maximum sludge capacity level on the marker when this mark is underwater.

Response 17

The Executive Director states that TCEQ rules do not require Executive Director review or approval of the process an applicant will use to enlarge an RCS or its operational plans while the enlargement is taking place.

Factual basis of dispute:

The City responds that this is an abdication of the Executive Director's responsibility to protect water quality. The applicant has proposed construction that seems almost impossible without changing the assumptions that went into the water balance and NMP. The potential for environmental harm during the enlargement process is significant. Because of the potential impacts of this enlargement, special provisions should have been included in the permit to prevent adverse impacts. Although the City believes that preliminary construction plans and operational plans during enlargement should be part of the application, the Executive Director should at a minimum require these plans to be submitted to the TCEQ for approval within 30 days of permit issuance and prior to commencing construction.

Response 18

The Executive Director states that descriptions of structural controls will be maintained in the PPP and that this is not part of the permit application review process.

Factual basis of dispute:

The Executive Director's response does not address the City's comment that there is a failure to provide an adequate description of structural controls. The City believes a detailed description of the structural controls should be provided during the permit application process, not in a PPP that is unreviewable by the public. Structural controls such as berms are an integral part of the facility design that are necessary to prevent contaminated runoff from leaving the site. If these structural controls are not adequate and much of the runoff does not reach the RCS, it does not matter how large the RCS is.

Even if the PPPs are the sole repository for descriptions of structural controls, as the Executive Director contends, the requirement in the draft permit for these descriptions is entirely inadequate. The draft permit simply requires "the location and a description" with no details as to what the description should include. Based on PPPs that the City has seen, there is usually virtually no detailed description. The City restates its comment that structural controls should be described in sufficient detail with respect to location, size, and construction that TCEQ inspectors (who generally are not registered engineers) can determine if the berms are adequate and that the facility is in compliance.

The Executive Director failed to respond to the City's comment on certification of the structural controls by a licensed Texas professional engineer.

Response 19

The Executive Director states that the NRCS 590 Standard does account for nutrients available to plants through the soil test level component of the phosphorus index.

Factual basis of dispute:

This response does not address the City's comment. As the Executive Director is aware, while the phosphorus index does to a certain extent account for the nutrients in the soil, it does so only in the limited range of 0 to 60 ppm soil P. Above 60 ppm, there is no such accounting for the nutrients in the soil. Using the Phosphorus Index from Agronomy Tech Note TX-15 in conjunction with the Texas NRCS Code 590 Standard, for optimum growth, crops would require the addition of just as much phosphorus with 199 ppm soil P as with 60 ppm soil P. It is disingenuous at best to say that the standard does account for nutrients available to plants when there is no difference between application rates for soils with 60 ppm P and soils with 199 ppm P. In any case, the phosphorus index was only intended to provide an assessment of site vulnerability to P loss in surface runoff, not as a method to calculate the application rate needed to satisfy the agronomic needs of crops for optimum growth.

The Executive Director does not address the City's comment that the application rate should only allow application of nutrients that will benefit optimum crop production (i.e., beneficial reuse), as required by the rules.

Response 20

The Executive Director states that the representation made by the Applicant in Section 6.2 of the application is a goal. The Executive Director dismisses the comment that 100% of the waste will be going off-site by the end of the permit term because the applicant has five options for dealing with its waste.

Factual basis of dispute:

The representation made by the applicant in Section 6.2 of the application is not a goal but should be part of the permit. The Applicant has stated that it *will* limit maximum P levels in the soil to 200 ppm to be consistent with the TMDL. The Applicant has not indicated that this is a goal.

As a practical matter, the City does not believe that all of the five options for dealing with waste are available to the Applicant. The LMUs cannot accept all of the wastewater in the first year much less the following years even at maximum allowable rates. It is not economically feasible to haul wastewater out of the watershed. Landfills would not accept wastewater. Compost facilities would probably not accept wastewater. Finally, wastewater cannot be used on third party fields on a continual basis because of the very nature of wastewater collection and conveyance. The Executive Director must acknowledge that it is a virtual impossibility for large quantities of wastewater to be applied to third party fields without violating the requirements of section 321.42(j) which require that third party fields be areas of land not controlled or operated by the Applicant. The dairy operator must be in control of the wastewater pumping from its RCSs. The dairy operator must determine when to pump and what quantity to pump. Otherwise, the dairy operator could not comply with its RCS Management Plan or avoid serious problems during major rainfall events when third party field owners would be unlikely to need or want water. If the owner of the third party field determined when pumping were to occur and in what quantity, the dairy operator could not manage the RCS levels as required by the rules.

Response 21

The Executive Director states that the RCS management plan is not required to be reviewed by the TCEQ prior to issuance of the permit.

Factual basis of dispute:

The Executive Director's response is not responsive to the City's comments. Even though there may be no specific requirement in the rules to review the RCS management plan, it is a necessary requirement as a practical matter to determine if the RCS has been properly sized. It does not matter whether the RCS has been constructed or certified yet. Pre-construction design should be sufficient to create a preliminary RCS management plan to determine if the design is reasonable.

Even if the RCS management plan is not submitted prior to the permit being issued, the Executive Director has not addressed the City's comment that the RCS Management Plan should be submitted to the TCEQ permitting staff for review and approval. The City reiterates that, as a practical matter, there is not adequate time for inspectors in the field to properly evaluate the validity of RCS Management Plans and that it is unlikely that they have the proper engineering background and expertise to do so.

Response 24

The Executive Director states that RCS management plan is sufficient to account for sludge levels on a continuing basis and that the accumulated sludge volumes are not required as a part of the permit application.

Factual basis of dispute:

The City disagrees that the RCS management plan is sufficient. It is a plan for determining what volumes should be at each level. It has nothing to do with what is *actually* present now or in the future. Existing sludge accumulation can be far in excess of what is required to be maintained. Nevertheless, the Executive Director has missed the point of the City's comment. The capacity certification under permit provision VII.A.3(a)(2) does not make it clear as to whether it refers to total as-built capacity or whether it refers to available capacity above the sludge.

Response 25

The Executive Director states that the requirement in 30 T.A.C. § 321.38(g)(3)(A) is not a specific liner requirement.

Legal basis of dispute:

The City disagrees. 30 T.A.C. § 321.38(g)(3) specifically states that "RCSs must have a liner consistent with the requirements of this subsection." Within (A) of that subsection, the rules require that the documentation must include information on hydraulic conductivities of the natural material "underlying and forming the walls of the containment structure up to the wetted perimeter." This appears to be a pretty specific requirement to obtain samples from both the bottom and sides of the RCS.

Response 27

The Executive Director states that evaluation of structural controls by an engineer is not part of the permit application review process.

Factual basis of dispute:

A certification by a licensed Texas professional engineer should occur immediately upon issuance of the permit. Otherwise, a facility could operate for five full years without any assurance that the structural controls are adequate to prevent contaminated runoff from leaving the site.

Response 28

The Executive Director's response is that the sampling provisions are consistent with the current CAFO rules and NRCS Code 590.

Factual basis of dispute:

This does not address the issues raised in the City's comments. The rules are minimum requirements and do not preclude additional requirements if they are warranted based on available information. Additionally, the Executive Director did not address the comments made concerning the location of the sampling point.

The dairies have indicated time and again that they often remove accumulated sludge by agitating the RCSs and irrigating. Taking a sample from the surface of a quiescent RCS versus taking it from the irrigation pipeline after agitation of the RCS will result in significantly different sample concentrations. The latter is more realistic and should be employed. The Executive Director has provided no response indicating how one annual sample from a quiescent RCS could possibly be representative of the actual application rate of nutrients. Failure to take representative samples will result in a significant underestimation of the nutrient application rate.

Similarly, taking only annual samples from manure can result in significant errors in calculating the amount of nutrients applied to the land. Moisture content plays an important role in calculating the amount of nutrients applied. If the sample is not taken concurrently with the application of the manure, significant errors may exist when calculating the application rates. If the manure is sampled while having a high moisture content and then applied much later when it has a much lower moisture content, the calculated nutrient application rate will be significantly underestimated.

Response 29

The Executive Director states that land application to third party fields will be in accordance with the rules. The Executive Director once again states that the application to third party fields will allow beneficial use of the nutrients for crop production and that the crops will take the phosphorus from the soil, binding it such that it is not available for runoff.

Factual basis of dispute:

The Executive Director has once again failed to respond to the City's comment. The City asserts that over 90% of the phosphorus from this facility will be applied to third party fields throughout the watershed with less oversight than accorded the regulated LMUs. These fields will not have any nutrient management plans which might help prevent improper application of wastes. As pointed out in an earlier response, it is incomprehensible how nutrient runoff would be reduced by putting out three times as much nutrients as is needed by the crop. This excess nutrient would not be bound by the crops and would be available for runoff. The failure to plan for proper management will lead to further degradation of water quality in the North Bosque River.

Response 30

The Executive Director states that the TMDL for the North Bosque "recommends" removal of 50% of the collectible manure, but does not require it.

Legal basis of dispute:

First of all, the TMDL and the City's comment were based on removal of 50% of the solid manure, not 50% of the "collectible" manure. Secondly, if recommendations in the TMDL are not translated into requirements in permits, the predicted water quality improvements in the North Bosque River will simply not occur. The TCEQ must translate recommendations in the TMDL into permit requirements or the TMDL process is totally meaningless.

Response 31

The Executive Director's response is that the TMDL I-Plan allows application to fields in excess of 200 ppm if applied according to an approved NUP and is consistent with the CAFO rules.

Factual and legal bases of dispute:

The CAFO rules may allow this, and the Enforcement Program may have allowed this in the year 2000 (as indicated on p.39 of the TMDL I-Plan prior to adoption of the TMDL), but the fact remains that the 200 ppm phosphorus is over seven times the amount of phosphorus needed for optimum growth of the proposed crops (i.e., seven times the agronomic need). The rules require NUPs to ensure the beneficial use of manure, litter, or wastewater. The definition of "beneficial use" in the rules is the "application of manure, litter, or wastewater to land in a manner that does not exceed the agronomic need or rate for a cover crop." Applying waste to soil that contains seven times the agronomic need cannot possibly be considered beneficial. No application should be allowed on fields which contain phosphorus exceeding the agronomic needs of the crop, much less on fields which contain more than seven times the agronomic needs of the crop.

Response 35

The Executive Director's response is that the actual yield of each harvested crop will be recorded monthly and will be in the annual report submitted to the Executive Director.

Factual and legal bases of dispute:

Section VIII.B.7 of the draft permit states what must be submitted to the Executive Director in the annual report. Contrary to the Executive Director's assertion, none of the 10 specific items listed in Section VIII.B.7 of the permit require submittal of the actual crop yields. If the Executive Director is requiring this in the annual report, as the City believes is necessary and the Executive Director claims in its response is the case, then this requirement needs to be specifically listed.

Additionally, recording the crop and crop yield monthly does not allow the TCEQ to determine if the permit requirements are being met, except once a year when they might be examined in an annual inspection or in the annual report. These records should be required quarterly for third party fields in Section VII.A.8(e)(5)(iv).

Response 37

The Executive Director states that a five-year NMP would be impracticable and implies that a five-year NMP would not be flexible.

Factual and legal bases of dispute:

The City disagrees. A five-year NMP is a planning tool to determine if an operation can remain sustainable for the five years of the permit. It would not necessarily require application rates to remain the same if soil P concentrations or crops changed. The TCEQ is ignoring the issue of whether an operation has sufficient land to remain sustainable for the five years of the permit. The Texas State Soil & Water Conservation Board requires smaller AFOs to remain sustainable. There is no reason that the TCEQ should require a lesser standard of CAFOs.

EPA apparently does not agree with the Executive Director's position. EPA, in its proposed plan for NMPs under *Waterkeeper*, has proposed three approaches for developing NMPs: "All three approaches would require the CAFO operator to develop an NMP that projects for each field and for each year of permit coverage, the crops to be planted, crop rotation, crop nutrient needs, expected yield, and projected rates of application of manure, litter, and process wastewater." Note that EPA is proposing to require NMP projections for *each* year of the permit, not just the first year.

Response 40

The Executive Director states that bacteria applied to LMUs are limited by the BMPs that limit nutrient application.

Factual basis of dispute:

The Executive Director is unresponsive to the City's comment. Aside from the fact that the TCEQ is not requiring the BMPs for phosphorus recommended by the TMDL to be implemented as requirements in the permit, there has been no demonstration by the Executive Director that these phosphorus BMPs would have any effect on bacteria. It is simply speculation. The City has pointed out in its comments how the processes and transport mechanisms for phosphorus and bacteria differ. The Executive Director has not provided any indication that the TCEQ has even looked at the differences between the two.

THE CITY REITERATES ITS REQUEST FOR A CONTESTED CASE HEARING.

For all of the reasons stated herein, the City of Waco requests a contested case hearing on each of the disputed issues of fact identified herein and, therefore, requests a referral of the case to SOAH for hearing and proposal for decision on each of the identified factual issues, any other factual issues that arise in the course of the hearing, and on all applicable issues of law and policy.

The City appreciates the consideration that the Executive Director, the Public Interest Counsel, and the Commission will give to this request for a contested case hearing.

Respectfully submitted,

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By ______________________
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EXHIBITS

In Support Of

CITY OF WACO'S REQUEST FOR CONTESTED CASE HEARING

DRAFT PERMIT FOR MAJOR AMENDMENT
TPDES PERMIT NO. WQ0003675000
PETER HENRY SCHOUTEN, SR. AND
NOVA DARLENE SCHOUTEN, DBA P&L DAIRY

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ATTORNEYS FOR THE CITY OF WACO

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 the *Opinions Regarding Nutrient Loading to Lake Waco and Resulting Impacts*, prepared 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 hereto as Exhibit 7.

6. Based on my own professional experience, my review of the referenced studies and others performed by other experts, and my review of the Wagner Opinion, I have the following opinions:

- The North Bosque River contributes approximately 64% of the total flow to Lake Waco.
- The North Bosque River contributes, on average, 72% of the total phosphorus (TP) loading to Lake Waco and 44% of the total nitrogen (TN) loading.
- Dairy operations in the watershed of the North Bosque River contribute at least 30% of the TP load and 10% of the TN 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 and sometimes just a matter of hours.
- Such rainstorm events carry phosphorus and bacteria from reaches of the North Bosque River watershed as distant from Lake Waco as is the P&L 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 North Bosque River watershed.
- Discharges from municipal wastewater treatment facilities into the North Bosque River account for less than 10% of the TP and less than 4% of the TN loadings to Lake Waco.
- Because other sources of TP and TN are largely uncontrollable, control of loadings from dairy CAFOs in the North Bosque River watershed is necessary to reduce the loadings to Lake Waco to a point that overgrowth of blue-green algae can be reduced.
- Discharges from dairy CAFOs in the North Bosque River watershed are the primary cause of the low N:P ratio in Lake Waco that results in the large growths of blue-green algae that impairs the quality of Waco's water supply.

- It is not possible to remedy the impairment of water quality in Lake Waco without substantially reducing the runoff and other discharges of total phosphorus from dairy CAFOs in the North Bosque River watershed.

- Source tracking studies indicate that dairy CAFO operations in the North Bosque River watershed are a probable source of Enterococcus and e-coli, which can possibly be accompanied by cryptosporidium, giardia, and other pathogens, entering Lake Waco.

7. 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 six dairy permits have been issued to include provisions from the new rules. Another 44 dairy permits (42 expired permits and 2 misrepresented general permits) have yet to be drafted or 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.

8. I have reviewed the draft permit that the TCEQ Executive Director has prepared for P&L Dairy (TPDES Permit No. WQ0003675000), the Fact Sheet and Executive Director's Preliminary Decision accompanying the draft permit, and the entirety of P&L Dairy's application for a major amendment of its TPDES permit to authorize an expansion of its dairy herd and facility. I participated in preparing the "Public Comment" that the City of Waco submitted on the P&L 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 P&L Dairy.

9. 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 P&L 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 P&L 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 P&L Dairy and its authorized increase in herd size from 580 to 990 cows, in that the amounts of phosphorus and pathogens transported from P&L 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 P&L 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 P&L 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 anywhere from a matter of hours to a few days.

10. 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 P&L 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 P&L Dairy. With no more effective waste management methods than are required by this permit and application, P&L's addition of 410 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.

11. As described in Dr. Wagner's study, the phosphorus-laden runoff from the LMUs and third-party fields, to which this permit would allow P&L Dairy'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 P&L. This problem is compounded by the fact that the draft permit prepared for P&L Dairy allows P&L 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.

12. 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 P&L 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.

13. 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 P&L Dairy is simply misinformed and wrong.

Further, Affiant sayeth not.

Bruce L. Wiland

Bruce L. Wiland, P.E.

SUBSCRIBED AND SWORN to before me by the said Bruce L. Wiland, P.E., on this the 4th day of April 2008, to certify which witness my hand and seal of office.

NOTARY PUBLIC STATE OF TEXAS
DOROTHY ROEBER
Notary Public, State of Texas
My Commission Expires
JAN. 25, 2009

Dorothy Roeber

Notary Public in and for the
State of Texas

4085210.1
30419.2

BRUCE L. WILAND, P.E.

Education

Master of Science in Environmental Health Engineering; The University of Texas at Austin, Austin, Texas; December, 1975.

Bachelor of Engineering Science with Highest Honors; The University of Texas at Austin, Austin, Texas; January, 1974.

Continuing Education

Nutrient Management Short Course, Texas Cooperative Extension/Natural Resources Conservation Service, College Station, Texas, October, 2005.

Design Criteria for Sewerage Systems, Central Texas Section of the Water Environment Association of Texas in cooperation with TNRCC, Austin, Texas, March, 2000.

Innovations and New Horizons in Livestock and Poultry Manure Management; Texas Agricultural Extension Service, Austin, Texas, September, 1995.

Urban Storm Water Quality Management; American Society of Civil Engineers, Austin, Texas; May, 1991.

Industrial Wastewater Pretreatment Short Course; The University of Toledo, San Antonio, Texas; September, 1989.

USCE-EPA CAPDET Workshop; USAE Waterways Experiment Station, Dallas, Texas; June, 1978.

Water Quality Management Short Course; Vanderbilt University, Nashville, Tennessee; June, 1978.

Institute of Mathematical Modeling of Natural Water Systems; Manhattan College, New York, New York; May 1977.

Experience

President, Wiland Consulting, Inc., Austin, Texas; October, 1991 - present.

Division Director/Chief Engineer; Jones and Neuse, Inc., Austin, Texas; September, 1988 - October, 1991.

Project Manager/Project Engineer; Jones and Neuse, Inc., Austin, Texas; February, 1986 - October, 1988.

Engineer/Hydrologist/Engineering Technician; Texas Water Commission/Texas Department of Water Resources/Texas Water Quality Board, Austin, Texas; September, 1976 - February, 1986.

Associate Research Scientist; Environmental Health Engineering Department, The University of Texas at Austin; April, 1975- August, 1976.

Registration

Licensed Professional Engineer, State of Texas; No. 45700.
Licensed Professional Engineer, State of Louisiana; No. 31981.
Certified Texas Nutrient Management Specialist, TCE/USDA/NRCS; No. TX20167
Passed Principles and Practices Examination; April, 1978.
Passed Engineer-in-Training Examination; November, 1973.

Affiliations

Water Environment Federation
Water Environment Association of Texas, Past President of the Central Texas Section
American Society of Civil Engineers
American Society of Agricultural and Biological Engineers

Honors

Tau Beta Pi, National Engineering Honor Society

Detailed Experience Record

As an Independent Consultant. Mr. Wiland conducts engineering and environmental studies and evaluations for water quality. air quality, and hazardous and solid waste projects. Projects have included the following:

- Development of the water quality model LA-QUAL for the Louisiana Department of Environmental Quality.

- Technical assistance to the City of Waco in evaluating the potential water quality impacts from confined animal feeding operations in the Lake Waco watershed (Erath County, Hamilton County, Bosque County) including soil sampling and evaluation of hydrology and nutrient management plans.

- Technical assistance in evaluating the potential water quality impacts from proposed permits for land disposal of municipal biosolids and industrial wastewater (Colorado County, Wharton County, Moore County) including evaluation of the nutrient management plans and expert witness testimony.

- Evaluation of potential air and water quality impacts from numerous dairies, feedlot operations, swine facilities, and other confined animal feeding operations in Erath County, the Texas Panhandle, and other counties in Texas. Preparation of affidavits and expert witness testimony in State permit hearings.

- Preparation of industrial permit applications and permit application assistance for various industries including several power plants, a reverse osmosis system for the City of Electra, and a hazardous waste incinerator operated by Rollins Environmental

- Dissolved oxygen modeling of various water bodies and evaluation of wastewater discharges including the following:
  Arroyo Colorado canal system (Pelican Pointe Development).
  Bear Creek (Hays County WCID #1)
  Blanco River
  Cowleech Fork of Lake Tawokoni (Cobisa)
  Eckert Bayou (Galveston County MUD #1)
  Hackberry Creek/Aquilla Reservoir (City of Hillsboro)
  Lake Conroe (Far Hills UD)
  Lake Conroe (UA Holdings)
  Lake Conroe (Point Aquarius MUD)
  Little Cleveland Creek (City of Jacksboro WWTP)
  Nueces Bay (Valero)
  Padera Lake/Newton Branch (City of Midlothian)
  Rio Grande (City of Brownsville)
  San Marcos River (City of San Marcos)
  South San Gabriel River (private developer)
  Still Creek/Thompson Creek (City of Bryan)
  Taylor Bayou (Motiva)
  Texas Ship Channel tributary (Marathon Oil)

- Temperature modeling of a tributary to the Calcasieu River in Louisiana to determine impacts of a low temperature discharge (Trunkline LNG) and of the Comal River to determine the effects of reduced flows from Comal Springs (City of San Antonio).

- Preparation and implementation of water quality surveys and hydraulic/dye studies to determine impacts from wastewater discharges including the following:
  Bear Creek (Hays County WCID #1)
  Little Cleveland Creek (City of Jacksboro WWTP)
  Nine Mile Creek (City of Mineola WWTP)
  Post Oak Creek/Choctaw Creek (City of Sherman)
  Rio Grande (City of Brownsville)
  San Marcos River (City of San Marcos WWTP).
  Still Creek and Thompson Creek (City of Bryan WWTP)
  Texas Ship Channel tributary (Marathon Oil)

- Evaluation of discharge alternatives for proposed power plants in Panola County, Henderson County, Upshur County, and Johnson County.

- Investigation, sampling, and evaluation of various wastewater/permit issues including raw sewage discharge from a lift station upstream of a horse breeding operation in Bowie County (included expert witness testimony in State District Court), contaminated wastewater from a sewer line that was part of the wastewater system at an abandoned Air Force Base in Maverick County, and a City of Sherman wastewater discharge to Post Oak Creek.

- Preparation of comments to the TNRCC on proposed composting regulations. Evaluation of various proposed composting facilities (Tarrant County, Travis County).

- Outfall diffuser design and modeling using Cormix.

- Evaluation of air emissions from a proposed cement batch plant and expert witness testimony in a TNRCC permit hearing.

- Evaluation of a 9.7 MGD industrial wastewater discharge to Lavaca Bay. The work included review of the water quality impacts, wastewater treatment system design, and compliance with State and Federal water quality standards and effluent limitations. Expert witness testimony was provided in a TWC permit hearing.

- Preliminary engineering design of a lift station and force main to serve a maintenance facility at a county club.

- Evaluation of a proposed wastewater permits and permit renewals to determine adherence with normal permitting procedures and water quality standards including the Longhorn Army Depot on Caddo Lake, a uranium mill reclamation site, and limestone quarries (Limestone County, Burnet County) .

- Evaluation of the City of Austin's South Austin Outfall (Phase II) Project to determine if feasible alternatives existed. The work included review of existing wastewater lines and lift stations, existing and projected wastewater flows, and the proposed 48-inch wastewater line including a three-barrel siphon under Barton Creek. The work was performed for the Save Barton Creek Association and included deposition testimony.

- Participation as the quality control/quality assurance officer in a trial burn at a cement kiln incinerating hazardous wastes. The trial burn for Texas Industries, Inc. (TXI) was required as part of the new boiler and industrial furnace (BIF) permitting regulations.

As Division Director of the Water Quality and Environmental Impacts Division for Jones and Neuse, Inc. (JN), Mr. Wiland directed a staff of engineers and biologists responsible for water quality projects, environmental site assessments, environmental audits, evaluation of regulatory impacts, and preliminary engineering assistance in industrial wastewater design. Mr. Wiland was also Director of the Air and Water Quality Division during the initial development of JN's air program. Due to the success of this program, a separate Air Quality Division was eventually created. Specific projects and areas of responsibility and engineering application included the following:

- Development of procedures, execution, and review of environmental site assessments and audits for over 100 sites and facilities in numerous states, Mexico, and Central America. Investigations involved solid and hazardous waste, water quality, and air quality issues. Types of properties and facilities including office buildings, apartments, hospitals, oil field service facilities, pipeline terminals, refineries, electroplaters, manufacturing facilities, iron and steel smelters, and numerous other industrial properties.

- Preparation of environmental impact documents involving issues related to air quality, water quality, solid and hazardous waste, and other natural resources (wetlands and endangered species). Clients included AES Corporation, American General Insurance Corporation, and the Port of Corpus Christi.

- Review of Federal and State environmental regulations and preparation of recommendations to various industrial clients with particular attention to the RCRA toxicity characteristic, RCRA primary sludge issues, SARA Title III requirements, and the State of Texas Water Quality Standards. Clients included Fina Oil and Chemical, La Gloria Oil and Gas, Mobil Oil, and Texaco.

- Wastewater system evaluations of industrial treatment facilities for Fina Oil and Chemical, Alcoa, and RTF Industries. Types of facilities have included electroplaters, petroleum refiners, and chemical manufacturers.

- Performance of industrial wastewater treatability studies for Alcoa in Point Comfort, Texas.

- Preliminary engineering and design of wastewater collection and treatment facilities for several petroleum refineries, including Fina Oil and Chemical Company in Big Spring, Texas, Howell Hydrocarbon in San Antonio, Texas, and Trifinery in Corpus Christi, Texas. Processes have included caustic and acid neutralization, oil/water separation, and biological treatment.

- Development of procedures and review of dye dispersion studies for Alcoa, Koppers Industries, Empak, Inc., Champion International Corporation, and Gulf Coast Waste Disposal Authority.

- Development of NPDES stormwater permitting strategies for Pride Refining, Quantum Chemical, and Central Tractor.

- Preparation of NPDES and TWC industrial wastewater permit applications and supporting information for industries, including Carrier Corporation, Alcoa, Tex-Trac, Inc., Hoechst-Celanese, Fina Oil and Chemical Company, and Howell Hydrocarbon. Types of facilities have included refineries, bulk handling terminals, and manufacturing plants.

- Preparation of NPDES and TWC municipal wastewater permit applications, technical representation before the TWC, and expert witness testimony at public hearings for several cities and private developers.

- Development of procedures and review of benzene NESHAP studies for Fina Oil and Chemical Company, Shell Oil Company, and Howell Hydrocarbons.

- Preparation of TACB air permit applications and supporting technical information for industries including Tex-Trac, Inc., Kenaf International, H. B. Zachary, Great Lakes Carbon, and Fina Oil and Chemical Company. Types of facilities have included bulk handling terminals, petroleum coke storage facilities, asphalt plants, kilns, cogeneration units, landfills, and wastewater treatment units.

- Preparation of responses to TACB Notices of Violation (NOVs) and assistance in enforcement negotiations.

- Evaluation of computer programs and mathematical models used to predict water quality for the Lower Colorado River Authority.

- Development of permit applications for water appropriation, including irrigation and off-channel reservoirs for the City of Robinson, Texas.

- Water and wastewater rate studies and evaluations, including expert witness testimony for the City of Mission, City of Copperas Cove, Williamson County MUD #3, and Hidalgo County Irrigation District #7.

In addition to his duties as Division Director, Mr. Wiland served as Chief Engineer for Jones and Neuse, Inc. In this position, Mr. Wiland was responsible for non-project related administrative and technical duties including the following:

- Preparation and presentation of technical seminars on such subjects as environmental site assessments, the RCRA Toxicity Characteristic rule, the RCRA primary sludge rule for refineries, the benzene NESHAP rule, and the NPDES industrial stormwater regulations.

- Development of JN's professional services agreement and contract procedures and review of all contracts.

- Development of JN's project accounting and billing system.

- Development of standard proposal procedures/formats and preparation of major project proposals.

As an Engineer for the Texas Water Commission and predecessor agencies, Mr. Wiland was responsible for performing work in water resource analysis and mathematical modeling of water quality. His responsibilities included the following:

- Analysis of existing water quality data, design and execution of water quality surveys, and assessment of the impact of wastewater discharges upon the receiving waters.

- Design, development, and modification of various computer programs used to predict the water quality of natural and man-made systems including the steady-state stream model, QUAL-TX, used by the State of Texas to evaluate all discharge permits and determine all wasteload allocations.

- Development of a detailed methodology manual describing data requirements and modeling techniques for the evaluation and performance of wasteload allocations.

- Performance of wasteload evaluations and AST/AWT justifications including performance of economic analyses and cost-benefit justifications.

- Review of wasteload evaluations performed by the Modeling Unit for technical accuracy and consistency.

- Review and evaluation of the technical aspects of the Houston Ship Channel instream aeration studies and nonpoint source studies.

- Participation in a major hydrodynamic study of Laguna Madre involving measurement of currents and tidal dispersion.

- Participation as representative to the TDWR Executive Review Committee, which entailed reviewing and evaluating all injection well, solid waste, municipal and industrial discharge permits to be certain they were in compliance with wasteload evaluations and would not seriously degrade water quality in the receiving water.

- Coordination between the Construction Grants and Water Quality Management Division and the Permits Division to ensure consistency between grant projects and discharge permits. Participation as a member of the Innovative Alternative Technology Ad Hoc Support Group to resolve issues pertaining to specific Construction Grants projects proposed for funding as IA technology.

- Performance of wasteload evaluations including data collection and computer modeling for the Houston Ship Channel, West Fork San Jacinto River, Spring Creek, Cypress Creek, Clear Creek, and the San Jacinto River Tidal.

- Development of a methodology and nomograph for evaluating discharges into undesignated stream segments and tributaries.

- Assistance in the development of the water quality ranking system for the State of Texas.

- Design of water quality surveys and evaluation of results to determine the necessity of nutrient limitations in the Clear Lake watershed to prevent eutrophication.

- Administration of a contract for the development of an apparatus and methodology to measure benthal demand in stream sediments.

- Development of steady-state and stormwater models for the State's "208" Designated and Non-Designated Area Planning activities as required by PL 92-500.

- Analysis of hydrologic data and performance of a comprehensive hydraulic balance on the Edwards Aquifer to support water quality regulations over the Edwards Aquifer.

- Review of the EPA policy on land application and determination of its effects on Texas

While employed as an Associate Research Scientist for the Environmental Health Engineering Department at The University of Texas, Mr. Wiland conducted laboratory analyses and evaluations including the following:

- Determination of quantities of certain contaminants in stormwater runoff from highways using analytical techniques of infrared spectrophotometry and atomic absorption, and assessment of the impact of highway stormwater runoff on the environment.

- Characterization of various wastewaters for typical pollution parameters, such as COD, BOD, TOC, suspended solids, TKN, phosphates, TDS, and MPN.

- Performance of wastewater treatability studies for Texas Eastman and Kerr-McGee utilizing bench-scale biological treatment processes, including oxidation ponds, activated sludge, aerated lagoons, and anaerobic columns and physical-chemical processes such as lime coagulation, carbon absorption, and ozonation.

Existing Nutrient Sources and Contributions to the Bosque River Watershed

Anne McFarland and Larry Hauck

TARLETON STATE UNIVERSITY

TEXAS INSTITUTE FOR APPLIED ENVIRONMENTAL RESEARCH

TIAER
PR 9911

EXISTING NUTRIENT SOURCES AND CONTRIBUTIONS TO THE BOSQUE RIVER WATERSHED

Anne McFarland and Larry Hauck

September 1999

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Over about a two and a half-year period (November 1, 1995 – March 30, 1998), flow and nutrients were monitored consistently at 17 sites in the Bosque River watershed. Drainage areas above sampling sites differed in the percent of dairy waste application fields, row crop (corn, grain sorghum, soybeans and cotton), non-row crop (forage sorghum and winter wheat), improved pasture (primarily coastal bermudagrass fields), wood/range, and urban land area. A statistical approach was used to develop nutrient export coefficients of orthophosphate-phosphorus (PO_4-P), total phosphorus (TP), and total nitrogen (TN) for the major land uses in these mixed land-use drainage areas. Nutrient export coefficients represent the amount of nonpoint source loading associated with a given land use per unit area for a specified length of time, such as pounds TP per acre per year. Of the major land uses in the Bosque River watershed, the largest export coefficients for PO_4-P and TP were associated with dairy waste application fields (3.08 lbs PO_4-P/acre/yr and 5.81 lbs TP/arce/yr) followed by urban (0.98 lbs PO_4-P/acre/yr and 2.73 lbs TP/acre/yr), pasture/cropland (0.14 lbs PO_4-P/acre/yr and 0.70 lbs TP/acre/yr), then wood/range (0.07 lbs PO_4-P/acre/yr and 0.31 lbs TP/acre/yr). The largest TN export coefficients were associated with row-crop areas (19.0 lbs TN/acre/yr) followed by dairy waste application fields (12.3 lbs TN/acre/yr), urban (11.5 lbs TN/acre/yr), pasture/non-row crop fields (7.2 lbs TN/acre/yr) then wood/range (2.2 lbs TN/acre/yr).

An empirical model was developed to assess nutrient contribution by source using the developed export coefficients for nonpoint sources and information from the eight permitted municipal wastewater treatment plants within the watershed for point source loadings. This model was verified by comparing estimated loadings to measured loadings at four stream sites located along the North Bosque River. These four sites were not included in the development of the land-use nutrient export coefficients to allow an independent verification of the model. Monte Carlo sampling techniques were applied to the variance associated with the derived nutrient export coefficients to provide an uncertainty analysis for nutrient loads by source for the Bosque River watershed and for selected points within the watershed.

The largest loadings of PO_4-P and TP contributing to the Bosque River watershed were from dairy waste application fields and wood/rangeland, while the largest loadings of TN were associated with row-crop fields. Dairy waste application fields comprise about 2 percent of the total watershed area and were associated with 35 $\pm$ 4 percent PO_4-P, 21 $\pm$ 3 percent TP and 5 $\pm$ 2 percent TN loadings to the watershed. Wood/range comprise 63 percent of the watershed area and were associated with 22 $\pm$ 5 percent PO_4-P, 31 $\pm$ 6 percent TP and 22 $\pm$ 12 percent TN loadings to the watershed. Row-crop agriculture is associated with 15 percent of the watershed drainage area and was associated with 11 $\pm$ 1 percent PO_4-P, 17 $\pm$ 2 percent TP and 49 $\pm$ 10 percent TN loadings. Most dairy waste application fields in the watershed are found in the upper portion of the North Bosque River subwatershed, while most row-crop fields are found in the southern portion of the Bosque River watershed within the Hog Creek, Middle Bosque and South Bosque River subwatersheds. The derived nutrient export coefficients and, thus, the source-contribution model results are specific to the time period November 1, 1995 through March 30, 1998 and care should be taken in extrapolating these results to other timeframes or watersheds.

ACKNOWLEDGMENTS

Funding sources for this study include the United States Department of Agriculture - Natural Resources Conservation Service, the Clean Rivers Program of the Texas Natural Resource Conservation Commission, the United States Environmental Protection Agency and the State of Texas. The authors acknowledge the support of landowners that allowed access to their property for in-stream monitoring. Without the willing cooperation of these individuals, this study would not have been possible. The authors would also like to acknowledge the dedicated work of the many field personnel and laboratory chemists involved with the monitoring program, particularly since rain often falls on weekends requiring staff to be on call seven days a week.

Mention of trade names or equipment manufacturers does not represent endorsement of these products or manufacturers by TIAER.

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INTRODUCTION

The Bosque River watershed of north-central Texas is defined by the drainage area to Lake Waco (Figure 1). This drainage area includes the North Bosque River, Hog Creek, Middle Bosque River, and South Bosque River as major tributaries to Lake Waco as well as a few minor tributaries representing small drainage areas near the reservoir.

The City of Waco constructed Lake Waco in 1929 as a municipal water supply. The reservoir was enlarged to its present size in 1964 by the U.S. Army Corps of Engineers for flood control, conservation storage, and recreation. Lake Waco is formed by a rolled earthfill dam and provides the public water supply for Waco and surrounding communities with a service population of approximately 140,000. The Brazos River Authority and the City of Waco jointly hold the rights to water in the conservation storage of the reservoir, which was built to contain about 152,00 acre-feet of water at the spillway elevation (Wyrick, 1978). Lake Waco has a surface area of about 7,270 acres and a normal pool elevation of about 455 feet (TNRCC, 1996). The designated uses for Lake Waco (segment 1225) are contact recreation, high aquatic life and public water supply with agricultural operations thought to be the major contributors of nonpoint source pollution in the reservoir watershed (TNRCC, 1996).

Point and nonpoint sources contribute nutrient loadings to the Bosque River watershed. In general terms, point sources represent nutrients that can be traced to a single point of discharge, such as a pipe or culvert, while nonpoint sources represent nutrients that cannot be traced to a specific point. There are eight permitted wastewater treatment plants (WWTPs) representing permitted point source discharges within the Bosque River watershed (Table 1). Of the eight WWTPs in the Bosque River watershed, only Stephenville and McGregor require advanced wastewater treatment for the attainment of stream standards (TNRCC, 1996). The Brazos River Authority and Texas Institute for Applied Environmental Research (TIAER) have collected grab samples of the effluent from all eight WWTP since January 1996 on a monthly or bi-weekly basis. Combined with the monthly discharge information reported to the TNRCC by each WWTP this nutrient data can be used to estimate nutrient loadings from the point sources within the Bosque River watershed.

Figure 1. Bosque River watershed.

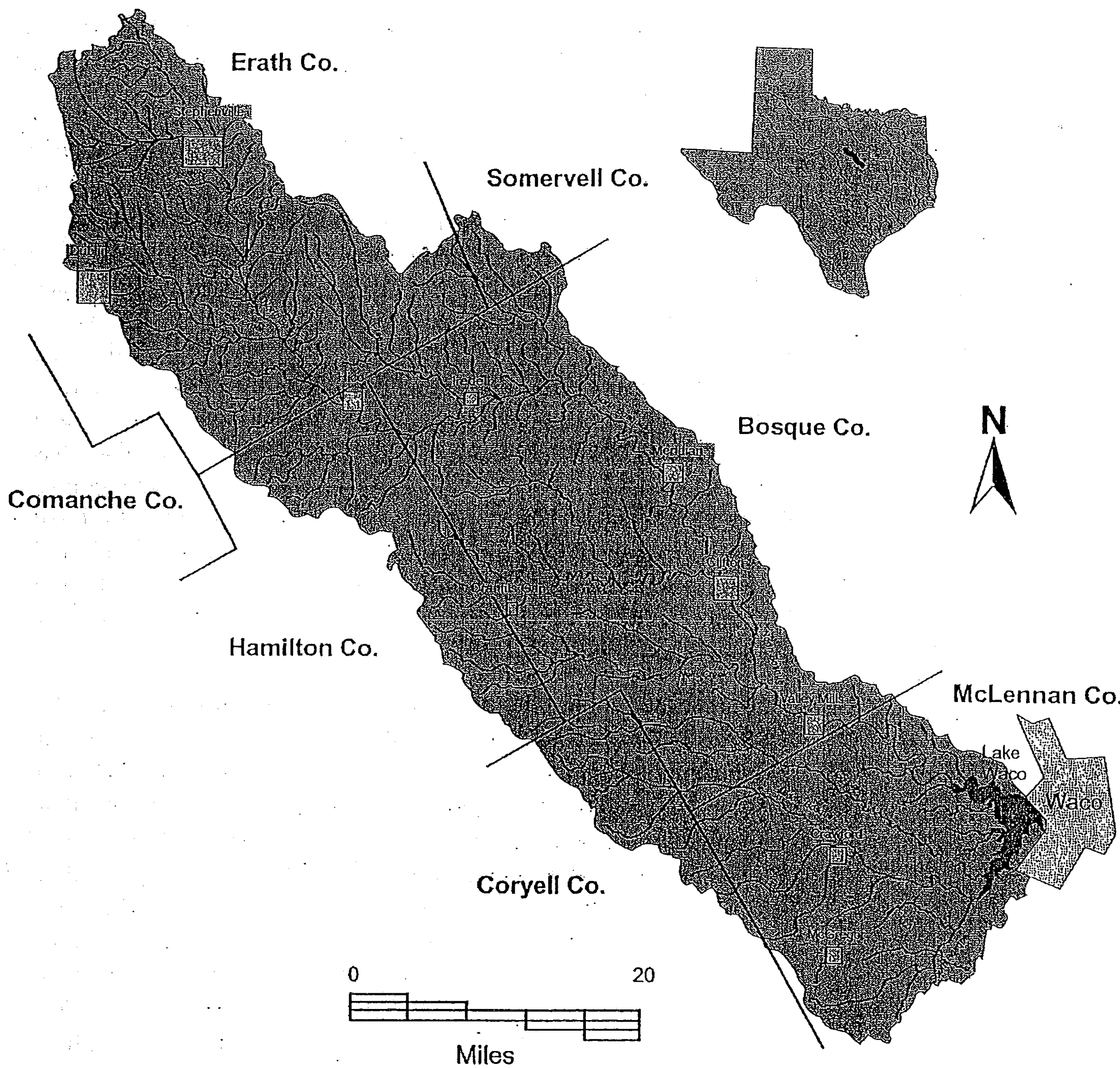


Table 1. Point sources in the Bosque River watershed as represented by the eight permitted wastewater treatment plants (WWTPs) within the watershed. Discharge in million gallons per day (MGD).

WWTP	Permitted Daily Average Discharge (MGD)	Major Receiving Stream
Stephenville†	3.000	North Bosque River
Hico	0.200	North Bosque River
Iredell	0.050	North Bosque River
Meridian	0.450	North Bosque River
Clifton	0.400	North Bosque River
Valley Mills	0.360	North Bosque River
Crawford	0.026	Middle Bosque River
McGregor†	1.100	South Bosque River

†Discharge limitation for ammonia (NH_3-N).

Nonpoint source nutrient loadings come from the variety of land uses within the watershed. The North Bosque River, with its headwaters located about 10 miles northwest of Stephenville, Texas represents about 74 percent of the drainage area for Lake Waco (Figure 2). In 1990, the North Bosque River watershed was identified as an impacted watershed due to nonpoint source pollution (Texas Water Commission and Texas State Soil and Water Conservation Board, 1991) and has been on the Texas 303(d) list of impaired waters since 1992. The prominence of the dairy industry in the upper portion of the North Bosque River drainage has been identified as major contributor of nonpoint source nutrients within the upper North Bosque River watershed (McFarland and Hauck, 1998a). Noticeable eutrophication of several small water bodies within the drainage of the North Bosque River and elevated nutrient concentrations in tributaries to the North Bosque River support the need for a reduction in nutrient loadings to the North Bosque River (Brazos River Authority, 1994; McFarland and Hauck, 1997a, 1997b).

In a recent State of Texas Water Quality Inventory (TNRCC, 1996), several comments address the water quality of classified stream segments along the North Bosque River (Figure 3). Segment 1226 is defined as the North Bosque River from a point 328 feet upstream of Farm-to-Market Road 185 in McLennan County to a point immediately above the confluence of Indian Creek in Erath County. Segment 1255 is defined as the North Bosque River from a point immediately above its confluence with Indian Creek to the confluence of the North and South Forks of the North Bosque River. Nonpoint source loadings are associated with elevated nutrient and fecal coliform levels within segments 1226

Figure 2. Major subwatersheds of the Bosque River watershed.

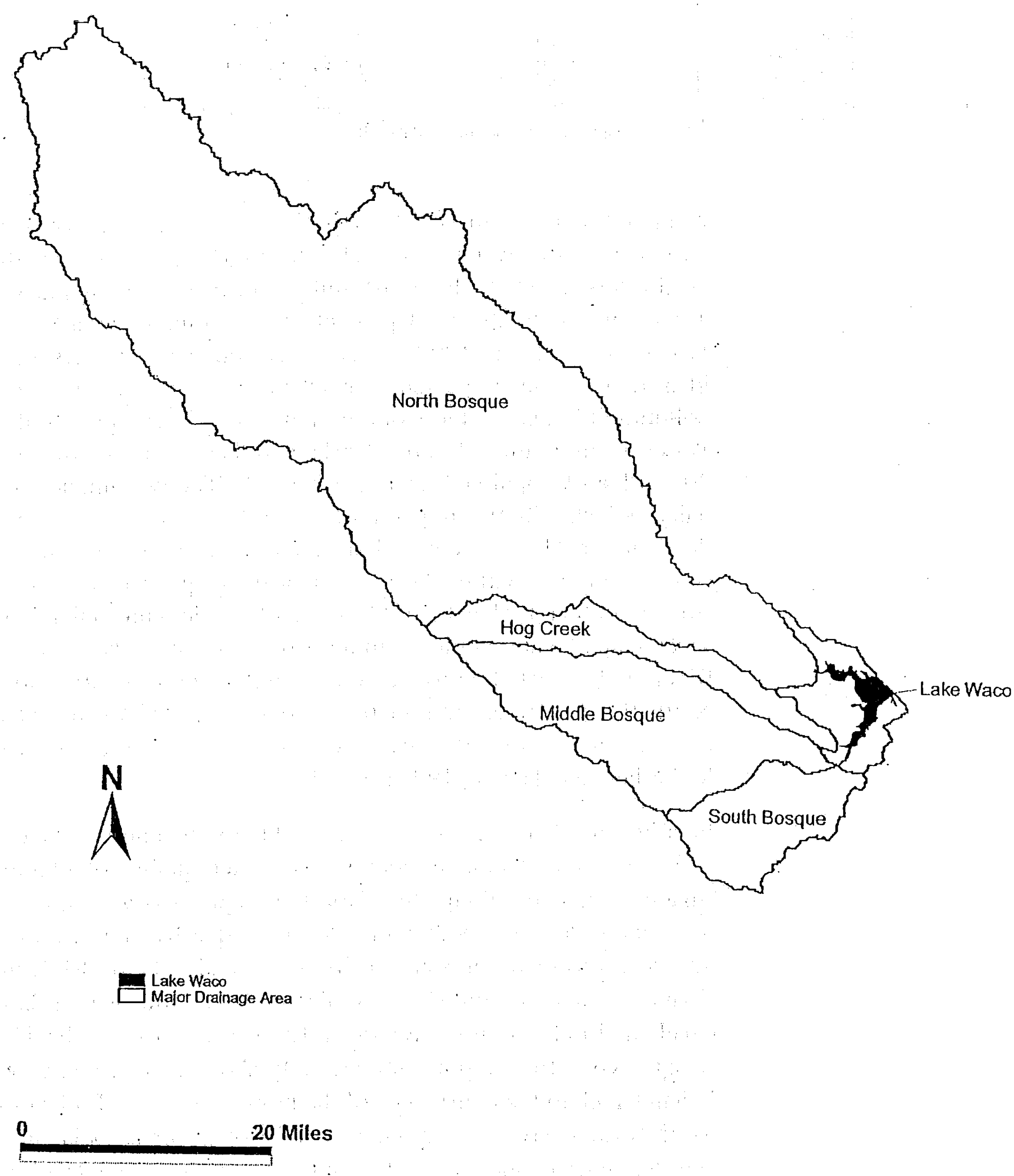
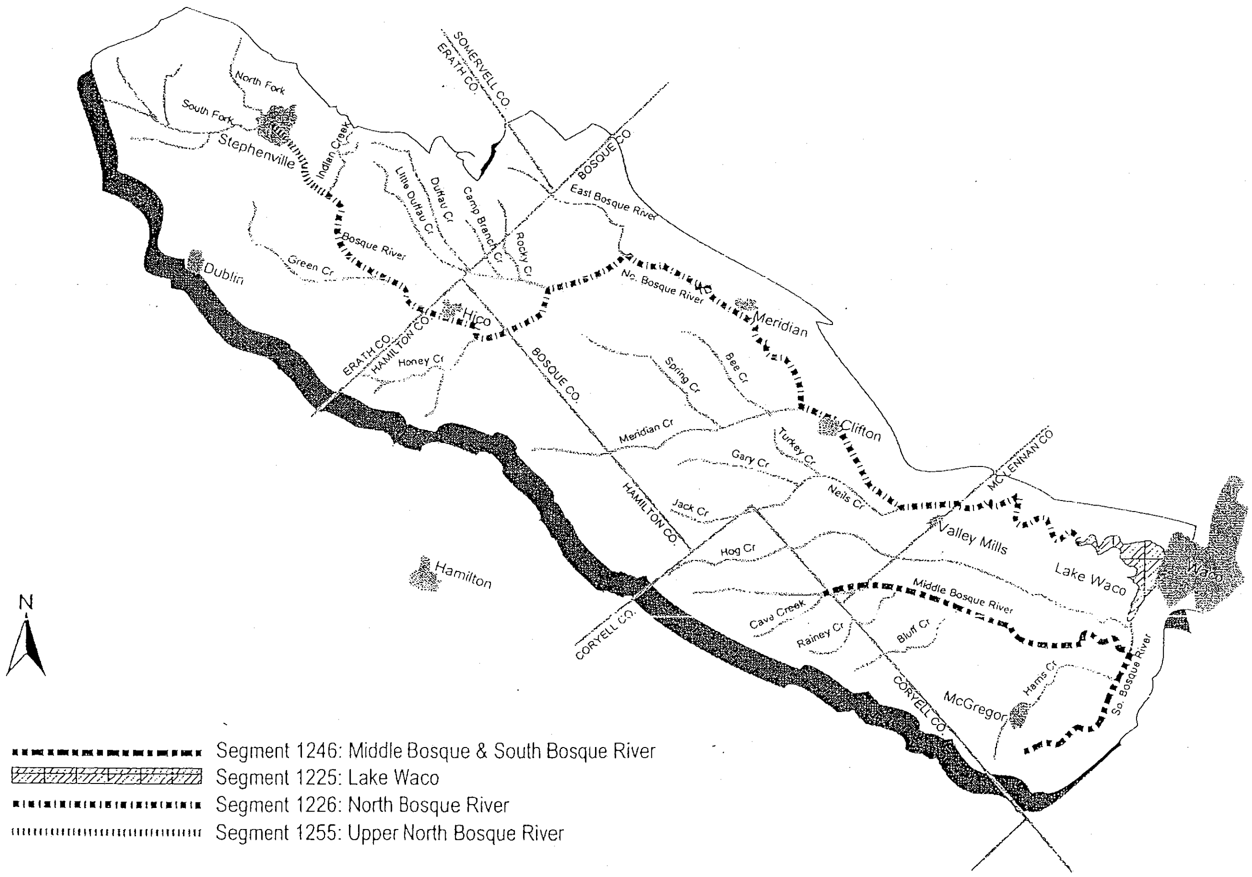


Figure 3. Classified segments within the Bosque River watershed



and 1225 and are described as the most serious threat to meeting the designated uses of these segments. The State of Texas 1999 303(d) list contains the two North Bosque River segments, 1226 and 1255, and a draft schedule of total maximum daily load (TMDL) development for these segments (TNRCC, 1999). Nutrients are the focus of this TMDL effort due to the role of nutrients in promoting excessive algae growth as indicated by elevated chlorophyll-α levels throughout segments 1226 and 1255 (TNRCC, 1999).

Of the other designated segments within the Bosque River watershed, nonpoint source pollution loadings from agricultural operations are noted as concerns for segment 1246, the Middle Bosque/South Bosque River, and for segment 1225, Lake Waco. Elevated nitrogen levels are also noted for segment 1246. Segment 1246 includes those portions of the Middle and South Bosque Rivers located in McLennan County as well as a small portion of the Middle Bosque River in Coryell County up to the confluence with Cave Creek (Figure 3).

Estimating nutrient loading from nonpoint sources is confounded by the fact that they originate from widespread areas that are diffuse by nature and often only contribute following rainfall. Land-use export coefficients are one tool often used to estimate nutrient loadings from nonpoint sources (Loehr *et al.*, 1989). A nutrient export coefficient represents the amount of a nutrient transported from a given land use per unit area per unit time. Export coefficients are generally expressed in units, such as lbs/acre/yr, or on a per capita basis as a function of population density (lbs/person/yr). Often generalized land-use export coefficients are used in watershed management planning rather than direct monitoring of land-use loadings due to the high cost and labor involved in direct monitoring. Recently released watershed loading models, such as WATERSHEDSS (WATER, Soil, and Hydro-Environmental Decision Support System) developed by the North Carolina State University Water Quality Group (Osmond *et al.*, 1997) and BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) developed by the U.S. Environmental Protection Agency (1998), present generalized export coefficients for many land uses, but allow the user to input regionally specific coefficient values when available. Regionally specific export coefficients are recommended, because precipitation, soils, and management practices associated with specific land uses often vary between regions leading to very different coefficient values for the same land use at different locations (Clesceri *et al.*, 1986).

In early 1991, TIAER began monitoring stream water quality in the drainage area of the North Bosque River above Hico, Texas. While most early monitoring consisted of grab samples, a number of automatic samplers were installed from late 1992 through 1993 in the upper North Bosque River watershed (McFarland and Hauck, 1995). In the fall of 1995, TIAER's monitoring network was expanded to include sampling sites throughout the Bosque River watershed (McFarland and Hauck, 1998a). While the monitoring network has changed over the years with regards to the number of sites and specific site locations, a largely consistent record from November 1995 through March 1998 was available at 17 automatic sampling sites representing locations throughout the Bosque River watershed (Figure 4). These 17 stream sampling sites represent the best available watershed specific monitoring data for estimating nutrient export coefficients for the various land uses within the Bosque River watershed.

The automatic samplers at these sites are programmed to collect stormwater samples and continuously measure water level. Site specific stage-discharge relationships are developed from manual measurements of flow and used to derive streamflow from the water level data. Routine grab sampling at monthly or bi-weekly intervals complements the stormwater monitoring to provide characterization of base flow water quality conditions. Stormwater and routine grab samples are analyzed for orthophosphate-phosphorus (PO_4-P), total phosphorus (TP), total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), nitrite-nitrogen (NO_2-N), nitrate-nitrogen (NO_3-N), and total suspended solids (TSS). NO_2-N, NO_3-N and TKN are summed to provide a measurement of total nitrogen (TN) in the water. Specific information on the location and water quality associated with these sampling sites can be found in TIAER's semi-annual water quality reports, such as Easterling et al. (1998) and Pearson and McFarland (1999).

There are two objectives to this report. The first is to use a statistical approach to develop nutrient export coefficients specific to the land uses within the Bosque River watershed using in-stream monitoring data for the period November 1, 1995 through March 30, 1998 for PO_4-P, TP and TN. This specific time period was chosen to maximize the number of sites available for use in loading calculations, while maintaining as long a data period as possible to account for temporal fluctuations in weather. Prior to November 1995, very little flow and water quality data were available for locations in the lower portion of the watershed (McFarland and Hauck, 1998a). After March 1998, several of the sampling sites in the upper portion of the watershed were removed due to a reprioritization of sampling needs (Pearson and McFarland, 1999). Two additional sites (NF020 on a tributary to the North Fork of the North Bosque River and NC060 on Neils Creek) were considered for this analysis but were removed from the analysis data set due to backwater impacts on level recordings during large storm events.

TP and TN were chosen as constituents for evaluation because phosphorus and nitrogen are the primary nutrients impacting the growth of algae in aquatic systems. PO_4-P was included as a separate phosphorus constituent, because PO_4-P represents most of the soluble phosphorus that is readily bioavailable for algal growth. In these freshwater systems, phosphorus is generally the limiting nutrient for the growth of algae (Gibson, 1997), and site specific studies indicate that this is the case for most locations within the Bosque River watershed (Dávalos-Lind and Lind, 1999; Matlock and Rodriguéz, 1999). The second objective is to determine the relative nutrient contribution of the various point sources and nonpoint sources for the Bosque River watershed and for specific locations within the watershed. Loadings by source will be determined using the developed nutrient export coefficients and quantification of point source loadings for the WWTPs for the November 1, 1995 through March 30, 1998 time period.

Figure 4. Location of sampling sites used in nutrient export coefficient analysis for the Bosque River watershed.

Land use information in conjunction with monitoring data were used to estimate nutrient export coefficients for nonpoint sources of PO_4-P, TP and TN by land-use category and to estimate the relative nutrient loadings by sector for point and nonpoint sources within the watershed using the following steps:

1. Determine the dominant land uses within the watershed and the percent of the drainage area above each monitoring site associated with these land uses.
2. Combine flow information with discrete measurements of nutrient concentrations taken during storm events and base flow to provide mass loadings for each sampling site.
3. Determine the nutrient export coefficients for urban land areas using mass loading information from the sole long-term, urban monitoring site (MB040).
4. Apply statistical models to determine optimal estimates of the nutrient export coefficients for the major agricultural land use categories within the watershed.
5. Compare estimated nutrient export coefficients for urban and agricultural land uses within the Bosque River watershed to values from other studies to evaluate the reasonableness of the developed export coefficients.
6. Determine mass loadings for the eight-permitted point source discharges (municipal WWTPs effluents) in the watershed using monitoring data and self-reporting effluent discharge information.
7. Develop an empirical source-contribution model using the nutrient export coefficients, land-use, and point source information to estimate loadings by source.
8. Validate the empirical source-contribution model by comparing measured nutrient loadings to predicted loadings for four sites along the North Bosque River (BO040, BO070, BO090 and BO100) not used in the development of the nutrient export coefficients (Step 4).

9. Determine the nutrient contribution by source for the entire watershed and various points within the watershed, and the uncertainty associated with these loading estimates.

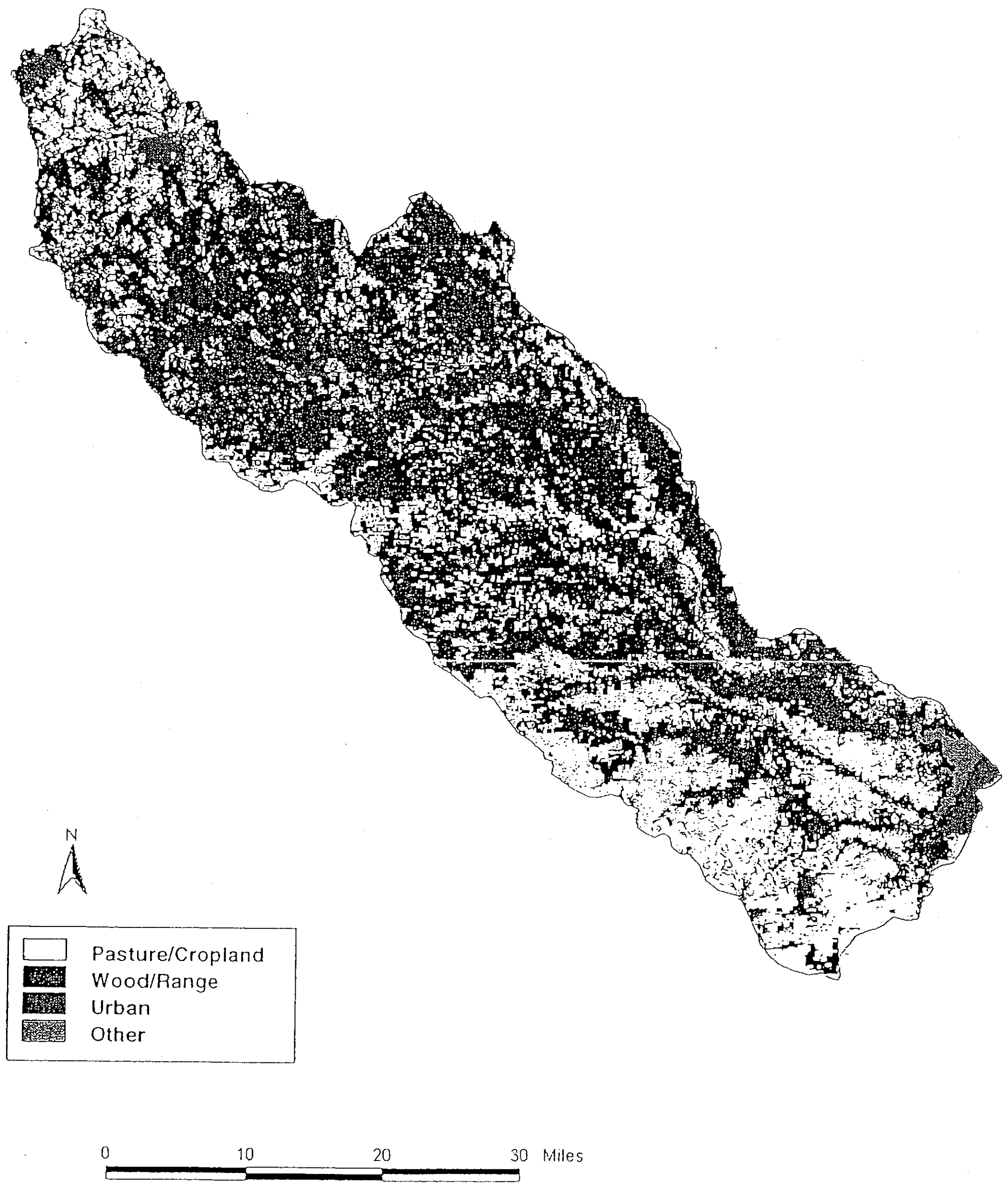
Step 1. Determine Land Uses Above Stream Sampling Sites

General land use descriptions were based on Landsat Thematic Mapper imagery classification provided by the USDA-Natural Resources Conservation Service (NRCS) Temple State Office as a Geographic Information System (GIS) data layer. The land use data were developed from an August 1992 overflight for Erath County and a June 1996 overflight for Bosque, Coryell, Erath, Hamilton, and McLennan counties. The June 1996 image was taken during a drought period, which caused difficulties in clearly distinguishing signatures between the different vegetation types. Cloud cover in the June 1996 image also caused problems in classifying the different land uses within the image. A 1992 land use classification was available from a previous TIAER project for the upper portion of the North Bosque River drainage from Hico, Texas and above. Extensive ground truthing implemented in January through April 1998 indicated very little change in land use from 1992 to 1998 for the area of the watershed within Erath County. The 1992 land use classification was updated to reflect the minor landuse changes from 1992 to 1998 and electronically inserted into the 1996 scene to represent the upper portion of the watershed within Erath County. For the lower portion of the Bosque watershed, digital orthophotography quadrangles from 1995 through 1996 and extensive ground truthing were used to verify and update the land use classification. The dominant land-use categories classified from the Landsat images were wood/range, pasture, cropland, urban and other (Figure 5).

The wood/range areas of the Bosque River watershed are part of the Cross Timbers vegetation region of Texas and are comprised primarily of scrub live oak (*Quercus virginiana*) and juniper (*Juniperus* spp.) in the woodland areas with tallgrass species such as little bluestem (*Schizachyruim scoparium*), indiangrass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*) in the native rangeland areas (Schuster and Hatch, 1990). Pasture fields are predominately Coastal bermudagrass (*Cynodon* spp.).

A refinement was made to the cropland land use category based on the location of cropland areas within the watershed. Distinct differences in soil types and, thus, crops and management practices

Figure 5. General land use within the Bosque River watershed.



occur in different portions of the watershed. Most cropland areas in the upper portion of the watershed (Hico and above) are used to grow forage sorghum (*Sorghum* spp.) and winter wheat (*Triticum* spp.) as a double-crop system. In the lower portion of the watershed, particularly in the Hog Creek, Middle Bosque and South Bosque drainage areas, most cropland is used to grow row crops such as corn (*Zea mays* L.), grain sorghum (*Sorghum* spp.), soybeans (*Glycine* spp.) and cotton (*Gossypium hirsutum* L.). For evaluating nutrient export, cropland fields located in the Bosque River watershed above Hico were categorized as non-row crop and cropland fields located in the watershed below Hico were categorized as row crop.

Dairy locations and waste application fields could not be determined from the Landsat imagery. This information was obtained from dairy permits and dairy waste management plans on file with the State's environmental regulatory agency (the Texas Natural Resource Conservation Commission) and overlaid on the general land use data layer to represent a separate land use category (Figure 6). Waste application fields represent areas permitted for liquid and/or solid manure application and are primarily Coastal bermudagrass fields. Solid manure is generally surface applied without incorporation on Coastal bermudagrass fields, while a variety of irrigation systems are used to apply the liquid effluent. In the watershed, over 74 percent of the permitted dairy waste application fields are described as Coastal bermudagrass fields (McFarland and Hauck, 1995), although crop rotations of sorghum and winter wheat are not uncommon. Operating dairies and the location of dairy waste application fields represent information as of January 1995.

The drainage areas above sampling sites (Table 2) were delineated from U.S. Geological Survey (USGS) 1:24,000 digital elevation models (DEMs) and USGS 7 ½-minute quadrangle maps digitized by the USDA-NRCS. The size of drainage areas for specific sites may vary somewhat from previous TIAER reports (less than 0.1 percent), particularly in the lower portion of the watershed, due to re-calculation of these drainage areas using an ARC/INFO rather than a GRASS (Geographic Resources Analysis Support System) based GIS platform. Land use composition within the drainage area above each sampling site was calculated by overlaying the drainage area and land use data layers within the GIS system. This was done for the individual sampling sites (Table 2) and for the entire Bosque River watershed and its major subwatersheds (Table 3).

Figure 6. Location of dairy waste application fields within the Bosque River watershed based on dairy permit information as of January 1995.

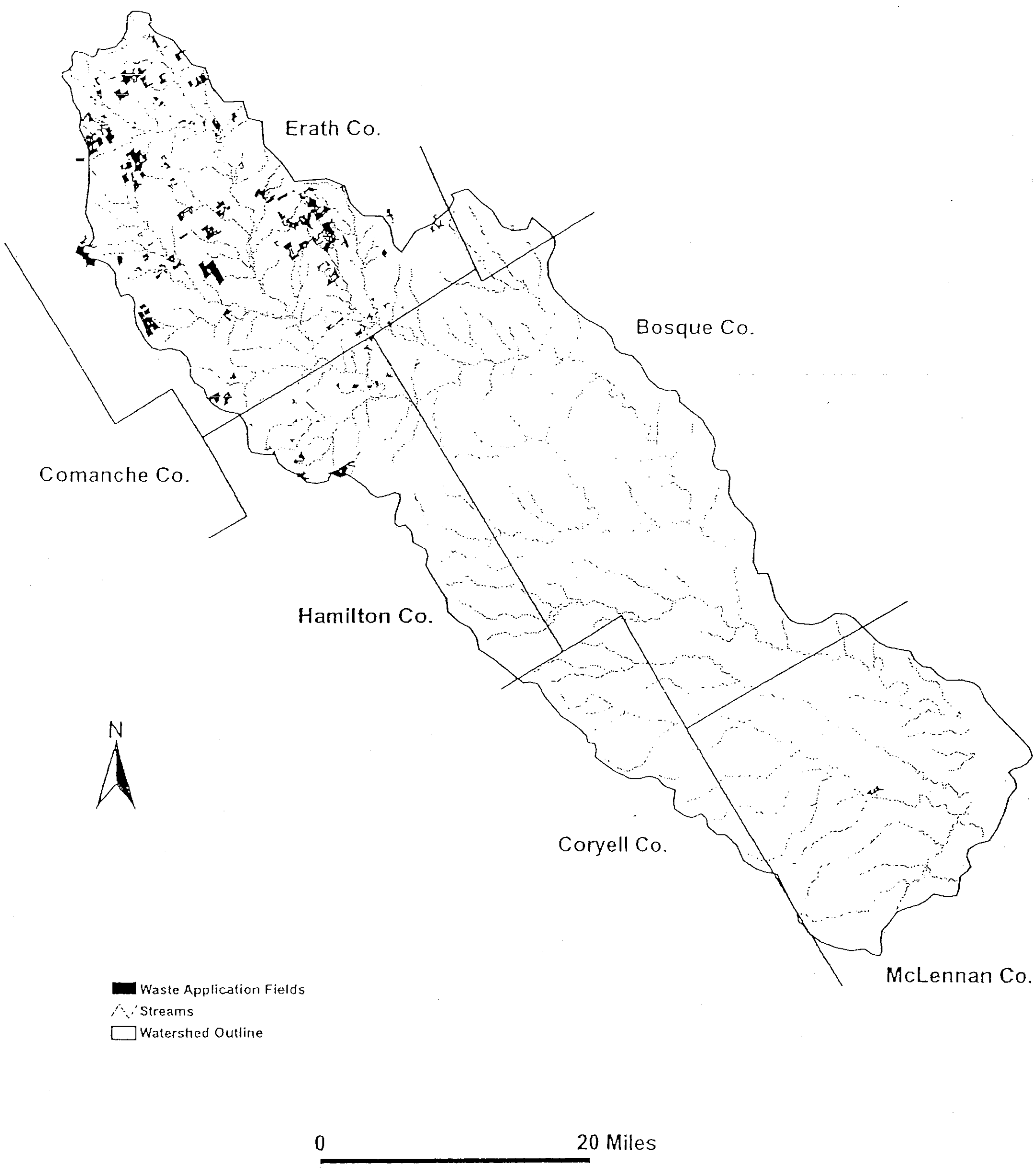


Table 2. Land uses above sampling sites and drainage area sizes for TIAER sampling sites in the Bosque River watershed used in nutrient export coefficient analyses.

Site	Wood/ Range (%)	Pasture (%)	Non-Row Crop (%)	Row Crop (%)	Dairy Waste Appl. (%)	Urban (%)	Other (%)	Drainage Area (acres)†
BO020	49.4	30.1	6.4	0.0	12.3	0.8	1.1	53,264
BO040	51.0	23.8	8.4	0.0	11.7	3.8	1.4	63,504
BO070	68.3	15.4	6.5	0.0	7.2	1.7	1.0	230,243
BO090	71.9	13.8	2.4	6.5	3.7	1.5	0.2	626,518
BO100	72.4	13.6	2.0	7.4	3.1	1.4	0.2	746,459
GB020	51.0	2.3	5.8	0.0	40.7	0.0	0.2	1,007
GC100	71.2	13.3	7.2	0.0	6.9	0.7	0.7	64,605
HC060	46.2	19.2	0.0	34.1	0.0	0.5	0.0	50,532
IC020	65.2	9.5	7.5	0.0	17.3	0.0	0.5	4,494
MB040	0.0	0.0	0.0	0.0	0.0	100.0	0.0	421
MB060	47.9	13.1	0.0	38.7	0.0	0.3	0.0	76,406
NF009	58.3	27.2	10.8	0.0	3.4	0.0	0.3	1,278
SC020	79.3	11.6	2.5	0.0	5.9	0.0	0.7	4,495
SF020	96.1	3.3	1.0	0.0	0.0	0.0	0.3	2,095
SF050	57.4	23.8	2.2	0.0	15.9	0.0	0.6	1,847
TC020	8.4	17.8	0.0	73.5	0.0	0.2	0.0	7,483
WC020	8.1	24.0	0.0	67.7	0.0	0.3	0.0	2,396

†Reported drainage areas determined using ARC/INFO vary somewhat from previously reported values determined using GRASS.

Table 3. Land use and drainage area size for major tributary drainages and total land area within the Bosque River watershed.

Drainage	Wood/ Range (%)	Dairy Waste Appl. (%)	Pasture (%)	Row Crop (%)	Non-Row Crop (%)	Urban (%)	Other (%)	Water (%)	Drainage Area (acres)†
North Bosque	72.2	3.0	13.6	6.7	2.7	1.4	0.2	0.2	781,403
Hog Creek	44.2	0.0	18.5	36.4	0.0	0.7	0.3	0.0	57,297
Middle Bosque	40.4	0.2	15.6	41.8	0.0	1.1	0.9	0.0	127,519
South Bosque	22.4	0.0	19.8	48.1	0.0	8.8	2.1	0.0	58,135
Other Minor Tribs.	35.4	0.0	6.7	12.6	0.0	21.9	1.0	0.0	30,842
Surface Area Lake Waco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	7,270
Total	**62.8**	**2.2**	**14.4**	**15.2**	**2.0**	**2.3**	**0.4**	**0.7**	**1,062,466**

†Reported drainage areas determined using ARC/INFO vary somewhat from previously reported values determined using GRASS.

Step 2. Calculate Cumulative Nutrient Loadings for Each Site

Stormwater and routine grab samples were measured directly for TP, while TN values were derived as the sum of TKN, NO_2-N and NO_3-N. All nutrient analyses were performed using U. S. Environmental Protection Agency (EPA) approved methods (USEPA, 1983) and all samples were collected and analyzed under an EPA or TNRCC approved Quality Assurance Project Plan (e.g., TIAER, 1998).

Water level was monitored at each sampling site at five-minute intervals throughout the evaluation period. A stage-discharge relationship for most sites was determined from individual measurements of flow taken at a variety of water levels or stream stages. Manual flow measurements were made on an opportunistic basis representing a variety of streamflow conditions. Pairs of water level and flow data were then related to the cross-sectional area of the stream at each site and stream stage to develop site specific stage-discharge relationships. These relationships are updated if meaningful changes occur to a site's cross-sectional area. A semi-log relationship of average stream velocity to water level (log) was used to extrapolate flow for stream levels above which manual measurements could not be safely made. Because stream sites TC020 and WC020 are located at road culverts, hydraulic equations were applied to determine the stage-discharge relationship for these sites. At sites BO090 and BO100 flow data from corresponding USGS sites, 08095000 and 08095200 respectively, were obtained for use in this report. Flow at BO070 was calculated using the USGS stage-discharge relationship for station 08094800 in conjunction with level data measured by TIAER.

Flow data were then combined with the nutrient concentration data to calculate cumulative nutrient loadings at each site. This was done using a midpoint rectangular integration method to calculate loadings by dividing the flow hydrograph into intervals based on the collection date and time of each water quality sample (Stein, 1977). Stormwater samples were generally collected using a set sampling frequency depending on the size of the drainage area above the sampling site with more frequent sampling on the typically fast rising portion of the hydrograph and less frequent sampling on the typically slow receding portion of the hydrograph. A typical storm sampling sequence involved 1) an initial sample, 2) three samples at one-hour intervals, 3) four samples at two-hour intervals, and 4) all remaining samples for a storm event at six-hour intervals. Grab samples were collected bi-weekly during the study period and used to characterize base flow conditions. The history of nutrient loading at each site was summed for the evaluation period to obtain cumulative loadings over the study period. Cumulative loadings were prorated on an annual basis and area weighted for use in deriving nutrient export coefficients (Table 4).

In addition to the land use and WWTP loadings, the loadings of soluble phosphorus and nitrogen in precipitation to the surface area of Lake Waco were estimated based on analysis of precipitation data collected in the wet-dry atmospheric samplers located near Stephenville and Lake Waco. The Stephenville site was installed October 1996, while the Lake Waco site was installed in August 1997. No statistical differences were indicated in the constituent concentrations measured at these two sites, so data were combined to estimate precipitation loadings of nutrients to Lake Waco.

Table 4. Volume and nutrient loadings measured at TIAER sampling sites for November 1, 1995 through March 30, 1998 prorated to an annual basis.

Site	Flow (10^6 ft^3/yr)	Flow (ft^3/acre/yr)	PO_4-P (lbs/yr)	PO_4-P (lbs/acre/yr)	TP (lbs/yr)	TP (lbs/acre/yr)	TN (lbs/yr)	TN (lbs/acre/yr)
BO020	944.6	17,735	26,148	0.49	58,416	1.10	240,877	4.52
BO040	1,295.4	20,399	51,917	0.82	85,914	1.35	358,041	5.64
BO070	5,696.4	24,741	88,171	0.38	201,973	0.88	876,631	3.81
BO090	14,769.7	23,574	112,425	0.18	495,465	0.79	2,419,325	3.86
BO100	19,856.9	26,602	130,229	0.17	592,638	0.79	3,006,456	4.03
GB020	6.5	6,417	1,188	1.18	2,586	2.57	6,507	6.46
GC100	1,667.2	25,806	18,523	0.29	42,192	0.65	247,178	3.83
HC060	1,774.6	35,118	6,216	0.12	29,505	0.58	238,479	4.72
IC020	107.4	23,889	3,667	0.82	7,828	1.74	33,788	7.52
MB040	25.0	59,265	413	0.98	1,149	2.73	4,847	11.50
MB060	3,191.2	37,970	9,087	0.12	38,059	0.50	478,926	6.27
NF009	30.7	24,028	674	0.53	1,724	1.35	6,983	5.46
SC020	129.9	28,894	1,283	0.29	2,627	0.58	14,236	3.17
SF020	48.4	23,116	124	0.06	627	0.30	3,916	1.87
SF050	26.0	14,081	1,005	0.54	1,492	0.81	5,813	3.15
TC020	252.8	33,785	940	0.13	5,426	0.73	131,022	17.51
WC020	48.4	20,187	302	0.13	1,355	0.57	39,252	16.38

During the monitoring period, a total of 87.39 inches of rain was measured at the National Weather Service station at Waco Dam. The surface area of Lake Waco was estimated at 7,270 acres (TNRCC, 1996). During the monitoring period, 76 measurements were made of PO_4-P and 44 measurements of TP and TN from precipitation at the two locations. The median concentration values from these rainfall events were used to estimate loadings due to precipitation (Table 5). Compared to loadings at BO100 on the North Bosque River, precipitation loadings to Lake Waco contribute a very small percentage of the total loadings to Lake Waco (less than 1.5 percent of the loadings at BO100). Direct loadings of nitrogen and phosphorus from precipitation do occur, but because precipitation loading is a relatively minor contributor to the overall nutrient loadings to Lake Waco, it will be ignored in all further analyses in this report.

Table 5. Nutrient contribution to Lake Waco via precipitation for November 1, 1995 through March 30, 1998. Assumes a reservoir surface area of 7,270 acres and 87.39 inches of rainfall prorated to an annual basis.

Nutrient Constituent	Median Concentration (mg/L)	Loading (lbs/yr)
PO_4-P	0.030	1,792
TP	0.075	4,480
TN	0.590	35,242

Step 3. Determine Nutrient Export Coefficients for Urban Land Areas

Most of the sampling sites represent predominately rural or agricultural land uses with urban areas comprising less than 3 percent of the total watershed area (Table 3). Site MB040, located in Stephenville, was the only sampling site representing 100 percent urban land (Table 2). The city of Waco is currently monitoring two urban runoff sites representing direct urban runoff into Lake Waco. The Waco urban runoff sites were installed in January and July 1997. The more limited data collection period for the two Waco sites precluded their use in this study. However, a general comparison of phosphorus and nitrogen at the Waco urban sites indicated that the values are comparable to data collected at site MB040. The nutrient export coefficients for urban land were, thus, calculated based on the area-weighted mass loadings for site MB040 (Table 4). Prorated to an annual basis, the area-weighted nutrient loadings for MB040 for November 1, 1995 through March 30, 1998 produced urban export coefficients of 0.98 lbs PO_4-P/acre/year, 2.73 lbs TP/acre/year and 11.5 lbs TN/acre/year. While MB040 represents urban runoff from only one site within the watershed, the standard deviation associated with the urban nutrient export coefficients was set equal to the derived coefficient values for MB040 for use in Steps 7-9 to help evaluate the uncertainty associated with predicted urban loadings.

Step 4. Determine Nutrient Export Coefficients for Agricultural Land Uses

Typically export coefficients are determined by monitoring land uses, such as forest, row crops or urban, using field plots isolating individual land uses (Reckhow *et al.*, 1980). While monitoring single land-use watersheds may be ideal, most watersheds are comprised of a variety of land uses. The sampling network in the Bosque River watershed was designed to monitor nutrients and flow at stream sites with upstream drainage areas comprised of mixtures of land uses (McFarland and Hauck, 1998a).

To isolate the loading contribution from these mixed land-use drainage areas, multiple regression techniques were used to develop the nutrient export coefficients for the major agricultural land uses in the watershed based on procedures described by Hodge and Armstrong (1993). The dependent variable was the nutrient loading at each site (Table 4), and the independent variables were the fraction of the drainage area above each site represented by each land-use category (Table 2). The coefficients from the resulting multiple regression models define optimized export coefficients across all sites for each land use category for the time period evaluated. All multiple regression models were developed using a forced zero intercept, thus, giving a loading of zero if all land-use categories represented a zero fraction of the watershed. The procedures used follow closely those outlined in McFarland and Hauck (1998a) in their development of preliminary nutrient export coefficients for this watershed.

Of the 17 sites considered, 12 sites were used in estimating nutrient export coefficients for agricultural land uses. Sites BO040, BO070, BO090 and BO100 were reserved to validate the derived nutrient export coefficients, while site MB040 was used to calculate the urban nutrient export coefficients. Only the major land use categories of dairy waste application fields, pasture, non-row crop fields, row-crop fields and wood/range were considered as independent variables in the multiple regression models. All minor land uses represented as "other" in the land use classification represented relatively small percentages of the land cover and were assumed to be minor contributors (Table 2). Contributions for the "other" land-use category were considered part of the error term in the coefficient calculations.

Land uses were judiciously categorized to minimize multicolinearity effects in the multiple regression model procedures to obtain reasonable export coefficient estimates. Different groupings of sites were used to evaluate phosphorus and nitrogen export coefficients for the various land use categories due to observed loading differences at predominately cropland sites throughout the watershed. Specific methods used for estimating the phosphorus and nitrogen export coefficients are described below.

Phosphorus Export Coefficients: Three land-use category groupings were used to develop the phosphorus export coefficients for the rural land uses in the watershed: dairy waste application fields, pasture/cropland and range/wood. To minimize the impacts of multicolinearity, the pasture and cropland categories were joined into the combined land use category of pasture/cropland. Cropland for the phosphorus constituents included both non-row and row-crop fields as there appeared to be little difference in the phosphorus runoff at sites associated with these two land uses (Table 4).

In comparing the information in Tables 2 and 4, much larger phosphorus loadings are generally associated with sites containing substantial percentages of dairy waste application fields than with other sites. To avoid confounding phosphorus loadings from dairy waste application fields with other land uses, rural sampling sites without (or with minimal) dairy waste application fields in their drainage areas were grouped to estimate phosphorus export coefficients for the less impacted land uses of wood/range and pasture/cropland. The sites with no or minimal dairy waste application fields included HC060, MB060, SF020, TC020 and WC020. A multiple regression model using the fraction of pasture/cropland and wood/range as the independent variables and the phosphorus loading at these sites as the dependent variable was developed to estimate the phosphorus export coefficients for pasture/cropland and wood/range as follows:

$$P_i = \beta P_1 X_{i,1} + \beta P_2 X_{i,2} + \varepsilon_i \qquad (1)$$

Where

i = the individual sites used in the regression model (for this specific model only data from sites HC060, MB060, SF020, TC020 and WC020 was used),

P_i = the annualized phosphorus loading at site i on a per acre basis of either PO_4-P or TP for the time period (lbs/acre/yr),

βP_1 = the phosphorus export coefficient for pasture/cropland (lbs/acre/yr),

$X_{i,1}$ = the fraction of the land area above site i represented by pasture/cropland,

βP_2 = the phosphorus export coefficient for wood/range (lbs/acre/yr),

$X_{i,2}$ =	the fraction of the land area above site i represented by wood/range,
ε_i =	the random error associated with the difference between the measured and predicted loadings that is not explained by the model for site i.

The model was run separately for PO_4-P and TP. Prorated to an annual basis, the nutrient export coefficients derived are 0.14 lbs PO_4-P/acre/yr and 0.70 lbs TP/acre/yr for pasture/cropland and 0.07 lbs PO_4-P/acre/yr and 0.31 lbs TP/acre/yr for wood/range (Table 6).

Table 6. Phosphorus export coefficient parameter estimates on an annual basis for land-use variable versus nutrient loadings based on data from November 1, 1995 through March 30, 1998. 'na' indicates not applicable.

	PO_4-P (lbs/acre/yr)			TP (lbs/acre/yr)		
Land Use	Parameter Estimate	p-value	n	Parameter Estimate	p-value	n
Urban†	0.98±0.49	na	1	2.73±1.37	na	1
Dairy Waste Appl. Fields	3.08±0.34	0.0001	7	5.81±0.79	0.0003	7
Pasture/Cropland	0.14±0.01	0.0012	5	0.70±0.06	0.0013	5
Wood/Range	0.07±0.02	0.0184	5	0.31±0.07	0.0253	5

†The standard deviation for urban was estimated as one-half the value of the parameter estimate for use in further analyses.

A regression model evaluating the change in phosphorus loadings with changes in the fraction of land area represented by dairy waste application fields was determined using the seven sampling sites with drainage areas containing dairy waste application fields (BO020, GB020, GC100, IC020, NF009, SC020 and SF050) as shown below:

$$\mathbf{P_{i(adjusted)}} = \beta P_3 X_{i,3} + \varepsilon_i \qquad (2)$$

Where

i =	the individual sites used in the regression model (for this specific model, only data from sites with dairy waste application fields in their drainage areas were used),
$\mathbf{P_{i(adjusted)}}$ =	$P_i - (\beta P_1 X_{i,1} + \beta P_2 X_{1,2})$ from equation (1),
$\boldsymbol{\beta P_3}$=	the phosphorus export coefficient for dairy waste application fields (lbs/acre/yr),
$\mathbf{X_{i,3}}$ =	the fraction of the land area above site i represented by dairy waste application fields,

ε_i = the random error associated with the difference between the measured and predicted loadings that is not explained by the model for site i.

As indicated, equation (2) adjusts the loading P_i for the loading due to pasture/cropland and wood/range as calculated from equation (1). Prorated to an annual basis, the export coefficients derived for dairy waste application fields are 3.08 lbs PO_4-P/acre/yr and 5.81 lbs TP/acre/yr (Table 6).

Nitrogen Export Coefficients: The land-use category groupings used to estimate the rural total-N export coefficients are the same as those for the phosphorus export coefficients (i.e., wood/range, pasture/cropland, and dairy waste application fields) except a refinement was made to the pasture/cropland grouping. Previously developed export coefficients for the upper North Bosque River watershed indicated the validity of grouping pasture and cropland together for all nutrients for that subwatershed of the Bosque River watershed (McFarland and Hauck, 1998b). The nutrient loading data (Table 4) and known differences in farming practices and soil types in the Bosque River watershed south of Hico, however, indicated the need to redefine the pasture/cropland grouping for the nitrogen export coefficients.

Much of the cropland in the upper portion of the watershed involves a double-cropping pattern of forage sorghum in the summer followed by a winter small grain, such as wheat or rye, as described in Step 1. Conditions, particularly soils, in the lower portion of the watershed are favorable for row crops such as corn and soybeans, which are typically not associated with a winter crop. Soil differences throughout the watershed contribute greatly to this change in cropping patterns as noted in USDA-NRCS soil surveys for Bosque, Coryell, Erath, Hamilton and McLennan counties. The nutrient loading data for sites in the lower portion of the watershed associated with row crop agriculture (TC020 and WC020, and to a lesser extent HC060 and MB060) showed high nitrogen loadings but fairly low phosphorus loadings in comparison to the other sites in the watershed (Table 4). These same high nitrogen loadings did not appear to be associated with the non-row crop agriculture associated with sites in the upper portion of the watershed. To account for this observed difference in nitrogen loadings between the row crop and non-row crop categories, row crop was evaluated as a separate land use category, although pasture and non-row crop areas were still combined for determining the export coefficients for TN.

As with the phosphorus coefficients, a two-step procedure was implemented to estimate the nitrogen export coefficients. This time the focus was on minimizing the confounding of the large nitrogen loading values associated with sites dominated by row-crop agriculture (Table 4). First, a multiple regression model was used to estimate the total-N export coefficients for the land-use categories of dairy waste application fields, pasture/non-row crop, and wood/range based on loading data using rural sampling sites only in the upper portion of the watershed above Hico. This approach was comparable to the procedures used in McFarland and Hauck (1998b) to estimate nutrient export coefficients for the upper North Bosque River watershed as follows:

$$N_i = \beta N_1 X_{i,1} + \beta N_2 X_{i,2} + \beta N_3 X_{i,3} + \varepsilon_i \qquad (3)$$

Where

i =	the individual sites used in the regression model (for this specific model only data from sites above Hico were used),
N_i =	the annualized nitrogen loading at site i on a per acre basis for the time period (lbs/acre/yr),
βN_1=	the nitrogen export coefficient for dairy waste application fields (lbs/acre/yr),
$X_{i,1}$ =	the fraction of the land area above site i represented by dairy waste application fields,
βN_2=	the nitrogen export coefficient for pasture/non-row crop (lbs/acre/yr),
$X_{i,2}$ =	the fraction of the land area above site i represented by pasture/ non-row crop,
βN_3=	the nitrogen export coefficient for wood/range (lbs/acre/yr),
$X_{i,3}$ =	the fraction of the land area above site i represented by wood/range,
ε_i =	the random error associated with the difference between the measured and predicted nitrogen loadings that is not explained by the model for site i.

Although statistically nonsignificant (α = 0.05) coefficient values were estimated for pasture/non-row crop and wood/range using this procedure (Table 7), these coefficient values still represent the best optimized estimates from the current data set. Prorated on an annual basis the nitrogen export coefficients are 12.3 lbs TN/acre/yr for dairy waste application fields, 7.2 lbs TN/acre/yr for pasture/non-row crop fields, and 2.2 lbs TN/acre/yr for wood/range.

Table 7. Nitrogen export coefficient parameter estimates on an annual basis for land-use variable versus nutrient loadings based on data from November 1, 1995 through March 30, 1998. 'na' indicates not applicable.

	TN (lbs/acre/yr)		
Land Use	Parameter Estimate	p-value	n
Urban[†]	11.5 ± 5.8	na	1
Dairy Waste Appl. Fields	12.3 ± 4.2	0.0340	8
Pasture/Non-Row Crop	7.2 ± 4.0	0.1312	8
Wood/Range	2.2 ± 1.5	0.1974	8
Row Crop	19.0 ± 3.0	0.0078	4

[†]The standard deviation for urban was estimated as one-half the value of the parameter estimate for use in further analyses.

To estimate the TN export coefficient for row crops, a regression model was developed evaluating the change in TN loading with changes in the fraction of row crop in the drainage area above sites HC060, MB060, TC020 and WC020 as follows:

$$N_{i(adjusted)} = \beta N_4 X_{i,4} + \varepsilon_i \qquad (4)$$

Where

i = the individual sites used in the regression model (for this specific model only data from sites HC060, MB060, TC020 and WC020 were used),

$N_{i(adjusted)}$ = $N_i - (\beta N_1 X_{i,1} + \beta N_2 X_{i,2} + \beta N_3 X_{i,3})$ from equation (3),

βP_4 = the total nitrogen export coefficient for row-crop fields (lbs/acre/yr),

$X_{i,4}$ = the fraction of the land area above site i represented by row-crop agriculture,

ε_i = the random error associated with the difference between the measured and predicted loadings that is not explained by the model for site i.

As indicated, equation (3) adjusts the loading of N_i for the loadings due to dairy waste application fields, pasture/cropland and wood/range as derived in equation (4). Prorated to an annual basis the nitrogen export coefficient for row crop is 19.0 lbs TN/acre/yr (Table 7).

Step 5. Compare Calculated Export Coefficients to Literature Values

To evaluate the reasonableness of the nutrient export coefficients derived in Step 4, the nutrient export coefficients for TP and TN were compared to values for similar land uses from other studies. Export coefficients for PO_4-P are generally not presented in nutrient export coefficient studies and, thus, could not be directly compared. Table 8 presents a general review of the range of published literature values for nutrient export coefficients focusing primarily on values for land uses most comparable to those in the Bosque River watershed. The coefficient values generated from the multiple regression models for TP and TN fit well within the range of literature values for the evaluated land use categories. The wide variability in literature values reflects site-specific variations in management and environmental conditions and emphases the advantage of using regional or site-specific export coefficients.

Table 8. Literature values for TP and TN export coefficients compared to calculated values for land uses in the Bosque River watershed.

Land Use	TP (lb/ac/yr)	TN (lb/ac/yr)	Source
Waste Appl. Fields	0.90 - 3.25	4.5 - 14.6	Loehr *et al.* (1989)
Waste Appl. Fields	1.68 - 13.78	7.4 - 111.8	Overcash *et al.* (1983)
Dairy Waste Appl. Fields	5.81	12.3	Bosque River Watershed
Pasture	0.06 - 0.67	3.6 - 15.7	Loehr *et al.* (1989)
Non-Row Crop	0.11 - 3.25	1.1 - 8.7	Reckhow *et al.* (1980)
Pasture/Non-Row Crop	0.70	7.2	Bosque River Watershed
Row Crop	0.02 - 20.83	2.8 - 89.2	Reckhow *et al.* (1980)
Row Crop	0.70	19.0	Bosque River Watershed
Forest	0.01 - 0.99	1.1 - 7.1	Loehr *et al.* (1989)
Idle Land	0.06 - 0.28	0.6 - 6.7	Loehr *et al.* (1989)
Native Pasture	0.02 - 2.08	0.2 - 10.3	Menzel *et al.* (1978)
Native Pasture	0.01 - 0.28	0.2 - 1.9	Timmons and Holt (1977)
Wood/Range	0.31	2.2	Bosque River Watershed
Urban	0.34 - 4.14	5.3 - 28.0	Loehr *et al.* (1989)
Urban	2.73	11.5	Bosque River Watershed

Step 6. Calculate Municipal WWTP Discharge Loadings

Nutrient loadings for the eight permitted WWTPs within the Bosque River watershed were estimated by integrating nutrient concentrations from monthly or bi-weekly grab samples of the effluent discharge with the average daily discharge data reported by each plant to the TNRCC. Since sampling at many of the WWTPs did not begin until January 1996, median values were used to represent the nutrient constituent concentrations for months during which samples were not collected. Cumulative loadings for November 1, 1995 through March 30, 1998 are presented in Table 9 prorated to an annual basis.

Table 9. Calculated wastewater treatment plant nutrient loadings for November 1, 1995 through March 30, 1998 prorated to an annual basis.

Site	Flow (10^6 ft^3/yr)	PO_4-P (lbs/yr)	TP (lbs/yr)	TN (lbs/yr)
Stephenville	86.4	11,523	14,381	37,542
Hico	3.9	658	751	2,872
Iredell	1.2	209	1,318	365
Meridian	9.3	1,468	1,763	10,214
Clifton	14.9	1,621	2,191	7,735
Valley Mills	4.6	710	793	4,820
Crawford	0.2	24	34	147
McGregor	34.8	2,210	3,330	21,693

Step 7. Develop an Empirical Source-Contribution Model

The export coefficient values, land-use classification, and point source data for the Bosque River were combined into an empirical source-contribution model. This model allows an estimation of the loading of nitrogen and phosphorus by source to the Bosque River watershed and other selected points for the time period of November 1, 1995 through March 30, 1998 as prorated on an annual basis. This simple empirical model can be expressed algebraically as follows:

$$L_{i,m} = \sum_{j=1}^{7} (EC_{j,m} \times SA_{i,j}) + \sum_{k=1}^{8} PS_{i,k,m} \qquad (5)$$

Where

m = the nutrient: m=1 for PO_4-P, m=2 for TP, and m=3 for TN,

i = a location with the Bosque River watershed, such as site BO040, for which land use information within the drainage of the site is defined,

$L_{i,m}$ = annualized loading for nutrient m on a per acre basis to location i (lbs/acre/yr),

$j =$ nonpoint sources: j = 1 for dairy waste application fields, j = 2 for pasture fields, j = 3 for non-row crop fields, j = 5 for row crop fields, j = 6 for wood/range, and j = 7 for urban,

$EC_{j,m} =$ land-use export coefficient (lbs/acre/yr) for source j and nutrient m,

$SA_{i,j} =$ land-use surface area within the drainage above location i associated with source j (acres),

$k =$ the WWTPs: k = 1 for Stephenville, k = 2 for Hico, k = 3 for Iredell, k = 4 for Meridian, k = 5 for Clifton, k = 6 for Valley Mills, k = 7 for Crawford and k = 8 for McGregor, and

$PS_{i,k,m} =$ the annualized contribution at location i of nutrient m from the k municipal WWTP discharges above location i (lbs/yr).

Values for the variables in equation (5) can be obtained from Tables 2, 3, 6, 7 and 9. Percent contribution by source is calculated by dividing the total loading (L) to a given location by the calculated loading for each source.

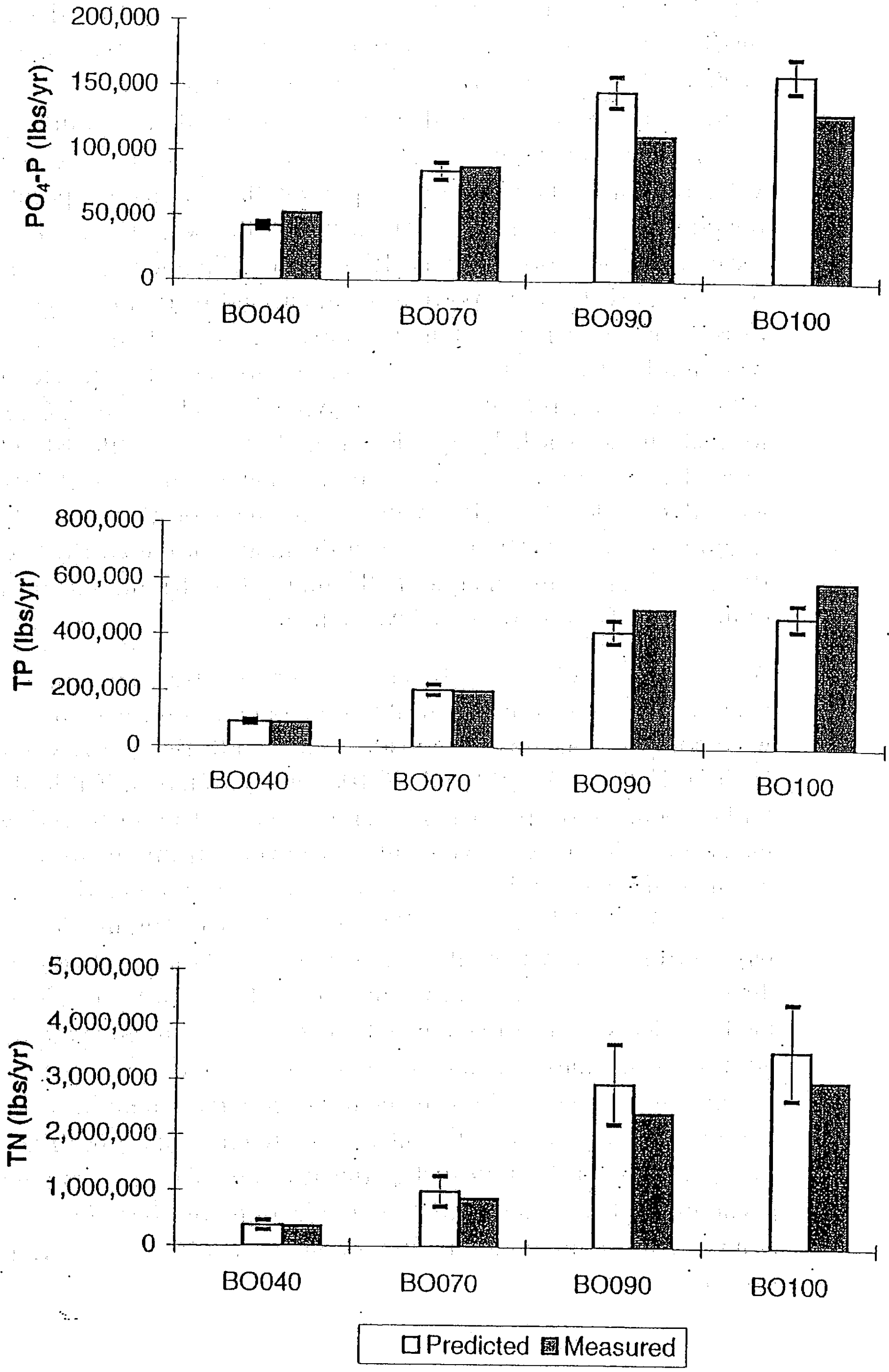
Because relatively large standard deviations were associated with the nutrient export coefficients for the agricultural land-use sectors using the regression methods (Tables 6 and 7), a Monte Carlo sampling technique (Law and Kelton, 1982) was integrated into the source-contribution model to take into account this variability. Monte Carlo simulation methods were used to predict loadings assuming a normal probability distribution as defined by the export coefficient and its standard deviation. As noted in Step 3, the standard deviation for each urban export coefficient was set equal to the derived coefficient value for this analysis. A total of 10,000 Monte Carol simulations were made. The results from the simulations were statistically analyzed to provide the average predicted loadings as well as a measure of the variance associated with the predicted loadings. The variability in WWTP loadings was not explored because these loadings were directly monitored, i.e., loadings from the WWTP were input as a constant value.

Step 8. Compare Estimated Nutrient Loadings with Monitored Loadings

Of the 17 automatic sampling sites in the watershed used for this analysis, four sites located along the North Bosque River (BO040, BO070, BO090 and BO100) were excluded from the export coefficient analysis, so they could be used to validate the coefficients developed. These four sites were selected as validation sites, because they represent the variety of point and nonpoint source nutrient loadings within the watershed. BO040, located on the North Bosque River below Stephenville, contains only a relatively small portion of urban land in its drainage basin (less than 4 percent) but is impacted by urban influences, particularly at base flow, due to its location about a quarter mile below the discharge of the Stephenville WWTP. Site BO070 is located on the North Bosque River at Hico, Texas, site BO090 is located near Clifton on the North Bosque River, and BO100 is located outside of Valley Mills along the North Bosque River (Figure 4). Site BO100 is also near the mouth of the North Bosque River drainage, thus, integrating the nutrient contributions for most of the North Bosque River subwatershed.

As validation of the estimated export coefficients, predicted loadings from the source-contribution model, as outlined in Step 7, were compared to measured loadings for North Bosque River sites BO040, BO070, BO090 and BO100, as presented in Table 4. A fairly good fit of predicted with measured data occurred with increasing differences generally occurring from upstream to downstream sites with values more closely predicted at sites BO040 and BO070 than at BO090 and BO100 (Figure 7). The larger errors at downstream sites were expected to some degree as drainage area and travel times increase. The source-contribution model reflects overall loadings into a watershed stream system and does not take into account in-stream losses and transformations beyond those accounted for by the use of in-stream data in deriving the nutrient export coefficients. In-stream transformations or losses may occur through such pathways as uptake of nitrogen and phosphorus by aquatic life, volatilization of NH_3-N to the atmosphere, sedimentation, and binding of PO_4-P to sediment particles.

Figure 7. Comparison of predicted with measured nutrient loadings on an annual basis for four sites along the North Bosque River for November 1, 1995 through March 30, 1998. Error bars represent plus and minus one standard deviation from the predicted mean.



While transformations and losses most likely explain the overestimation of PO_4-P and TN at sites BO090 and BO100 in the predicted values, the opposite is seen for TP. The predicted values for TP are notably underestimated at sites BO090 and BO100. This is an indication that the source-contribution model may not be accounting for all of the sources of TP contributing to the North Bosque River at sites BO090 and BO100 or that there may be some discrepancies in the measured data. A large amount of stream bank erosion was noted at sites BO090 and BO100 in association with large storm events that occurred in February 1997 and March 1998. This stream bank erosion may be an additional source of TP as increased in-stream TP concentrations were indicated for storm samples during these events in association with very high TSS concentrations. A fact confounding this explanation is that higher TN concentrations were also noted with these same samples, although predicted TN values on average overestimate rather than underestimate measured values at BO090 and BO100.

Another possible explanation for the poorer fit of the predicted versus measured data at BO090 and BO100 is the fact that the sampling program during the large February 1997 and March 1998 storm events had to be modified for safety reasons due to stream bank erosion at both sites. For at least part of each of these multi-day storm events, twice a day grab sampling from bridges near BO090 and BO100 was used rather than automatic sampling at set intervals.

Despite the discrepancies between predicted and measured phosphorus and nitrogen loadings apparent at sites BO090 and BO100, the overall agreement of predicted and measured nutrient loadings at the four North Bosque sites was very encouraging. The errors in predictions from the application of an export coefficient approach were within reasonable expectations. Even for direct measurements of in-stream loadings, an error of ± 25 percent in nutrient loadings is not uncommon (Loehr *et al.*, 1989). The differences between estimated and measured nutrient loadings are well within the range of what should reasonably be expected from an approach using export coefficients to estimate loadings. This verification exercise corroborates the validity of the nutrient export coefficients for the intended use of providing estimates of nutrient loadings by contributing sector for Bosque River watershed.

Step 9. Calculate Loadings and Percent Contribution by Subwatershed and Land-Use Sector

The source-contribution model, was applied to estimate loadings by subwatershed and source for the Bosque River watershed. The subwatersheds included the North Bosque River, Hog Creek, Middle Bosque River, South Bosque River, and a minor tributary group that included urban runoff from the city of Waco and smaller drainage areas near Lake Waco that were not included in other subwatershed areas (Figure 2).

As expected, the North Bosque River subwatershed was estimated to contribute the largest amount of nutrients to the Bosque River watershed compared to the other subwatersheds (Table 10). The North Bosque River watershed represents about 74 percent of the surface area of the entire Bosque River watershed and is estimated to contribute 78 percent of PO_4-P, 73 percent of TP and 57 percent of TN. A breakdown of the estimated percent contribution by land use for the entire Bosque River watershed is provided in Table 11. While comprising about 2 percent of the watershed area, dairy waste application fields were estimated to contribute on average 35 $\pm$ 4 percent of the PO_4-P, 21 $\pm$ 3 percent of the TP and 5 $\pm$ 2 percent of the TN within the Bosque River watershed during the period November 1, 1995 through March 30, 1998. Row crops were estimated to contribute the largest proportion of TN, averaging 49 $\pm$ 10 percent of the total loadings.

Table 10. Predicted annual loadings and percent of total loadings from major tributaries to the Bosque River watershed for November 1, 1995 through March 30, 1998.

	PO_4-P		TP		TN		Drainage Area
	Predicted (lbs/yr)	Percent of Total	Predicted (lbs/yr)	Percent of Total	Predicted (lbs/yr)	Percent of Total	Percent of Total
North Bosque River	163,605	78%	483,646	73%	3,710,493	57%	74%
Hog Creek	6,603	3%	30,744	5%	534,076	8%	5%
Middle Bosque River	16,076	8%	71,991	11%	1,291,180	20%	12%
South Bosque River	13,718	7%	48,827	7%	724,860	11%	6%
Other Minor Tributaries	8,369	4%	26,541	4%	195,195	3%	3%
Total Bosque River Watershed	208,371	100%	661,749	100%	6,455,805	100%	100%

Table 11. Estimated percent contribution of nutrients by source to the Bosque watershed for November 1, 1995 through March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	34.7	3.7	20.6	2.9	4.6	1.8	2.2
Row Crop	11.0	1.3	17.0	2.0	48.7	9.6	15.2
Non-Row Crop	1.4	0.2	2.2	0.3	2.4	1.4	2.0
Pasture	10.3	1.2	16.1	1.9	16.7	8.2	14.4
Wood/Range	22.4	4.4	30.5	5.6	21.7	11.7	62.8
WWTP	8.9	0.8	3.6	0.4	1.4	0.3	na
Urban	11.4	5.1	10.1	4.6	4.6	2.3	2.3

For the North Bosque River drainage area, the largest PO_4-P loadings were associated with dairy waste application with wood/range representing the next largest loading source (Table 12). For TP, these two land uses were reversed with wood/range being the largest contributing source followed by dairy waste application fields. Row-crop agriculture and wood/range were the largest contributing sources of TN to the North Bosque River drainage, both contributing about 31 percent of the total estimated loading. Pasture was the next largest contributor of TN representing almost 21 percent of the total estimated. A breakdown of the estimated loadings by source for the major subwatersheds within the Bosque River watershed is provided in Appendix A.

Table 12. Estimated percent contribution of nutrients by source to the North Bosque River watershed for November 1, 1995 through March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	43.7	4.0	28.0	3.8	8.1	3.5	3.0
Row Crop	5.0	0.6	8.4	1.1	31.2	9.0	7.4
Non-Row Crop	1.4	0.2	2.3	0.3	3.3	2.0	2.0
Pasture	9.2	1.1	15.5	1.9	20.6	10.3	13.6
Wood/Range	24.1	4.6	35.4	6.0	31.2	15.7	72.2
WWTP	10.0	0.8	4.2	0.4	1.9	0.5	na
Urban	6.6	3.1	6.3	3.0	3.7	2.1	1.4

Because the TMDL effort is specifically directed at segments 1226 and 1255 on the North Bosque River, the percent contribution by land-use sector was estimated for the drainage areas above eight points along the North Bosque River. These eight points correspond to sampling sites BO020, BO040, BO060, BO070, BO080, BO085, BO090, and BO100 (Figure 8). Sites BO040, BO070, BO090 and BO100 were used in Step 8 for model validation. Site BO020, located above Stephenville, was used in deriving the nutrient export coefficients in Step 7. Sites BO060, located between Stephenville and Hico, BO080, located near Iredell, and BO085, located near Meridian, do not have automatic samplers and are used only as grab sampling sites for water quality analysis in the monitoring program (Pearson and McFarland, 1999).

Of interest is the spatial distribution of loadings in the North Bosque River drainage (Figure 9). A disproportionately high percentage of the phosphorus loadings, particularly PO_4-P, occur in the upper portion of the North Bosque River drainage, while nitrogen loadings appear to be more evenly distributed throughout the drainage. The land use for these sites indicates that most of the dairy waste application fields, which are associated with relatively high phosphorus and nitrogen loadings, are found in the upper portion of the watershed, while row-crop areas, which are associated with relatively high nitrogen loadings, are located in the lower portion of the watershed (Table 13). Detailed results of estimated loadings by source presented in Appendix B confirm this distribution of loadings.

Table 13. Land uses within the drainage areas above TIAER sampling sites along the North Bosque River.

Site	Wood/ Range (%)	Pasture (%)	Non-Row Cropland (%)	Row Crop (%)	Dairy Waste Appl. Fields (%)	Urban (%)	Other (%)	Drainage Area† (Acres)
BO020	49.4	30.1	6.4	0.0	12.3	0.8	1.0	53,264
BO040	51.1	23.8	8.4	0.0	11.7	3.8	1.2	63,504
BO060	60.6	19.1	7.3	0.0	9.2	2.8	1.1	120,936
BO070	68.2	15.4	6.5	0.0	7.2	1.7	1.0	230,243
BO080	69.0	16.0	4.1	2.5	6.4	1.7	0.3	361,014
BO085	71.3	14.5	3.2	4.1	5.0	1.6	0.3	468,115
BO090	71.9	13.8	2.4	6.5	3.7	1.5	0.2	626,518
BO100	72.4	13.6	2.0	7.4	3.1	1.4	0.1	746,469

†Reported drainage areas determined using ARC/INFO vary somewhat from previously reported values determined using GRASS.

Figure 8. Location of TIAER sampling sites along the North Bosque River.

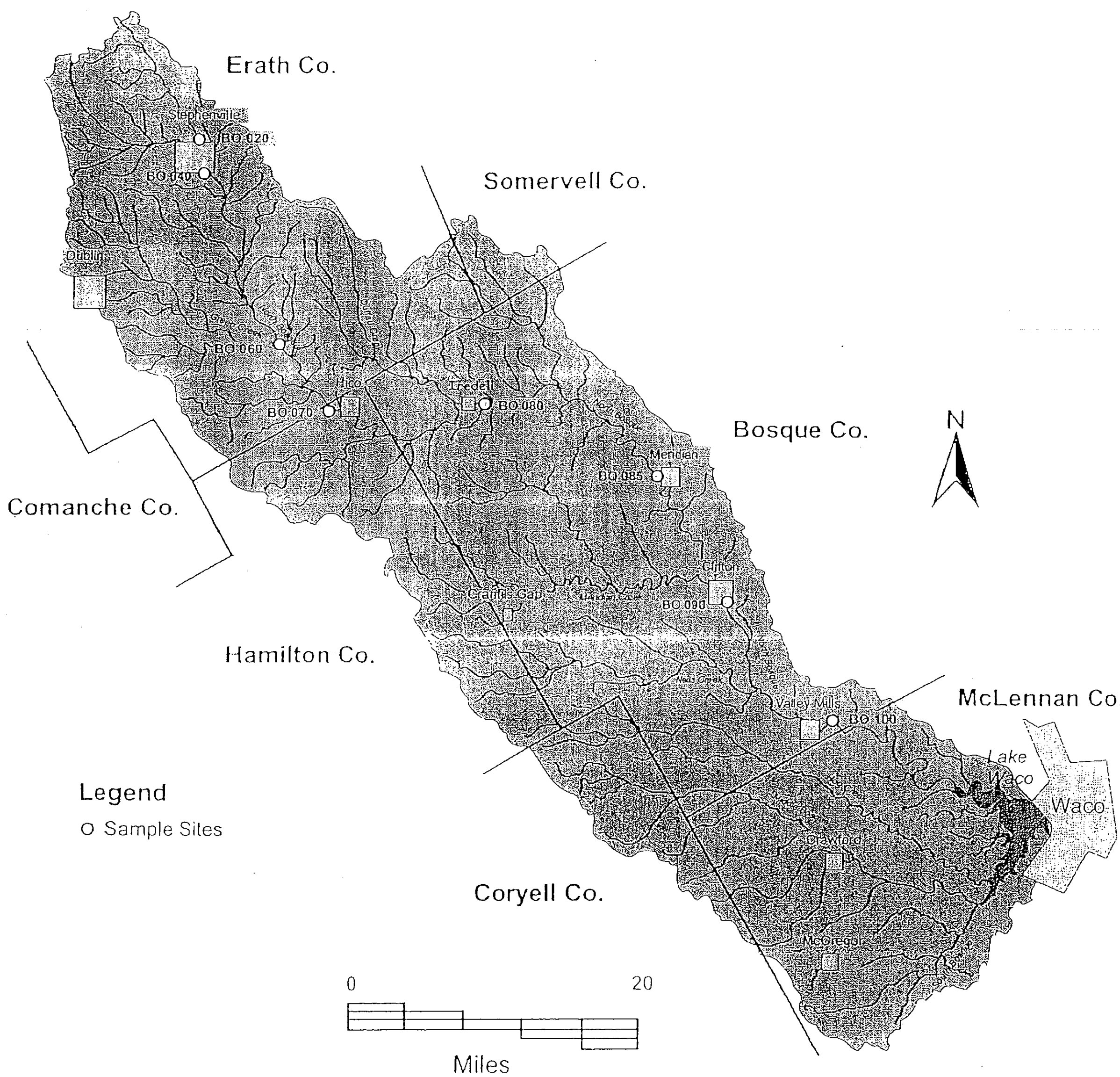
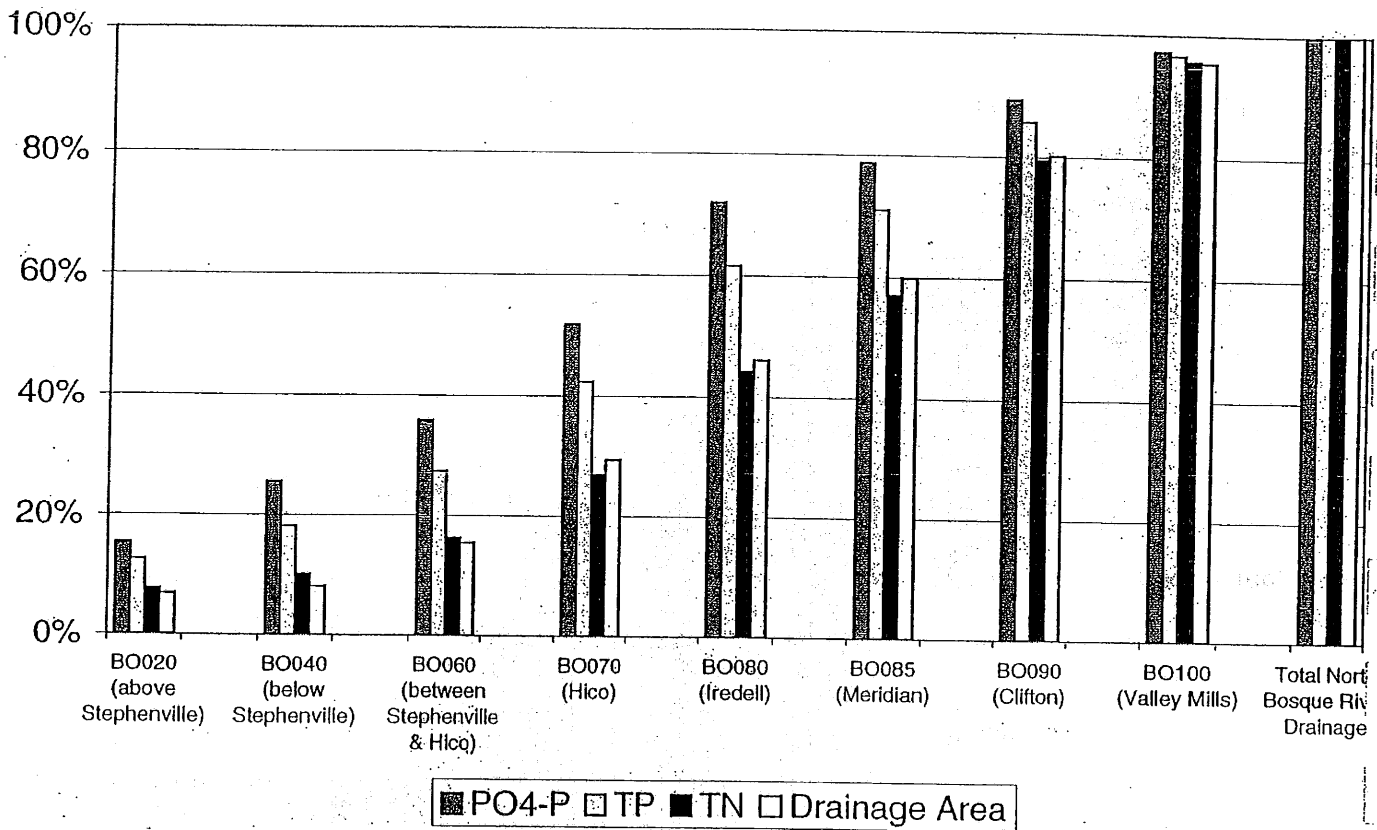


Figure 9. Percent of predicted nutrient loadings compared with percent of total drainage area represented for selected sites along the North Bosque River.



The agricultural export coefficients, while based on an extremely large database from a monitoring perspective, represent a relatively small database (12 sites) from a statistical perspective. Ideally, 30 or more sites would be used in such an analysis to give adequate power to the regression analysis approach of estimating nutrient export coefficients. The relatively large standard deviations associated with the nutrient export coefficients partially reflect the size of the data set from which these coefficients were derived as well as the inherent variability in environmental characteristics. This variability arises from the spatial distribution in slope, soils, and management practices associated with each land use. Additional sites, representing a broader range of each land use category, both urban and agricultural, might help refine these nutrient export coefficients. The Monte Carlo analysis used in this study helps take into account a large portion of the variability associated with the individual export coefficients for the various land uses without the expense and time of collecting additional data.

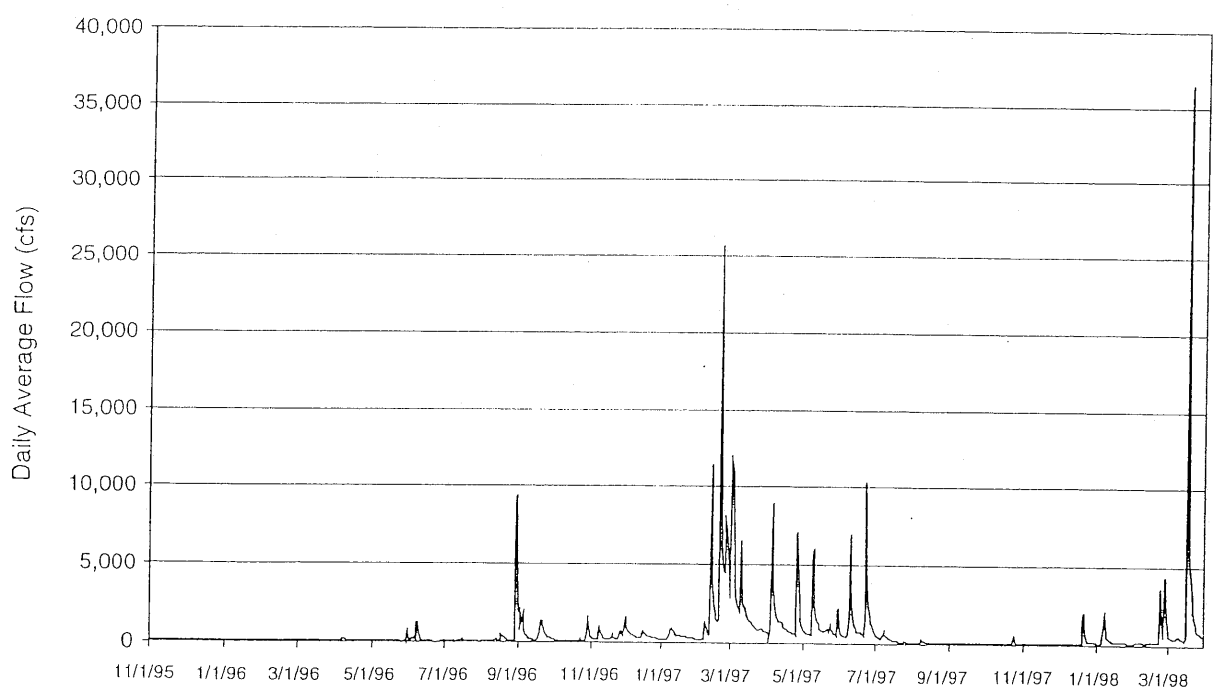
The multiple regression approach for determining nutrient export coefficients maximizes the use of streamflow and water quality data from steam sites with mixed land-use drainage areas within a monitoring network without the need for isolating individual land uses. Further, the multiple regression method provides export coefficients representing the average of conditions and practices (e.g., soils, planting and harvest dates, fertilization timing and amounts, slopes, tillage practices, and proximity to streams) of each land use across the Bosque River watershed, as opposed to export coefficients determined for the more limited practices and conditions of small, single land-use drainage areas. Whether determined by regression techniques from in-stream monitoring sites, as in this study, or from monitoring of individual land uses, the export coefficients are indicative of the climatic conditions under which the monitoring data were collected. The longer the duration of the monitoring data set, the more likely the export coefficients include a range of weather conditions (e.g., high and low rainfall periods), typifying average nutrient contributions, and do not include potentially undesirable biases from over representation of meteorological extremes.

Export coefficients are highly dependent on the environmental conditions from which they are based and extrapolation to other time periods or regions can be problematic. It should be emphasized that large storm events carry the majority of the nutrient loadings within the Bosque River watershed. For the monitoring period November 1, 1995 and March 30, 1998 about 50 percent of the flow at BO100, North Bosque River near Valley Mills, occurred in the months of February 1997 and March 1998 (Figure 10). In comparison to long-term monthly flow data for the USGS gauging station near BO100, February 1997 represents the highest month of flow on record and March 1998 represents the third highest month of flow on record. During the study period, the flow at BO100 averaged 630 cfs more than double the long-term average of 283 cfs for 1960 through 1995. These above average hydrologic conditions should be considered in using the calculated export coefficient values beyond the time period evaluated and in evaluating the relative nutrient contribution by sector. A reasonable expectation is that point source loadings associated with WWTPs will increase in relative importance as contributors of nutrients with decreasing rainfall and stream flow. This underscores the importance of understanding the climatic and hydrologic conditions under which export coefficients are determined before using them in watershed planning efforts. The derived nutrient export coefficients and, thus, the source-contribution model results presented in this study are specific to the time period November 1, 1995 through March 30, 1998 and care should be taken in extrapolating these results to other timeframes or watersheds.

The calculated agricultural and urban nutrient export coefficients do provide a good indication of the nutrient contribution from land uses within the upper North Bosque River watershed for PO_4-P, TP and TN for November 1, 1995 through March 30, 1998. Export coefficient values from this study were within the range of values for similar land uses reported in the literature for other studies. Predicted loadings of PO_4-P, TP and TN using export coefficient values in the source-contribution model also compared favorably with measured loadings at North Bosque River sites BO040, BO070, BO090 and BO100 used for model validation.

The largest relative contributions of PO_4-P, TP and TN within the Bosque River watershed were associated with the North Bosque River subwatershed, which is expected as the North Bosque River drainage represents about 74 percent of the total Bosque River watershed. For the study period, over 70 percent of the PO_4-P and TP and over 50 percent of the TN loadings were associated with the North Bosque River subwatershed. Almost 40 percent of the TN and less than 25 percent of the phosphorus loadings were associated with subwatersheds in the southern part of the watershed, i.e., Hog Creek, Middle Bosque River and South Bosque River. The largest contributing source of PO_4-P and TP to the Lake Waco/Bosque River drainage were dairy waste application fields and wood/rangeland, while the largest contributing source of TN was row-crop fields. Most dairy waste application fields in the watershed are found in the upper portion of the North Bosque River drainage area, while most row-crop fields are found in the southern portion of the watershed within the Hog Creek, Middle Bosque and South Bosque River drainage areas.

Figure 10. Average daily flow at site BO100 on the North Bosque River near Valley Mills for November 1, 1995 through March 30, 1998.



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APPENDIX A: NUTRIENT CONTRIBUTION BY SOURCE FOR MAJOR SUBWATERSHEDS WITHIN THE BOSQUE RIVER WATERSHED

Table A-1. Estimated percent contribution of nutrients by source within the North Bosque River drainage area for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	43.7	4.0	28.0	3.8	8.1	3.5	3.0
Row Crop	5.0	0.6	8.4	1.1	31.2	9.0	7.4
Non-Row Crop	1.4	0.2	2.3	0.3	3.3	2.0	2.0
Pasture	9.2	1.1	15.5	1.9	20.6	10.3	13.6
Wood/Range	24.1	4.6	35.4	6.0	31.2	15.7	72.2
WWTP	10.0	0.8	4.2	0.4	1.9	0.5	na
Urban	6.6	3.1	6.3	3.0	3.7	2.1	1.4

Table A-2. Estimated percent contribution of nutrients by source within the Hog Creek drainage area for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	0	0	0	0	0	0	0
Row Crop	44.7	3.9	47.4	3.8	74.8	8.3	36.4
Non-Row Crop	na	na	na	na	na	na	na
Pasture	22.7	2.4	24.1	2.4	14.0	6.9	18.5
Wood/Range	26.8	4.9	25.0	4.8	10.4	6.2	44.2
WWTP	0	0	0	0	0	0	na
Urban	5.8	2.7	3.5	1.7	0.9	0.5	0.7

Table A-3. Estimated percent contribution of nutrients by source within the Middle Bosque River drainage area for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	4.9	0.7	2.1	0.3	0.3	0.1	0.2
Row Crop	46. 9	3.9	51.7	3.8	78.8	7.1	41.8
Non-Row Crop	na	na	na	na	na	na	na
Pasture	17.6	1.9	19.4	1.9	11.0	5.6	15.6
Wood/Range	22.4	4.4	21.8	4.4	8.8	5.3	40.4
WWTP	0.2	0.0	0.1	0	0.0	0	na
Urban	8.1	3.7	5.1	2.4	1.2	0.6	1.1

Table A-4. Estimated percent contribution of nutrients by source within the South Bosque River drainage area for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	0	0	0	0	0	0	0
Row Crop	29.7	5.9	40.7	6.3	73.5	6.5	48.1
Non-Row Crop	na	na	na	na	na	na	na
Pasture	12.3	2.6	16.8	2.8	11.3	5.7	19.8
Wood/Range	6.8	2.0	8.2	2.2	4.0	2.5	22.2
WWTP	16.7	3.2	7.0	1.1	3.1	0.5	na
Urban	34.5	12.5	27.3	10.6	8.2	3.9	8.8

Table A-5. Estimated percent contribution of nutrients by source within the minor tributaries within the Bosque River Watershed near Lake Waco area for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	0	0	0	0	0	0	0
Row Crop	8.2	5.4	11.9	5.8	39.7	10.4	12.6
Non-Row Crop	na	na	na	na	na	na	na
Pasture	4.4	2.9	6.3	3.1	7.9	4.4	6.7
Wood/Range	13.3	9.0	17.0	8.7	14.4	8.7	41.3
WWTP	0	0	0	0	0	0	na
Urban	74.1	16.9	64.8	16.9	38.0	13.9	21.9

APPENDIX B: NUTRIENT CONTIBUTION BY SOURCE FOR SELECTED SITES ALONG THE NORTH BOSQUE RIVER

Table B-1. Estimated percent contribution of nutrients by source for the drainage area above site BO100 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	44.9	4.0	29.0	3.9	8.5	3.6	3.1
Row Crop	4.9	0.6	8.3	1.1	31.2	9.0	7.4
Non-Row Crop	1.4	0.2	2.3	0.3	3.3	2.0	2.0
Pasture	9.0	1.0	15.2	1.9	20.5	10.3	13.6
Wood/Range	23.7	4.6	35.0	6.0	31.2	15.7	72.4
WWTP	9.8	0.8	4.2	0.4	1.8	0.5	na
Urban	6.4	3.0	6.1	2.9	3.6	2.0	1.4

Table B-2. Estimated percent contribution of nutrients by source for the drainage area above site BO090 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	49.0	4.0	32.7	4.2	10.2	4.3	3.7
Row Crop	4.0	0.5	6.9	0.9	27.8	8.2	6.5
Non-Row Crop	1.5	0.2	2.6	0.3	3.9	2.4	2.4
Pasture	8.4	1.0	14.7	1.8	21.1	10.5	13.8
Wood/Range	21.6	4.3	33.0	5.8	31.4	15.7	71.9
WWTP	9.5	0.8	4.2	0.4	1.9	0.5	na
Urban	6.1	2.9	6.0	2.9	3.8	2.1	1.5

Table B-3. Estimated percent contribution of nutrients by source for the drainage area above site BO085 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

Source	PO_4-P (%) Mean	PO_4-P (%) Std	TP (%) Mean	TP (%) Std	TN (%) Mean	TN (%) Std	Land Use (%)
Dairy Waste Appl.	55.3	4.0	39.3	4.5	14.2	6.0	5.0
Row Crop	2.1	0.3	3.9	0.5	18.5	6.0	4.1
Non-Row Crop	1.7	0.2	3.1	0.4	5.4	3.3	3.2
Pasture	7.5	0.9	13.9	1.7	23.0	11.4	14.5
Wood/Range	18.2	3.8	29.5	5.5	32.4	16.3	71.3
WWTP	9.7	0.8	4.5	0.5	2.1	0.7	na
Urban	5.6	2.6	5.8	2.8	4.3	2.5	1.6

Table B-4. Estimated percent contribution of nutrients by source for the drainage area above site BO080 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	59.9	3.7	44.7	4.6	18.1	7.5	6.4
Row Crop	1.1	0.1	2.1	0.3	11.3	3.9	2.5
Non-Row Crop	1.8	0.2	3.5	0.4	6.9	4.2	4.1
Pasture	7.0	0.8	13.6	1.6	25.1	12.3	16.0
Wood/Range	14.9	3.0	25.5	5.0	31.4	16.1	69.0
WWTP	10.4	0.8	5.1	0.5	2.7	0.8	na
Urban	5.0	2.4	5.5	2.6	4.5	2.6	1.7

Table B-5. Estimated percent contribution of nutrients by source for the drainage area above site BO070 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	60.4	3.5	47.2	4.6	21.7	9.0	7.2
Row Crop	na	na	na	na	na	na	0.0
Non-Row Crop	2.5	0.3	5.1	0.6	11.4	6.7	6.5
Pasture	5.9	0.7	12.1	1.4	25.5	12.7	15.4
Wood/Range	13.0	2.9	23.4	4.8	32.5	16.7	68.3
WWTP	13.7	1.1	7.1	0.7	4.1	1.4	na
Urban	4.5	2.2	5.2	2.5	4.9	2.9	1.7

Table B-6. Estimated percent contribution of nutrients by source for the drainage area above site BO060 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)		TP (%)		TN (%)		Land Use (%)
Source	Mean	Std	Mean	Std	Mean	Std	
Dairy Waste Appl.	58.1	3.9	48.5	4.3	23.3	8.9	9.2
Row Crop	na	na	na	na	na	na	0.0
Non-Row Crop	2.1	0.2	4.7	0.6	10.9	6.2	7.3
Pasture	5.6	0.6	12.2	1.4	26.8	12.6	19.1
Wood/Range	8.8	2.0	16.9	3.7	25.6	13.9	60.5
WWTP	19.8	1.5	10.9	1.0	6.6	1.9	na
Urban	5.6	2.7	6.9	3.2	6.8	3.7	2.8

Table B-7. Estimated percent contribution of nutrients by source for the drainage area above site BO040 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)			TP (%)			TN (%)			Land Use (%)
Source	Mean	Std		Mean	Std		Mean	Std		
Dairy Waste Appl.	54.4	3.2		48.8	4.1		24.8	8.8		11.7
Row Crop	na	na		na	na		na	na		0.0
Non-Row Crop	1.8	0.2		4.2	0.5		10.5	5.8		8.4
Pasture	5.1	0.6		12.0	1.3		27.9	12.5		23.8
Wood/Range	5.5	1.3		11.3	2.6		18.7	10.8		51.0
WWTP	27.7	1.9		16.4	1.4		10.6	2.7		na
Urban	5.6	2.6		7.3	3.4		7.6	4.0		3.8

Table B-8. Estimated percent contribution of nutrients by source for the drainage area above site BO020 on the North Bosque River for November 1, 1995 though March 30, 1998. 'na' indicates not applicable.

	PO_4-P (%)			TP (%)			TN (%)			Land Use (%)
Source	Mean	Std		Mean	Std		Mean	Std		
Dairy Waste Appl.	80.0	2.5		62. 5	4.0		29.8	11.8		12.3
Row Crop	na	na		na	na		na	na		0.0
Non-Row Crop	1.9	0.2		3.9	0.5		9.2	5.7		6.4
Pasture	9.0	1.1		18.5	2.1		38.7	16.1		30.1
Wood/Range	7.4	1.8		13.2	3.1		20.4	12.3		49.4
WWTP	0.0	0.0		0.0	0.0		0.0	0.0		na
Urban	1.7	0.8		2.0	1.0		1.9	1.2		0.8

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Lake Waco-Bosque River Initiative

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Acknowledgments

The United States Department of Agriculture Lake Waco-Bosque River Initiative supported this study with additional funding provided by the State of Texas. The authors wish to acknowledge the support and dedicated work of the many field personnel and laboratory chemists involved with the monitoring program. Particularly with regards to storm water monitoring on tributaries flowing into Lake Waco, as rain often falls on weekends requiring staff to be on call seven days a week.

Mention of trade names or equipment manufacturers does not represent endorsement of these products or manufacturers by TIAER.

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USDA02.08

Abstract

Monitoring data collected between June 1996 and December 1999 were used to characterize water quality within Lake Waco with particular emphasis on factors influencing algal growth. A spatial analysis of surface water quality for Lake Waco established two different longitudinal patterns within the reservoir based on distance from major tributary inflows. For physical characteristics, such as conductivity and Secchi depth, riverine, transition, and lacustrine zones were identified along the northern and southern arms of the reservoir with increasing distance from major tributary inflows. For chemical and biological characteristics, such as chlorophyll-α (CHLA) and nitrogen (N) concentrations, a longitudinal gradient within the reservoir was followed based on proximity to either the northern or southern tributary inflows. The highest CHLA concentrations occurred nearest the inflow of the North Bosque River, while the highest total N and dissolved inorganic N concentrations occurred nearest the inflow of the Middle-South Bosque River. Over time, reservoir concentrations of soluble nutrients showed a strong positive correlation with the amount of inflow from the major tributaries. A strong depletion of soluble nutrients with increasing CHLA concentrations was apparent between inflow events, particularly during summer months when warmer temperatures allowed more active algal growth. The reservoir showed very little temperature stratification, although a decrease in dissolved oxygen and pH with depth was indicated during summer months. A slight release of ammonia from bottom sediments was also indicated during the summer, but no corresponding release of orthophosphate was apparent. During the summer, Lake Waco was characterized as eutrophic using a trophic state index based on CHLA or Secchi depth measurements. Phosphorus was identified as the limiting nutrient for algal growth within the reservoir with potential N limitation occurring in late summer or early fall.

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CHAPTER 1

Introduction

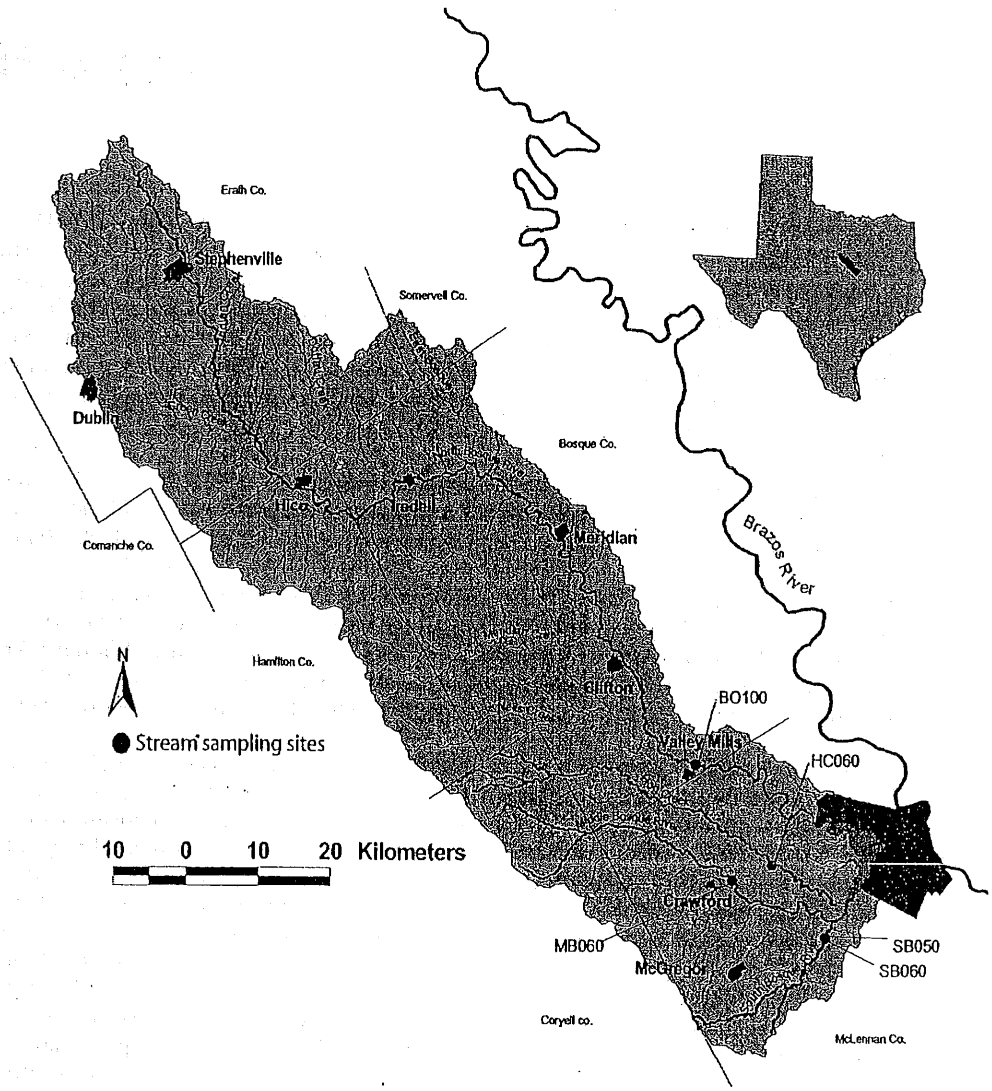
Lake Waco in McLennan County, Texas is an impoundment of the Bosque River. The drainage area of the reservoir covers about 430,000 hectares (1,060,000 acres) and extends northwest to southeast from Stephenville to Waco, Texas (Figure 1). The North Bosque River, Middle Bosque River, South Bosque River, and Hog Creek are major tributaries to the reservoir, with the North Bosque River drainage area representing about 74 percent of the total area. These four tributaries converge at Lake Waco to form the Bosque River. The Bosque River is only about 10 river kilometers (6 miles) in length below Lake Waco and merges with the Brazos River on the northeast side of Waco.

The city of Waco constructed Lake Waco as a municipal water supply in 1929. The reservoir was enlarged in 1964 by the U.S. Army Corps of Engineers (USACE) to 18,760 hectare-meters (152,500 acre-feet) within the conservation storage pool, with an additional 68,000 hectare-meters (550,00 acre-feet) allocated to flood control (USACE, 1982). From October 1964 to February 1965, the reservoir was operated only as a detention basin. On February 26, 1965, deliberate impoundment began in the enlarged reservoir (Sullivan et al., 1995). More recently, the USACE began work in September 1998 to raise the dam height an additional 1.5 meters (5 feet) to increase flood storage and protect dam integrity in case of extreme rainfall events (Smith, 1999). The dam height extension was completed during the summer of 1999.

Based on a 1995 volumetric survey, Lake Waco encompasses a surface area of about 2,914 hectares (7,194 acres) and contains a volume of 17,814 hectare-meters (144,830 acre-feet) at the top of the conservation pool, an elevation of 138 meters (455 feet) above mean sea level (USACE, 1995). The Brazos River Authority and the city of Waco jointly hold the water rights to the conservation storage and supply water to a service population of about 150,000 in Waco and nearby communities. There are plans to reallocate 5,840 hectare-meters (47,500 acre-feet) from flood control storage to the conservation pool to increase the water supply storage for expected increasing population demands (USACE, 1982). This reallocation according to the USACE (1982) would increase the conservation pool elevation by 2.1 meters (7 feet) and increase the land area permanently inundated by 484 hectares (1,195 acres). There is no firm time line for this project, as Waco city officials and the USACE are developing plans for handling the recreational areas that will be submerged by the expanded reservoir (Smith, 1999). A draft Environmental Assessment for raising of the conservation pool is available from the USACE Fort Worth District and Waco Area Offices (USACE, 2000).

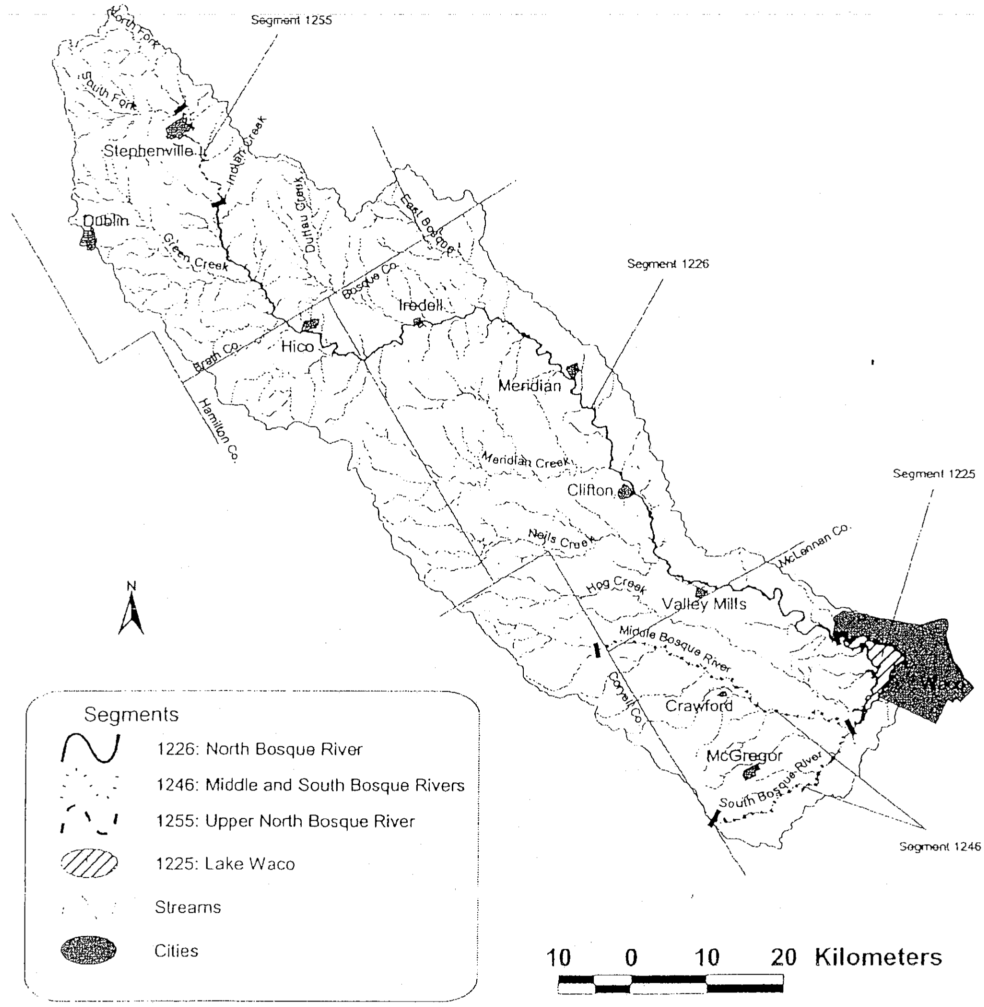
The Texas Natural Resource Conservation Commission (TNRCC) classifies Lake Waco as segment 1225 (Figure 2). The designated uses for Lake Waco (segment 1225) are contact recreation, high aquatic life, and public water supply. Agricultural operations are thought to be the major contributors of nonpoint source pollution within the reservoir watershed (TNRCC, 1996). Three stream segments are also classified within the Bosque River watershed above Lake Waco. These are segments 1226, 1255, and 1246 (Figure 2). Segment 1226 is defined as the North Bosque River from a point 100 meters (328 feet) upstream of Farm-to-Market (FM) Road 185 in McLennan County to a point immediately above the confluence of Indian Creek in Erath County. Designated uses for segment 1226 include contact recreation, high aquatic life, and public water supply. Segment 1255 is defined as the North Bosque River from

Figure 1 Bosque River and Lake Waco watershed area.
Stream sampling site locations near the reservoir are referenced.



a point immediately above its confluence with Indian Creek to the confluence of the North and South Forks of the North Bosque River. Designated uses for segment 1255 include contact recreation and intermediate aquatic life. Segment 1246 includes those portions of the Middle and South Bosque Rivers located in McLennan County as well as a small portion of the Middle Bosque River in Coryell County up to its confluence with Cave Creek. Designated uses for segment 1246 include contact recreation and high aquatic life.

Figure 2 Classified segments in the Bosque River watershed.



In a recent State of Texas Water Quality Inventory (TNRCC, 1996), water quality concerns were indicated for all three classified stream segments in the watershed above Lake Waco. Nonpoint source pollution loadings from agricultural operations were noted as concerns for segment 1246, the Middle Bosque-South Bosque River, in association with elevated nitrogen levels. Nonpoint source loadings associated with elevated nutrient and fecal coliform levels were described as the most serious threat to meeting designated uses within segments 1226 and 1225 (TNRCC, 1996). The two North Bosque River segments, 1226 and 1255, are included on the State of Texas 1999 Section 303(d) and the draft 2000 Section 303(d) list for total maximum daily load (TMDL) development (TNRCC, 1999a; 2000). Nutrients are the focus of this TMDL effort due to the role of nutrients in promoting excessive growth of algae as indicated by elevated chlorophyll-α levels throughout segments 1226 and 1255 (TNRCC, 1999a; 2000). Although Lake Waco is not listed on the State of Texas Section 303(d) list, water quality in Lake Waco is a concern because of nutrient loadings from the North Bosque River.

While nutrient and chlorophyll-α concentrations within Lake Waco are not currently at levels to be considered a concern based on TNRCC water quality assessments, the rate of algal production within the reservoir has been a concern almost since its inception. As early as 1967, taste and odor problems associated with algal blooms were an issue within Lake Waco. As a mitigation effort, an aerator was located near the dam to help circulate water to avoid temperature stratification near the water supply outlet (Biederman and Fulton, 1971). The city of Waco has been very interested in the rate of algal growth within the reservoir, because water treatment for controlling taste and odor problems associated with algae can be quite costly.

Increases in the production of algae are often associated with accelerated eutrophication. Eutrophication refers to the natural nutrient enrichment of a water body that occurs over time, while accelerated or cultural eutrophication refers to an increased rate of nutrient enrichment associated with human activities. Increases in algal production associated with accelerated eutrophication are often characterized by undesirable or even noxious algal blooms. These large, dense, persistent populations of algae can produce aesthetic as well as chemical and biological changes in a lake or reservoir. When an algal bloom occurs, the water often takes on a greenish color, and water clarity decreases. In some cases, algal mats form. Mats of filamentous or branched algae may interfere with swimming, boating, and fishing.

From an ecosystem perspective, algae from a bloom may weaken or kill submerged aquatic plants by blocking sunlight needed for photosynthesis. In addition, algal blooms can harm fish and other aquatic life by decreasing oxygen available in the water. Algae, like all plants, require oxygen for respiration. A sudden increase in the population of algae can cause large diurnal swings in the amount of dissolved oxygen in a water body. Oxygen levels can become greatly depleted, particularly at night, when algae use oxygen in respiration but are not resupplying oxygen through photosynthesis. As the algae from a bloom die off, the decomposition of dead algae can further deplete water oxygen supplies. Without adequate oxygen, fish kills may occur (Boyd, 1990).

From a drinking water perspective, algal blooms are undesirable, because they can significantly increase water treatment costs, particularly in small drinking water reservoirs, by increasing filtration and disinfection requirements (Walker, 1983). Some algae release undesirable substances, such as geosmin from *Oscillatoria chalybea* or 2-methylisoborneol (MIB) from *Anabaena circinalis* (Izaguirre et al., 1982). Geosmin and MIB are associated with taste and odor problems in drinking water that are very costly to treat. The chlorination step in many water treatment processes may also lead to the formation of chlorinated hydrocarbons, such as trihalomethanes. Trihalomethanes are a potential health risk, because they exhibit, or are suspected of having, carcinogenic or mutagenic properties (Palstorm et al., 1988; Martin and Cooke, 1994). These undesirable chlorination by-products increase with increases in organic matter and ammonia from the decay of algae (Rook, 1976). In addition, cyanobacteria (blue-green algae), which are often associated with algal blooms, are capable of producing potent toxins (Codd, 1995). These toxins have been linked to animal poisonings and several forms of human illness (Lawton and Codd, 1991).

As nutrients, particularly nitrogen and phosphorus, are necessary components for the growth and reproduction of algae, increased availability of these nutrients is likely to stimulate an increase in the production of algae (e.g., Edmondson, 1972). Most nutrient contributions to Lake Waco come from terrestrial sources via rainfall-runoff events. The land area above Lake Waco is primarily rural and used for farming and livestock grazing, although it also supports some intensive agriculture. Dairy operations are concentrated in the headwaters of the North Bosque River, while row-crop agriculture is prominent in the southern portion of the watershed (McFarland and Hauck, 1999). The cities of Stephenville (estimated population 16,000), Hico (1,500), Iredell (370), Meridian (1,500), Clifton (3,600), Valley Mills (1,200), Crawford (700), and McGregor (4,800) represent urban runoff as well as point source contributions via wastewater treatment plant discharges to tributaries within the watershed

(Figure 1). Small portions of the cities of Dublin and Waco also contribute urban runoff within the reservoir's drainage area.

To provide an understanding of nutrient loadings and water quality dynamics within Lake Waco, the Texas Institute for Applied Environmental Research (TIAER) initiated water quality monitoring of Lake Waco in June 1996. Stream monitoring on all four major tributaries flowing into Lake Waco has occurred since November 1996 (McFarland and Hauck, 1998). This monitoring is part of the Lake Waco-Bosque River Watershed Initiative funded through the United States Department of Agriculture. The purpose of the Initiative is to demonstrate the integration of community involvement with scientific information in identifying, assessing, and implementing ways to meet water quality targets using Lake Waco and streams within the Bosque River watershed (TIAER, 1998). The monitoring data herein provide background information on current conditions within Lake Waco and explore the dynamics influencing eutrophication within the reservoir. The stream and reservoir monitoring data have also been used in calibrating computer models to evaluate the impact of changing land management practices on stream loadings and water quality within Lake Waco (Flowers et al., 2001) and in developing nutrient targets for Lake Waco (Kiesling et al., 2001).

The purpose of this report is to characterize the water quality within Lake Waco for samples collected between June 1996 and December 1999 with particular emphasis on factors influencing algal growth. In assessing the water quality within Lake Waco, this report focuses on answering the following questions:

1. Is there spatial variability in the surface water quality within the reservoir, and, if so, how does it vary with regard to physical characteristics, such as conductivity and Secchi depth, versus chemical and biological characteristics, such as nutrient and chlorophyll-α concentrations?
2. Can tributary loadings be related to nutrient and algal dynamics within the reservoir, and if so, how best can these relationships be described?
3. Does water quality vary with depth within the main body of the reservoir, and, if so, are internal nutrient loadings an important source of available nutrients for algal growth?
4. What is the trophic status and overall assessment of water quality within Lake Waco, based on Texas assessment guidelines, and what variable or variables best describe the trophic state of the reservoir for tracking future changes?
5. What is the limiting nutrient for algal growth within Lake Waco, and can a functional relationship be developed between the limiting nutrient and algal biomass as a guide for controlling algal growth?

CHAPTER 2

Morphometric Characteristics

The presented summary of morphometric characteristics for Lake Waco is based on a 1995 volumetric survey conducted for the USACE (Table 1). The conservation pool capacity for Lake Waco was estimated as 18,758 hectare-meters (152,500 acre-feet) in 1964 as measured from the top of the conservation pool at 138 meters (455 feet) above mean sea level. Sedimentation over time has changed this volume. In 1970, the USACE performed a sedimentation survey and measured a 408 hectare-meter (3,300 acre-feet) decrease in conservation storage volume (USACE, 1975). This equates to a loss rate of about 70 hectare-meters per year (550 acre-feet per year) between 1964 and 1970. In January 1995, the Texas Water Development Board (TWDB) conducted a volumetric survey of Lake Waco for the USACE (Sullivan et al., 1995). Results of this survey indicated a further reduction in the conservation storage volume to 17,800 hectare-meters (144,830 acre-feet) with an estimated loss rate of about 20 hectare-meters per year (175 acre-feet per year) from 1970 to 1995.

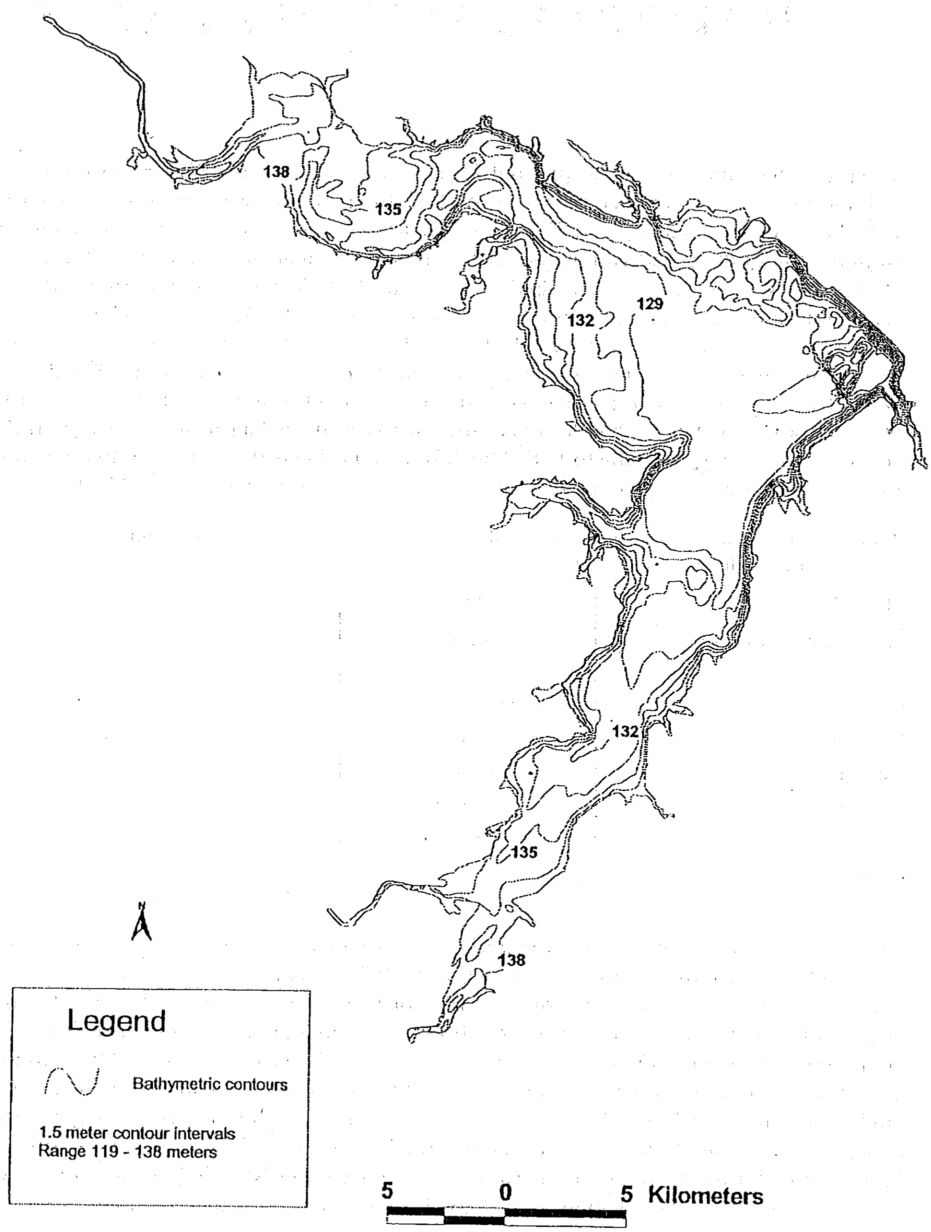
Table 1 Morphometric characteristics of Lake Waco at conservation pool elevation (adapted from Sullivan et al., 1995).

Characteristic	Value
Elevation above mean sea level	138 meters
Surface area	2,914 hectares
Volume	17,814 hectare-meters
Maximum depth	22 meters
Mean depth	6 meters
Watershed area	430,000 hectares
Length of shoreline	91 kilometers
Shoreline development index	4.8

The length of the shoreline was estimated as 91 kilometers (57 miles) at a pool elevation of 138 meters (455 feet) above mean sea level using the 1995 survey data (Sullivan et al., 1995). This length leads to a shoreline development index of 4.8 reflecting the irregular and dendritic shape of the reservoir (Table 1). The shoreline development index relates the length of the shoreline to the circumference of a circle with the same surface area (Cole, 1994). An index of 1.0 is the smallest possible value indicating that the shoreline of a water body forms a perfect circle. As an impoundment, Lake Waco has an irregular shoreline and two elongated stretches associated with the North Bosque River and the Middle-South Bosque Rivers (Figure 1). The longest stretch runs from the south arm near the entry of the Middle-South Bosque Rivers to the dam. This stretch lies at about a 30-degree angle from the north and almost parallels the prevailing southerly wind direction (Larkins and Bomar, 1983).

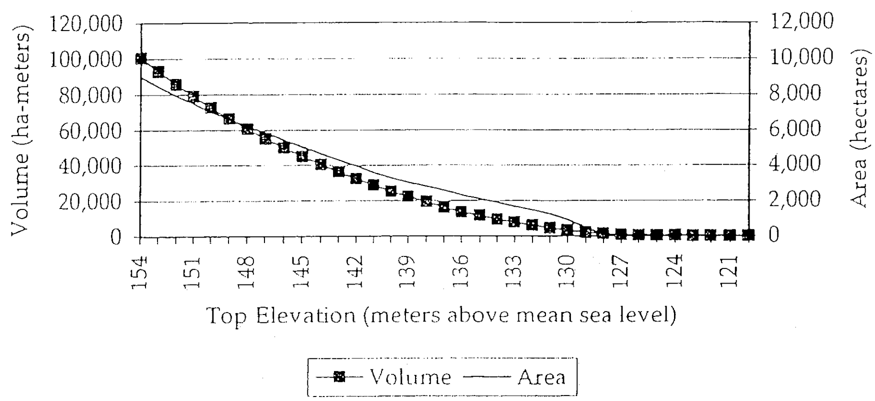
The bathymetry of the reservoir as derived from the 1995 TWDB survey is presented in Figure 3. The reservoir is relatively shallow with a maximum conservation-pool depth near the dam of 22 meters (72 feet). The main body of the reservoir is generally between 9 to 11 meters (30 to

Figure 3 Lake Waco bathymetry (adapted from Sullivan et al., 1995).



36 feet) deep. A notable decrease in depth occurs along the northern and southern arms of the reservoir to about 1.5 meters (5 feet) where the North Bosque River, Hog Creek, and the Middle-South Bosque Rivers merge with the reservoir. The hypsographic curves relating volume to depth and area to depth provide a summary of the subsurface information for Lake Waco (Figure 4).

Figure 4 Hypsographic curves for Lake Waco (adapted from Sullivan et al., 1995).



CHAPTER 3

Monitoring Program

In June 1996 TIAER initiated a monitoring program on Lake Waco which includes routine water quality sampling on a monthly or biweekly basis at sites throughout the reservoir. Data collected between June 1996 and December 1999 are presented with particular emphasis given to analyzing nutrient constituents due to their potential impact on accelerated eutrophication of Lake Waco. All data collection and analyses were conducted under the TNRCC approved Quality Assurance Project Plan or QAPP for the Lake Waco-Bosque River Watershed Initiative (e.g., TIAER, 1998).

Complementing the TIAER reservoir monitoring program is a stream monitoring program that includes sampling sites on each of the four major tributaries flowing into Lake Waco (Figure 1). Stream sampling sites are located in the lower reaches on the North Bosque River (BO100), Hog Creek (HC060), Middle Bosque River (MB060), and South Bosque River (SB050 and SB060). Water quality samples are collected routinely on a biweekly basis using manual grab samples, and collected on an event basis using automatic storm water monitoring equipment. Water level is recorded continuously for each stream site at five-minute intervals and combined with stage-discharge relationships as a measure of stream flow. At BO100 provisional flow data are obtained from the USGS for station 08095200.

Lake Waco Sampling Sites

The sampling program for Lake Waco consists of 13 sites (Figure 5). Twelve of the 13 sites were initiated in June 1996 (Table 2). LW070 was added to the sampling program in November 1996. To offset lab costs associated with constituent analyses and to focus the monitoring more specifically on the main body of the reservoir, reductions were made in the number of sites monitored. Five sites (LW011, LW016, LW020, LW030, and LW040) were removed from the monitoring program in March 1998 and three more sites (LW010, LW017, and LW050) were removed in October 1998. Routine monitoring was conducted on a monthly or biweekly schedule with specific sampling dates for each site outlined in Tables 3-6. In addition, grab samples were collected at sites LW013, LW015, and LW070 on a monthly basis between December 1996 and November 1998 for bioassay experiments. Sampling and analysis methods specific to the bioassay experiments are discussed in Chapter 8, "Nutrient Limitation and Algal Growth Responses."

Figure 5 Sampling sites on Lake Waco.

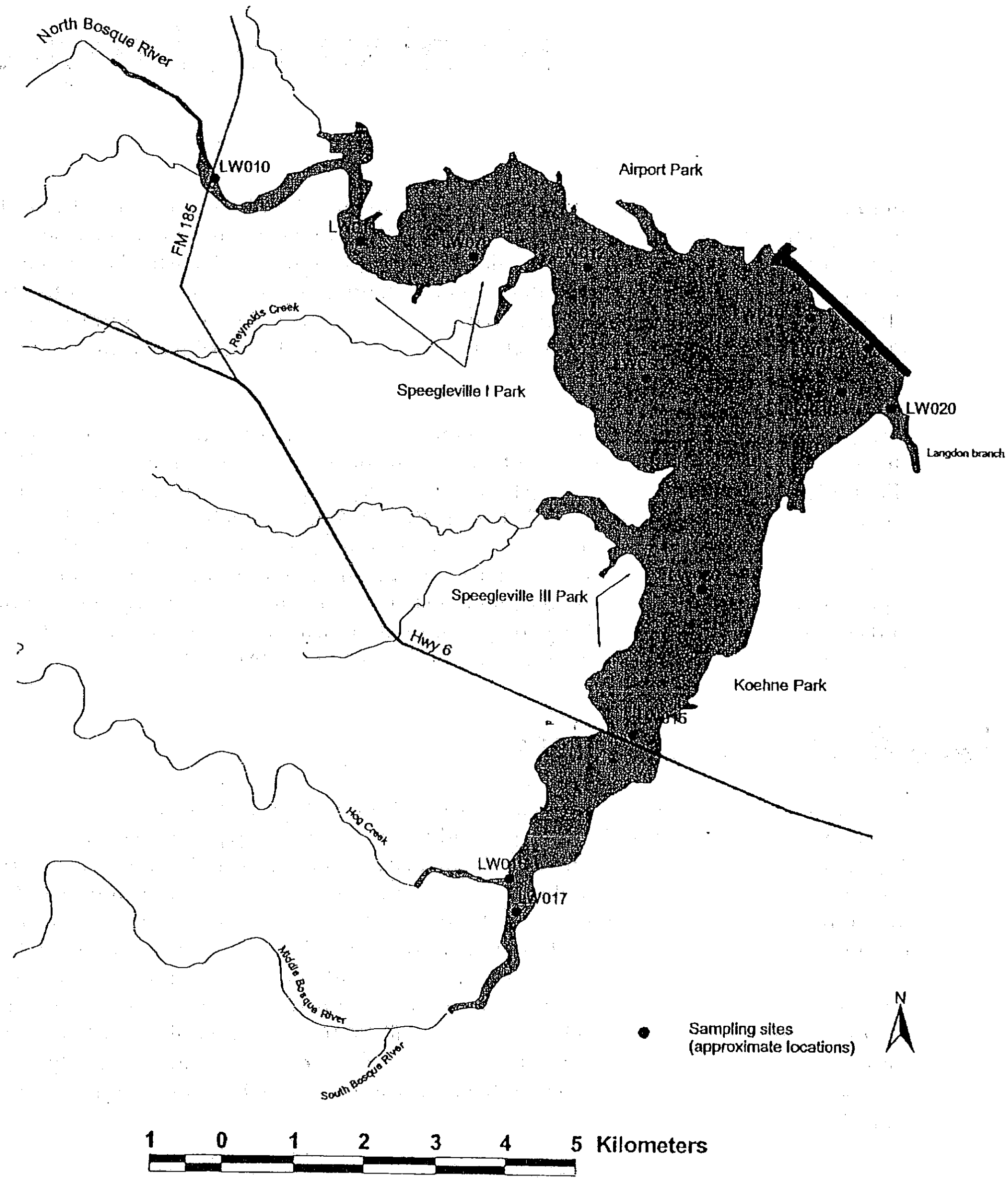


Table 2 Sampling history of Lake Waco sites.

Site	TNRCC ID	Description	Date of First Sample	Date of Final Sample (if discontinued)
LW010	11946	North Bosque arm at FM 185 bridge	11-Jul-96	07-Oct-98
LW011	not assigned	North arm near mouth of North Bosque River	14-Jun-96	12-Mar-98
LW012	11945	North Bosque arm across from Airport Park	14-Jun-96	
LW013	not assigned	At structure of dam	14-Jun-96	
LW015	11948	Middle and South Bosque arm near SH6 bridge	14-Jun-96	
LW016	not assigned	South arm near mouth of Hog Creek	14-Jun-96	12-Mar-98
LW017	11949	South Arm near mouth of Middle-South Bosque River	14-Jun-96	07-Oct-98
LW020	11944	Langdon Branch arm	14-Jun-96	12-Mar-98
LW030	not assigned	Body of reservoir south from dam	14-Jun-96	12-Mar-98
LW040	not assigned	Between dam and retainer gates	14-Jun-96	12-Mar-98
LW050	not assigned	Body of reservoir southwest of spillway	14-Jun-96	07-Oct-98
LW060	not assigned	Body of reservoir between SH6 bridge and dam	14-Jun-96	
LW070	not assigned	In front of the Bosque Bend Clubhouse	20-Nov-96	

Table 3 Routine grab sampling on Lake Waco for 1996.
"x" indicates a sample was taken.

Year: 1996		Site												
Month	Day	LW010	LW011	LW012	LW013	LW015	LW016	LW017	LW020	LW030	LW040	LW050	LW060	LW070
June	11 - 14	x	x	x	x	x	x	x	x	x	x	x	x	
July	11	x	x	x	x	x	x	x	x	x	x	x	x	
August	20	x	x	x	x	x	x	x	x	x	x	x	x	
September	30	x	x	x	x	x	x	x	x	x	x	x	x	
October	23	x	x	x	x	x	x	x	x	x	x	x	x	
November	20	x	x	x	x	x	x	x	x	x	x	x	x	x[a]
December	12	x	x	x	x	x	x	x	x	x	x	x	x	x

a. Date of first sample at new site

Table 4 Routine grab sampling on Lake Waco for 1997.
"x" indicates a sample was taken.

Year: 1997		Site												
Month	Day	LW010	LW011	LW012	LW013	LW015	LW016	LW017	LW020	LW030	LW040	LW050	LW060	LW070
January	22	x	x	x	x	x	x	x	x	x	x	x	x	x
February	17	x	x	x	x	x	x	x	x	x	x	x	x	x
March	20	x	x	x	x	x	x	x	x	x	x	x	x	x
April	15	x	x	x	x	x	x	x	x	x	x	x	x	x
May	14	x	x	x	x	x	x	x	x	x	x	x	x	x
June	25	x	x	x	x	x	x	x	x	x	x	x	x	x
July	17	x	x	x	x	x	x	x	x	x	x	x	x	x
August	14	x	x	x	x	x	x	x	x	x	x	x	x	x
September	17	x	x	x	x	x	x	x	x	x	x	x	x	x
October	15	x	x	x	x	x	x	x	x	x	x	x	x	x
November	12	x	x	x	x	x	x	x	x	x	x	x	x	x
December	8	x	x	x	x	x	x	x	x	x	x	x	x	x

Table 5 Routine grab sampling on Lake Waco for 1998.
"x" indicates a sample was taken

Year: 1998		Site												
Month	Day	LW010	LW011	LW012	LW013	LW015	LW016	LW017	LW020	LW030	LW040	LW050	LW060	LW070
January	15	x	x	x	x	x	x	x	x	x	x	x	x	x
February	18	x	x	x	x	x	x	x	x	x	x	x	x	x
March	12	x	x[a]	x	x	x	x[a]	x	x[a]	x[a]	x[a]	x	x	x
April	22	x		x	x	x		x				x	x	x
May	6	x		x	x	x		x				x	x	x
	20	x		x	x	x		x				x	x	x
June	3	x		x	x	x		x				x	x	x
	17	x		x	x	x		x				x	x	x
July	2	x		x	x	x		x				x	x	x
	15	x		x	x	x		x				x	x	x
	29	x		x	x	x		x				x	x	x
August	12	x		x	x	x		x				x	x	x
	27	x		x	x	x		x				x	x	x
September	9	x		x	x	x		x				x	x	x
	24	x		x	x	x		x				x	x	x
October	7	x[a]		x	x	x		x[a]				x[a]	x	x
	14			x	x	x							x	x
	21			x	x	x							x	x
November	3			x	x	x							x	x
	17			x	x	x							x	x
December	14			x	x	x							x	x

a. Grab sampling discontinued.

Table 6 Routine grab sampling on Lake Waco for 1999.
"x" indicates a sample was taken.

Year: 1999		Site												
Month	Day	LW010	LW011	LW012	LW013	LW015	LW016	LW017	LW020	LW030	LW040	LW050	LW060	LW070
January	14			x	x	x							x	x
February	17			x	x	x							x	x
March	15			x	x	x							x	x
April	6			x	x	x							x	x
	21			x	x	x							x	x
May	6			x	x	x							x	x
	18			x	x	x							x	x
June	3			x	x	x							x	x
	16			x	x	x							x	x
	28			x	x	x							x	x
July	13			x	x	x							x	x
	28			x	x	x							x	x
August	10			x	x	x							x	x
	24			x	x	x							x	x
September	9			x	x	x							x	x
	22			x	x	x							x	x
October	5			x	x	x							x	x
	19			x	x	x							x	x
November	3			x	x	x							x	x
	16			x	x	x							x	x
	30			x	x	x							x	x
December	9			x	x	x							x	x
	15			x	x	x							x	x

Lake Waco at FM 185 Bridge (site LW010) LW010 was a riverine site located in the northern reservoir arm represented by the North Bosque River. The site was located midchannel upstream from FM 185 bridge. This site was inaccessible by boat due to shallow water during drought conditions. The last routine sample at this site was performed on October 7, 1998.

Lake Waco west of Speegleville Park I (site LW011) LW011 was located along the northern arm of the reservoir at the western end of Speegleville Park I between sites LW010 and LW070. A buoy indicating the channel formed by the North Bosque River marked the site. Routine sampling at this site ended after March 12, 1998.

Lake Waco across from Airport Park (site LW012) LW012 is located midchannel at the lower end of the original North Bosque River channel between Reynolds Creek and Airport Park.

Lake Waco at structure of dam (site LW013) LW013 is located about 27 meters (30 yards) southwest of the dam.

Lake Waco State Highway 6 bridge (site LW015) LW015 is located just north of State Highway 6 bridge midchannel as marked by a USACE buoy.

Lake Waco near mouth of Hog Creek (site LW016) LW016 was located at a white buoy near the south shore just inside the mouth of Hog Creek. The last routine sample at this site was taken March 12, 1998.

Lake Waco at Middle-South inflow (site LW017) LW017 was located near the mouth of the Middle-South Bosque River on the north side of the channel. The last routine sample at this site was taken on October 7, 1998.

Lake Waco at Langdon Branch arm (site LW020) LW020 was located at the center buoy that marks the confluence of Langdon Branch with the reservoir. Langdon Branch enters the reservoir near the dam on the eastern side of the reservoir. Routine sampling ended at this site after March 12, 1998.

Lake Waco within the main body south of dam (site LW030) LW030 was located in the body of the reservoir just south of the dam. The last routine sample at this site was taken on March 12, 1998.

Lake Waco between dam and retainer gates (site LW040) LW040 was located at a point between the dam and the retainer gates. Routine sampling at this site ended after March 12, 1998.

Lake Waco within main body west of dam (site LW050) LW050 was located within the western portion of the main body of the reservoir opposite the dam. The last routine sample at this site was taken on October 7, 1998.

Lake Waco between SH 6 bridge and dam (site LW060) LW060 is located between the State Highway 6 bridge and the dam. The site is midchannel between Speegleville III and Koehne Parks.

Lake Waco near Bosque Bend Clubhouse (LW070) LW070 is located at a white buoy directly in front of the Bosque Bend Clubhouse at Speegleville Park I on the northern arm of the reservoir.

Sampling Sites on Major Tributaries

Water quality sampling sites are located on the North, Middle, and South Bosque Rivers and Hog Creek, which are the major tributaries to Lake Waco (Figure 1). All four sites are monitored using automatic storm samplers and manual grab samples for routine biweekly sampling.

North Bosque River at Valley Mills (site BO100) An automated sampler site is located south of the USGS station 08095200 on the North Bosque River near the crossing of FM Road 56 northeast of Valley Mills. BO100 is located about 45 kilometers (28 miles) upstream from the mouth of the North Bosque River at Lake Waco.

Hog Creek (HC060) An automated sampler is located on Hog Creek at the crossing of FM Road 185 near USGS station 08095400 about 10 kilometers (6 miles) east of Crawford, Texas. Site HC060 is about 16 kilometers (10 miles) upstream from Lake Waco.

Middle Bosque River (site MB060) An automated sampler is located on the Middle Bosque River at the crossing of FM Road 185, east of Crawford. Site MB060 is located about 19 kilometers (12 miles) upstream from Lake Waco.

South Bosque River (sites SB050 and SB060) South Bosque River site SB050 is located on private property near Church Road, which is about 1.2 kilometers (0.75 miles) south of U.S. Highway 84. Site SB050 is located about 2.4 kilometers (1.5 miles) upstream of Lake Waco. Site SB060 is located about 0.4 kilometers (0.25 miles) downstream from SB050 at FM Road 2837, south of U.S. Highway 84. The location of site SB050 presented safety hazards to personnel taking grab samples, thus, the collection of grab samples was moved to the bridge off FM Road 2837 designated as site SB060. Site SB060 was also initially used for storm sampling, but backwater at high water levels from the reservoir necessitated moving the automated sampling instrumentation upstream to its current location at SB050. As in other TIAER reports (e.g., Pearson and McFarland, 1999), sampling data from sites SB050 and SB060 are combined and referred to as data from site SB050 in this report.

Water Quality Sampling and Laboratory Analyses

For Lake Waco, water sample collection generally consisted of grab samples from the surface, middle, and bottom depths at each sampling site. Surface samples were collected at 0.3 meters (1 foot) below the water surface. Bottom samples were collected at 0.3 meters above the bottom of the reservoir. Middle samples were collected at a mid-depth between surface and bottom depths. If a site was particularly shallow at the time of a sampling event, only surface and bottom samples were collected. Sampling depth for chlorophyll-α (CHLA) was dependent on the Secchi depth. If the Secchi depth was less than 0.46 meters (1.5 feet) then the CHLA sample was collected at a depth of 0.3 meters. If the Secchi depth was greater than 0.46 meters, the CHLA sample consisted of a composite sample from subsamples taken at top, middle, and bottom depths of the Secchi reading, with the top sample occurring with the sampler just submerged below the surface of the water.

Field parameters were measured using a Hydrolab Recorder™ Water Quality Multiprobe Logger connected to a Scout®2 Display (Hydrolab Corporation, Austin, TX). Readings were taken at 1-meter (3.28 feet) intervals for water temperature, dissolved oxygen (DO), pH, and conductivity to profile the physical characteristics of the reservoir with depth. Starting in August 1998, light attenuation measurements were added to the monitoring program based on irradiance measurements conducted at 0.3-meter (1-foot) intervals from just below the water surface to the depth at which the reading was one percent or less of the surface reading. Light attenuation from irradiance at each depth was calculated as outlined by methods in Wetzel and Likens (2000) in reference to the irradiance at the water surface. A Li-Cor Model LI-250 Light Meter (Li-Cor, Lincoln, NB) was used to measure light irradiance.

At the major tributary stream sites to Lake Waco, routine grab samples were taken at a depth of about 0.3 meters (1 ft) below the surface when water was flowing. Field parameters of DO, pH, water temperature, and conductivity were recorded at the time grab samples were taken. Storm sampling was initiated upon a 4-cm (1.5-inch) rise in water level. The actuation level of 4 cm was selected to avoid undesired actuation from nonrainfall event causes, such as wave action, and to allow actuation for all but the smallest rainfall-runoff events. Once activated, samplers were programmed to retrieve one-liter sequential samples until the water receded to preactivation levels or the sampler was manually deactivated. A typical sampling sequence included an initial sample, three samples taken at one-hour intervals, two samples taken at two-hour intervals, and all remaining samples taken at eight-hour intervals. This sampling sequence allowed for more frequent sample collection during the typical rapid hydrograph rise and peak periods following sampler actuation and less frequent sample collection during the longer, receding portion of a storm hydrograph.

A general outline of water quality constituents measured, abbreviations used in this report, and units of measurements are provided in Table 7. Methods of analysis are listed in Table 8. Specific laboratory method detection limits (MDLs) for various time periods are presented in Table 9. In data management, left censored data (values measured below the laboratory method detection limit) were entered into TIAER's water quality database as one-half the method detection limit (MDL), as recommended by Gilliom and Helsel (1986) and Ward et al. (1988). Field constituents measured in situ included water temperature, DO, specific conductance, pH, and light penetration. Chemical constituents were generally analyzed for ammonia-nitrogen (NH_3-N), nitrite-nitrogen plus nitrate-nitrogen (NO_2-N + NO_3-N), total Kjeldahl nitrogen (TKN), orthophosphate-phosphorus (PO_4-P), total phosphorus (TP), total suspended solids (TSS), chemical oxygen demand (COD), and CHLA.

The following derived water quality variables were also included as part of the data analysis:

1) Total nitrogen(TN) = $NO_2\text{-}N + NO_3\text{-}N + TKN$

2) Dissolved inorganic nitrogen(DIN) = $NH_3\text{-}N + NO_2\text{-}N + NO_3\text{-}N$

3) Organic nitrogen(Organic-N) = $TKN - NH_3\text{-}N$

4) Particulate phosphorus(PP) = Total-P – $PO_4\text{-}P$

5) Ratio of total-N to total-P(Total-N:Total-P) = Total-N/Total-P

6) Ratio of DIN to PO_4-P($DIN:PO_4\text{-}P$) = $DIN/PO_4\text{-}P$

7) Percent oxygen saturation($DO_{\%sat}$) = $DO/O_s \cdot 100$

where O_s is the potential for oxygen solubility in water, based on water temperature as outlined in APHA (1995).

Table 7 Descriptions, abbreviations, and units of water quality constituents:

Constituent	Abbreviation	Units	Description
Ammonia-Nitrogen	NH_3-N	mg/L	Inorganic form of nitrogen that is readily soluble and available for plant uptake. Elevated levels are toxic to many fish species.
Chemical Oxygen Demand	COD	mg/L	Indication of oxygen demanding properties of the water in terms of complete chemical oxidation.
Chlorophyll-α	CHLA	μg/L	Indicator of phytoplankton biomass.
Specific Conductance	Conductivity	μmhos/cm	Measure of the ability of water to carry an electric current. Used as an indicator of the salt content of the water.
Dissolved Oxygen	DO	mg/L	Indicator of the amount of oxygen available in the water for biological activity and chemical reactions.
Light Attenuation		micro-Einstein	Measures the penetration of light with depth into a water body and is used to indicate the light available for photosynthesis.
Nitrite-Nitrogen	NO_2-N	mg/L	Inorganic form of nitrogen. Generally a transitory phase in the nitrification of NH_3 to NO_3.
Nitrate-Nitrogen	NO_3-N	mg/L	Inorganic form of nitrogen that is readily soluble and available for plant uptake. Considered the end product in the conversion of N from the ammonia form to nitrite then to nitrate under aerobic conditions.
Orthophosphate-Phosphorus	PO_4-P	mg/L	Inorganic form of phosphorus that is readily soluble and available for plant uptake. This constituent is often referred to as soluble or dissolved reactive phosphorus.
pH		Standard units	Measures the hydrogen ion activity in a water sample.
Total Kjeldahl Nitrogen	TKN	mg/L	Organic and ammonia forms of nitrogen are included in TKN.
Total Phosphorus	total-P	mg/L	Represents both organic and inorganic forms of phosphorus.
Total Suspended Solid	TSS	mg/L	Measures the solid materials, i.e., clay, silts, sand, and organic matter suspended in the water.
Water Temperature		°C	Indicator of temperature conditions for aquatic life.
Secchi Depth	ZSD	meters	Indicator of light penetration within a water body.

Table 8 Analysis methods for water quality constituents.

Constituent	Method	Source
Field Measurements		
Conductivity	SM 2510B	APHA (1995)
Dissolved Oxygen	EPA 360.1	USEPA (1983)
pH	EPA 150.1	USEPA (1983)
Water Temperature	EPA 170.1	USEPA (1983)
Secchi Depth	TNRCC 0078	TNRCC (1999b)
Laboratory Measurements		
Ammonia-Nitrogen	EPA 350.1	USEPA (1983)
Chemical Oxygen Demand	Hach 8000	Hach (1991)
Chlorophyll-α	SM 10200H	APHA (1995)
Fecal Coliform	SM 9222D	APHA (1995)
Nitrite-Nitrogen + Nitrate-Nitrogen	EPA 353.2	USEPA (1983)
Total Kjeldahl Nitrogen	EPA 351.2	USEPA (1983)
Orthophosphate-Phosphorus	EPA 365.2	USEPA (1983)
Total Phosphorus	EPA 365.4	USEPA (1983)
Total Suspended Solids	EPA 160.2	USEPA (1983)

Table 9 Laboratory method detection limits effective March 1996 through December 1999.

Effective Dates	NH_3-N (mg/L)	NO_2-N + NO_3-N (mg/L)	PO_4-P (mg/L)	Total-P (mg/L)	TKN (mg/L)	COD (mg/L)	TSS (mg/L)	CHLA (µg/L)
21 Mar 96–27 Oct 96	0.015	0.015	0.003	0.110	0.299	5	10	5.36
28 Oct 96–04 May 97	0.037	0.006	0.010	0.101	0.194	6	10	8.63
05 May 97–30 Nov 97	0.022	0.016	0.008	0.077	0.173	4	10	12.20
01 Dec 97–16 Dec 97	0.022	0.008	0.011	0.153	0.195	4	3	3.30
17 Dec 97–14 May 98	0.022	0.008	0.011	0.024	0.195	4	3	3.30
15 May 98–30 Nov 98	0.009	0.016	0.006	0.048	0.113	6	7	8.84
01 Dec 98–01 Jun 99	0.015	0.016	0.006	0.052	0.165	4	6	1.14
02 Jun 99–10 Dec 99	0.030	0.010	0.003	0.053	0.150	4	4	0.99
11 Dec 99–31 Dec 99	0.037	0.013	0.006	0.086	0.122	4	6	2.46

Spatial Analysis of Surface Water Quality

Two major riverine zones influence the characteristics of Lake Waco. The North Bosque River forms the northern arm of Lake Waco, while the Middle-South Bosque River and Hog Creek form the southern arm (Figure 5). The North Bosque River comprises about 74 percent of the drainage area to Lake Waco, while Hog Creek comprises 5 percent and the Middle-South Bosque River 18 percent. Although wood and range are the dominant land uses within the watershed, dairy operations are a prominent feature in the upper portion of the North Bosque River watershed and row crop agriculture is prominent within the Middle-South Bosque watershed (McFarland and Hauck, 1999). Because the amount of water flowing through these two riverine zones varies greatly and water quality varies somewhat between these major tributary inflows (McFarland and Hauck, 1998), differences in water quality are expected to occur within the reservoir. In this section, differences in surface water quality between sampling sites are evaluated to explore spatial patterns with regard to physical, chemical, and biological variables as influenced by these major tributary inflows.

Methods

In comparing between monitoring sites for the spatial analysis, it was important to maintain a consistent period of record across sites. Using a consistent period of record for all sites avoided introduction of possible bias from expected temporal variability in the data. Data were restricted to samples collected between November 1996 and March 1998. In November 1996, site LW070 was added to the sampling program, and, in March 1998, sampling at five reservoir sites was discontinued (Table 2). Only surface samples were used in this analysis as the average depth of each site varies greatly (Table 10).

Table 10 Depth in meters for sampling sites on Lake Waco.
Measurements taken with monthly samples collected between November 1996 and March 1998. Sites are listed from north to south along the reservoir.

Site	Mean (meters)	Median (meters)	Std (meters)	Min (meters)	Max (meters)	Number of Observations
LW010	5	5	1	4	7	17
LW011	4	4	1	3	5	17
LW070	6	6	1	5	8	17
LW012	7	7	2	3	10	17
LW050	7	7	1	6	9	17
LW040	11	11	1	8	13	17
LW013	15	15	1	12	17	17
LW030	15	14	2	12	18	17
LW020	16	16	1	15	18	17
LW060	7	7	2	5	11	17
LW015	6	5	1	5	9	17
LW016	2	2	1	1	4	17
LW017	2	2	1	1	5	17

As water quality data often follow a log normal distribution rather than a normal distribution, the Shaprio-Wilkes test for normality and the Hartley's F-test for equal variances were performed on the data set by constituent (SAS, 1990; Ott, 1984). A log normal data transformation better fit the assumptions of normality and equal variances for all constituents except conductivity, DO, organic-N, and water temperature. As pH already represents a log transformed variable (the log of the hydrogen ion concentration), pH data were evaluated to see if the hydrogen ion concentration values better fit the normality and equal variances assumptions. In this case, pH data in standard units better fit these assumptions than the hydrogen ion concentration values.

An analysis of variance (ANOVA) was performed to evaluate differences for each constituent between sites. If significant differences were indicated at $\alpha = 0.05$ by the ANOVA, a test of least significant differences (LSD) was used as a multiple comparison test to distinguish the differences between sites (Ott, 1984).

In association with the ANOVA results, cluster analysis techniques were used to evaluate groupings of sites based on multiple constituents (e.g., Ludwig and Reynolds, 1988). Two clustering scenarios were evaluated. The first one used the physical constituents indicating significant differences ($\alpha = 0.05$) in the ANOVA. The second used only the chemical and biological constituents that indicated significant differences in the ANOVA. The distance measure used in the clustering algorithm was the percent absolute difference between mean (or geometric mean) constituent values using the average linkage method as described in SAS (1992). The optimal number of clusters was based on changes between clustering cycles in the normalized root mean square of the distance measure. A large increase in the normalized root mean square as clusters fuse indicates an increase in the within cluster variance compared to the between cluster variance. When a large increase in the normalized root mean square occurs, it is recommended that fusing should stop at the previous cycle (Ludwig and Reynolds, 1988).

Results By Constituent

ANOVA indicated significant differences between sites for several water quality constituents (Table 11). These differences (or lack of differences) at sampling sites across the reservoir are presented below, first for the physical constituent and then for the chemical and biological constituents.

Physical Constituents

The physical constituents characterizing water quality between sites used in the ANOVA included water temperature, DO, $DO_{\%sat}$, conductivity, pH, TSS, and Secchi depth. Water temperature is an indicator of temperature conditions for aquatic life, while DO measures the amount of oxygen in the water for biological activity and chemical reactions. There are physical limitations to how much oxygen water can hold based on temperature, so $DO_{\%sat}$ indicates the measured DO level relative to the saturation DO level at a specified water temperature. TSS and Secchi depth are measures of turbidity or water clarity. Secchi depth gives an indication of the depth of light penetration into the water, while TSS measures the concentration of suspended organic and inorganic materials that may be limiting light penetration.

Table 11 Results of the analysis of variance comparing Lake Waco sites.
Data evaluated represent surface samples collected between November 1996 and March 1998.

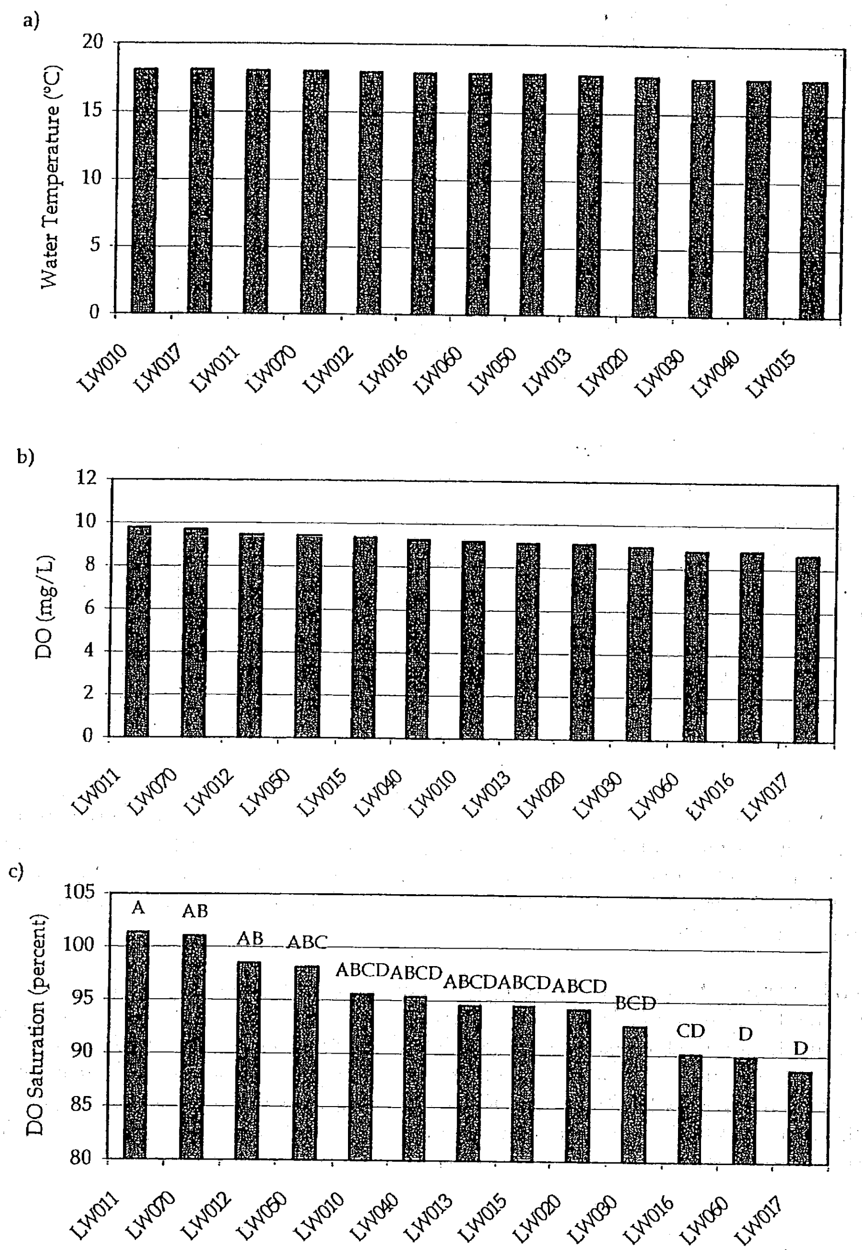
Constituent	Natural Log Transformation	p-value	Significance[a]
Physical			
DO	No	0.2863	ns
$DO_{\%sat}$	Yes	0.0417	*
Conductivity	No	0.0001	**
pH	No	0.0001	**
TSS	Yes	0.0001	**
Water Temperature	No	1.0000	ns
ZSD	Yes	0.0001	**
Chemical			
COD	Yes	0.8326	ns
NH_3-N	Yes	0.5971	ns
NO_2-N + NO_3-N	Yes	0.0687	ns
Organic-N	No	0.0066	**
PO_4-P	Yes	0.9503	ns
PP	Yes	0.6000	ns
TKN	No	0.0231	*
Total-P	Yes	0.5940	ns
DIN	Yes	0.0077	**
Total-N/Total-P	Yes	0.0012	**
DIN/PO_4-P	Yes	0.0023	**
Total-N	Yes	0.0001	**
Biological			
CHLA	Yes	0.0025	**

a. "ns" indicates not significant at α=0.05, * indicates significance at α=0.05, and ** indicates significance at α=0.01.

For DO and water temperature, no significant differences were indicated between sites (Table 11). Average surface water temperatures ranged from 17.6°C at LW015 to 18.1°C at LW010 (Figure 6a) with temperatures for all sites averaging 17.9 $\pm$ 7.4°C. Surface DO values averaged 9.2 $\pm$ 1.3 mg/L across the reservoir with average DO concentrations by site ranging from 8.7 mg/L at LW017 to 9.8 mg/L at LW011 (Figure 6b).

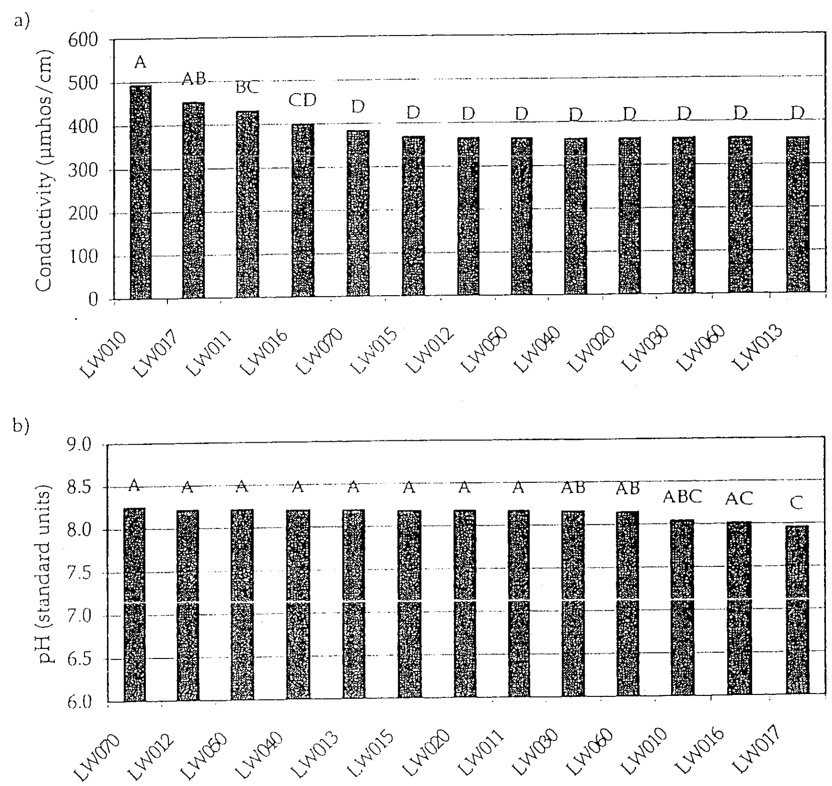
When DO and water temperature were combined to determine $DO_{\%sat}$, significant differences between sites were indicated at $\alpha = 0.05$ but not $\alpha = 0.01$ (Table 11). Differences in $DO_{\%sat}$ between sites showed a great deal of overlap within the reservoir (Figure 6c). These differences appear to show a slight split between the northern and southern arms of the reservoir with slightly higher geometric mean $DO_{\%sat}$ values occurring at sites along the northern arm (LW011, LW070, and LW012) than for sites along the southern arm (LW016, LW060, and LW017).

Figure 6 Mean a) water temperature and b) DO, and c) geometric mean DO saturation for surface samples collected between November 1996 and March 1998. Means followed by the same letter are not significantly different at a probability level of 0.05 according to a test of least significant differences.



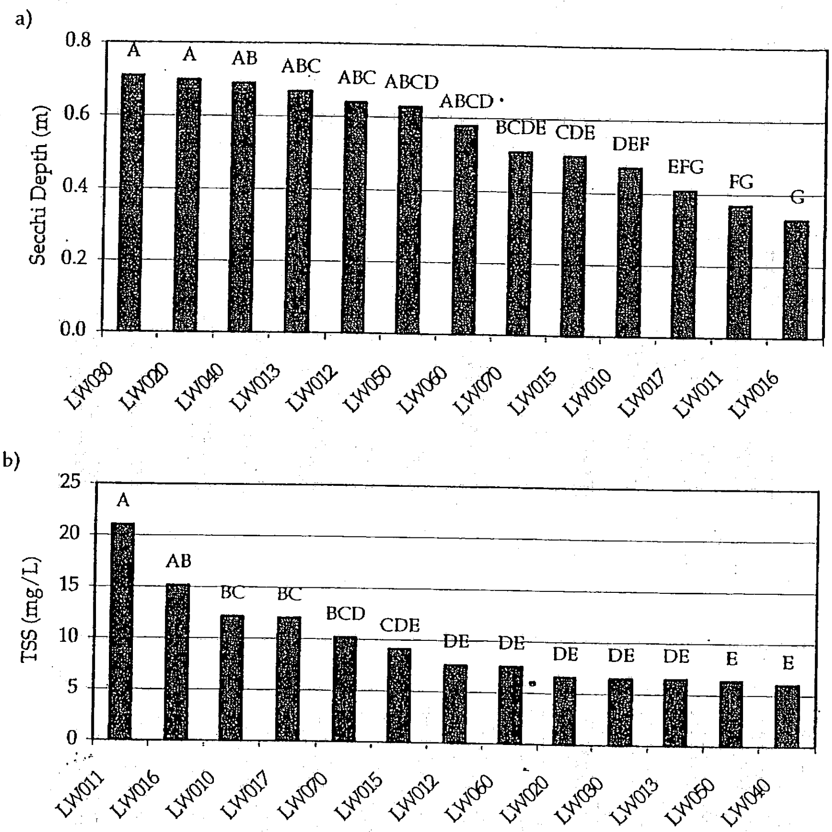
Highly significant differences (α = 0.01) between sites were indicated for conductivity and pH (Table 11). The highest conductivity values were associated with the more riverine sites (LW010 and LW017) with values ranging from 494μmhos/cm at LW010 to 360μmhos/cm at LW013 (Figure 7a). As with conductivity, differences between sites for pH were distinct with the lowest values occurring at the more riverine sites (LW010, LW016, and LW017). The average values for pH ranged from 7.95 at LW017 to 8.25 at LW070 (Figure 7b).

Figure 7 Mean a) conductivity and b) pH.
Surface samples were collected between November 1996 and March 1998. Means followed by the same letter are not significantly different at a probability level of 0.05 according to a test of least significant differences.



Highly significant differences (α = 0.01) between sites were also indicated for Secchi depth and TSS (Table 11). Secchi depth showed a trend similar to that of conductivity and pH, with the more riverine sites generally indicating the lowest geometric mean Secchi depth values compared to the rest of the reservoir (Figure 8a). With Secchi depth, a fair amount of overlap occurred between site groupings indicating a transition zone between the more riverine sites and the main body of the reservoir. Geometric mean Secchi depth values ranged from 0.7 m at LW030 to 0.3 m at LW016. TSS values appeared to correlate with Secchi depth values in that those sites with lower Secchi depths generally indicated higher TSS concentrations (Figure 8b). Geometric means TSS concentrations ranged from 21 mg/L at LW011 to 6 mg/L at LW040.

Figure 8 Geometric mean a) Secchi depth and b) TSS.
Surface samples were collected between November 1996 and March 1998. Means followed by the same letter are not significantly different at a probability level of 0.05 according to a test of least significant differences.

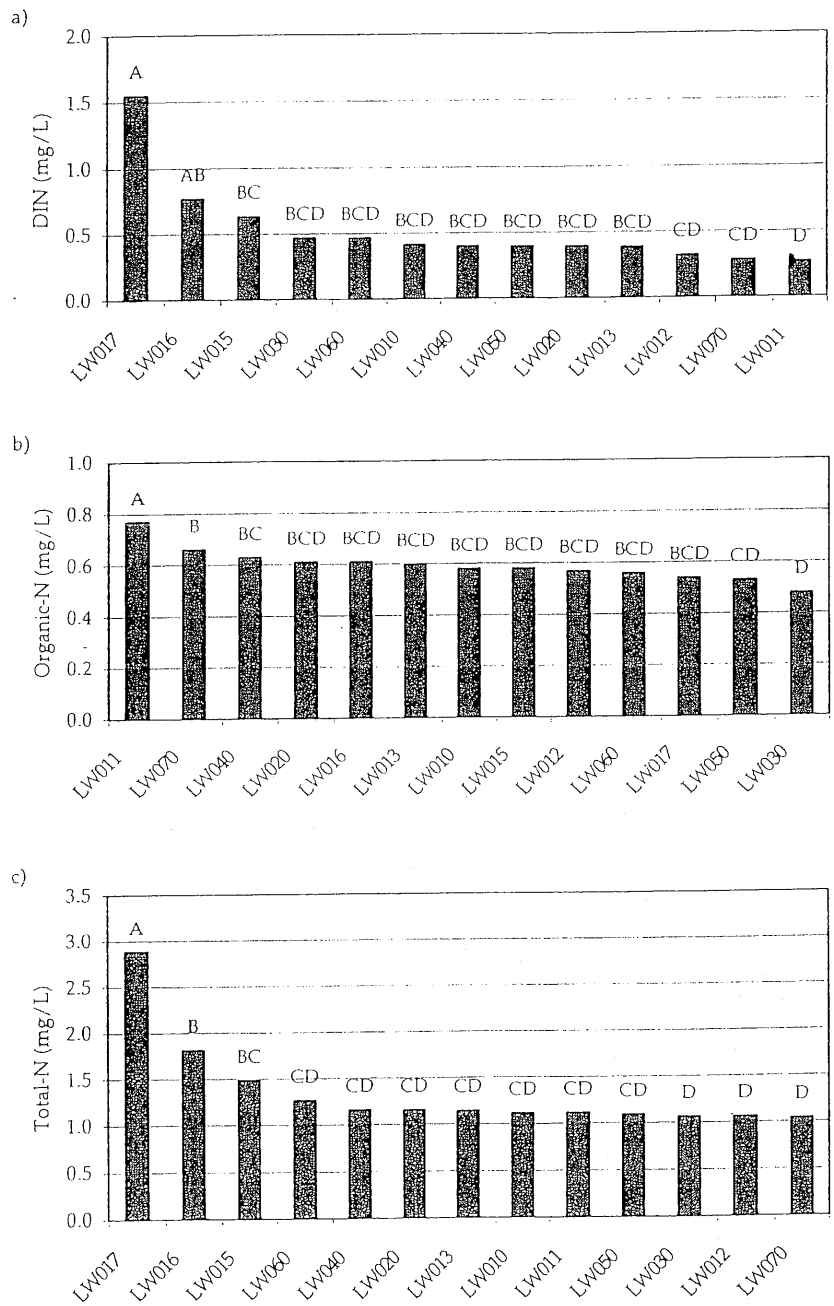


Chemical and Biological Constituents

Monitoring of chemical and biological constituents focused primarily on nutrients and CHLA as factors influencing or indicating the production of algae. Nitrogen and phosphorus are required macronutrients for the growth of algae, and the ratio of nitrogen to phosphorus is often used to indicate the limiting nutrient within a system (Thomann and Mueller, 1987). Chemical oxygen demand is also presented as an indicator of the total oxygen demanding properties of the water in terms of pollutant loadings. As COD indicated no significant differences between sites (Table 11), and the fact that DO levels are not of concern in this system (Figure 8b), this section will focus exclusively on nutrients and CHLA. For reference, the overall geometric mean COD concentration for Lake Waco was 7.1mg/L for surface samples collected between November 1996 and March 1998.

Nitrogen concentrations in Lake Waco as represented by DIN, organic-N, and total-N are summarized in Figure 9. Geometric mean DIN concentrations varied greatly within the reservoir (Figure 9a) with the highest concentrations occurring in the southern arm at LW017 and LW016 and the lowest concentrations occurring primarily in the northern at LW011,

Figure 9 Geometric mean a) DIN, b) mean organic-N, and c) geometric mean total N for surface samples collected between November 1996 and March 1998. Means followed by the same letter are not significantly different at a probability level of 0.05 according to a test of least significant differences.



LW012, and LW013. Geometric mean DIN concentrations ranged from 1.55 mg/L at LW017 to 0.27 mg/L at LW011. Mean organic-N concentrations showed a very different spatial distribution in the reservoir, compared to DIN, with the highest organic-N concentrations occurring in the northern arm at site LW011 (geometric mean 0.77 mg/L) and the lowest organic-N concentrations occurring in the main body of the reservoir at LW030 (geometric mean 0.48 mg/L; Figure 9b). Except for site LW011, all other sites showed a fair amount of overlap in organic-N concentrations (Figure 9b).

Due to the limited variability apparent in mean organic-N concentrations between sites, site groupings for total-N were quite similar to groupings for DIN with the highest geometric mean concentrations occurring at sites associated with the southern arm of the reservoir (LW017, LW016, and LW015). The highest total-N concentration occurred at LW017 (geometric mean 2.88 mg/L), while the lowest total-N concentration occurred at LW070 (geometric mean 1.04 mg/L; Figure 9c).

For PO_4-P, PP, and total-P, no significant differences were indicated between sites (Table 11). The geometric mean concentration of PO_4-P ranged from 0.012 mg/L at LW017 to 0.019 mg/L at LW060 with a geometric mean of 0.016 mg/L across sites (Figure 10a). For PP, geometric mean concentrations ranged from 0.03 mg/L at LW040 to 0.08 mg/L at LW010 with a geometric mean of 0.05 mg/L PP across sites (Figure 10b). PP represented about 78 percent of total-P measured in surface samples from the reservoir. The overall geometric mean for total-P was 0.07 mg/L with values ranging from 0.10 mg/L at LW011 to 0.05 mg/L at LW040 (Figure 10c).

The ratio of N to P provides information in determining which nutrient may be limiting or controlling the growth of algae within a lake or reservoir. Thoman and Mueller (1987) provide the following rough guidelines for interpreting ratios of total-N to total-P:

$N/P \gg 10$ — indicates that algal growth is probably limited by phosphorus

$N/P \approx 10$ — indicates that neither N nor P can be determined to control algal growth

$N/P \ll 10$ — indicates that algal growth is probably limited by nitrogen

$N/P < 4$ — indicates that blue-green algae (cyanobacteria) may dominate the system

A distinct difference by site was indicated for the ratio of total-N to total-P (Figure 11a) that, as expected, closely followed site differences indicated by total-N (Figure 9c). In general, phosphorus appeared to limit the growth of algae throughout much of the reservoir, although at sites, such as LW010 and LW030, with total-N to total-P ratios about equal to 10 neither phosphorus nor nitrogen could be determined to control algal growth (Figure 11a). The ratios of total-N to total-P appeared to follow a gradient within the reservoir with higher total-N to total-P ratios generally occurring in the southern arm of the reservoir and lower values in the northern arm. The ratio of DIN to PO_4-P showed less of a gradient, but indicated a distinct difference between the extreme southern and northern arms of the reservoir (Figure 11b). The guidelines used to interpret the ratio of total-N to total-P can be applied to the ratio of DIN to PO_4-P and support the conclusion that within much of the reservoir P rather than N was the limiting nutrient during the study period.

CHLA, as an indicator of algae biomass, is also a response variable to the relative availability of nutrients within the reservoir. The highest geometric mean CHLA concentrations were observed at sites in the northern arm of the reservoir (Figure 12), where ratios of total-N to total-P close to 10 suggest that neither N nor P were clearly controlling algal growth (Figure 11a). The lowest geometric mean CHLA concentrations were indicated in the southern arm of the reservoir where P was indicated as limiting. Geometric mean CHLA concentrations ranged from a high of 24.5 μg/L at LW011 to a low of 7.3 μg/L at LW017.

Figure 10 Geometric mean a) PO_4-P, b) PP, and c) total-P.
Surface samples were collected between November 1996 and March 1998.

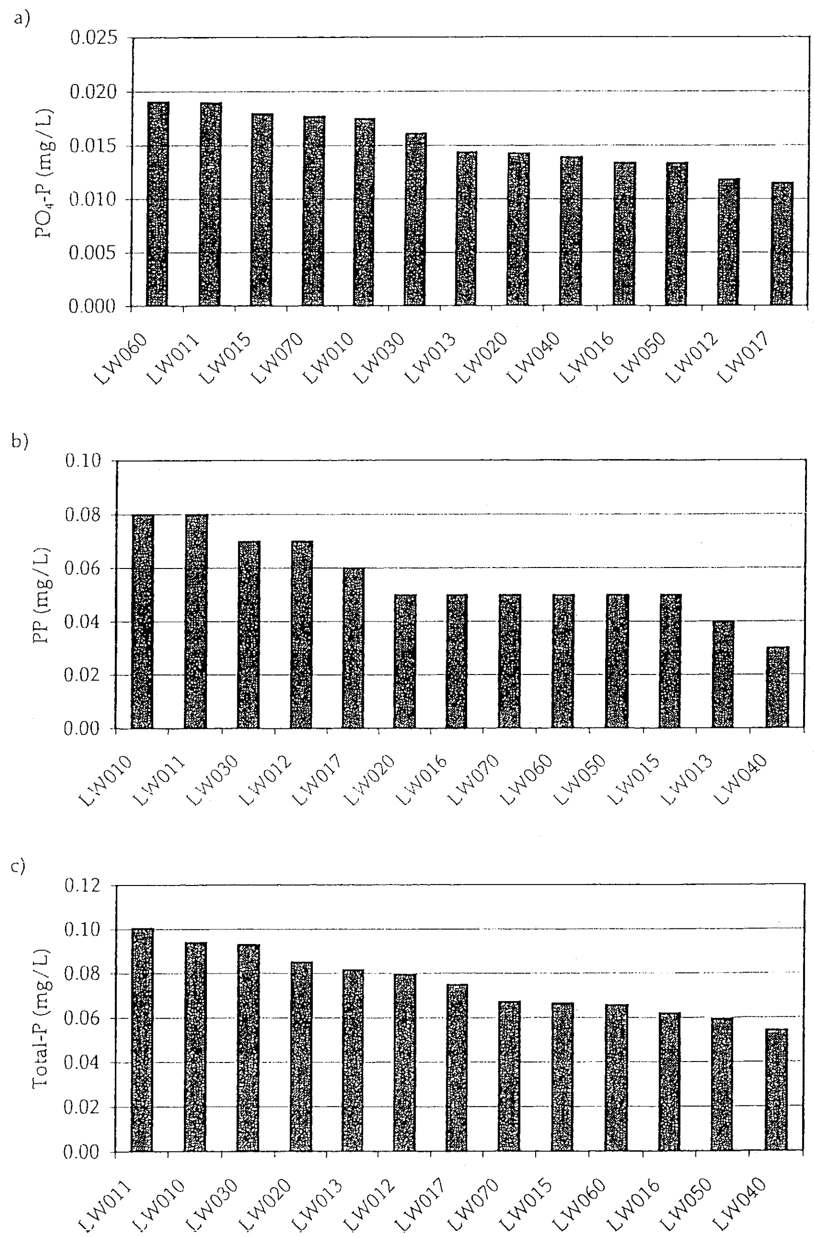
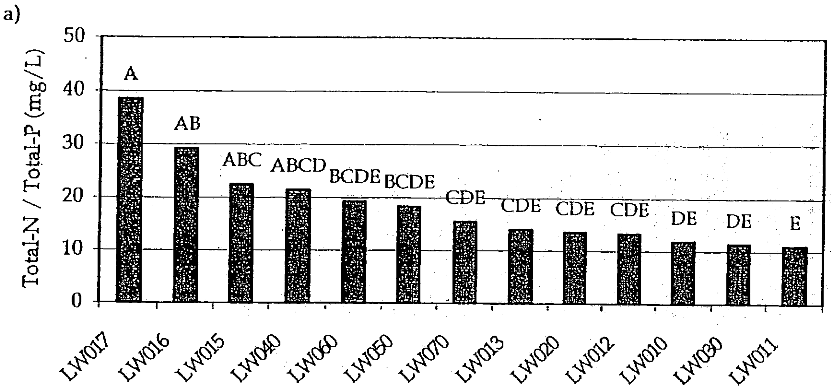


Figure 11 Geometric mean a) total-N/total-P and b) DIN/PO_4-P.
Surface samples were collected between November 1996 and March 1998. Means followed by the same letter are not significantly different at a probability level of 0.05 according to a test of least significant differences.

a)



b)

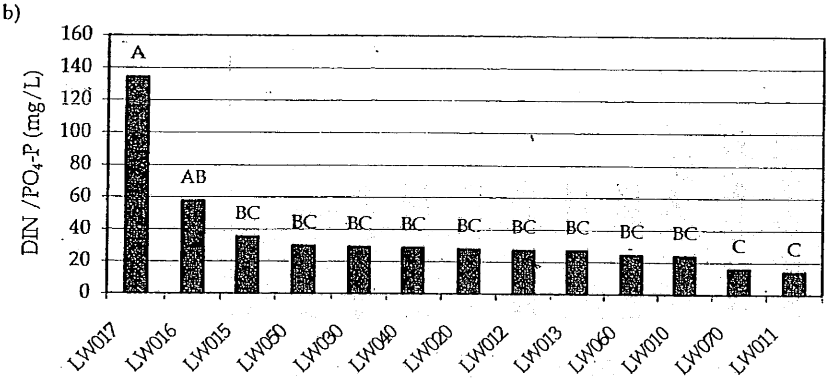
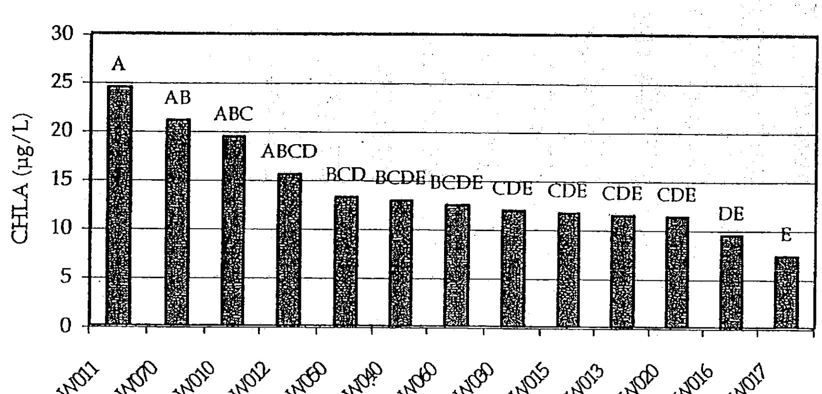


Figure 12 Geometric mean CHLA.
Surface samples were collected between November 1996 and March 1998. Means followed by the same letter are not significantly different at a probability level of 0.05 according to a test of least significant differences



Results of Cluster Analysis

To aid in the spatial interpretation of the results from the ANOVA and LSD analyses, cluster analysis techniques were performed. A separate cluster analysis was performed on the physical data and on the chemical and biological data.

In the first cluster analysis (Figure 13), the evaluation included physical constituents with significant differences (α=0.05) in the ANOVA, (i.e., conductivity, $DO_{\%sat}$, pH, Secchi depth, and TSS). Differences in the normalized root mean square indicated an optimum of five clustering groups from this analysis. A distinct grouping of sites associated with distance from the major river inflows into the reservoir was indicated by these five cluster groups (Figure 14). The largest cluster, labeled group 1 in Figure 14, represents sites within the main body of Lake Waco. The four other cluster groups represent sites located within the north and south arms of the reservoir. Groups 2 and 3 represent sites at almost comparable distances from the two major tributary river inflows. Groups 4 and 5, while distinct, are located between groups 2 and 3 on opposite arms of the reservoir.

Figure 13 Tree diagram of site clustering based on physical constituents. (DO% sat, conductivity, pH, TSS, and Secchi depth)

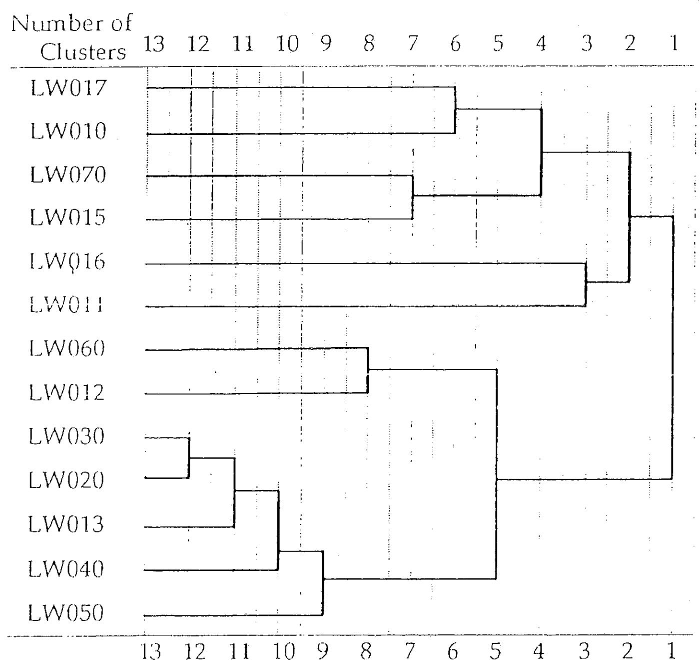
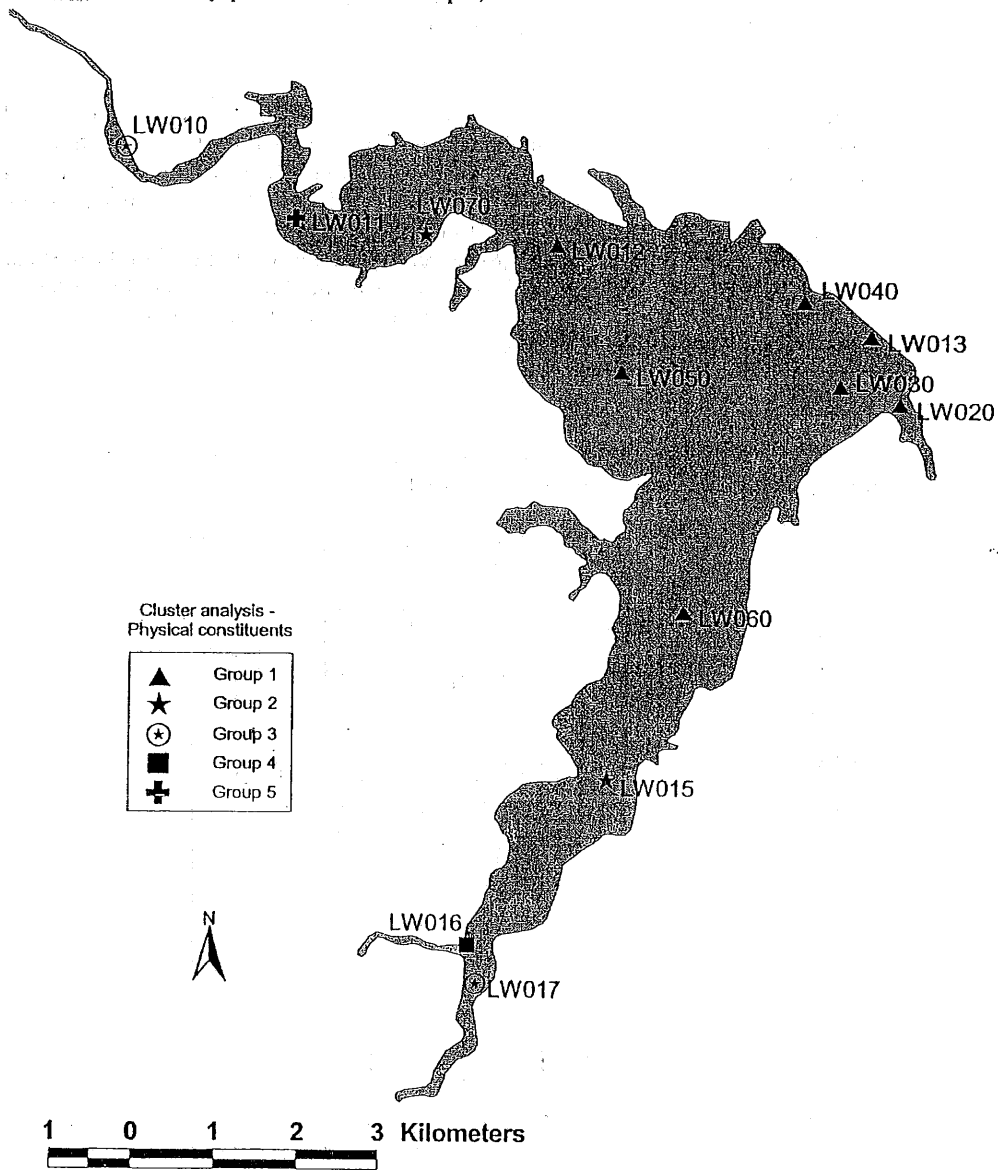
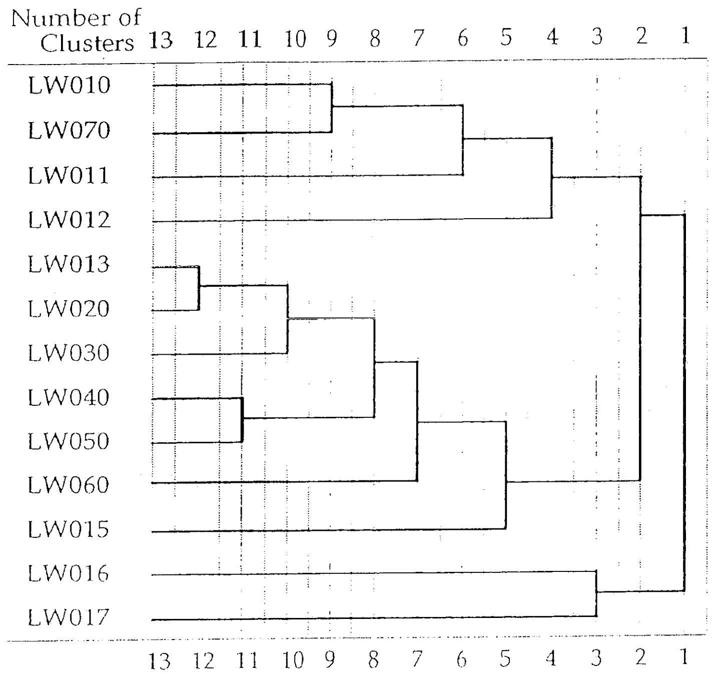


Figure 14 Mapping of cluster analysis results for physical constituents. ($DO_{\%\ sat}$, conductivity, pH, TSS, and Secchi depth)



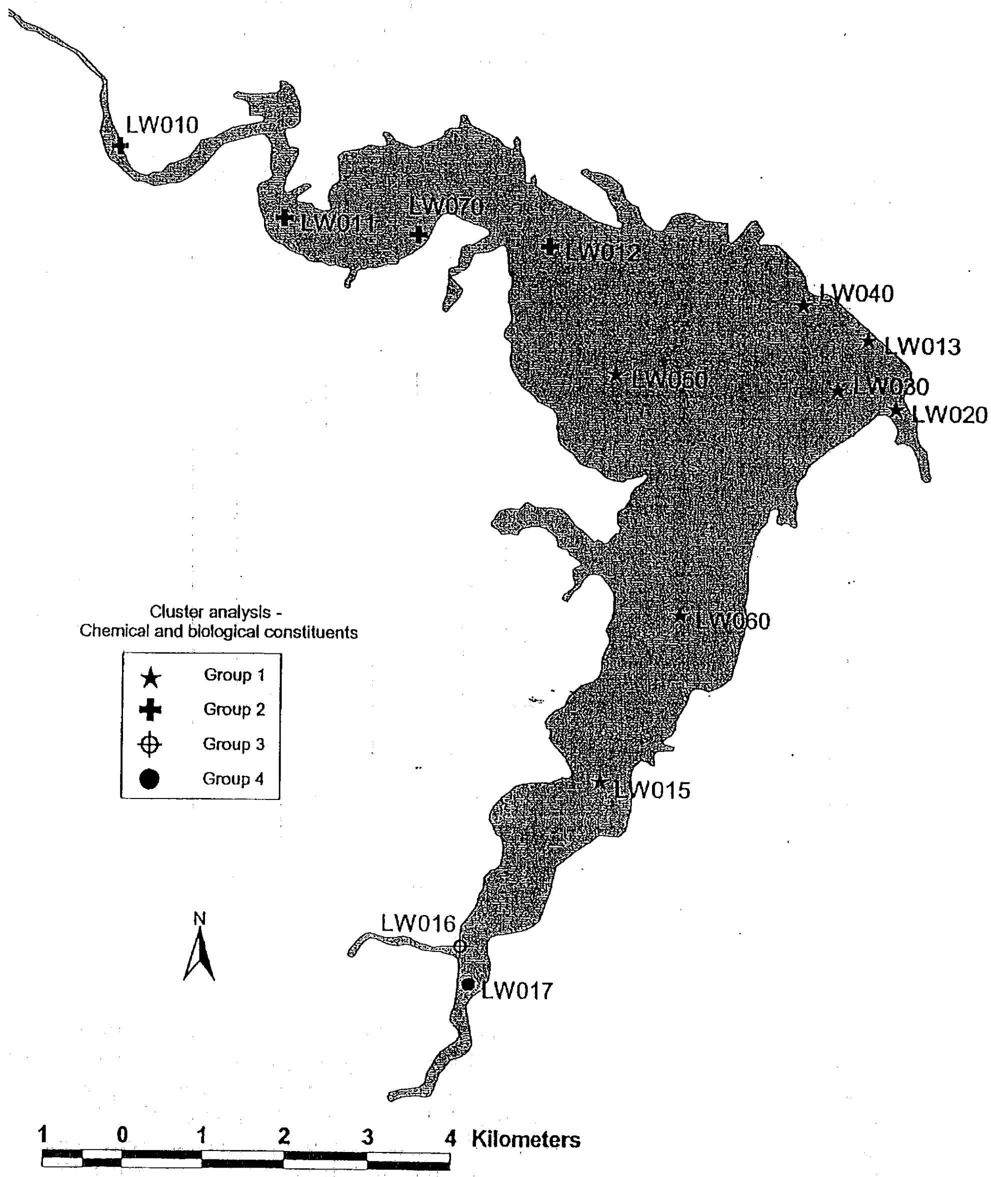
The second cluster analysis focused on the chemical and biological constituents indicated to have highly significant differences in the ANOVA (i.e., DIN, organic-N, total-N, and CHLA). Because DIN, organic-N, and total-N all represent nitrogen fractions, only CHLA and total-N were used in the cluster analysis to balance the spatial influence of CHLA and the nitrogen constituents (Figure 15). Differences in the normalized root mean square indicated an optimum of four clustering groups from this analysis.

Figure 15 Tree diagram of site clustering based on chemical and biological constituents. (CHLA and total-N)



These clustering groups appear to follow a gradient associated with the proximity of sites to either the southern or northern arm of the reservoir (Figure 16). The main body of the reservoir and the upper portion of the southern arm of the reservoir comprised one group (sites LW013, LW015, LW020, LW030, LW040, LW050, and LW060), while sites along the north arm of the reservoir (LW010, LW011, LW012, and LW0170) formed a distinct clustering group. Site LW017, nearest the inflow of the Middle-South Bosque River, and site LW016, near the inflow of Hog Creek, separated out as single site clusters.

Figure 16 Mapping of cluster analysis results for chemical and biological constituents. (CHLA and total-N)



Discussion

For the physical characteristics of conductivity, $DO_{\%sat}$, pH, TSS, and Secchi depth, similarities between sites appear to be based on their proximity to the major tributary inflows. That is, sites near the inflow of the northern tributary were more likely to be similar to sites near the inflow of the southern tributary than to sites in the main body of the reservoir. This pattern of site similarities suggests a longitudinal gradient of riverine to transition to lacustrine as described by Thornton (1990) for reservoir systems.

In contrast, for the chemical and biological constituents of total-N and CHLA, similarities between sites depended on their proximity to either the northern or southern tributary inflow producing gradients of CHLA and nitrogen from north to south across the reservoir. Total-N concentrations increased from north to south across the reservoir with the highest concentrations near the inflow from the Middle-South Bosque River, while the highest CHLA concentrations were associated with the northern arm of the reservoir. CHLA gradients along lakes and reservoirs are well documented and generally follow a pattern of increasing CHLA concentrations with decreasing depth and distance from the main external input to the water body (Perkins and Underwood, 2000). The main external input to Lake Waco is the North Bosque River, which comprises about 74 percent of the reservoir's drainage area (McFarland and Hauck, 1999). CHLA concentrations within Lake Waco clearly followed this pattern with concentrations highest near the inflow associated with the North Bosque River and decreasing with longitudinal distance and increasing depth towards the main body of the reservoir. The lowest CHLA concentrations occurred in the southern portion of the reservoir.

Underlying this CHLA gradient should be a pattern of changes in the nutrients limiting algal growth. Although spatial variability in PO_4-P and total-P concentrations was not significant between sampling sites, differences in total-N and DIN were quite apparent with the highest N concentrations occurring in the southern arm of the reservoir. Differences in the ratio of N to P, thus, varied significantly, influencing the pattern of algal production. N to P ratios clearly indicated a phosphorus limitation in the southern portion of the reservoir near the inflow of the Middle-South Bosque River and Hog Creek. The southern portion of the reservoir was also associated with the lowest geometric mean CHLA concentrations. The N to P ratios calculated for the rest of the reservoir sites were more difficult to interpret, but showed a pattern of P limitation, with P being less limiting within the northern arm than in the main body of the reservoir. To more clearly define the nutrient limiting algal growth within Lake Waco, controlled experiments are necessary. N to P ratios can only be used as a guide, because different species of algae uptake different ratios of N to P. Controlled bioassay experiments were included as a special study on Lake Waco to more directly assess nutrient limitation and are discussed in Chapter 8, "Nutrient Limitation and Algal Growth Responses." The association of major tributary loadings and flow with the patterns of CHLA and nutrients within the reservoir will be further explored in Chapter 5, "Influence of Tributary Inflows and Loadings".

CHAPTER 5

Influence of Tributary Inflows and Loadings

The previous section established two distinct horizontal spatial patterns across Lake Waco based on the proximity of sampling sites to major tributary inflows. Unlike natural lakes that receive most of their inflow from overland flow and small streams, reservoirs receive most of their inflow from major rivers (Ford, 1990). As introduced previously, the major tributaries flowing into Lake Waco are the North Bosque River, Hog Creek, Middle Bosque River, and South Bosque River (Figure 1). The Middle Bosque River merges with the South Bosque River just prior to joining with Lake Waco, and, along with Hog Creek, it forms the southern arm of the reservoir. The North Bosque River forms the northern arm of the reservoir and represents the majority of inflow volume into Lake Waco.

While other sources of loadings to Lake Waco exist, such as atmospheric loadings and loadings from minor tributaries surrounding the reservoir, these sources are relatively minor compared to the major tributary loadings and were not included in the analysis for this report. Contributions from these smaller sources have been evaluated in previous reports (see McFarland and Hauck, 1998; McFarland and Hauck, 1999). Direct precipitation was found to contribute less than 0.5 percent of P and N loadings to Lake Waco (McFarland and Hauck, 1998), while contributions from smaller tributaries, including runoff from the city of Waco, comprised less than 5 percent of P and N loadings (McFarland and Hauck, 1999).

The purpose of this section is to present information on the relative inflow volumes and loadings from the major tributaries to the reservoir and to evaluate the relationship between tributary inflow and water quality within the lacustrine zone of the reservoir. This evaluation focuses specifically on inflow influences on reservoir nutrient and CHLA concentrations.

Methods

To evaluate the impact of tributary loadings on Lake Waco, stream flow and water quality data for sampling sites along each major tributary were evaluated. Stream sampling sites used in this analysis were located near Valley Mills on the North Bosque River (site BO100), about ten kilometers (six miles) northeast of Crawford on Hog Creek (site HC060), near Crawford on the Middle Bosque River (site MB060), and about 16 kilometers (ten miles) east of McGregor on the South Bosque River (sites SB050 and SB060; Figure 1). Detailed descriptions of the locations of these sites are provided in Chapter 3, "Monitoring Program." As described in Chapter 3, the data for SB050 and SB060 were merged in evaluating stream loadings. These two sites are jointly referred to as SB050 in this chapter. An overview of the monitoring data collected at these stream sites can be found in TIAER's Semiannual Water Quality Report for the Bosque River Watershed (e.g., Pearson and McFarland, 1999). Biweekly grab and automated storm samples were collected at each site and routinely analyzed for NH_3-N, NO_2-N+NO_3-N, TKN, PO_4-P, total-P, and TSS.

Flows for HC060, MB06, and SB050 were determined from site-specific stage-discharge relationships and continuous monitoring of water level at five-minute intervals. For BO100, flow data from a corresponding United States Geological Survey (USGS) site (08095200) were used. Although water quality data were collected at SB050 starting in November 1996 (Pearson and McFarland, 1999), storm data and water level data were not available until August 1997. Daily flows at SB050 for June 1996 though July 1997 were estimated from flows at MB060 using the drainage area ratio as a correction factor. Water quality loadings for June 1996 through July 1997 were estimated for SB050 using median storm and grab data values for 1997 and associating these median values appropriately with base flow or storm event conditions. At all tributary sites, flow data were combined with nutrient concentration data from water quality samples to calculate nutrient loadings. A midpoint rectangular integration method was used to calculate loadings by dividing the flow hydrograph into intervals based on the collection date and time of each water quality sample (Stein, 1977).

A drainage area ratio of the total area to the ungauged area was then applied to the gauged flow and loadings to estimate the total flow and loadings represented by each major tributary to Lake Waco. The flow and constituent loadings for the South Bosque River, Middle Bosque River, and Hog Creek were added together to represent inflow and loadings to the southern arm of Lake Waco. The North Bosque River constituted the inflow and loadings to the northern arm. Cumulative flow, loadings, and volume-weighted mean concentrations were calculated for June 1, 1996 through December 31, 1999 to compare volume and loadings between the northern and southern tributaries. Loadings and inflow volume were also summed on a monthly basis for comparison with monthly reservoir water quality data.

Mean retention time for monthly inflow was estimated based on average monthly reservoir volume. Daily values for reservoir elevation were obtained from the USACE and averaged for each month. Average monthly reservoir volume was derived from the hypsographic curve representing the relationship between elevation and reservoir volume (Figure 4). For elevations between 136 and 143 meters above mean sea level, reflecting the range of reservoir elevations during the study period, reservoir volume was calculated as follows:

8) $$volume = (3180 \cdot elevation) - (419{,}253)\ ; \quad R^2 = 0.99$$

where

volume is the reservoir volume in hectare-meters

elevation is reservoir elevation in meters.

Average monthly reservoir volume was divided by the sum of monthly inflow from the north and south arm tributaries and adjusted to a daily basis for retention time.

In the previous chapter, the data period was restricted to samples collected between November 1996 and March 1998 to avoid the introduction of possible bias from uneven sampling periods between sites. Reservoir data for this chapter focuses on monthly water quality averaging across sites within the main body (lacustrine zone). Because of similarities in water quality indicated in Chapter 4, "Spatial Analysis of Surface Water Quality" between sites in the main body of the reservoir, the data analysis period was extended to include a broader time frame (June 1996 through December 1999). Available data from sites representing the main body of the reservoir (LW0013, LW015, LW020, LW030, LW040, LW050, and LW060) as determined from the cluster analysis results for the chemical and biological constituents (see Figure 16) were averaged by month to represent average monthly reservoir water quality. Correlation analysis and stepwise regression techniques were used to infer relationships between average monthly reservoir water quality and total monthly tributary inflow and constituent loadings.

Correlation With Inflow

Cumulatively, 69 percent of the tributary inflow into Lake Waco was associated with the North Bosque River for June 1996 through December 1999 (Table 12). For N constituents, 72 percent of the DIN and 44 percent of the total-N loading was associated with the southern tributaries. The majority of the total-N and P constituent loading was associated with the North Bosque River. An estimated 56 percent of total-N, 80 percent of PO_4-P, and 77 percent of total-P loadings were associated with inflow from the North Bosque River. The North Bosque River was also the dominant source of TSS loading.

Table 12 Calculated inflow into Lake Waco for June 1996 through December 1999.

Location	Drainage Area (hectares)	Volume (m^3)	DIN (kg)	Total-N (kg)	PO_4-P (kg)	Total-P (kg)	TSS (kg)
North Tributary	316,500 76%	1,510,000,000 69%	808,000 28%	3,550,000 56%	151,000 80%	699,000 77%	1,140,000,000 87%
South Tributaries	98,400 24%	683,000,000 31%	2,060,000 72%	2,820,000 44%	37,000 20%	206,000 23%	164,000,000 13%
Total[a]	415,000	2,190,000,000	2,870,000	6,367,000	188,000	905,000	1,304,000,000

a. Total slightly underestimated as minor tributaries representing about three percent of the drainage area were not included in loading calculations.

Associated volume-weighted concentrations help to interpret these loadings (Table 13). Inflow from the southern tributaries had DIN concentrations almost six times greater than the northern inflow. Total-N concentrations from the southern tributaries were almost double that of the northern tributary. In contrast, PO_4-P concentrations from the northern inflow were double that of the southern inflow, and total-P concentrations from the north were over half as great as from the south. TSS concentrations from the north were also three times as high as from the south. The relatively high inflow concentrations of DIN and total-N from the southern tributaries explain the relatively high DIN and total-N concentrations noted in the previous chapter within the southern portion of Lake Waco, particularly near the inflow of the Middle-South Bosque River and Hog Creek (Figure 5).

Table 13 Volume-weighted tributary inflow concentrations into Lake Waco for June 1996 through December 1999.

Location	DIN (mg/L)	Total-N (mg/L)	PO_4-P (mg/L)	Total-P (mg/L)	TSS (mg/L)
North Tributary	0.54	2.36	0.10	0.46	758
South Tributaries	3.02	4.12	0.05	0.30	239
Total	1.31	2.91	0.09	0.41	596

Two relatively large inflow events, the first occurring in February and March 1997 and the second in March 1998, dominated the study period (Figure 17). Reservoir levels in March 1997 were some of highest on record for Lake Waco, peaking at 143 meters (470 feet) above mean sea level (Figure 18). Residence time in February 1997 decreased to a low of 19 days, as inflows exceeded the average monthly reservoir volume by more than half (Table 14).

Figure 17 Inflow from the northern and southern tributaries to Lake Waco.

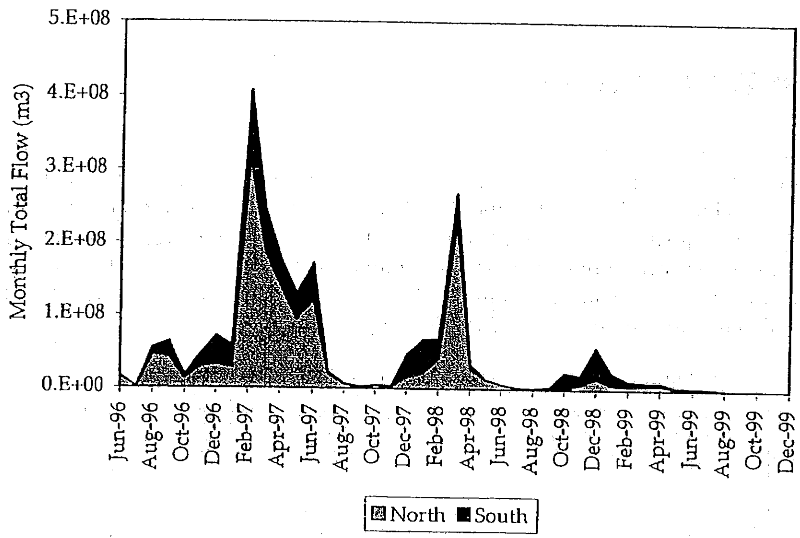


Figure 18 Elevation of Lake Waco compared to the conservation pool elevation (data obtained from USACE).

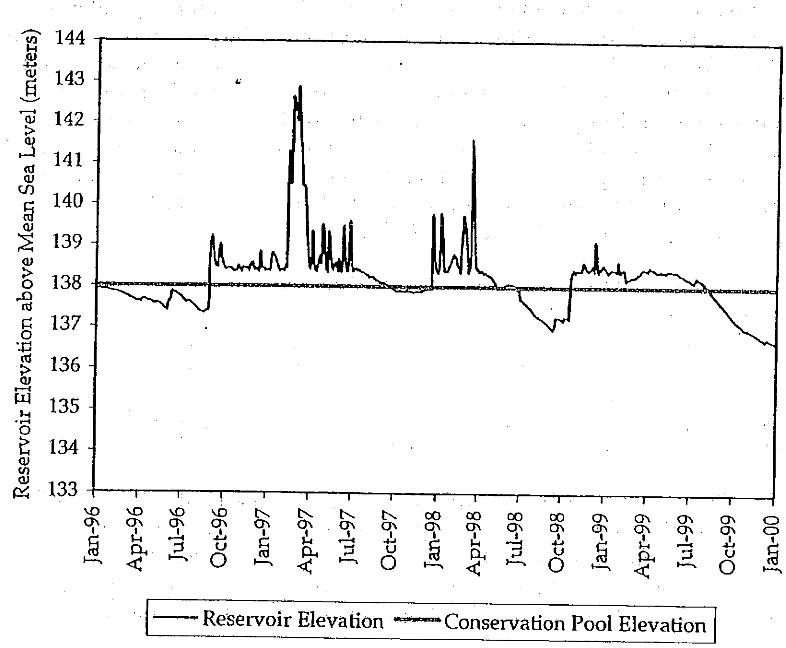


Table 14 Monthly average reservoir volume, total inflow, and estimated residence time.

Date	Average Reservoir Volume (hectare-meters)	Total Inflow (hectare-meters)	Residence Time (days)
Jan-96	19,296	346	1,729
Feb-96	19,050	351	1,573
Mar-96	18,558	258	2,234
Apr-96	18,398	361	1,531
May-96	18,025	922	606
Jun-96	18,810	1,575	358
Jul-96	18,268	166	3,405
Aug-96	17,937	5,629	99
Sep-96	21,946	6,386	103
Oct-96	20,849	1,709	378
Nov-96	20,952	4,720	133
Dec-96	21,005	7,144	91
Jan-97	21,304	5,909	112
Feb-97	27,082	40,631	19
Mar-97	27,818	24,611	35
Apr-97	21,960	17,826	37
May-97	21,537	13,091	51
Jun-97	21,977	17,184	38
Jul-97	20,732	2,220	289
Aug-97	20,180	676	926
Sep-97	19,651	261	2,261
Oct-97	19,239	473	1,260
Nov-97	19,193	451	1,276
Dec-97	20,507	4,731	134
Jan-98	21,757	6,747	100
Feb-98	22,067	6,923	89
Mar-98	23,558	26,787	27
Apr-98	20,601	3,363	184
May-98	19,690	1,335	457
Jun-98	19,575	636	924
Jul-98	18,143	229	2,456
Aug-98	17,091	153	3,457
Sep-98	16,807	322	1,564
Oct-98	18,633	2,310	250
Nov-98	21,001	1,972	319
Dec-98	21,329	5,798	114
Jan-99	20,902	2,267	286
Feb-99	20,514	1,208	476
Mar-99	20,689	1,028	624
Apr-99	20,912	1,022	614
May-99	20,824	398	1,621
Jun-99	20,482	322	1,910
Jul-99	20,134	265	2,352
Aug-99	19,199	40	14,873
Sep-99	17,874	36	15,033
Oct-99	16,717	34	15,352
Nov-99	16,041	34	14,143
Dec-99	15,547	37	13,049

These two large inflow events complicate the interpretation of correlations of inflow and constituent loadings with reservoir water quality, for it is not clear if there is a cause and effect relationship, or whether the timing of these large events just happens to correspond with normal seasonal dynamics (Table 15). To aid in mitigating seasonal impacts, reservoir water temperature was added to the correlation analysis. Monthly inflow and estimated retention time showed highly significant (α=0.01) correlations with reservoir CHLA, DIN, total-N, and PO_4-P concentrations as well as with water temperature (Table 15). Total-P showed no correlation with inflow or retention time, while reservoir TSS concentrations indicated a significant (α=0.05), but fairly weak correlation. In general, correlations of reservoir water quality with tributary loadings for specific constituents were fairly comparable to correlations of reservoir water quality with tributary inflow volume. Only reservoir PO_4-P concentrations showed a notable improvement when related to PO_4-P loadings rather than inflow volume. For CHLA, the strongest correlation relationship was with inflow volume. These relationships reflect the dominate role of flow in determining tributary loadings.

Table 15 Correlation of inflow, retention time, and inflow mass with reservoir water quality within the lacustrine zone. The data evaluated represent monthly values for June 1996 through December 1999. "r" is the correlation coefficient, and "p" is the probability value relating to the significance of the correlation. "na" indicates not applicable.

Constituent		ln(Inflow) (m^3)	ln(retention) (days)	ln(Mass DIN) (kg)	ln(Mass Total-N) (kg)	ln(Mass PO4-P) (kg)	ln(Mass Total-P) (kg)	ln(Mass TSS) (kg)
ln(CHLA) (µg/L)	r	-0.48	0.47	-0.45	-0.46	-0.42	-0.45	-0.36
	p	0.0013	0.0016	0.0025	0.0021	0.0056	0.0026	0.0167
ln(DIN) (mg/L)	r	0.67	-0.66	0.69	na	na	na	na
	p	0.0001	0.0001	0.0001	na	na	na	na
ln(Total-N) (mg/L)	r	0.53	-0.52	na	0.52	na	na	na
	p	0.0003	0.0004	na	0.0004	na	na	na
ln(PO_4-P) (mg/L)	r	0.65	-0.66	na	na	0.73	na	na
	p	0.0001	0.0001	na	na	0.0001	na	na
ln(Total-P) (mg/L)	r	-0.03	0.03	na	na	na	0.05	na
	p	0.8545	0.8702	na	na	na	0.7601	na
ln(TSS) (mg/L)	r	-0.39	0.38	na	na	na	na	-0.35
	p	0.01170	0.01250	na	na	na	na	0.0225
Water temp. (°C)	r	-0.46	0.46	na	na	na	na	na
	p	0.0019	0.0018	na	na	na	na	na

In comparing the relationships of inflow and retention time with reservoir water quality, almost the same correlation values were obtained, except opposite in sign. Positive correlations were indicated for reservoir DIN, total-N, and PO_4-P concentrations with inflow indicating an increase in concentration with increasing inflow. Negative correlations were indicated between inflow and reservoir CHLA, TSS, and water temperature levels. The negative correlation of inflow with CHLA may represent a lag in the production of algae, as algae grow and reproduce in response to nutrient loadings.

Because algae are generally more productive at higher temperatures, the "lag" in CHLA response to inflow may also be a function of water temperature as inflow events were negatively correlated with warmer temperatures (Table 15). A time series evaluation of tributary inflow in comparison to reservoir CHLA, DIN, and PO_4-P concentrations clearly shows the potential influence of seasonal dynamics on water quality within Lake Waco (Figure 19). Sterner and Grover (1998) found in their studies on Eagle Mountain and Cedar Creek Lakes in Texas that algal production was generally not influenced by nutrient additions at temperatures below 22° C, but at temperatures above 22° C, algal growth was frequently nutrient limited. As algal growth rates increase with warmer temperatures, an increased consumption of PO_4-P and DIN by algae would be expected and may partially explain the decrease in DIN and PO_4-P concentrations seen during the summer within the reservoir (Figure 19). Within the main body of Lake Waco, CHLA concentrations showed a strong positive correlation with water temperature and a strong negative correlation with DIN, total-N, and PO_4-P concentrations (Table 16). CHLA concentrations were not significantly correlated with total-P or TSS concentrations.

Figure 19 Tributary inflow compared to reservoir CHLA, DIN, and PO_4-P concentrations in the lacustrine zone.

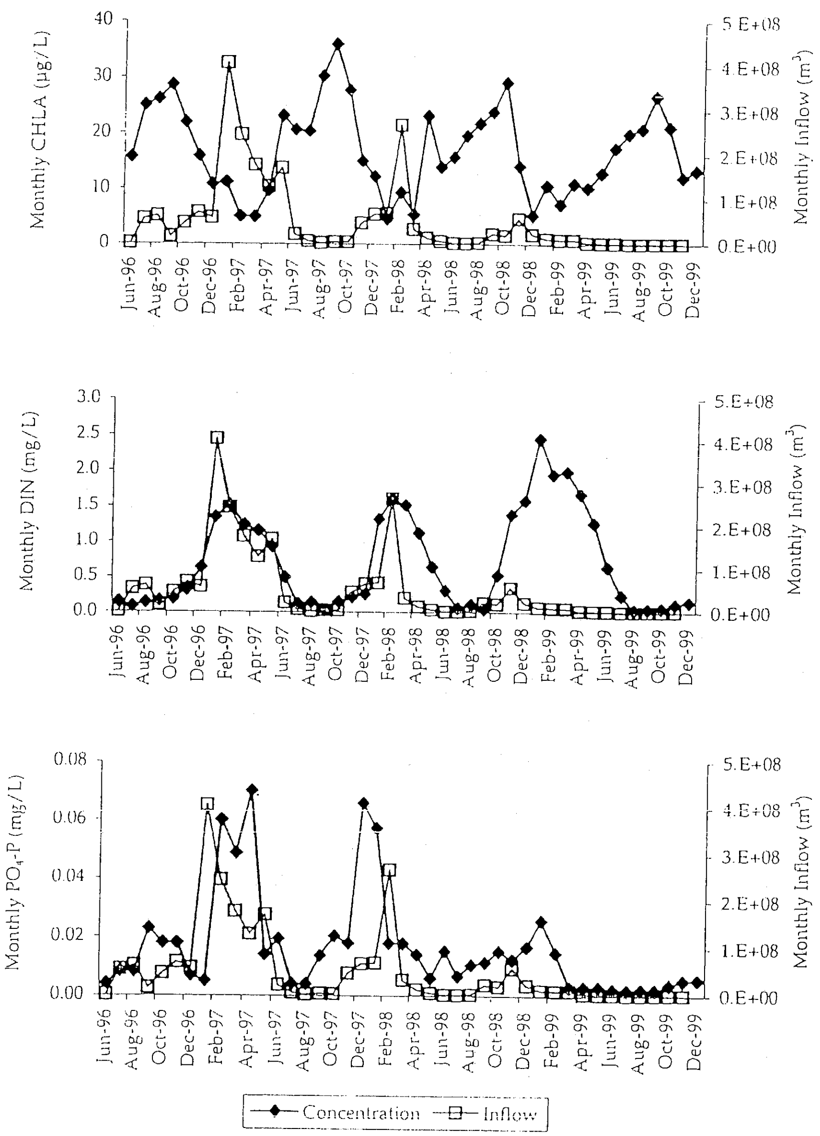


Table 16 Correlation of CHLA with Secchi depth, total-P, and TSS for Lake Waco.
Data evaluated included monthly average water quality concentrations for surface samples collected between June 1996 and December 1999 within the main body of the reservoir. "r" is the correlation coefficient, and "p" is the probability value relating to the significance of the correlation.

Constituent		ln(CHLA) (µg/L)
DIN (mg/L)	r	-0.72
	p	0.0001
Total-N (mg/L)	r	-0.69
	p	0.0001
PO_4-P (mg/L)	r	-0.49
	p	0.0009
Total-P (mg/L)	r	-0.20
	p	0.2086
TSS (mg/L)	r	-0.09
	p	0.5618
Water temp. (°C)	r	0.77
	p	0.0001

Stepwise Regression Models

To further explore the role of inflow and seasonal dynamics on reservoir water quality, explanatory multiple regression models were developed for monthly average DIN, PO_4-P, and CHLA concentrations for the main body of Lake Waco. Stepwise regression techniques, as outlined by Fruend and Littell (1991), were used in variable selection of the best fit model for each constituent. The variables included in the stepwise regression for DIN included monthly average CHLA, PO_4-P, total-P, TSS, water temperature, and organic-N for the main body of the reservoir and the monthly sum of DIN inflow as independent variables. Total-N was not included as a potential variable in the model for DIN, as DIN comprises over 40 percent of total-N. Including total-N in the DIN model might mask the influence of the other variables. Total-N was also excluded from the models for PO_4-P and CHLA, because of the very high correlation between DIN and total-N. For the PO_4-P model, the full set of variables included monthly average DIN, organic-N, CHLA, total-P, TSS, and water temperature for the main body of the reservoir and the monthly sum of PO_4-P inflow. Although PO_4-P is a component of total-P, PO_4-P generally represented only a small percentage of total-P (<20 percent), and PO_4-P was not highly correlated with total-P. Total-P was, thus, included as a potential independent variable in the PO_4-P multiple regression model. For CHLA, the full set of variables included the monthly average DIN, organic-N, PO_4-P, total-P, TSS, and water temperature for the main body of the reservoir and the monthly sum of tributary inflow. Both the natural log transformation and untransformed forms of each variable were considered in model development. A significance level of 0.15 was set for entering variables into the model using forward variable selection. The best fit model was then evaluated to remove multicollinearity effects as indicated by highly correlated independent variables based on the variance inflation factor (Fruend and Little, 1991).

The following "best fit" models were obtained:

9) $$\ln(PO_4\text{-}P) = -2.84 - 0.59\ln(CHLA) - 0.39\ln(DIN) + 0.77\ln(\text{Total-P}) + 0.71\ln(\text{Organic-N}) + 0.30\ln(massPO_4\text{-}P)$$

10) $$\ln(DIN) = -0.74 - 1.33\ln(CHLA) - 28.41(PO_4\text{-}P) + 6.18(\text{Total-P}) + 0.33\ln(massDIN)$$

11) $$\ln(CHLA) = 2.53 - 0.43(DIN) - 8.48(PO_4\text{-}P) + 2.36(\text{Total-P}) + 0.03(watertemp) - 0.02(TSS)$$

Basic statistics for coefficient values including the standardized estimates for coefficient values are presented in Table 17. Standardized coefficients allow interpretation of multiple regression coefficients without the affect of differing scales and vary from a range of negative one to positive one (Fruend and Littell, 1991).

Table 17 Multiple regression models for reservoir PO_4-P, DIN, and CHLA concentrations.

Dependent Variable: ln(PO_4-P)			Model R-square = 0.74	
Variable	Parameter Estimate	Standard Error	Prob > |T|	Standardized Estimate
Intercept	-2.84	0.70	0.0002	0
ln(CHLA)	-0.59	0.21	0.0065	-0.33
ln(DIN)	-0.39	0.10	0.0004	-0.52
ln(total-P)	0.77	0.17	0.0001	0.39
ln(org-N)	0.71	0.38	0.0689	0.15
ln(mass PO_4-P)	0.30	0.03	0.0001	0.92
Dependent Variable: ln(DIN)			**Model R-square = 0.80**	
Variable	Parameter Estimate	Standard Error	Prob > |T|	Standardized Estimate
Intercept	-0.74	0.85	0.3859	0
ln(CHLA)	-1.33	0.21	0.0001	-0.56
PO_4-P	-28.41	7.15	0.0003	-0.38
Total-P	6.18	1.60	0.0004	0.30
ln(mass DIN)	0.33	0.05	0.0001	0.63
Dependent Variable: ln(CHLA)			**Model R-square = 0.74**	
Variable	Parameter Estimate	Standard Error	Prob > |T|	Standardized Estimate
Intercept	2.53	0.36	0.0001	0
DIN	-0.43	0.11	0.0003	-0.51
PO_4-P	-8.48	3.35	0.0159	-0.27
Total-P	2.36	0.90	0.0125	0.27
Water temp.	0.03	0.01	0.0179	0.35
TSS	-0.02	0.01	0.1292	-0.16

These empirical models infer the complexity of the reservoir system. A strong positive interaction occurred between reservoir DIN and PO_4-P concentrations in association with the timing of inflow events, while decreases in DIN and PO_4-P were associated with increasing CHLA concentrations related to the uptake of soluble nutrients with increasing algal populations (Table 17). Algal productivity as measured by CHLA concentrations was greatly influenced by water temperature and the availability of soluble nutrients (DIN and PO_4-P). A slight shading effect on algal growth was indicated by the negative coefficient value associated with TSS in the CHLA model. Lake Waco is quite turbid. It has been suggested that algal growth within Lake Waco at times may be light limited (Kimmel and Lind, 1972), although nutrient availability appears to be a stronger limiting factor in the data set analyzed. Tributary inflow was not selected as a variable in the best fit multiple regression model for CHLA. In reference to the seasonal trends indicated in Figure 19, it appeared that inflow events increased DIN and PO_4-P concentrations through loadings, while consumption by algae with increasing water temperatures acted to decrease DIN and PO_4-P concentrations between inflow events.

These complex interactions indicate the advantage of using mechanistic models in evaluating reservoir systems. The empirical models developed above while indicating relatively high coefficients of determination (R^2 values) only partially explain the system. These regression equations are also specific to the time period of the data used to develop them. As only three and a half years of data were used to develop these empirical models, these models may not be directly applicable to other time frames without further evaluation. The inflow events noted in February 1997 and March 1998 were atypically large and were the major influences on reservoir inflow and loadings during the study period. Regardless, these empirical models do indicate general explanatory trends associated with dominating influences on CHLA, DIN, and PO_4-P concentrations within Lake Waco for the time frame evaluated. A mechanistic model, CE-QUAL-W2, has been applied to Lake Waco to evaluate the impact of varying inflow loadings on algal dynamics (Flowers et al., 2001). Within this mechanistic model, the complex interactions of nutrient loading, nutrient availability, light availability, water temperature, and algal growth can be more fully explored to evaluate changes in the dynamics within Lake Waco with changes in inflow and nutrient loadings.

CHAPTER 6

Vertical Influences

Although Lake Waco is a relatively shallow, well-mixed reservoir, some changes in water quality are expected with depth. Temperature stratification, for example, often occurs in the summer as rapid heating of upper waters makes them less dense than lower waters. This density differential makes the reservoir more resistant to wind mixing and strengthens thermal stratification. In the classical pattern of lake stratification, the upper stratum is called the epilimnion and holds warmer waters, while the lower stratum is called the hypolimnion and holds cooler waters (Wetzel, 1983). Between the epilimnion and the hypolimnion, a middle stratum representing a thermocline occurs. The thermocline is defined as a layer in which water temperature drops rapidly at a rate of at least one degree Celsius per meter of depth (Boyd, 1990).

For DO, two types of vertical profiles commonly occur. DO concentrations may remain fairly constant throughout the vertical profile of a lake or reservoir or decrease between the epilimnion and the hypolimnion often in a manner that mimics the decrease in temperature when thermal stratification occurs (Ruttner, 1963). In the hypolimnion, sediment oxygen demand may deplete oxygen supplies, because insufficient light is available within the hypolimnion for photosynthesis to produce oxygen and only limited DO transport (advection and dispersion) occurs between the oxygen rich waters of the epilimnion and the oxygen depleted waters of the hypolimnion, particularly when a lake is thermally stratified. A gradual decrease in DO with depth is, thus, expected to occur even in unstratified lakes or reservoirs. If DO concentrations within the hypolimnion approach zero and bottom sediments become anoxic or anaerobic, nutrient release from bottom sediments may occur as an internal source of nutrients for algae growth (Boyd, 1990). The purpose of this chapter is to evaluate the influence of depth on water quality within Lake Waco in defining whether internal nutrient loadings are an important source of available nutrients for algal growth.

Methods

To evaluate the impact of depth on water quality in the main body of the reservoir, data collected between June 1996 and December 1999 representing surface, mid-depth, and bottom samples from site LW013 were evaluated using ANOVA techniques. Site LW013 is located near the dam (Figure 5) and is one of the deepest sites monitored (Table 10). Data for each constituent were evaluated prior to conducting the ANOVA to determine if a lognormal transformation was needed. An ANOVA was conducted for each constituent with season and depth as main effects, and season-by-depth as an interaction effect. The months May through September were categorized as summer, and the months October through April as winter, based on observed differences in the one-meter profile data for water temperature and DO (Figures 20-23). While water temperature did not show a clear thermal stratification within Lake Waco (Figures 20 and 21), decreases in DO with depth were quite apparent during the summer months (Figures 22 and 23). Of note was an increase in DO with depth during specific winter months (see DO profile data for 10/7/98, 12/14/98, and 01/14/99 shown in Figure 23). Field notes indicate that the aerator near LW013 was functioning when samples were collected

Figure 20 Water temperature profile at LW013 for June 1996 through March 1998.

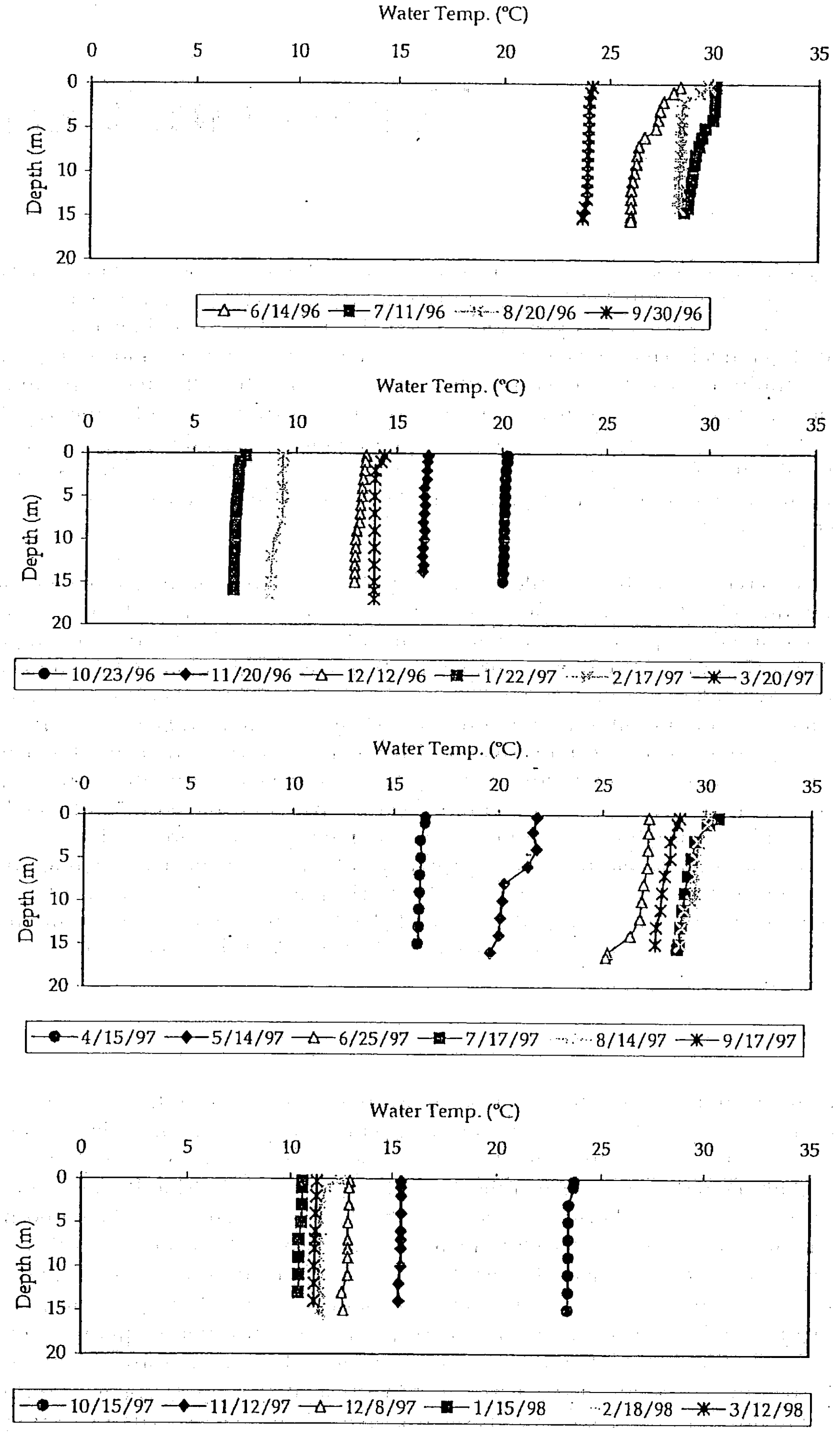


Figure 21 Water temperature profile at LW013 for April 1998 through December 1999.

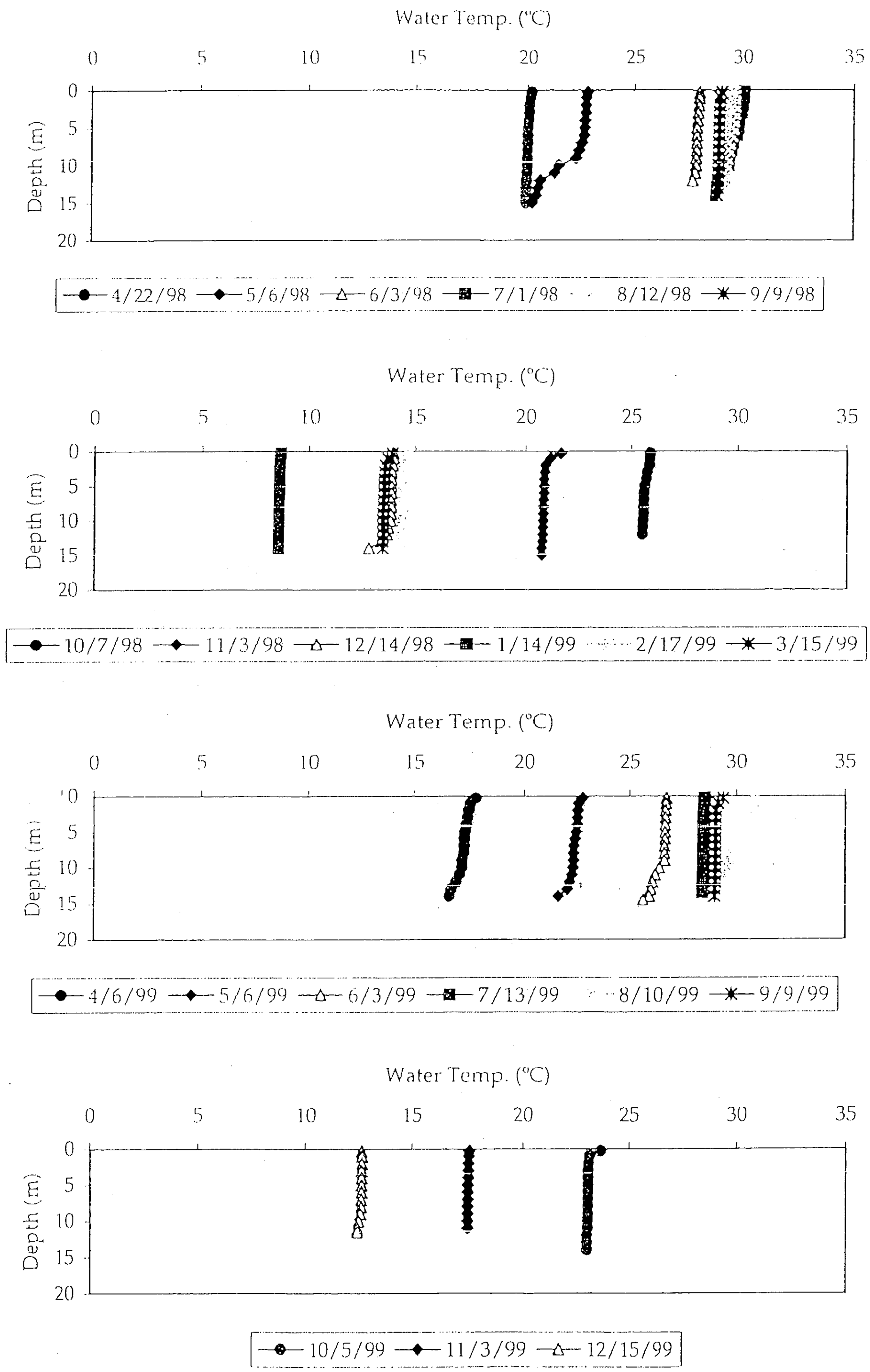


Figure 22 Dissolved oxygen profile at LW013 for June 1996 through March 1998.

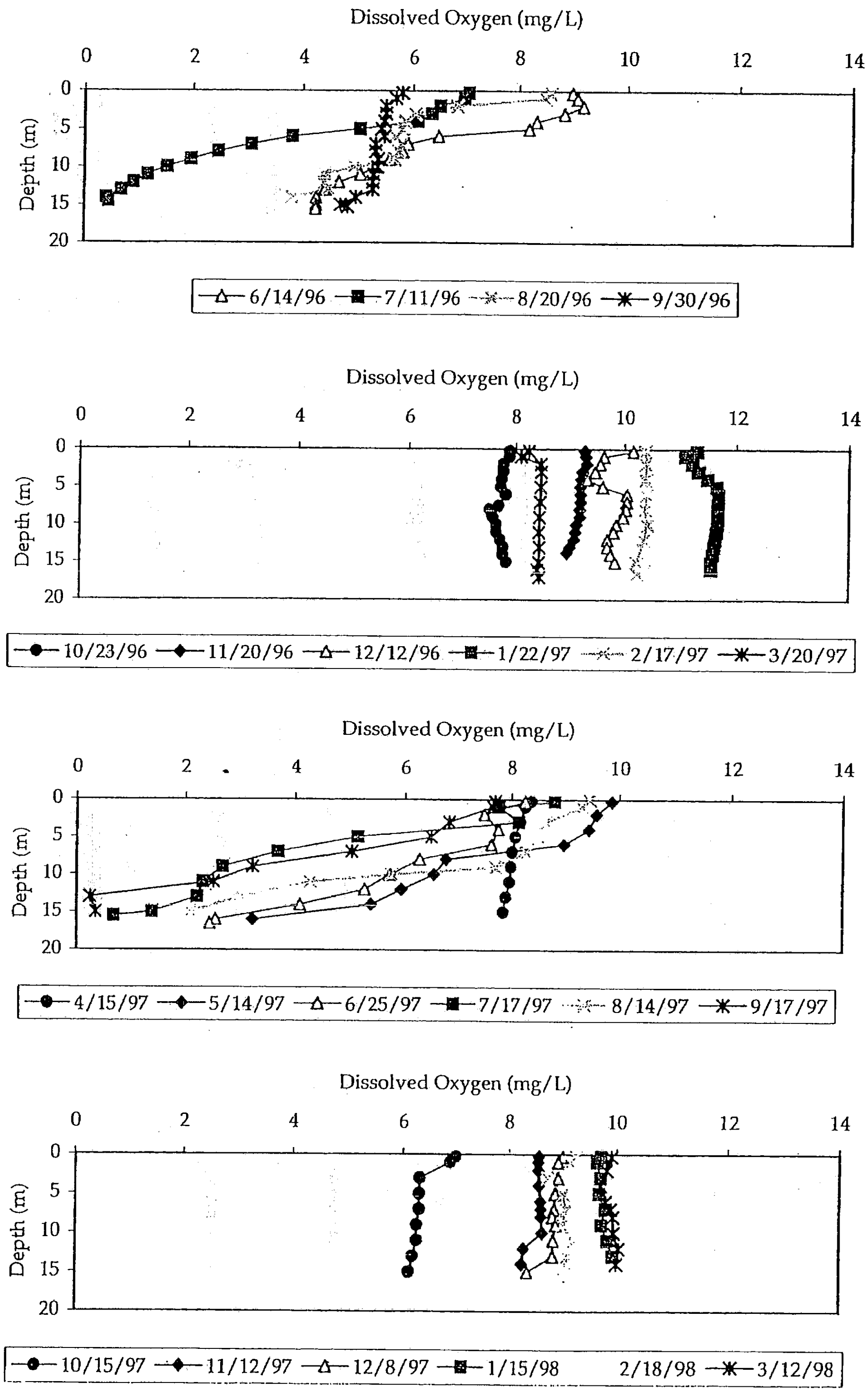
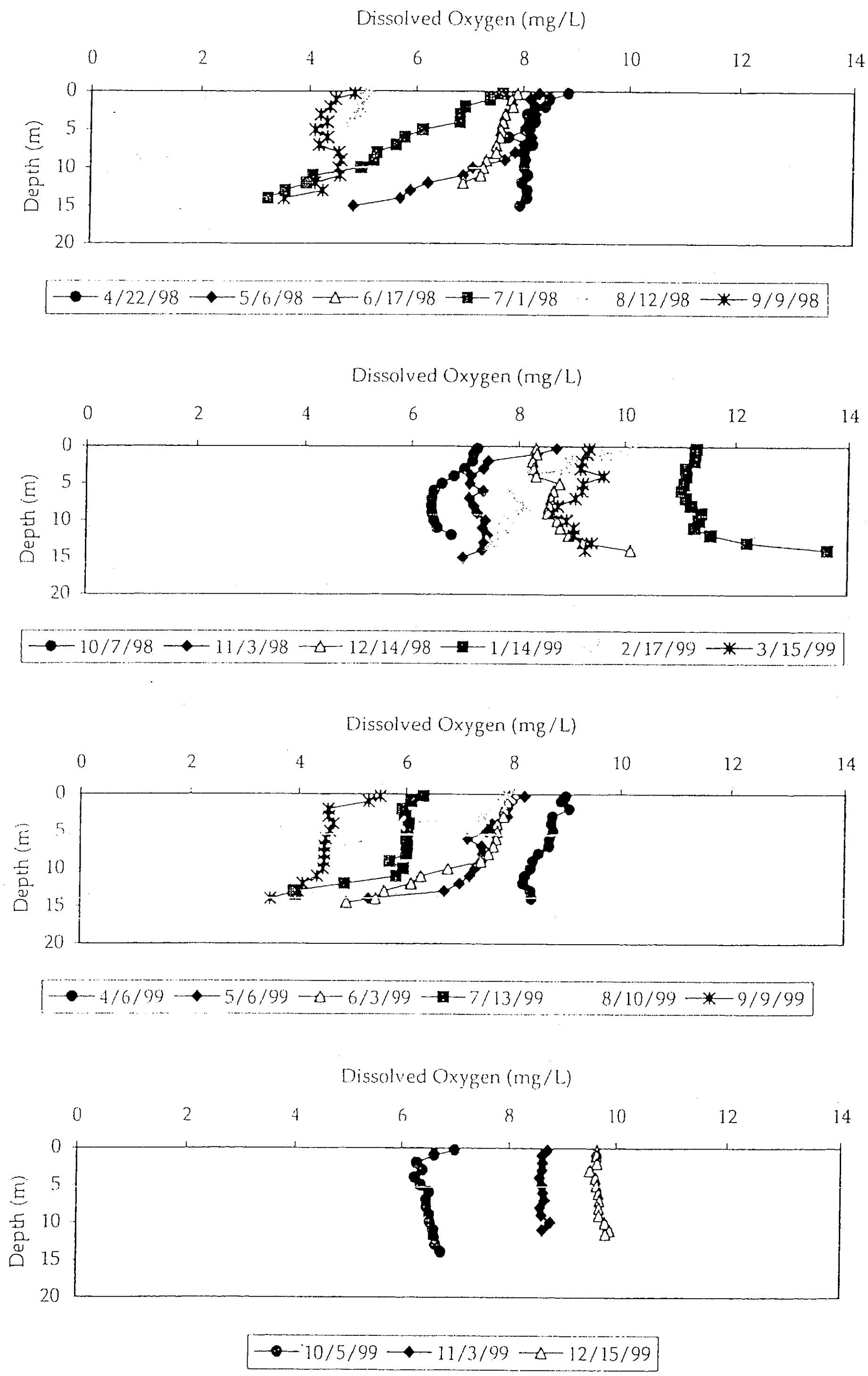


Figure 23 Dissolved oxygen profile at LW013 for April 1998 through December 1999.



on these dates indicating that these increases in DO with depth are probably associated with operation of the aerator near LW013 (see Biedeman and Fulton, 1971).

In evaluating the impact of depth on water quality, differences between depths for constituent values were evaluated using a test of least significant differences if depth was a significant variable in the ANOVA. Correlation relationships between constituents were also explored to evaluate the potential relationships between constituents for samples collected at the bottom depth.

Results Of Analysis With Depth and Season

In the ANOVA, seasonal differences were significant (α=0.05) for almost all constituents except COD, conductivity, NH_3-N, PP, and total-P (Table 18). Only a few constituents (DO, $DO_{\%sat}$, NH_3-N, pH, TKN, and TSS) indicated significant differences with depth. Of these, DO, $DO_{\%sat}$, and pH indicated a significant (α=0.05) season-by-depth interaction effect. Basic statistics for constituents showing no variation with depth are given in Table 19. CHLA, water temperature, and Secchi depth indicated higher values in the summer than in the winter. In contrast, DIN, NO_2-N+NO_3-N, organic-N, and PO_4-P showed higher concentrations in the winter than in the summer. The lower nutrient concentrations in the summer most likely represent the uptake of nutrients by algae with increasing summer temperatures.

Table 18 Effect of season and depth on water quality in Lake Waco at site LW03 for samples collected between June 996 and December 1999. "p-value" represents the probability value relating to the significance level.

Constituent	Data Transformed	Season (p-value)	Depth (p-value)	SeasonxDepth (p-value)
CHLA	yes	0.0001 **[a]	na[b]	na
COD	yes	0.3654	0.2372	0.6518
Conductivity	no	0.1672	0.6423	0.9761
DIN	yes	0.0001 **	0.1275	0.3334
DO	no	0.0001 **	0.0001 **	0.0001 **
$DO_{\%sat}$	no	0.0001 **	0.0001 **	0.0001 **
NH_{3-N}	yes	0.1333	0.0014 **	0.0698
NO_2-N + NO_3-N	yes	0.0001 **	0.3186	0.6729
Organic-N	yes	0.0002 **	0.1289	0.8116
PP	yes	0.8722	0.0505	0.9953
PO_4-P	yes	0.0001 **	0.4386	0.8047
pH	no	0.0001 **	0.0001 **	0.0001 **
TKN	yes	0.0005 **	0.0126 *[c]	0.7448
Total-P	yes	0.0932	0.1252	0.4841
TSS	yes	0.0002 **	0.0001 **	0.1671
Total-N	yes	0.0001 **	0.1055	0.8777
Water Temperature	no	0.0001 **	0.7544	0.9699
Secchi Depth	no	0.0001 **	na	na

a. ** indicates significance at α=0.01
b. "na" indicates analysis was not applicable
c. * indicates significance at α=0.05

To compare between constituents, all constituents showing significant differences by depth were evaluated for differences in depth by season. A distinct decrease in DO, $DO_{\%sat}$, and pH occurred in the summer with depth, but not during the winter at LW013 (Table 20). Average DO values at LW013 during the summer ranged from 7.65 mg/L at the surface to 2.97 mg/L at the bottom depth (about 15 meters). During the winter, the similarity in DO values with depth indicates how well mixed the reservoir was from top to bottom, with an average DO across depths of 8.69 mg/L. $DO_{\%sat}$ values followed a similar trend, with DO near saturation at the

Table 19 Basic statistics for constituents showing no variation with depth at site LW013.

Constituent	Season	Mean or Geometric Mean	Lower Std	Upper Std	n
COD (mg/L)	All	6.07	2.99	12.33	173
Conductivity (µmhos/cm)	All	336.18	291.00	381.36	184
PP (mg/L)	All	0.06	0.02	0.19	182
Total-P (mg/L)	All	0.08	0.03	0.18	188
CHLA (µg/L)	Summer	19.37	14.13	26.56	30
	Winter	11.33	6.07	21.15	33
DIN (mg/L)	Summer	0.19	0.06	0.64	93
	Winter	0.45	0.13	1.58	95
NO_2-N+NO_3-N (mg/L)	Summer	0.09	0.02	0.50	93
	Winter	0.34	0.07	1.67	95
Organic-N (mg/L)	Summer	0.50	0.34	0.74	92
	Winter	0.61	0.45	0.82	95
PO_4-P (mg/L)	Summer	0.004	0.002	0.011	93
	Winter	0.012	0.004	0.033	92
Water Temp. (°C)	Summer	27.60	24.30	30.90	92
	Winter	16.09	11.46	20.73	92
Secchi Depth (meters)	Summer	3.50	2.83	4.17	31
	Winter	2.06	1.34	2.79	33

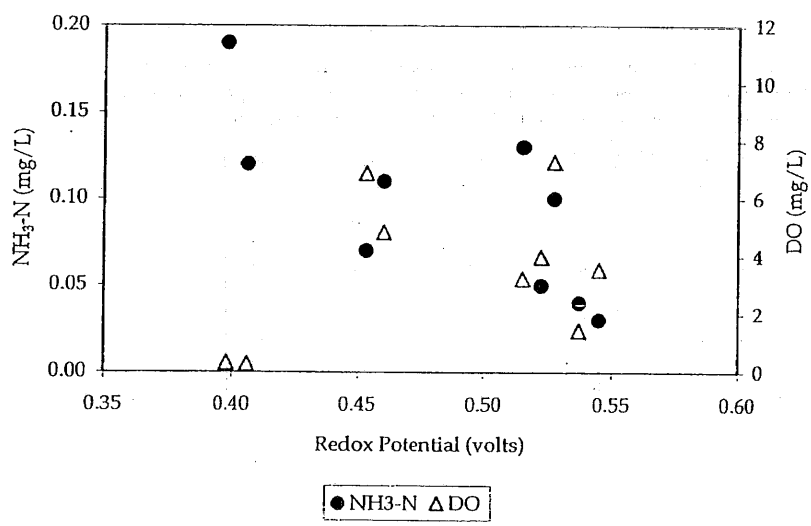
Table 20 Basic statistics for constituents showing significant variation with depth at site LW013. Mean values followed by different letters indicate significant differences between depths within a season for a constituent at a probability value of 0.05 based on a test of least significant differences.

Constituent	Depth	Season	Mean or Geometric Mean		Lower Std	Upper Std	n
$DO_{\%sat}$	Top	Summer	97.70	A	82.55	112.84	31
	Middle	Summer	74.59	B	57.34	91.83	31
	Bottom	Summer	36.58	C	10.58	62.59	30
	All	Winter	87.16		78.25	96.08	92
DO (mg/L)	Top	Summer	7.65	A	6.46	8.84	31
	Middle	Summer	5.92	B	4.49	7.35	31
	Bottom	Summer	2.97	C	0.85	5.08	30
	All	Winter	8.69		7.25	10.14	92
pH	Top	Summer	8.09	A	7.85	8.32	31
	Middle	Summer	7.76	B	7.49	8.04	31
	Bottom	Summer	7.54	C	7.31	7.78	30
	All	Winter	8.12		7.97	8.27	92
NH_3-N (mg/L)	Top	Summer	0.034	A	0.014	0.082	31
	Middle	Summer	0.037	A	0.014	0.093	31
	Bottom	Summer	0.078	B	0.038	0.163	31
	All	Winter	0.038		0.016	0.090	95
TKN (mg/L)	Top	Summer	0.53	A	0.38	0.75	31
	Middle	Summer	0.54	A	0.40	0.74	31
	Bottom	Summer	0.64	B	0.48	0.85	31
	All	Winter	0.66		0.50	0.88	95
TSS (mg/L)	Top	Summer	4.92	A	3.47	6.97	31
	Middle	Summer	6.00	A	3.92	9.18	31
	Bottom	Summer	14.10	B	6.29	31.60	31
	Top	Winter	7.39	A	4.27	12.78	32
	Middle	Winter	9.24	A	5.66	15.07	31
	Bottom	Winter	15.35	B	8.02	29.36	30

surface, 97.7 percent, and only about a third saturation at the bottom, 36.6 percent. A decrease in pH with depth was also noted in the summer (Table 20). Average pH values decreased from 8.09 at the top to 7.54 at the bottom of the reservoir. This decrease in pH was probably related to the release of carbon dioxide from the decomposition or respiration of plants and animals without the associated removal of carbon dioxide via photosynthesis (Boyd, 1990).

During the summer, release of some NH_3-N from the bottom sediments was indicated by significant increases in NH_3-N and TKN concentrations with depth. Organic-N concentrations were not significantly different with depth (Table 18), so differences in depth indicated for TKN were most likely associated with changes in NH_3-N concentrations. Increases in NH_3-N can occur as appreciable amounts of organic matter decompose on the bottom of a lake or reservoir (Wetzel, 1983). Under well-oxygenated conditions, NH_3-N that is not taken up by plants or algae quickly becomes nitrified to nitrite and nitrate. When anoxic or anaerobic conditions occur, and the redox potential is reduced below about +0.4volts, nitrification greatly slows or ceases, and accumulations of NH_3-N may occur (Wetzel, 1983). Redox measurements were taken on Lake Waco between May and November 1998. While limited, these redox measurements indicated a distinct increase in NH_3-N concentrations with decreasing redox values at the bottom depth (Figure 24).

Figure 24 Effect of redox potential on NH_3-N and DO concentrations.
Samples collected between May and September 1998 at the bottom depth of site LW013.



The lowest redox measurements also corresponded to the lowest DO measurements (Figure 24). On only one occasion, July 28, 1998, was redox measured below 0.4volts, which would tend to indicate a limited accumulation of NH_3-N within the bottom waters in Lake Waco. While phosphorus may also be released from bottom sediments under anaerobic conditions, no significant increase in PO_4-P was indicated with depth (Table 18). A lower redox potential than occurs in Lake Waco bottom waters is probably necessary before phosphorus release is seen from bottom sediments (Wetzel, 1983).

During both the summer and winter seasons, TSS indicated a significant difference with depth (Table 18). TSS concentrations were similar at the surface and mid-depths but increased significantly for samples taken at the bottom depth (Table 20). During the summer, TSS concentrations increased from a geometric mean of 4.9mg/L at the top to 14.1mg/L at the bottom depth. Very similar values were found during the winter with geometric mean TSS values of 7.4 mg/L for the top depth increasing to 15.4 mg/L at the bottom depth. Efforts were made to minimize disturbance of the bottom when collecting samples. The measured increase in TSS with depth was most likely associated with increases in the deposition of organic and inorganic materials and increased activity of benthic macroinvetrbrates within bottom sediments.

A cross-correlation matrix of DO, $DO_{\%sat}$, NH_3-N, pH, and TSS for samples taken at the bottom depth during the summer for LW013 is presented in Table 21. A highly significant (α=0.01) positive correlation between DO and $DO_{\%sat}$ with pH was indicated, while a significant (α=0.05), but weaker, negative correlation was found between DO, $DO_{\%sat}$, and pH with NH_3-N. For TSS, no correlation was indicated with DO, $DO_{\%sat}$, pH, or NH_3-N.

Table 21 Cross correlation bottom depth constituent values at LW013 during the summer. Data represents samples collected between June 1996 and December 1999. "r" is the correlation coefficient, "p" is the probability value relating to the significance of the correlation.

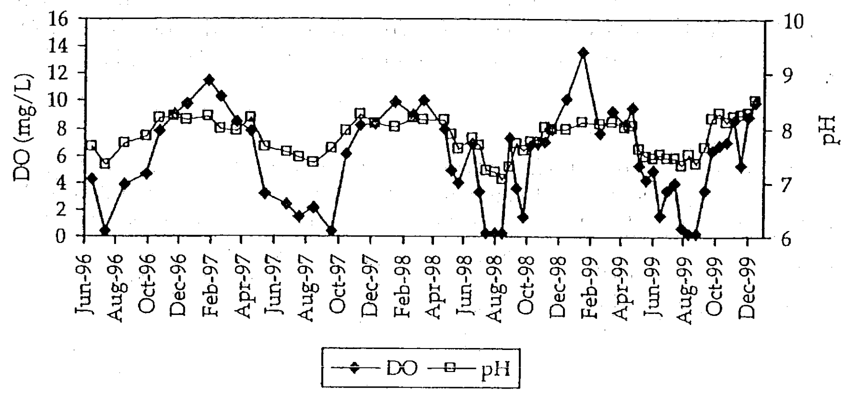
Constituent		DO (mg/L)	$DO_{\%sat}$ (%)	pH	ln(NH_3-N) (mg/L)	ln(TSS) (mg/L)
DO (mg/L)	r	1.00	1.00	0.60	-0.38	0.09
	p	0	0.0001	0.0001	0.0397	0.6330
$DO_{\%sat}$ (%)	r	---	1.00	0.58	-0.37	0.10
	p	---	0	0.0008	0.0463	0.6134
pH	r	---	---	1.00	-0.37	0.33
	p	---	---	0	0.0431	0.0726
ln(NH_3-N) (mg/L)	r	---	---	---	1.00	-0.04
	p	---	---	---	0	0.8288
ln(TSS) (mg/L)	r	---	---	---	---	1.00
	p	---	---	---	---	0

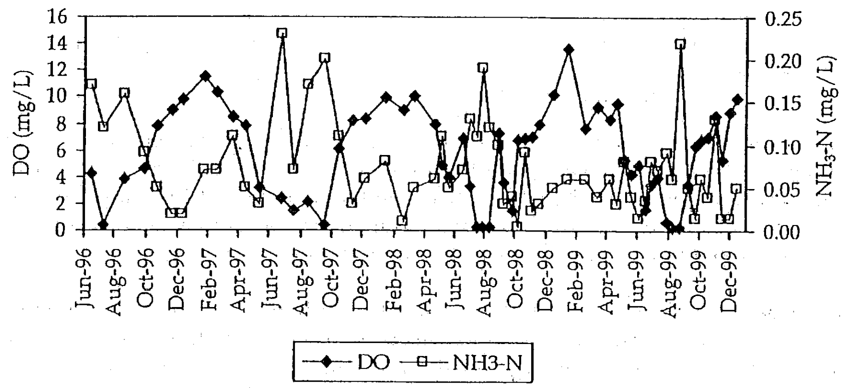
A clear temporal trend in DO concentrations compared to NH_3-N concentrations and pH was indicated for samples taken at the bottom depth (Figure 25). At LW013, a very distinct pattern occurred with highest NH_3-N values corresponding with lowest DO values indicating some release of NH_3-N from bottom sediments during occurrences of lower DO values. A very clear cyclic pattern of DO and pH with seasons was also apparent.

The changes in DO, $DO_{\%sat}$, NH_3-N, pH, and TSS with depth in Lake Waco are interrelated. The increase in TSS with depth was most likely associated with the deposition of decaying materials and settling of other suspended solids within the reservoir. As organic materials decay, primarily during the summer, oxygen is consumed, decreasing DO levels, and carbonic acids are released that may decrease pH. At extremely low DO concentrations, anaerobic or anoxic conditions may occur, reducing redox potential and facilitating release of some NH_3-N from bottom sediments. A corresponding release of PO_4-P was not indicated, and it is speculated that redox potential was too high to create conditions conducive to PO_4-P release. It appears that sediment release of nutrients plays a relatively minor role in contributing nutrients to Lake Waco.

The depth profiles of DO at LW013 shown in Figures 22 and 23 reinforce the results of the statistical analysis described above. Summer profiles from 1996 through 1998 clearly demonstrate depletion of oxygen with depth. More importantly, the strength of this depletion increased in the summer, reaching its peak in July 1996 and 1997 and in August 1998. In contrast, profiles from winter months for the same three years showed a nearly uniform distribution of DO with depth. These patterns in DO distribution suggest a strong oxygen demand below the euphotic zone in Lake Waco. Increases of NH_3-N in the bottom waters of the reservoir during the low-DO summer months (Table 20), and the close correspondence between minimum summer pH and DO values (Figure 25) indicate a low oxygen level, and, at times, a reducing environment. The patterns of DO, NH_3-N, and pH observed with depth were most likely the result of microbial respiration and sediment oxygen demand, which would be expected to have the greatest effect on more isolated waters in the deepest portions of Lake Waco.

Figure 25 Bottom DO compared to pH and NH_3-N at site LW013.





CHAPTER 7

Trophic Status and Assessment

Trophic state is a measure of productivity within a water body that generally reflects its nutrient level. Categories for trophic state range from oligotrophic, referring to low productivity, to mesotrophic, eutrophic, and hypereutrophic, referring to very high productivity (Wetzel, 1983). Trophic state is generally measured in units of CHLA in the water column as mass per unit volume, or on the stream bottom as mass per unit area, as a surrogate for primary productivity. Secchi depth and total-P are also suggested as variables that may be used in evaluating a water body's trophic state (Carlson, 1977). Trophic state is used by the TNRCC, along with other factors, as a guide in assessing reservoir water quality within the state of Texas (TNRCC, 1998).

Several reports have indicated Lake Waco to be either mesotrophic (moderately nutrient enriched) or eutrophic (highly nutrient enriched), depending upon the monitoring data and time frame evaluated (Kimmel, 1969; Lind, 1979; Wyrick, 1978; TNRCC, 1998). In assessing Lake Waco's trophic status, Kimmel (1969) considered Lake Waco to be eutrophic based on comparisons of summer mean net primary productivity (NPP) of phytoplankton compared to the trophic status and NPP of other water bodies. An intensive surface water monitoring survey conducted by the Texas Department of Water Resources (TDWR) on May 17 and 18, 1977 indicated chlorophyll-α values characteristic of eutrophic waters (20–100μg/L) observed throughout the reservoir (Wyrick, 1978). This survey further noted that although no problems had been reported associated with algal overgrowth, the potential for problems, particularly during the summer months, could occur, and that phosphorus was the chief growth-limiting factor.

Soon after the TDWR survey was conducted, Lind (1979) also observed a spring phytoplankton bloom (May 19, 1977), and then a smaller bloom in late June 1977. With continued monitoring throughout 1978, much lower chlorophyll-α values were indicated in 1978 than for 1977. Mean summer values (April to September) were 16.0–μg/L in 1977 and 6.4 μg/L in 1978 for the main body site nearest the dam. Bloom patterns from this two-year study appeared to correlate well with large rainfall events within the watershed leading to pulses of nutrient loadings to the reservoir (Lind, 1979).

In a more recent analysis of Lake Waco's trophic status, the TNRCC classified Lake Waco as mesotrophic (TNRCC, 1998). This assessment was done by applying Carlson's Trophic State Index for CHLA to data collected over a 10-year period between September 1985 and August 1995. This analysis produced a mean chlorophyll-α concentration of 6.1μg/L for the station nearest the dam in the main pool of the reservoir (TNRCC, 1998). While this level of algal biomass does not indicate a water quality concern for Lake Waco based on TNRCC assessment guidelines (TNRCC, 1999a), previous studies have indicated seasonal algal levels indicative of eutrophic conditions (Kimmel, 1969; Rendon-Lopez, 1997) and episodic algal blooms (Lind, 1979). The city of Waco has indicated that recurring algal blooms are a drinking water treatment concern with regard to taste and odor problems (Smith, 2000; Wallace, 1997; Walker, 2000).

The purpose of this chapter is to provide an assessment of the current trophic state of Lake Waco and an evaluation of some of the factors influencing the current trophic state of the reservoir in relation to algal productivity. An evaluation of surface water quality within Lake Waco will also be presented in relation to TNRCC screening levels and criteria.

Methods

To evaluate the current trophic status of Lake Waco, Carlson's trophic state index (TSI; Carlson, 1977) was calculated for CHLA, total-P, and Secchi depth for data collected at site LW013 by TIAER between June 1996 and December 1999 using the following equations:

12) $$TSI_{(Secchi\ depth)} = 60 - 14.41 \cdot \ln(Secchi\ depth)$$

13) $$TSI_{(\text{Total-P})} = 14.42 \cdot \ln(\text{Total-P} \cdot 1000) + 4.15$$

14) $$TSI_{(CHLA)} = 9.81 \cdot \ln(CHLA) + 30.6$$

where

Secchi depth is in units of meters
Total-P is in units of mg/L
CHLA is in units of μg/L

Differences in the trophic state obtained using these three equations were then evaluated using cross-correlation methods and time series plots.

For reference, constituent values of surface samples between June 1996 and December 1999 were compared to TNRCC screening levels for CHLA and nutrients and to criteria for DO and pH to obtain a general assessment of the water quality within Lake Waco. To maximize comparability among reservoirs, the TNRCC has used the station nearest the dam in the main pool for trophic classification, which is comparable to TIAER site LW013 (TNRCC, 1998). For more general water quality assessments of Lake Waco (e.g., TNRCC, 1996), the TNRCC has used combined data from stations comparable to TIAER sampling sites LW012, LW013, and LW060. For the water quality assessment of Lake Waco, these comparisons are presented as the percent of samples exceeding the screening level or criterion for site LW013 and for sites LW012, LW013, and LW060 combined.

The TNRCC provides the following guidelines for interpreting water quality data in comparison to constituent screening levels and criteria:

- If 0 to 10 percent of values exceed the numeric criterion or screening level, the segment is considered "fully supporting" of the criterion or of "no concern" with regard to the screening level.
- If 11 to 25 percent of values exceed the numeric criterion or screening level, the segment is considered "partially supporting"of the criterion or of "potential concern" with regard to the screening level.
- If greater than 25 percent samples exceed the numeric criterion or screening level, the segment is considered "nonsupporting" of the criterion or of "concern" with regard to the screening level.

State criteria are segment specific for DO and pH, and they are based on the water body's designated uses (TNRCC, 1996). For Lake Waco, the DO criterion is 5 mg/L for a minimum average over 24 hours, and the pH criteria specifies an acceptable range of 6.5 to 9 standard units (TNRCC, 1996). Because most dissolved oxygen data are collected during the day as instantaneous measurements rather than as continuous diurnal measurements, an average DO value across the mixed surface layer from the instantaneous values is accepted as a screening level in comparison to the minimum DO criterion (TNRCC, 1999a). For assessment purposes the TNRCC defines the mixed surface layer for reservoirs as the portion of the water column from the surface to a depth at which water temperature decreases by more than 0.5°C. All dissolved oxygen measurements made within the mixed surface layer from profile data are averaged for comparison with the minimum DO criterion. Individual pH measurements from profile data across the mixed surface layer are compared to the minimum and maximum pH criteria. Only one exceedence is counted for an individual profile when more than one pH measurement is above or below the pH criteria (TNRCC, 1999a).

Surface measurements, typically collected about 0.3 m (1 ft) below the water surface, are used in assessing nutrient and CHLA screening levels (TNRCC, 1999a). Screening levels for nutrients and CHLA are derived from the 85 percentile for each constituent using long-term surface water quality monitoring data (September 1, 1987 to August 31, 1997) for Texas reservoirs (TNRCC, 1999a). Screening levels used in this report were 0.11 mg/L for NH_3-N, 0.43 mg/L for NO_2-N+NO_3-N, 0.09 mg/L for PO_4-P, 0.18 mg/L for total-P, and 22.7 µg/L for CHLA (TNRCC, 1999a).

Trophic State of Lake Waco

The TSI calculated for CHLA, total-P, and Secchi depth for individual samples collected between June 1996 and December 1999 at LW013 was quite variable (Figure 26). Looking across values, a wide disparity was indicated in the trophic classification depending on the parameter used for calculation. Many of the total-P and some of the Secchi depth values indicated a hypereutrophic status, while many of the winter CHLA values indicated a lower mesotrophic status. If only the summer months (May to September) were evaluated, the disparity between Secchi depth and CHLA trophic states became less apparent, while total-P values often indicated much higher index values and much more variability in values between sampling periods (Figure 26). Lind (1986) suggested that the effect of nonalgal turbidity within Lake Waco made Secchi depth a poor indicator of algal productivity. This appears to be true if annual values are used, although monthly summer values of TSI for CHLA and Secchi depth showed a fairly close correspondence (Figure 26).

To help explain the variability in TSI results, correlation analysis of CHLA was done with Secchi depth, total-P, and TSS. Because Lake Waco has been characterized as a turbid reservoir (Kimmel and Lind, 1972), TSS may be an important factor in describing the relationships between CHLA, total-P, and Secchi depth. These correlations indicated a fairly strong positive correlation between CHLA and Secchi depth and a slight negative correlation between CHLA and TSS (Table 22). Total-P showed no relationship to CHLA or Secchi depth measurements but showed a significant positive correlation with TSS concentrations. These findings indicate that total-P may not be a good indicator of algae productivity for Lake Waco. Time series plots emphasize the observed disconnect between total-P and CHLA measurements (Figure 27).

Figure 26 Trophic State Index (TSI) at LW013 for all seasons and summer only.
TSI < 40 = oligotrophic; TSI ≥ 40 and < 50 = mesotrophic; TSI ≥ 50 and < 70 = eutrophic; TSI ≥ 70 = hypereutrophic.

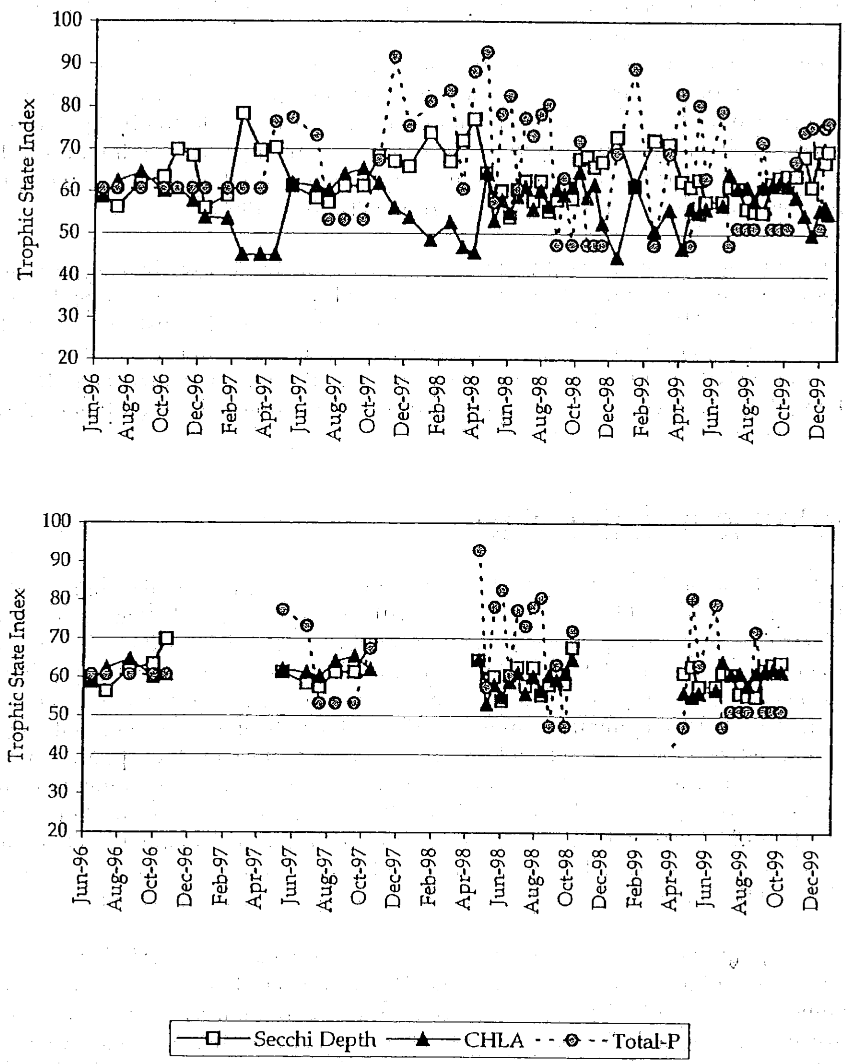
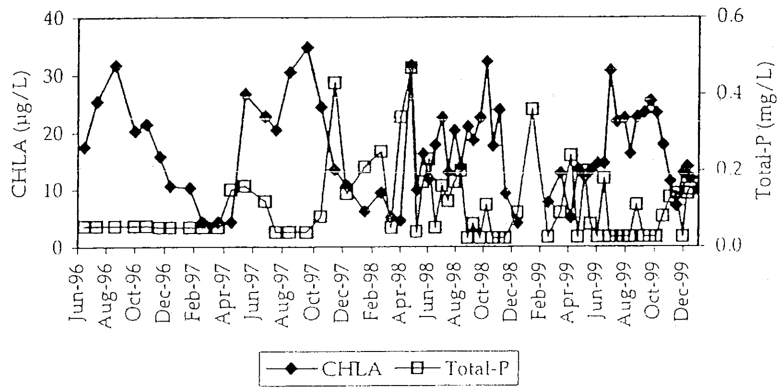
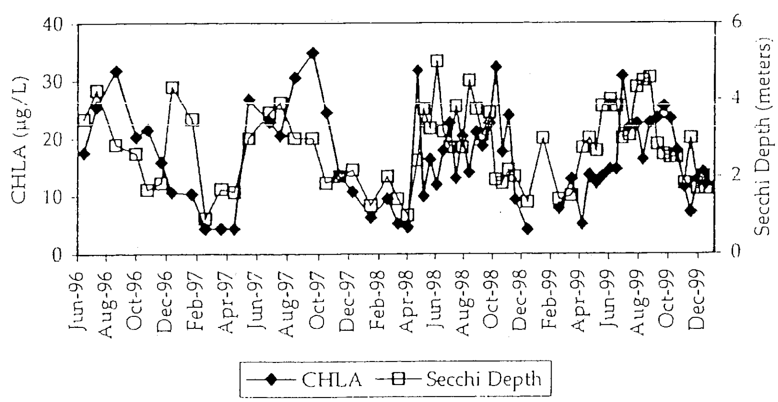


Table 22 Correlation of CHLA with Secchi depth, total-P, and TSS measurements for surface samples collected between June 1996 and December 1999 at LW013 (n = 84). "r" is the correlation coefficient, and "p" is the probability value relating to the significance of the correlation.

Constituent		ln(CHLA) (µg/L)	ln(Secchi Depth) (meters)	Total-P (mg/L)	TSS (mg/L)
ln(CHLA) (µg/L)	r	1.00	0.53	-0.19	-0.30
	p	0	0.0001	0.0908	0.0064
ln(Secchi Depth) (meters)	r	---	1.00	-0.14	-0.55
	p	---	0	0.1971	0.0001
Total-P (mg/L)	r	---	---	1.00	0.25
	p	---	---	0	0.0233
TSS (mg/L)	r	---	---	---	1.00
	p	---	---	---	0

Figure 27 CHLA compared to total-P and Secchi depth for surface samples collected at LW013.



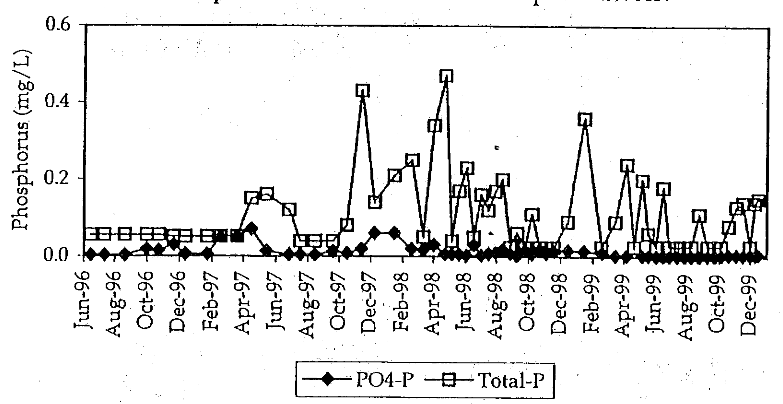


Much of the measured total-P may be attached to sediment rather than reflecting phosphorus as a function of algal biomass as assumed in the TSI for total-P developed by Carlson (1977). Particularly in turbid systems, such as Lake Waco, adsorption of PO_4-P to suspended sediment particles can be an important removal mechanism limiting available phosphorus for algal growth. Kimmel and Lind (1970) found that the mud substrate within Lake Waco was an important mechanism of orthophosphate removal.

Many simple empirical models of algal productivity use total-P as the driving variable for algal growth (e.g., Carlson, 1977; Vollenweider et al., 1980). These simple models generally assume an increase in algal growth with increasing total-P concentrations and often use an annual time-step. Summarizing TSI values for total-P as summer averages by year (1997 $TSI_{(total\text{-}P)}$=63, 1998 $TSI_{(total\text{-}P)}$=70, and 1999 $TSI_{(total\text{-}P)}$=58) does bring these values more in line with TSI values based on Secchi Depth and CHLA (Figure 26), although the variability in TSI for total-P between sampling periods indicates that care must be taken in the collection and interpretation of total-P data for Lake Waco.

Based on previous analysis evaluating variables impacting CHLA concentrations (Table 17), the depletion of PO_4-P may be a better predictor of trophic status and CHLA concentrations than total-P concentrations when evaluating time intervals shorter than a year. For empirical modeling of algal productivity, PO_4-P is not often used, because in aquatic systems with low productivity, ambient PO_4-P concentrations can be very hard to measure, e.g., Dillon and Rigler, 1974. In Lake Waco, most PO_4-P measurements were above the laboratory method detection limit, so this was not a problem (see Pearson and McFarland, 1999). Although PO_4-P on average represented only about 20 percent of total-P during the study period, the amount of total-P represented by PO_4-P was quite variable (Figure 28). A strong depletion pattern of soluble nutrients (DIN and PO_4-P) with increasing CHLA concentrations was quite apparent within Lake Waco (Figure 19), while no relationship between CHLA and total-P was established (Table 16).

Figure 28 Total-P and PO_4-P concentrations for surface samples at LW013.



Nutrients are an important component in predicting the productivity of algae. In freshwater systems, phosphorus is generally the limiting nutrient, while in marine or estuarine systems, nitrogen is more often limiting (Gibson, 1997). The limiting nutrient may then indicate a way to control eutrophication. Algal bioassay studies for Lake Waco have shown that additional phosphorus generally stimulates the growth of algae (Dávalos-Lind and Lind, 1998). These bioassay studies will be further evaluated and discussed in Chapter 8, "Nutrient Limitation and Algal Growth Responses."

Besides nutrients, light appears to be another factor partially controlling algal growth within Lake Waco. TSS was indicated in Chapter 5, "Influence of Tributary Inflows and Loadings" as a slightly significant factor, α=0.15, in describing CHLA concentrations within the main body of the reservoir (Table 17). The positive correlation between CHLA and Secchi depth in Table 22 indicates that CHLA concentrations increased as the photic zone, that is, the zone of light penetration increased. A negative relationship was indicated for TSS concentrations with

CHLA and Secchi depth. These negative relationships of TSS with CHLA and Secchi depth indicate a decrease in light penetration within Lake Waco with increases in TSS concentrations.

To further evaluate the influence of TSS on light availability within the reservoir and the resulting impact on algal growth, a regression model was used to partition the light attenuation coefficient into fractions associated with TSS and CHLA using data collected at LW013 between August 1998 and June 1999. Light attenuation coefficients estimate the composite effect of light dissipation by particles and the absorption of light by photosynthetic pigments. Light attenuation coefficients were derived from light profile data using a linear regression model. Light readings were fit to a log-linear version of the Beer-Bougher equation (Cole, 1994):

15) $$\ln(I_z) = \ln(I_0) - \eta_z$$

where:

I_z is the light intensity at depth z

I_0 is surface light intensity

η_z is the attenuation coefficient

The relative importance of light absorption by pigments, as represented by chlorophyll-α, and of light scattering by suspended particulates, as represented by total suspended solids, was assessed using linear regression techniques. Two models were run. The first focused on CHLA and TSS data, regardless of surface TSS concentrations. The second model used only CHLA data collected when TSS concentrations were below the laboratory MDL to minimize the influence of TSS in the regression relationship.

Chlorophyll-α did not explain a significant portion of the variance in light attenuation when all data from site LW013 were considered in a regression analysis (Table 23). Further analysis of the role of TSS and CHLA indicated that CHLA was a significant predictor of light attenuation at LW013 when the regression model was rerun, considering only measurements taken when TSS was less than the MDL (Table 24). These results agree with previous analysis (Lind, 1979; Kimmel, 1969) indicating the importance of turbidity in determining water column transparency and Secchi depth in Lake Waco. Only when TSS concentration was low did CHLA show a significant negative relationship with light penetration (Table 24). Reduced light availability associated with suspended inorganic sediment appears to have some influence on algal productivity in Lake Waco, although nutrient availability and water temperature were probably the dominant factors controlling algal growth during the study period. The influence of light on algal growth may be seasonal in that the TSI for Secchi depth was generally greater than the TSI for CHLA during the winter months (Figure 26).

Table 23 Regression partitioning of light attenuation coefficient without a TSS restriction for samples collected at LW013 between August 1998 and June 1999. Number of observations equals 14. Model p-value equals 0.0230 and R^2=0.50.

Variable	Parameter Estimate	Standard Error	p-value
Intercept	-0.146	0.104	0.1892
TSS	-0.033	0.010	0.0080
CHLA	-0.002	0.004	0.6009

Table 24 Regression partitioning of light attenuation coefficient with a TSS restriction for samples collected at LW013 between August 1998 and June 1999 with values for TSS less than the MDL. Number of observations equals 7. Model p-value equals 0.0469 and R^2=0.58.

Variable	Parameter Estimate	Standard Error	p-value
Intercept	-0.21	0.03	0.0009
CHLA	-0.0040	0.0016	0.0469

Lake Waco Water Quality Assessment

In comparing samples collected by TIAER between June 1996 and December 1999 to TNRCC screening levels and criteria, only NO_2-N+NO_3-N was found to be of concern based on TNRCC assessment guidelines (see pp. 68 and 69) with over 25 percent of samples exceeding the NO_2-N+NO_3-N screening level of 0.43 mg/L (Table 25). Potential concern was indicated for total-P with greater than 10 percent of samples exceeding the total-P screening level of 0.18 mg/L for both sets of sites. For CHLA, potential concern was indicated for site LW013 with 24 percent of samples exceeding the CHLA screening level of 22.7 µg/L. When data for LW012, LW013, and LW060 combined were evaluated, 46 percent of samples exceeded the CHLA screening level indicating concern with regard to CHLA concentrations in Lake Waco. Aquatic life criteria for DO and pH were fully supported within Lake Waco.

Table 25 Percent of Lake Waco samples exceeding TNRCC screening levels and criteria for surface samples collected between June 1996 and December 1999.

Constituent and Associated Screening Level or Criteria	LW013		LW012, LW013, and LW060	
	Percent Exceeding	Number of Samples	Percent Exceeding	Number of Samples
DO (<5.0 mg/L)	3%	61	3%	186
pH (<6.5 or >9.0)	0%	61	0%	186
CHLA (>22.7 µg/L)	24%	63	46%	189
NO_2-N+NO_3-N (>0.43 mg/L)	38%	63	72%	187
NH_3-N (>0.11 mg/L)	8%	63	9%	187
PO_4-P (>0.09 mg/L)	0%	63	1%	184
Total-P (>0.18 mg/L)	17%	63	17%	187

While aquatic life criteria for DO and pH were fully supported within Lake Waco, nutrient enrichment and its impact on algal growth as indicated by increased CHLA concentrations is a potential concern that may need to be addressed. This water quality assessment indicates the presence of abundant nitrogen and phosphorus within the reservoir for algal growth, but it does not clearly indicate the nutrient limiting the growth of algae within the reservoir. Controlling the limiting nutrient is generally one of the best ways to control algal growth. The nutrient screening levels developed by the TNRCC serve only as a guide to indicate potential nutrient problems. A fuller assessment using bioassay experiments to define the nutrient limiting algal growth within Lake Waco is presented in Chapter 8, "Nutrient Limitation and Algal Growth Response."

CHAPTER 8

Nutrient Limitation and Algal Growth Responses

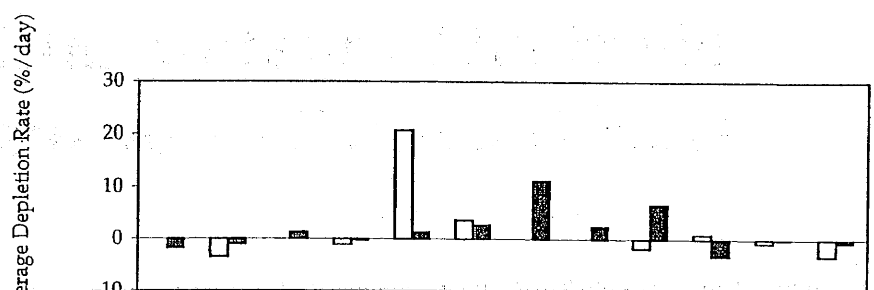
The analyses of nutrient and chlorophyll distributions within Lake Waco document a negative relationship between the concentration of soluble forms of nitrogen and phosphorus and algal biomass, measured as CHLA (Table 16; Figure 19). The time-series of ambient nutrient concentrations of DIN and PO_4-P in the main body of the reservoir is characteristic of a system where algal production is tightly coupled to nutrient resource supply. Both PO_4-P and DIN show a systematic relationship with hydraulic loading, as well as algal biomass, suggesting the pattern of CHLA with soluble nutrients is driven by loading from the surrounding watershed (Table 17; Figure 19).

The negative correlations of CHLA with DIN and PO_4-P are characteristic of resource depletion patterns associated with consumption, i.e., uptake, of required resources. In algae, soluble forms of the macronutrients nitrogen and phosphorus are essential resources for the production of new biomass through photosynthesis and cell reproduction. As new cells are produced, algal biomass increases. In order to produce new cells, DIN, PO_4-P, and other macronutrients must be consumed. If consumption rates exceed supply rates, the production of new algal biomass depletes the pool of an available essential resource and ambient concentrations are reduced. When this happens, the pattern of resource depletion usually follows a monotonic decline that is mirrored by an increase in consumer biomass as well as an elevated population growth rate. This pattern of decline is observed repeatedly in the Lake Waco data for PO_4-P and DIN, e.g., Figure 19. Estimates of nutrient depletion, calculated as an average daily percent change in ambient nutrient concentration during the sampling interval, support the conclusion that Lake Waco experiences periods of sustained resource loss (Figure 29).

In theory, these primary macronutrients in Lake Waco are essential resources that have the capacity to limit the growth of individual species of algae (Tilman, 1982). The pattern of limitation depends upon which nutrient is in shortest supply, a concept often referred to as Leibig's Law of the Minimum. Together, these two concepts define the role of a limiting, essential resource in controlling population growth and biomass accumulation in algae, while the specific mechanisms of nutrient-limited growth in algae are more complex. The supply rate of a limiting resource has the capacity to regulate population growth, while the external concentrations of a limiting nutrient control physiological response. Rates of physiological functions as well as population growth rates have been linked to specific limiting resources including light, nitrate, ammonia, phosphate, silica, and some vitamins (see Reynolds, 1984, for a review). Population growth rate responses have also been studied in detail. Numerous experiments have tested the role of limiting nutrients in controlling how single algal species (Tilman et al., 1981; Tilman and Kilham, 1976) or groups of species (Tilman et al., 1986) respond to changes in the supply or availability of limiting nutrients. These efforts have confirmed the predictive power of physiological models of population growth first explored for microorganisms by Monod (1950) and expanded into a more mechanistic form for nutrient-based growth for algae (Droop, 1974). The regulation of physiology by external

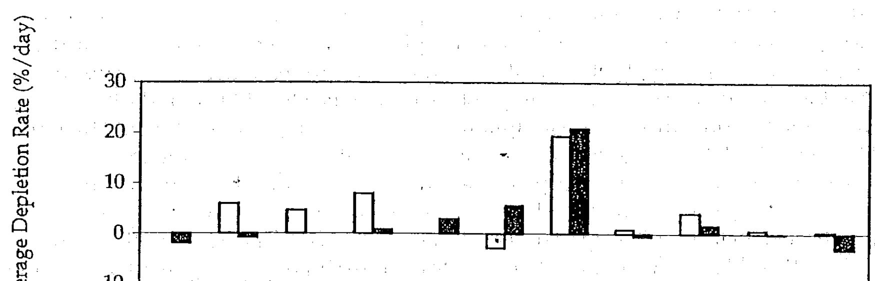
Figure 29 Ambient nutrient depletion rate in Lake Waco.
Nutrient depletion measured as the average daily percent change in concentration observed over the sampling interval. Data shown are for surface samples collected at LW013 during a) 1997 and b) 1998.

a)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
□ PO4-P	0.00	-3.46	0.00	-1.10	20.69	3.57	0.00	0.00	-1.76	0.89	-0.71	-3.21
■ DIN	-1.77	-1.01	1.25	-0.27	1.26	2.63	11.14	2.36	6.58	-3.18	-0.06	-0.62

b)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov
□ PO4-P	0.00	5.88	4.55	7.86	0.00	-2.86	19.35	0.83	4.08	0.58	0.25
■ DIN	-2.01	-0.84	-0.02	0.79	2.86	5.50	20.83	-0.62	1.68	-0.12	-3.13

nutrient concentration is linked through cellular processes to cell division and, therefore, to reproduction. This linkage explains the central role limiting nutrients can play in the production and accumulation of algal biomass.

The role of essential macronutrient resources in limiting planktonic algae growth and controlling algal biomass accumulation is well documented. Lakes and reservoirs are often categorized as being nitrogen-limited or phosphorus-limited, based on patterns of nutrient limitation. Although the true pattern of population growth limitation occurs at the species level, these terms are used as shorthand to summarize the pattern of nutrient supply and consumption that controls the production of algal biomass in lakes and reservoirs. While all algae consume macronutrients, such as nitrogen and phosphorus, algal growth, and therefore algal biomass accumulation, must be controlled by nutrient supply rates before algal populations are in fact nutrient limited. Therefore, nutrient limitation, or control, of algal biomass accumulation is a prerequisite for classifying a reservoir as N or P limited. Most nutrient loading models that seek to predict algal biomass, or its surrogate, CHLA, assume that nutrients have the potential to limit algal growth and production. Limitation is also an inherent assumption of most attempts to restore the trophic status of a reservoir or lake through control of nutrient loading.

Once it has been established that a specific nutrient limits algal growth, the functional relationship between increases in algal population size and external nutrients may be determined. Current understanding of algal growth and reproduction suggests this functional relationship is the culmination of a two step process: nutrient uptake followed by cell division. Although two-step algal growth models are available, simpler models exist that relate external nutrient concentrations directly to population growth (Monod, 1950), as do hybrid models that relate intercellular nutrient concentrations to algal growth (Droop, 1973). The Monod function has been useful in describing the nutrient-dependent growth of algae in culture, and in predicting the outcome of nutrient competition (Tilman, 1982). More importantly, only the Monod model predicts population growth rate based solely upon the external concentration of the limiting nutrient, which makes it a more straightforward model than the alternatives when dealing with natural algae communities (Grover, 1997). The Monod model has been incorporated into several more complex, mechanistic models, including the reservoir model CE-QUAL-W2 (Cole and Buchak, 1995). CE-QUAL-W2 has been successfully calibrated for Lake Waco (Flowers et al., 2001).

Methods

The primary aim of experimental work performed on Lake Waco phytoplankton was to determine the role, if any, of a limiting nutrient or nutrients in determining the trophic status of the reservoir. Identifying the limiting nutrient and testing its functional role in controlling algal growth responses were the two necessary steps in establishing a mechanistic role for nutrient limitation within the reservoir.

The first step was accomplished by performing a series of algal growth bioassays following standard EPA bioassay methods (APHA, 1995) to assess algal growth potential (AGP). These bioassays, similar in design to experiments performed in other Texas reservoirs to determine nutrient limitation patterns (Sterner, 1994; Sterner and Grover, 1998) were performed by Drs. Lind and Dávalos-Lind at the Baylor University Limnology Laboratory in collaboration with TIAER. Growth responses of the native phytoplankton community from Lake Waco site LW013 and a standard bioassay species *Selenastrum capricornutum* were assessed during the bioassays. AGP was assessed, as was the nature of nutrient limitation, by addition of NO_3-N and PO_4-P in a full factorial design. After the limiting nutrient was identified, it was added at increasing levels to determine the algal functional response, otherwise referred to as dose-response.

Water samples were collected from December 1996 through November 1998 at approximately monthly intervals from three reservoir sampling sites, LW070, LW015, and LW013, using a two meter integrated sampler. Water destined for bioassay treatments from all three sites was kept at 4°C until the experiments were initiated. An additional sample of native phytoplankton, collected from LW013, was maintained at ambient lake temperature until reaching the laboratory. The native phytoplankton were placed in an illuminated growth chamber at ambient water temperature until they could be processed into an inoculum. All other samples were maintained on ice until the start of the bioassay procedure. A subsample of each monthly water sample was analyzed for NH_3-N, NO_2-N+NO_3-N, and PO_4-P.

To develop a bioassay inoculum from the native phytoplankton, water samples were first filtered through a 35μm stainless steel screen to remove zooplankton grazers. Bioassay treatment water was prepared by filtration through capsule filter with a 0.45μm pore-size and stored in rinsed polyethylene containers. An inoculum was prepared from the native sample using gentle filtration (< 127mm Hg vacuum) through 0.45μm filters. Algae retained on the filter were resuspended in filtered Lake Waco water and used to inoculate the native phytoplankton bioassays.

All bioassays used an acclimated growth rate method and tracked changes in biomass using in vivo fluorescence (IVF) of CHLA. Tests were conducted in 25mm diameter Pyrex™ test tubes containing 23ml of filtered sample water. Each experiment consisted of five replicates of each of the four experimental treatments. One milliliter of the appropriate nutrient solution sufficient to increase the ambient nutrient concentration to 50μg/L PO_4-P or to 1000μg/L NO_3-N was added to each of the five replicates. One milliliter of a combination stock solution containing both N and P was added to the combined treatment at these same increases in concentration. One milliliter of demineralized water was added to control tubes, which also served to assess the AGP.

All tubes were inoculated with either *Selenastrum capricornutum* or with the native algae concentrate. *Selenastrum capricornutum* inoculum was prepared from a four or five-day old culture of actively growing cells. Cells were washed three times with a sodium bicarbonate buffer and concentrated by gentle centrifugation to provide an inoculum of approximately 10,000cells/ml. One milliliter was then added to each incubation tube. Tubes were stoppered with sterile foam plugs and initial fluorescence was measured with a Turner Designs model TD-700 fluorometer. The tubes were placed at random in Plexiglas® slant racks and the racks placed in a growth chamber at 24°C for *S. capricornutum* and at ambient lake temperatures for native phytoplankton. Bioassays were conducted under constant fluorescent illumination. Each incubator contained three shelves for cultures with three 20 watt SYLVANIA cool white fluorescent lamps placed directly under each culture shelf for a total of nine lamps. Each lamp has a reported output of 1300 lumens.

Algal growth in each tube was measured by increase in chlorophyll with fluorescence calibrated against cell counts at the beginning of each experiment. Following gentle vortexing to suspend settled cells, fluorescence measurements were made on alternate days for the first six days and were then made daily until the end of the experiment. Measurements continued until fluorescence reached a plateau or declined. Maximum fluorescence was usually reached in five to six days for the S. *capricornutum* samples and six to seven days for the native phytoplankton. The time for the cultures to reach the maximum fluorescence was always less than ten days.

From May through November of 1998, dose-response experiments were conducted with the limiting nutrient, as determined during the first year of the study. A standard dose series was established for these bioassays, with phosphorus added in concentrations of 6, 12.5, 25, 100, 200, and 300μg/L. For some samples an additional treatment group was added in which *S. capricornutum* and native phytoplankton maximum growth rates were determined under nutrient sufficient conditions. This treatment was identical to the other experimental treatments, except that a nutrient-complete media was used to maintain stock cultures.

For the dose-response bioassay experiments, population growth rates were calculated from fluorescence measurements using an exponential growth model. Data from each treatment replicate were fit to a simple log linear form of the exponential growth equation (Equation 16) using linear regression (SAS release 6.11). Daily (t) IVF measurements were used to estimate population growth. Measurements from each treatment replicate were right censored to include the first four increasing observations of algal biomass. The first observation in this series was defined as day zero (N_0). Subsequent observations were designated as days one (N_1) through four (N_4). These data were log-transformed and fit to a linear regression model to estimate "r," the daily population growth rate.

$$16) \quad \ln N_t = rt + \ln N_0$$

The resulting growth rates were fit to a Monod growth model (Monod, 1950; see Kilham, 1978, for a graphic example), using the PROC NLIN (SAS, 6.11) curve-fitting procedure. The Monod model uses external resource concentrations (S) to predict observed population growth rate (μ) as a function of two constants: maximum growth rate (μ_{max}) and the half-saturation constant (K_s). These two constants were estimated for each significant Monod regression from an iterative solution to equation 17.

$$17) \quad \mu = \frac{\mu_{max} \cdot S}{(K_s + S)}$$

Results of AGP and Nutrient-Limitation Bioassays

Nutrient-limitation bioassays were run every month from December of 1996 to November of 1998. Control groups were used to estimate AGP as a percent increase in IVF over the length of the experiment (Dávalos-Lind and Lind, 1998). Results clearly indicate that water from all three reservoir locations (LW070, LW013, and LW015) stimulated algal growth at similar times and in similar relative amounts during both 1997 and 1998 (Figure 30 and 31).

To determine whether any one site had a consistently higher growth potential over the entire bioassay period, AGP bioassay results for native phytoplankton were ranked from highest (1) to lowest (3) for all 3 sites on each sampling date. Based upon these ranks, an annual average site ranking was calculated for each year bioassays were performed (1997 and 1998). A one-way analysis of variance (ANOVA) was performed on these annual average AGP ranks (n=6 based on 2 years of bioassay data for each of 3 sites). On average, AGP was highest for LW013 in both years, followed by LW070 and finally by LW015 (Table 26).

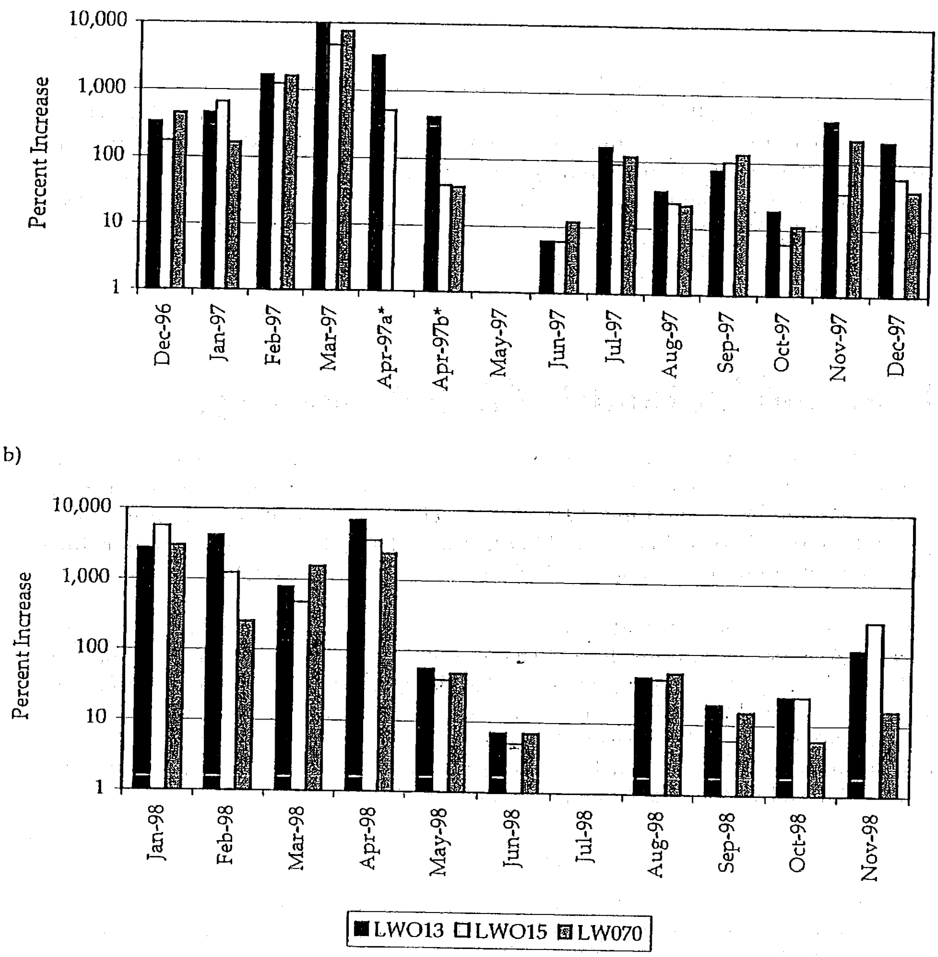
Table 26 Results of a one-way Analysis of Variance (ANOVA) of annual average AGP rank by sampling site for native Lake Waco phytoplankton. LW013 had the highest average rank AGP (i.e., largest growth response) for both 1997 and 1998. This result was significant at the $p<0.01$ level.

Sampling Station	Count	Rank Sum	Average Rank	Variance		
LW013	2	2.99	1.50	0.00		
LW015	2	4.50	2.25	0.00		
LW070	2	4.27	2.14	0.04		
ANOVA Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	P-Value	F Crit
Between groups	0.66	2	0.33	23.88	0.01	9.55
Within groups	0.04	3	0.01			
Total	0.70	5				

Figure 30 *Selenastrum capricornutum* algal growth response (AGP) for a) 1997 and b) 1998. During April of 1997, two time periods were evaluated in the same month. Results of both analyses are present in panel a below and labeled with an *.

a)

b)

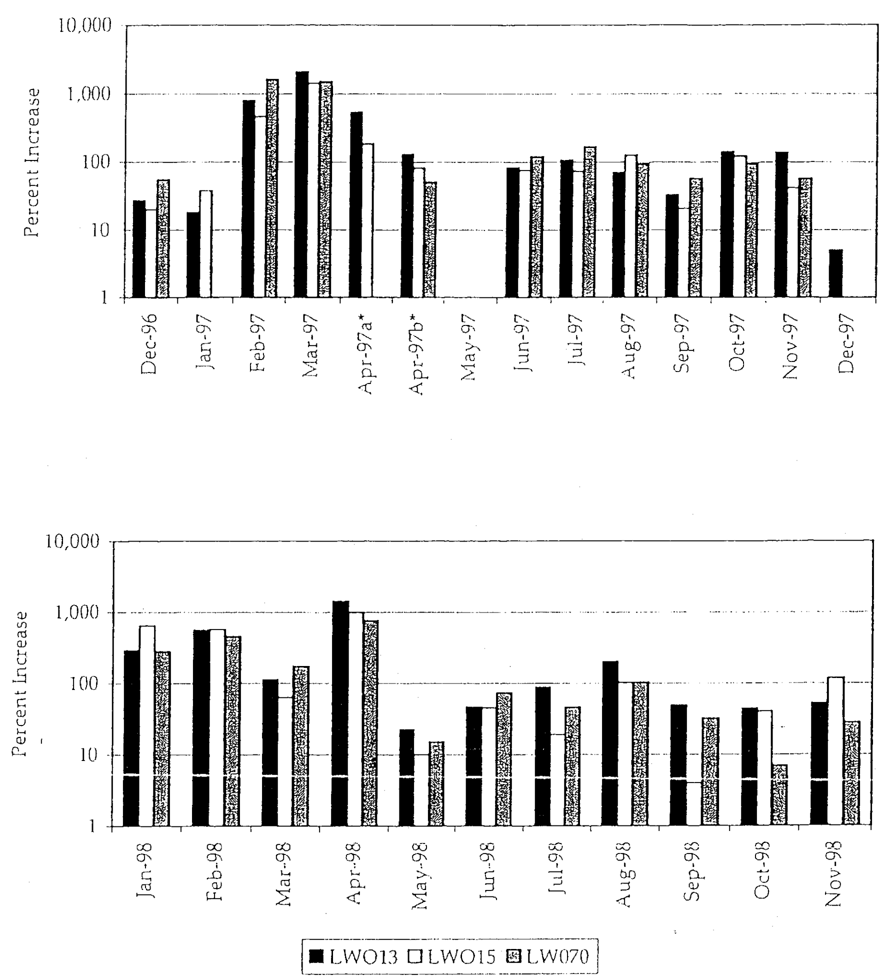


Native and cultured algae exhibited large growth potentials following large runoff events in both years, reaching peaks in March of 1997 and April of 1998. Peaks in AGP at site LW013 appear to coincide with substantial increases in growth potential in at least one of the two other stations. Both of these upstream stations are located in the transition zone of the reservoir (Figures 13 and 14). Data from both experimental populations were in close agreement, and the AGP response of native and cultured algae were strongly correlated (r = 0.88, p <0.001), but they showed some seasonal deviations.

Figure 31 Native phytoplankton algal growth response (AGP) for a) 1997 and b) 1998. During April of 1997, two time periods were evaluated in the same month. Results of both analyses are present in panel a below and labeled with an *.

a)

b)

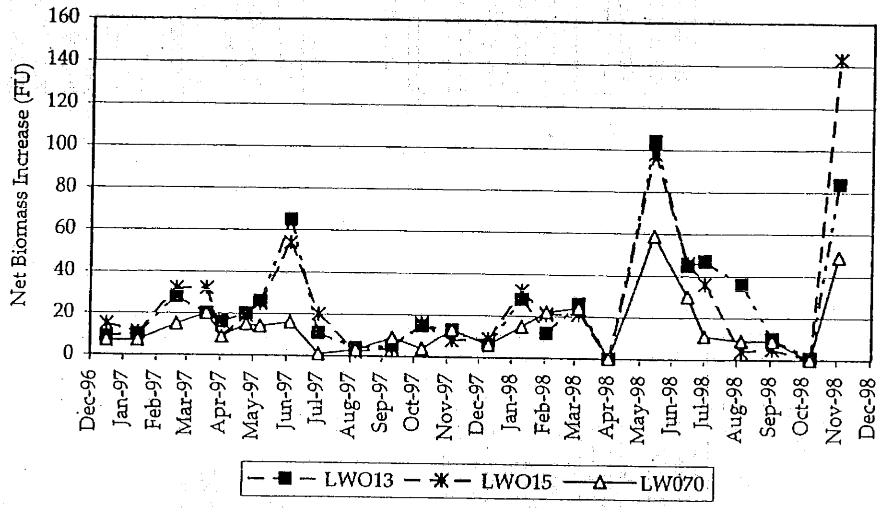


Results from all Lake Waco AGP bioassays strongly indicated that phosphorus limited algal biomass growth during most of the study period (Table 27). Ninety-four percent of the experiments show some level of phosphorus limitation, with 92 percent showing only phosphorus limitation. The magnitude of native algae growth responses to additions of phosphorus was strongly seasonal (Figure 32).

Table 27 Summary of Lake Waco bioassay results: 1997–1998.

Population Source	Experimental Results				
	P-limited	N-limited	Co-limited	Other	Total
Native Phytoplankton	71	3	1	0	75
Selenastrum capricornutum	67	5	2	1	75
Totals	138	8	3	1	150
Percent	92	5	2	1	100

Figure 32 Average native phytoplankton response to phosphorus addition.
Response of native phytoplankton to nutrient-limitation bioassay experiment. Growth response was measured as *in vivo* fluorescence (IVF) and is reported in fluorescence units (FU).



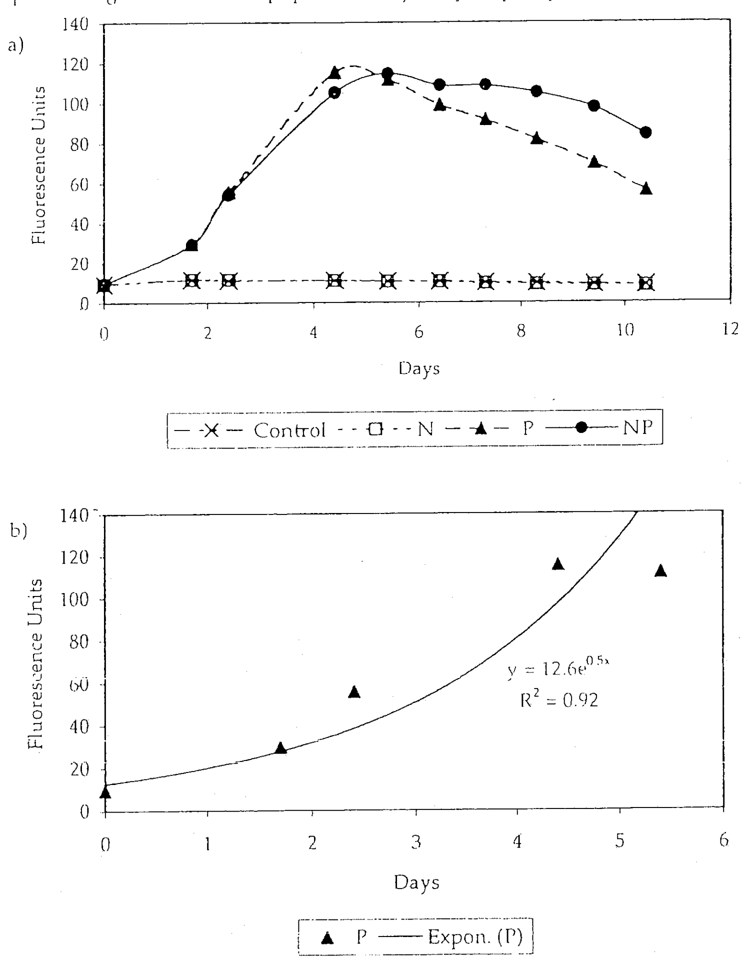
Based upon comparisons between control and treatment groups, final IVF response values in winter were moderate compared to very large spring and early summer growth. The intensity of numerical response appears to change as a function of time since last major loading, as well as being related to the intensity of nutrient depletion (Figures 19 and 29). In the bioassay experiments, neither phosphorus nor nitrogen additions alone were highly stimulatory during the summer months of July and August, indicating a potential seasonal movement towards colimitation by nitrogen and phosphorus.

Results from Dose-Response Bioassays

While the nutrient-limitation bioassay data clearly illustrate the importance of phosphorus to algal population growth and biomass accumulation, they did not establish a functional relationship between these two parameters. To test for this relationship between the availability of the limiting nutrient and algal growth or productivity, a set of dose-response bioassays were performed monthly from May 1998 through December 1998 to test the predictive capabilities of the Monod model. Native phytoplankton communities from site LW013 were subjected to an enrichment gradient in the laboratory to establish a dose-response relationship. Each treatment group was enriched with a specific amount of phosphorus as PO_4-P, the presumptive limiting nutrient.

Biomass-based algal growth rates were calculated using a simple exponential growth model (Equation 16). Growth rates were calculated for each treatment group replicate. A mean growth rate was calculated for each dose (i.e., treatment group). Figure 33 illustrates the application of this model to data collected from the May 1998 bioassay for the 50μg/L PO_4-P treatment.

Figure 33 Population growth trajectories from May 14, 1998, AGP bioassays.
a) Individual treatment means for native phytoplankton grown in water collected at site LW013. b) Fit of exponential growth model to population trajectory for phosphorus addition. Note change in x-axis scale.



The resulting growth rates from each nutrient dose were fit to a Monod function using the SAS statistical package. The resulting Monod curves were significant for all months May through November except for October. (Figure 34; Table 28).

Figure 34 Dose-response curves for natural phytoplankton communities.
Monod curves fits and parameter estimates are illustrated. All growth rates are reported as per day. Maximum growth rates (μ_{max}) and half-saturation constants (K_S) were estimated using the SAS PROCNLIN statistical program.

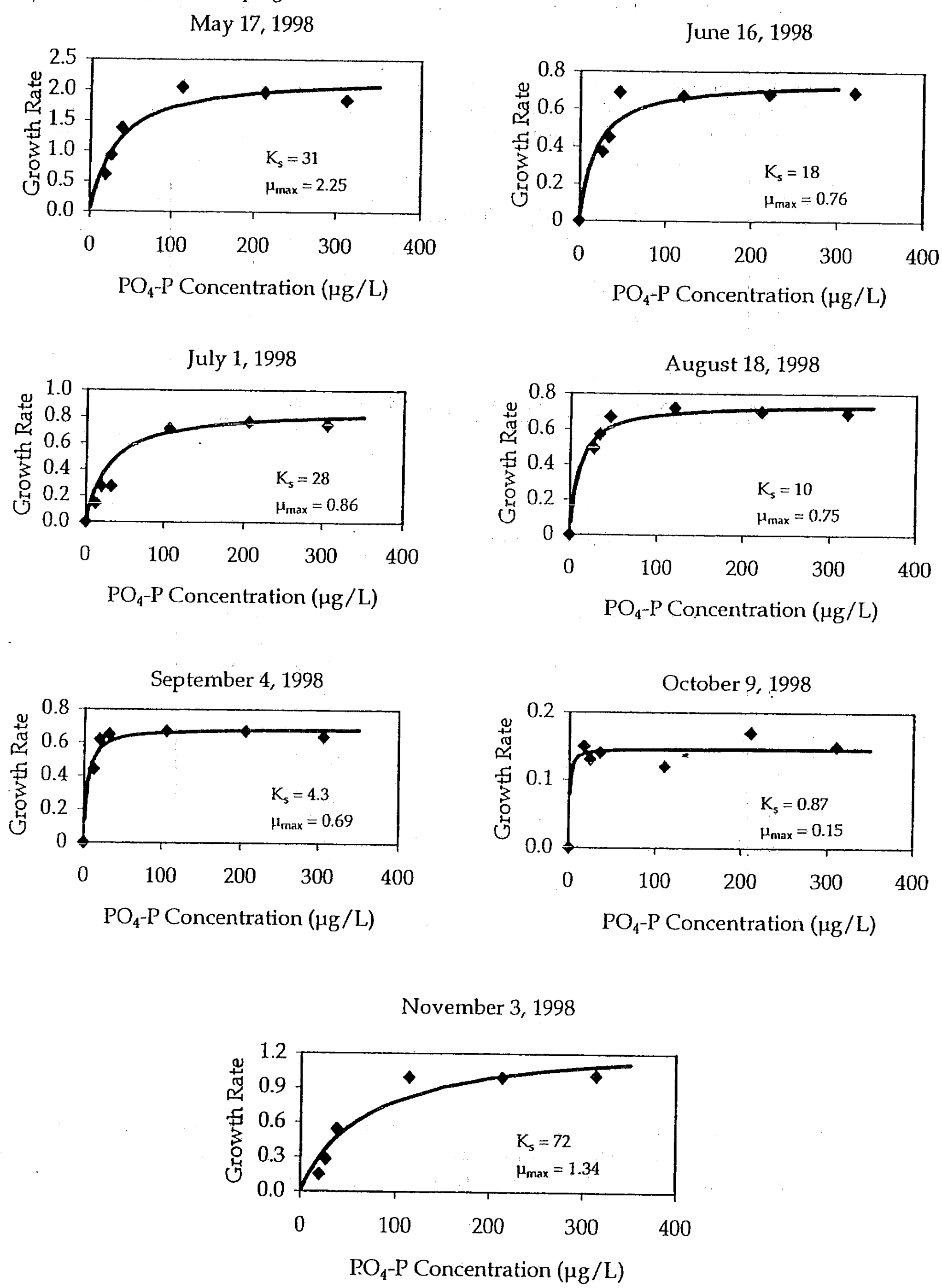


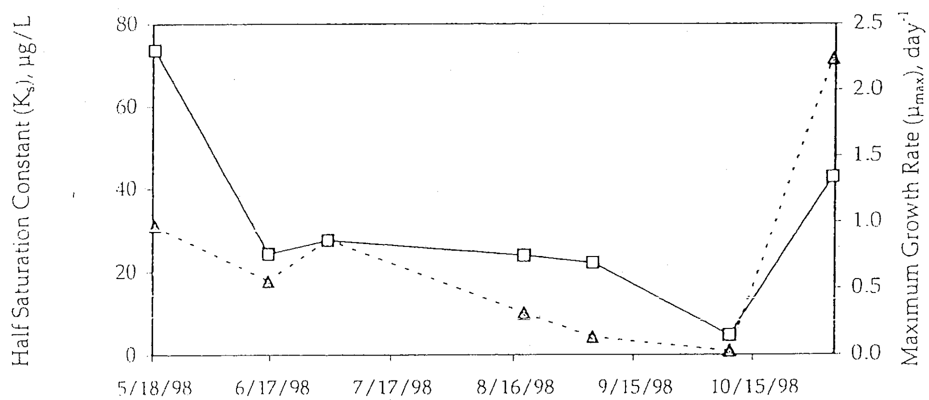
Table 28 Monod kinetic parameters for algal growth dose-response bioassays for PO_4-P.

Date	K_s (µg/L, mean + SE[1])	μ_{max} (d^{-1}, mean + SE)	p-value[2]	R-square[3]	E[4]
17-May-98	31.01 ± 10.81	2.25 ± 0.22	0.0048**	0.89	0.89
16-Jun-98	17.67 ± 8.34	0.76 ± 0.08	0.0381*	0.70	0.70
1-Jul-98	27.82 ± 12.95	0.86 ± 0.11	0.0083**	0.86	0.85
18-Aug-98	10.04 ± 3.15	0.75 ± 0.04	0.0162*	0.80	0.80
4-Sep-98	4.29 ± 1.77	0.69 ± 0.04	0.0374*	0.70	0.70
7-Oct-98	0.87 ± 2.67	0.15 ± 0.01	0.7627	0.03	0.03
3-Nov-98	71.54 ± 30.37	1.34 ± 0.20	0.0025**	0.92	0.92

1. SE represent asymptotic standard error.
2. p-value represents the significance of the regression model comparing measured with predicted values where * indicates significance at a probability level of 0.05 and ** indicates significance at a probability level of 0.01.
3. R-square represents the regression coefficient comparing measured with predicted values.
4. E represents the coefficient of efficiency comparing measured values to the 1:1 line of measured equals predicted.

Comparisons between the Monod-derived parameters of maximum growth rate (μ_{max}) and the half-saturation constant for growth (K_S) from all of the dose-response experiments reveal a strong seasonal decline in PO_4-P-based maximum growth rates (Figure 35).

Figure 35 Monod parameter values for dose-response bioassays with native phytoplankton. Monod curve fits and parameter estimates include maximum growth rates (μ_{max}) and half-saturation constants (K_s). K_s decreases over the course of the summer, indicating increased affinity, while growth rates decline



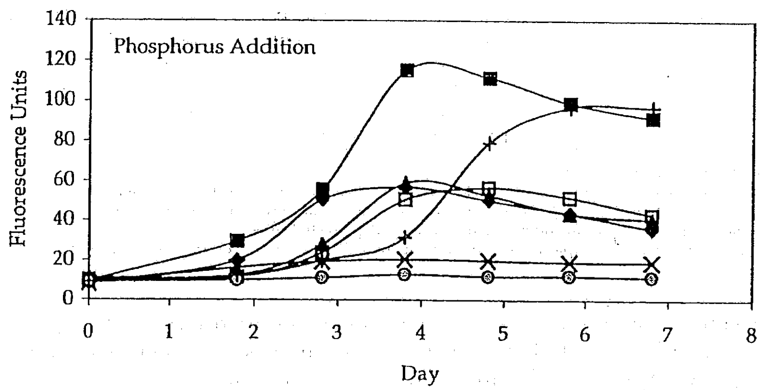
	5/18/98	6/16/98	7/1/98	8/18/98	9/4/98	10/9/98	11/3/98
Ks	31	18	28	10	4.3	0.87	72
µmax	2.3	0.76	0.86	0.75	0.69	0.15	1.3

The timing of this decline coincides with the observed decline in growth response to added phosphorus in the nutrient-limitation bioassay (Figure 36) as well as with the seasonal declines in AGP for native phytoplankton (Figures 31a and b).

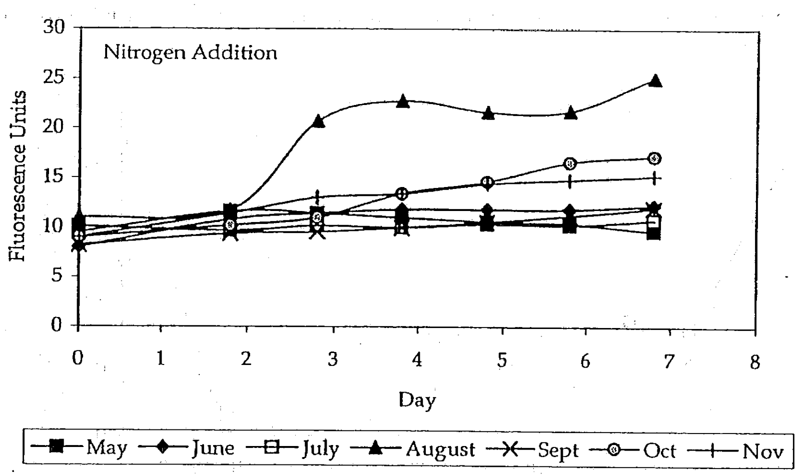
Changes in K_S can also be interpreted as a measure of changing affinity for the limiting nutrient. The strong seasonal decrease in K_S suggests an increase in the competitive ability for PO_4-P among the members of the algal community. However, there appears to be a trade off between this increase in affinity and maximum attainable biomass growth rates (Figures 34

Figure 36 Population growth trajectories from AGP bioassays.
Bioassays were conducted June through October 1998. a) Phosphorus addition treatment means for native phytoplankton grown in water collected at site LW013. b) Nitrogen addition treatment means for native phytoplankton grown in water collected at site LW013. Note change in y-axis scale.

a)



b)



and 35). This trend could reflect a change in species composition, average algal cell size, or limiting nutrient. Maximum growth rates were much larger in May and June than in September, suggesting a decline in maximum realized growth rate (Figure 35). September appears to be a transition month away from PO_4-P limitation (Figure 36a), although the PO_4-P-based Monod curve fit is still significant for the September data.

October data do not conform to the Monod model, but November growth rates again demonstrate a significant relationship between PO_4-P as the limiting nutrient and algal biomass. Population growth trajectories from the AGP bioassays, e.g., Figure 36, provide some insight into the nature of this declining response to added PO_4-P. Maximum algal biomass measured as IVF declines sharply in the September and October PO_4-P addition experiments compared to other months (Figure 36a). This decrease in numerical response to the addition of a limiting nutrient corresponds to the period of decline in Monod model parameter estimates of μ_{max} and K_s (Figure 34). As maximum growth rate declined so did the absolute amount of new algal biomass production associated with the addition of PO_4-P. Taken together, these results suggest that Lake Waco phytoplankton were still strongly limited by the available PO_4-P during these months. However, phytoplankton were experiencing an absolute reduction in the quantity of phosphorus supply necessary to deplete and make limiting other available resources. Once these other essential resources were exhausted, they could replace phosphorus as the limiting nutrient. PO_4-P ceased to be the limiting nutrient in October of 1998, being replaced by DIN (e.g., compare Figure 36a & b). Coupled with the sporadic appearance of colimitation and even specific limitation by nitrogen in nutrient-limitation bioassays (Table 27), these results suggest Lake Waco was becoming N-limited in late September or early October of 1998. Nitrogen limitation may result from the differential loss of nitrogen relative to phosphorus following the spring growth period, but the magnitude of these loses vary from month to month and year to year (Figure 29).

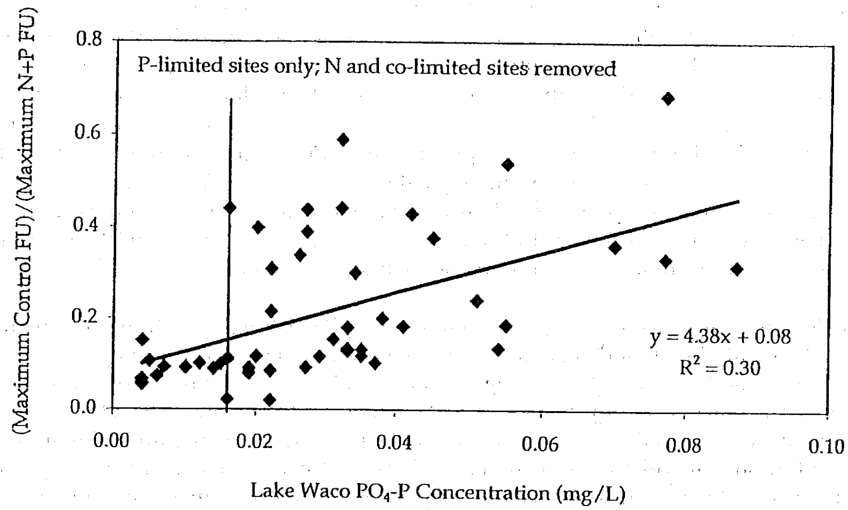
The dose-response bioassays have shown that PO_4-P elicits a population growth effect consistent with the Monod algal growth model. Although no direct connection has been made between Monod growth rates and algal biomass in Lake Waco, it may be possible to use K_s values as a benchmark for this purpose. Assuming algal population growth rate and primary productivity are directly proportional, it may be possible to identify an ambient PO_4-P concentration that will reduce current algal biomass by up to 50 percent. This approach has been taken in developing potential critical phosphorus levels as management benchmarks for Lake Waco (Kiesling et al., 2001).

Field Assessment of Phosphorus Response

What evidence exists that bioassay-derived growth rates are in anyway related to in-lake resource availability in Lake Waco? One simple test is to determine whether the control growth rates from the nutrient-limitation bioassays are a function of in-lake PO_4-P concentrations. Figure 37 shows the relationship between the relative biomass from the bioassay control groups and ambient PO_4-P concentrations determined at the same time the bioassays were initiated, where relative biomass is defined as the ratio of the maximum observed biomass from the control group divided by the maximum observed biomass of the N+P treatment group. Although the true relationship between these variables is neither univariate nor linear in its response, a simple linear regression provides an estimate of how the bioassay growth rates of the control treatments changed as a function of ambient phosphorous concentrations. The Monod growth rates from these dose-response bioassays appear to be functionally related to in situ availability of the limiting resource. As a whole, these results suggest the bioassays are acceptable estimates of how algae respond to comparable increases in nutrient availability (Figure 34).

The obvious threshold response in Figure 37 may be more important to understanding the nature of the relationship between ambient concentration, resource supply, and algal growth rates than the significant linear relationship between growth rates and PO_4-P concentrations. A break in how maximum biomass production responds to increasing nutrient availability occurs at 16µg/L PO_4-P. Below this level, little or no biomass response is recorded to increasing PO_4-P concentrations. This limited response may be an artifact of high flux rates and low concentrations of PO_4-P common to low productivity environments, e.g., Dillon and Rigler, 1974. Above this level, biomass becomes elevated in response to increased availability of the limiting nutrient. Biomass responses above the 16µg/L threshold are also much more variable, suggesting the increasing importance of additional controlling factors at higher ambient concentrations.

Figure 37 Relative maximum biomass of control bioassays as a function of in-lake PO_4-P concentrations. Simple linear regression is significant at $p<0.05$. Dashed line identifies hypothesized threshold for PO_4-P stimulation of algal growth.



Although previous correlation analysis (see Table 16 and Figure 19) have shown a negative relationship between individual measurements of CHLA and PO_4-P, this condition reflects the consumption of PO_4-P throughout the summer season. When individual values are averaged over the summer on an annual basis, a strong positive correlation occurs between CHLA and PO_4-P (Table 29). This relationship based upon seasonal averages is consistent with the results of the dose-response bioassays.

Table 29 Correlation of annual summer PO_4-P with CHLA concentrations for all Lake Waco main body sites for 1997, 1998, and 1999 ($n = 14$). "r" is the correlation coefficient, and "p" is the probability value relating to the significance of the correlation.

Constituent		CHLA (µg/L)	ln(CHLA) (µg/L)
PO_4-P (mg/L)	r	0.67	0.68
	p	0.008	0.007
ln(PO_4-P) (mg/L)	r	0.70	0.71
	p	0.005	0.007

In conjunction with the more substantial relationships between CHLA and PO_4-P shown in previous chapters, this analysis makes it clear that a strong linkage exists between limiting nutrient availability and net algal biomass accumulation in Lake Waco. The predictive nature of this relationship is the strongest and best understood when growing season averages are the focus of the analysis. At shorter time frames, other sources of variance begin to diminish the predictive power of these linkages. Despite these limitations, the availability of the limiting nutrient, estimated in the form of measurements of ambient PO_4-P concentrations, does predict the growth rate of algae as measured by laboratory bioassays.

CHAPTER 9

Summary and Conclusions

The analysis provided herein explores some of the factors influencing algal growth and eutrophication in Lake Waco. The following five questions were addressed with the following findings based on monitoring data collected between June 1996 and December 1999:

1. Is there spatial variability in the surface water quality within the reservoir, and, if so, how does it vary with regard to physical variables, such as conductivity and Secchi depth, versus chemical and biological parameters, such as nutrient and chlorophyll-α concentrations?

   Spatial variability among sites on Lake Waco follow two distinct patterns. For the physical characteristics of conductivity, $DO_{\%sat}$, pH, TSS, and Secchi depth, sites grouped into clusters based on proximity to major tributary inflows, suggesting a longitudinal gradient of riverine to transition to lacustrine. For the chemical and biological constituents, particularly total-N, NO_2-N+NO_3-N, and CHLA, sites also were grouped based on proximity to major tributary inflows, but in this case, the groupings varied depending on the site's proximity to the northern or southern tributary inflow. Organic-N concentrations were generally highest near the inflow of the North Bosque River, while DIN and total-N concentrations were generally highest near the inflow of the Middle-South Bosque River and Hog Creek. CHLA concentrations within Lake Waco clearly followed a gradient with the highest concentrations occurring near the main inflow to Lake Waco, the North Bosque River, and decreasing with longitudinal distance and increasing depth towards the main body of the reservoir. The lowest CHLA concentrations occurred near the inflow of the Middle-South Bosque River and Hog Creek.

   Underlying this CHLA gradient is a pattern of change in nutrient availability for algal growth. N:P ratios clearly indicated a phosphorus limitation in the southern portion of the reservoir near the inflow of the Middle-South Bosque River and Hog Creek. N to P ratios calculated for the rest of the reservoir sites were more difficult to interpret, but a pattern of P limitation seemed to be occurring, with P being less limiting within the north arm than in the main body of the reservoir.

2. Can tributary loadings be related to nutrient and algal dynamics within the reservoir, and if so, how best can these relationships be described?

   Two major riverine zones influence the characteristics of Lake Waco. The North Bosque River forms the northern arm of Lake Waco, while the Middle-South Bosque River and Hog Creek form the southern arm. The North Bosque River comprises about 74 percent of the drainage area to Lake Waco, while Hog Creek comprises 5 percent and the Middle-South Bosque River, 18 percent. Over the study period, almost 70 percent of the tributary inflow to Lake Waco was associated with the North Bosque River. The North Bosque River also accounted for about 80 percent of the phosphorus and almost 90 percent of the TSS tributary loadings. In contrast, about 70 percent of the DIN and 40 percent of the total-N loading to Lake Waco was associated with the southern tributaries.

   DIN, total-N, and PO_4-P concentrations within the main body of Lake Waco were positively correlated with total tributary inflows. In contrast, a significant negative correlation of CHLA concentrations to increasing inflow occurred. This negative correlation of inflow with reservoir CHLA concentrations may be a delay in the algal growth and uptake response to increased nutrient loadings, but it also appears to be a function of water temperature on algal production with increasing algal productivity associated with increasing temperatures. Two large early spring inflow events, one in February 1997 and the other in March 1998, dominated the period of record, and occurred when cooler water temperatures may be limiting algal growth. Regardless, there appeared to be a clear pattern of inflow events increasing concentrations of soluble nutrients within Lake Waco, with a pattern of nutrient depletion occurring during the summer months associated with increasing CHLA concentrations.

3. Does water quality vary with depth within the main body of the reservoir, and, if so, are internal nutrient loadings an important source of available nutrients for algal growth?

   Lake Waco shows very little variance in water temperature with depth, even during the summer months, indicating a well-mixed reservoir. DO did decrease with depth during the summer, particularly in the deeper lacustrine portion of the reservoir. At times, nearly anoxic conditions occurred near the bottom of Lake Waco allowing a reducing environment for the release of NH_3-N from bottom sediments. An associated release of PO_4-P from bottom sediments was not indicated. For samples taken by the dam near the bottom of Lake Waco, a decrease in pH followed decreasing DO concentrations. The patterns of DO, NH_3-N, and pH are most likely the result of microbial respiration and sediment oxygen demand, which have the greatest effect on more isolated waters in the deepest portions of Lake Waco. An increase in TSS with depth was indicated in both the summer and winter months. This increase in TSS with depth is likely associated with the deposition of decaying materials and the settling of other suspended solids within the reservoir.

4. What is the trophic status and overall assessment of water quality within Lake Waco based on Texas assessment guidelines, and what variable or variables best describe the trophic state of the reservoir for tracking future changes?

   Lake Waco was classified as a eutrophic reservoir during the summer months, based on the trophic state indices for CHLA and Secchi depth. Total-P does not appear to be a good indicator of trophic state for Lake Waco, because TSI values based on total-P showed large fluctuations in comparison to TSI values obtained using CHLA or Secchi depth. The reservoir is quite turbid and much of the total-P measured at the surface may be sediment bound, rather than reflecting phosphorus incorporated as algal biomass as assumed in the trophic state index for phosphorus. A light limitation due to turbidity, particularly during the winter, may also be partially limiting the growth of algae. During the winter, TSI values based on Secchi depth were much greater than for TSI values based on CHLA. It appears that during the summer months, either CHLA or Secchi depth would be a good indicator of the reservoir's trophic state, although if the winter months are considered, CHLA is probably the best indicator for tracking longer term trends.

   An assessment of the water quality within Lake Waco, in relation to TNRCC screening levels for nutrients and CHLA, indicated concern or potential concern for concentrations of NO_2-N+NO_3-N, total-P, and CHLA. Although Lake Waco is not currently listed as a priority reservoir for water quality issues, the reservoir appears to be nearing nutrient and CHLA concentrations that could move it into a higher priority category with regard to surface water quality concerns within the State of Texas.

5. What is the limiting nutrient for algal growth within Lake Waco, and can a functional relationship be developed between the limiting nutrient and algal biomass as a guide for controlling algal growth?

   Bioassay experiments were used to evaluate the limiting nutrient to algal growth within Lake Waco and to determine the functional response of algae to increases in the identified limiting nutrient. In comparing additions of nitrogen versus phosphorus to native and experimental algae, over 90 percent of the nutrient-limitation bioassays showed a phosphorus limitation, although the magnitude of this response varied seasonally. Maximum growth rates declined over an order of magnitude throughout the summer, as did the magnitude of the growth response to phosphorus additions, suggesting a move toward colimitation of phosphorus and nitrogen in the late summer or early fall.

The dose-response bioassays in which phosphorus was added at increasing levels showed a significant functional response of algal growth to added phosphorus following a Monod growth model. As with the nutrient-limitation bioassays, a decreasing response to added phosphorus was found throughout the summer months, indicating a seasonal influence in algal response to P.

The analysis provided within this report indicates a strong tie between tributary loadings and PO_4-P concentrations within the reservoir with an associated depletion of PO_4-P with increased algal growth and production in the summer. Although the time period evaluated is limited to about three years, it appears that spring inflows and loadings of PO_4-P are driving summer CHLA concentrations. When summer CHLA and PO_4-P concentrations were compared as annual averages for the main body of the reservoir, a significant positive correlation occurred. Although total-P is often used to model or estimate CHLA concentrations, it appears for Lake Waco that PO_4-P is a better predictor of CHLA concentrations than total-P. The turbid nature of Lake Waco allows a large portion of the total-P in the water column to be sediment bound rather than occurring as a function of algal biomass. As a eutrophic reservoir, most PO_4-P concentrations were also well above laboratory method detection limits rather than at lower levels that are difficult to detect. While targets and methods of controlling eutrophication within Lake Waco will be covered in other reports (see Kiesling et al., 2001; Flowers et al., 2001), it appears that limiting soluble phosphorus loadings to Lake Waco would reduce summer growth of algae.

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7/15/03 FINAL

White Paper

September 15, 2003

Management of Dairy Waste Application Fields in the North Bosque Watershed

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Charge to the "Waste Application Fields Committee"
On June 30, 2003, Congressmen Chet Edwards and Charlie Stenholm and Dr. R. Mack Gray, USDA Deputy Undersecretary for Natural Resources and Environment, co-chaired a meeting of about forty parties interested in working together to reduce nutrient loading and improve water quality in the North Bosque River. During the meeting, the committee received a draft white paper developed by the "Standards Committee." This white paper addressed the design and operation of dairy waste storage ponds and treatment lagoons in the watershed. The white paper was written to provide guidance to the dairy industry and other organizations involved in protecting water quality in the North Bosque River watershed.

At the meeting, a Waste Application Fields Committee was appointed to develop a companion white paper to address the management of waste application fields (WAFs) that are used to dispose of dairy wastes. This Committee anticipates that the industry and agencies will consider its recommendations and conclusions as they develop rules, policies, and programs designed to protect water quality in the North Bosque River watershed.

Reasons for Action
In 1998 the North Bosque River (Segments 1226 and 1255) was included in the Texas Clean Water Act 303(d) List of impaired waters under narrative water quality standards related to nutrients and aquatic plant growth. In February 2001 the Texas Natural Resources Conservation Commission (TNRCC) (now the Texas Commission on Environmental Quality (TCEQ) adopted "Two Total Maximum Daily Loads (TMDL) for Phosphorus in the North Bosque River" for segments 1226 and 1255 (TNRCC, 2001). The TMDL concluded that:

- The designated use (in this case, drinking water) of segments 1226 and 1255 were "impaired" by high levels of nutrients.
- The nutrient of principal concern was soluble reaction phosphorus (SRP), and cutting SRP concentrations in half would reduce the potential for problematic algal growth in the river.
- The major controllable sources of nutrients in the North Bosque River basin were municipal wastewater treatment plants (WWTPs) and dairy waste application fields (WAFs).

In December 2002 TCEQ and Texas State Soil and Water Conservation Board (TSSWCB) adopted "An Implementation Plan for Soluble Reactive Phosphorus in the North Bosque River Watershed." Four basic strategies to lessen phosphorus loadings to watershed were identified.

- Reducing phosphorus levels in the diet of dairy cows to reduce the phosphorus content of dairy wastes.
- Matching phosphorus application rates in WAFs with soil and crop needs.
- Removing approximately half of the dairy-generated manure from the North Bosque River watershed for use or disposal outside the watershed.
- Setting effluent limits on phosphorus for municipal wastewater treatment plants. (TCEQ and TSSWCB, 2002, p.12)

Data upon which the TMDL was based were collected in streams, and loading estimates derived from the data characterized all dairy-source loading as emanating from WAFs.

Some of the technical professionals involved in the TMDL analysis were convinced that a significant part of the dairy-source loading actually came from retention facilities.

The North Bosque River has been listed on the 303(d) list of impaired waters for bacteria in 1996, 1998, 1999, and 2000. The 2002 draft 303(d) listing identifies eleven stream segments in the Erath County portion of the North Bosque River watershed that are impaired due to bacteria: Green Creek (1226B), Indian Creek (1226E), Sims Creek (1226F), Upper North Bosque River (1255), Goose Branch (1255A), North Fork North (Bosque River (1255B), Scarborough Creek (1255C), South Fork North Bosque (1255D), unnamed tributary to Goose Branch (1255E), unnamed tributary to Scarborough Creek (1255F), and Woodhollow Branch (1255G). Although TMDLs have not yet been prepared for these stream segments, unauthorized discharges resulting from inadequate design, construction, and operation of dairy waste retention facilities may be contributing to water quality problems. Practices that reduce phosphorus losses from WAFs are expected to also reduce bacterial contamination.

The Scientific Basis for WAF Management

Waste Application Fields are the principal source of phosphorus from the dairy industry that enters the North Bosque River. Phosphorus can move off the WAF either dissolved in runoff water or attached to sediment suspended in runoff. In addition, for a particular soil, the concentration of phosphorus dissolved in runoff is directly proportional to the amount of phosphorus in the top few inches of soil. As a result, there are at least five means to reduce the amount of phosphorus that moves from a WAF into a stream (Sharpley, et al., 1996, 1998).

- Reduce the amount of phosphorus in the topsoil layer.
- Reduce the solubility of phosphorus in the topsoil layer to minimize its dissolution and movement in runoff water.
- Reduce the amount of runoff that can transport sediment and dissolved phosphorus from the topsoil layer to the stream.
- Use vegetative cover (such as perennial pastures) to protect the soil surface and prevent soil erosion.
- Filter sediment and/or adsorb dissolved phosphorus from the runoff before it can enter the stream.

Recommended rules, technologies, and management practices should address at least one of these means of reducing phosphorus loading of the North Bosque River.

Appendix I of this white paper summarizes some of the scientific research, data, and decision tools developed to help manage WAFs in the North Bosque River watershed.

TCEQ Rules.

TCEQ rules governing waste application fields in the North Bosque River watershed seek to eliminate discharges of nutrient-rich wastes directly into streams, to limit excessive build-up of phosphorus in topsoils of WAFs, and to reduce sediment loads reaching streams. Three relevant sections of the current rules are summarized in *Appendix II*. (TCEQ, Chapter 321 – Control of Certain Activities by Rule, Subchapter B: Concentrated Animal Feeding Operations, 2002)

TCEQ is in the process of revising its rules related to Confined Animal Feeding Operations (CAFOs). The Committee anticipates that recommendations in this white paper will be considered in the rulemaking process.

Programs to Improve Water Quality in the North Bosque River.
In response to concerns about water quality in the North Bosque River and Lake Waco, several programs have been initiated to:

- Educate dairy operators about proper waste management.
- Provide technical and financial assistance to improve dairy waste handling facilities and waste management practices.
- Provide incentives to transport manure to compost facilities.
- Provide education and financial assistance to improve compost markets.
- Remove nutrients from a portion of inflows into Lake Waco.
- Protect and restore riparian, wetland, and aquatic habitats within the North Bosque River watershed, and
- Develop Comprehensive Nutrient Management Plan (CNMPs) and implement management practices to reduce nutrient loads from WAFs and waste retention facilities.

Specific programs designed to help improve water quality in the North Bosque River are briefly described in *Appendix III.*

Recommendations.
The Committee has been able to reach consensus on a number of issues. More complete descriptions of several recommended technologies and management practices are found in *Appendix IV.*

Because two segments of the North Bosque River are impaired by soluble phosphorus, and WAFs are the source of a substantial amount of that phosphorus, additional precautions are needed for the management of WAFs in this watershed.

TCEQ's environmental threshold for soil test phosphorus is designed to limit the amount of topsoil phosphorus that can be dissolved in runoff water. Two critical elements in determining soil test phosphorus in the soils of WAFs are the soil sampling depth and the method of soil phosphorus extraction. The current threshold soil test phosphoprus is 200 ppm (parts per million) in the 0-2, 2-6, or 0-6 inch layer, as measured by the TAMU or Mehlich III methods. Soil test phosphorus typically decreases with depth below the soil surface, especially for soils in which animal wastes are applied to the surface and are not incorporated by tillage. In addition, recent research has demonstrated that the Mehlich III and Texas A&M methods can extract substantially different amounts of phosphorus from the same soil sample.

In order to facilitate comparison with environmental soil testing in other states, the Committee recommends that the Mehlich III soil test be used for all WAFs in the North Bosque River watershed. The Committee did not reach consensus on the recommended depth of sampling. Some members recommended that the 0-2 inch depth be selected because this layer most closely approximates the soil that affects phosphorus concentrations in runoff. Other members recommended the 0-6 inch depth because it is used in agronomic soil testing.

Preliminary research on soils typical of the North Bosque River watershed has shown that, for a particular soil test level, soils differ in the concentration of phosphorus in runoff. At a particular soil test value, runoff from fine-textured calcareous soils will have a lower concentration of dissolved phosphorus than runoff from a coarse-textured non-calcareous soils. The Committee recommends that these recent studies be expanded to include more soils of different textures and with wide variation in soil test phosphorus. This will provide a better scientific basis for fine-tuning soil test phosphorus thresholds, managing waste applications, and selecting WAFs based on soil characteristics.

CNMPs will mandate specific structures and management practices designed to minimize phosphorus movement from WAFs to streams. The Committee recommends that CNMPs require structures and practices appropriate to specific WAFs, considering their soils, slopes, vegetative cover, soil test values, and landscape position. CNMPs should also require that effluents applied to WAFs be analyzed periodically for nutrient concentrations.

The Committee recommends that the dairy industry, State and Federal agencies, and other stakeholders cooperate to implement cost-effective practices that balance imports of phosphorus into the watershed (as feed, fertilizer, and other products used on dairies) with exports of phosphorus from the watershed (as milk products, manure, and compost). Practices that can help achieve this goal include:

- Decreasing phosphorus concentrations in feeds and
- Removing manure and/or compost from the North Bosque River watershed.

The Committee recommends that dairy operators, with assistance from State and Federal agencies, manage WAFs to minimize concentrations of phosphorus in surface runoff and to reduce the amount of surface runoff that reaches streams. Structures and practices that can help achieve these goals include:

- Location of WAFs as far as possible from streams and on deep, fine-textured soils with great capacity to adsorb phosphorus and little potential for runoff.
- Installation and maintenance of vegetated buffers to filter runoff before it reaches a stream.
- Incorporation or injection of manure below the soil surface to minimize exposure of freshly applied manure to runoff.
- Application of manure at rates that prevent topsoil phosphorus concentrations from exceeding regulatory limits.
- Periodic deep ripping of WAFs to increase infiltration and to reduce runoff.
- Construction of terraces in WAFs to slow runoff and to increase infiltration.
- Construction of wetlands (and possibly filter beds of crushed limestone) to trap sediment and to reduce the concentration of soluble phosphorus in WAF runoff before it reaches a stream.
- Construction of ponds or berms to intercept WAF runoff before it reaches a stream, and use of this impounded water for irrigation or process water.

The Committee is aware of a number of promising management practices and technologies for which additional scientific and economic data are needed. The dairy industry, State and Federal agencies, and other stakeholders should cooperate to obtain scientific information needed to judge the cost effectiveness of such practices for the North Bosque River watershed. Examples include:

- Deep tillage of pastures (perhaps in strips to minimize soil erosion) to invert the soil and bury high-phosphorus topsoil layers below low-phosphorus subsoil.
- Application of agricultural limestone, water treatment residues, or other soil amendments that strongly bind soluble phosphorus and reduce its solubility in runoff water.
- Removal of phosphorus and other contaminants from the liquid waste stream to reduce buildup of phosphorus on WAFs and facilitate water reuse by dairies.

The Committee recommends that agencies managing cost-share programs evaluate technologies and practices like those listed above and, when scientific evidence and/or professional judgment warrant, include them on lists of practices approved for cost-share.

It is important that programs designed to reduce phosphorus loading of the North Bosque River by runoff from WAFs be targeted to produce the greatest load reductions for the least cost. The USDA-NRCS "Phosphorus Assessment Tool for Texas" and similar phosphorus index methodologies (such as those specified in NRCS General Manual Title 190, Part 402) take into consideration a number of factors affecting the risk of pollution from WAFs. State and Federal agencies should assemble a task force of soil scientists to evaluate and possibly fine tune the "Phosphorus Assessment Tool for Texas" or a similar tool for use in the North Bosque River watershed. The tool should then be used to choose the locations of new WAFs, to prioritize WAFs for cost-share programs, and to guide manure management and targeting of conservation or remedial measures.

The Committee encourages continuation and enhancement of the DOPA waste management education program and the APCO environmental certification program. These programs are designed to help dairy operators safeguard the environment while achieving production goals. Dairy operators who complete the DOPA program and participate in the APCO program should be recognized as "Master Animal Waste Managers."

The Committee recommends that Technical Service Providers developing CNMPs be Texas Certified Nutrient Management Specialists and that their training includes the structures and practices outlined above. This will help assure that CNMPs specify use of the most effective nutrient management practices.

The Committee recommends that the dairy industry work with Technical Service Providers and TCEQ to assure appropriate soil sampling, soil analysis, and record keeping for WAFs and associated structures. The data generated can document good management of WAFs, warn when soil phosphorus concentrations approach or exceed regulatory levels, alert the operator when soil water contents are low enough to permit irrigation without producing runoff, and estimate the amount of runoff due to rainfall. If producers regularly record data on soil sampling and analysis, as well as waste applications, the public will likely be more assured that WAFs are managed properly.

Finally, while the Committee recommends immediate action regarding the points listed above, it is aware that significant scientific uncertainties remain. We recommend the formation of a North Bosque River Scientific Advisory Committee (NBRSAC) to address scientific and technical issues specific to the watershed. This committee should meet on regular basis to:

- Develop a five-year research and demonstration plan to inform the next TCEQ rule making process for CAFOs (expected in 2008-2009).
- Prioritize studies and demonstrations of promising technologies and tools.
- Evaluate results of these studies and demonstrations, and
- Recommend cost-effective practices to be permitted and facilitated by cost-share, and other programs designed to reduce pollution of the North Bosque River.

Additional Observations.
The Committee achieved a broad consensus on the points described above. However, one or more members made each of the following obsservations.

In order to achieve consistent soil test phosphorus data, it is important to standardize the sizes of WAF land management units, the method of taking samples within the unit, and the number of subsamples composited to represent each unit. TCEQ should require that sampling of WAFs follow TCE soil sampling guidelines.

Under some conditions, the Phosphorus Index and TCEQ rules allow wastes to be added to fields with greater than 200 ppm soil test phosphorus. The current TCE threshold of 200 ppm for soil test phosphorus should be considered an upper bound, and TCEQ should require a phosphorus reduction plan for WAFs with soil test phosphorus greater than 200 ppm.

The Phosphorus Index uses the proximity of nearest edge of a WAF to a named stream or lake. Because of the nature of rainfall events and topography in te North Bosque River watershed, even unnamed tributaries quickly contribute their flows to the river. As a result, all streams and lakes shown on USGS maps (whether perennial or intermittent, whether named or unnamed) should be considered in calculating the weighting factor.

Conclusions.
Improving the management of WAFs in the North Bosque River watershed will require a long-term commitment of the dairy industry, State and Federal agencies, and other stakeholders. We do not expect to find a single "silver bullet." On the contrary, all the interested parties must work together to assure that every dairy has a CNMP that minimizes the movement of phosphorus (as well as nitrogen and bacteria) from waste storage facilities and WAFs into the North Bosque River and its tributaries. To be effective, the CNMPs should incorporate the best available scientific evidence; be tailored to the unique conditions of each dairy; and be supported by appropriate educational, technical/financial assistance, and regulatory programs. In the long term, CNMPs should move dairies toward a balance between phosphorus imports in feed and phosphorus exports in milk and manure-based products that leave the North Bosque River Watershed (or are deposited in approved land fills).

Appendix I

Selected Research and Decision Tools.

TCEQ's environmental threshold for soil test phosphorus is designed to limit the amount of topsoil phosphorus that can be dissolved in runoff water. The threshold is 200 ppm (parts per million) in the 0-2, 2-6, or 0-6 inch layer (as measured by the TAMU or Mehlich III methods). This environmental threshold was chosen in the 1980s when there was little concern for nitrogen or phosphorus contamination of streams. The soil test value of 200 ppm was chosen because higher concentrations were thought to be associated with micronutrient imbalances in plants. The threshold value was not chosen to minimize phosphorus in runoff. (B.L. Harris and Sam Feagley, personal communication)

In the 1990s scientists began to study the relationship between soil test phosphorus and the concentration of phosphorus in runoff from WAFs. This effort to predict the loss of phosphorus from WAFs has demonstrated that for a particular soil, the concentration of phosphorus in runoff increases linearly with increasing soil test phosphorus. However, the slope of the relationship varies among soils. In addition, for the same level of extractable soil phosphorus, runoff from cultivated fields typically contains substantially greater phosphorus concentrations than runoff from grassed fields. Also, for fields with similar soil test phosphorus levels, those on which manure has recently been applied produce greater concentrations of phosphorus in runoff than those on which the manure has had time to decompose. (Kamprath et al., 2000; Pote et al., 1999; Sharpley et al., 1996 and 1998).

Torbert, et al. (2002) determined the relationship between soil test phosphorus and the phosphorus concentration in runoff for four soils typical of the North Bosque River Watershed. For the study, coastal bermudagrass was the vegetation cover, and a runoff simulator was used to assure uniform treatments among soils. They found that for the same soil test value, runoff from fine-textured calcareous soils contains lower concentrations of soluble phosphorus than runoff from coarse-textured noncalcareous soils.

Jacoby and Feagley (2003) recently evaluated the correlation between the Mehlich III and TAMU soil tests for twenty-one soils from seven states, all of which had received substantial amounts of animal manure over a number of years. They found for all but two of the soils (and for seven of the eight soils that had received dairy waste) Mehlich III extracted more (often several times more) phosphorus than did the TAMU extractant. For the twenty-one soils, the TAMU method extracted from 44 to 887 ppm while the Mehlich III method extracted from 168 to 2735 ppm. (Sam Feagley, personal communication)

In 2002 dairies in the North Bosque River watershed submitted to TCEQ annual soil test reports (0-6 inches) for 198 land management units. Of these, 183 reported soil test phosphorus concentrations less than 200 ppm, 14 reported concentrations between 200 ppm and 500 ppm, and one reported a concentration greater than 500 ppm. To avoid possible conflicts of interest in collection of soil samples, effective September 2002, TCEQ has required that soil samples be collected by approved Technical Service Providers. (Clyde Bohmfalk, personal communication)

As scientific understanding of soil phosphorus dynamics has increased, soil scientists have realized that it is a complex process that depends on soil chemistry, soil physical properties, soil management and cover, hydrology, and landscape position. Today, there is no model that can accurately predict the impacts of all these factors on concentrations of soluble and sediment-attached phosphorus in runoff. As a result, soil scientists have used research-based expert opinion to characterize fields as probable sources of phosphorus contamination of water bodies. USDA-NRCS has developed the "Phosphorus Assessment Tool for Texas." It provides a framework by which a site can be rated for eight characteristics related to phosphorus losses in runoff (USDA-NRCS, 2000). The eight site characteristics and their respective weighting factors are listed below.

- Soil test phosphorus level (1.00).
- Fertilizer phosphorus application rate (0.75).
- Organic phosphorus application rate (0.75).
- Phosphorus fertilizer application method and timing (0.50).
- Organic phosphorus application method and timing (0.50).
- Proximity of nearest field edge to a named stream or lake (1.25).
- Runoff class (1.00).
- Soil erosion (1.50).

For each of the eight characteristics, the site receives a rating (based on a detailed worksheet):

- 0 none or very low
- 1 low
- 2 medium
- 4 high
- 8 very high.

A weighting factor for each site (in parentheses, above) is multiplied by the site rating for each factor. The sum of the products produces the total index points for the site, ranging from a minimum of 0 to a maximum of 58. The total index points are used in the NRCS Nutrient Management Practice Standard to make nutrient application recommendations. Sites in the eastern two-thirds of the state (including the North Bosque River watershed) and sites in watersheds with water bodies designated as impaired for nutrients have lower maximum acceptable soil test phosphorus values. TIAER has modified the phosphorus index for use in the Goose Branch watershed. It may be a more appropriate tool for use in the entire North Bosque River watershed. (USDA-NRCS, 2000)

The P Index can be used to assess the risk of phosphorus loss from specific WAFs. This information can be used to choose the location of new WAFs, to prioritize WAFs for cost-share programs, and to guide manure management and targeting of conservation or remedial measures.

USDA-ARS scientists in Temple, TX and University Park, PA are currently using field data to refine existing routines in the EPIC/APEX and SWAT models to simulate more accurately phosphorus cycling and transport in WAFs. The research is funded in part by TSSWCB, and it should improve evaluation of management practices designed to reduce phosphorus losses from WAFs. (Daren Harmel, personal communication)

TIAER is under contract with TCEQ to refine the modeling system used in development of the TMDL, to incorporate new data and knowledge regarding model-simulation activities and features, and to reanalyze the TMDL allocation. The project is scheduled for completion by the end of calendar year 2006. The major tasks within the project include: collection of data in support of refining the modeling system, implementation of modeling system refinements, validation of the modeling system against monitoring data for the North Bosque River watershed, and reanalysis of the TMDL allocation. (Larry Hauck, personal communication)

Appendix II

Current TCEQ Rules

321.19. Pollution Plans. This section describes pollution prevention plans required by TCEQ for CAFOs. NRCS waste management plans can be substituted for the TCEQ plans described in the section. Aspects of the pollution prevention plans dealing with WAFs include:

- Land application rates must take into account the nutrient contribution of any land applied manures.
- Discharge or drainage of irrigated wastewater into or adjacent to streams is prohibited.
- In general, manure must be uniformly applied to suitable land at appropriate times and at agronomic rates. Discharge (runoff) of waste from the application site is prohibited.
- Vegetated buffer strips separating WAFs from surface waters must be at least 100 feet wide (see Section 321.40 (7).
- Land subject to excessive erosion shall be avoided.
- Annual soil sampling using composite samples of ten to fifteen randomly sampled cores is required.
- Samples must be taken from 0 to 6 inches where wastes are incorporated into the soil, and from 0 to 2 inches and 2 to 6 inches where wastes are not incorporated.
- Extractable phosphorus must be analyzed by the Texas A&M or Mehlich III extractant.

321.48. Regulation of Certain Dairy Concentrated Animal Feeding Operations (CAFOs) In response to conditions in the North Bosque River watershed, TCEQ requires that in a major sole-source impairment zone (like the North Bosque River watershed), special rules apply. For example, every new or expanded CAFO must remove 100% of the collectable manure produced by the new or additional animals and dispose of it beneficially or in landfills outside the watershed, deliver it to a composting facility or dispose of it in an acceptable manner. This disposal may include use of a new (not previously used) waste application field, or a waste application field with less than 200 ppm extractable phosphorus in the top six inches. In fields with more than 200 ppm extractable phosphorus in the top six inches, application must be done in accordance with a detailed nutrient utilization plan approved by the TCEQ Executive Director.

321.49. Dairy Waste Application Field Soil Sampling and Testing. This section describes soil testing required in major sole-source impairment zones (like the North Bosque River watershed).

- For WAFs in which extractable soil phosphorus concentrations in the top six inches are greater than 200 ppm, the operator is required to submit a new or amended nutrient utilization plan with a certified phosphorus reduction component, or demonstrate that the existing nutrient utilization plan is certified.
- For WAFs with extractable soil phosphorus concentrations in the top six inches greater than 500 ppm, a new nutrient utilization plan with a certified phosphorus reduction component is required.

Appendix III

Programs to Reduce Phosphorus Loading in the North Bosque Watershed.
Several programs and projects have been implemented by public and private organizations to address concerns about water quality in the North Bosque River watershed. Not all of them involve WAFs.

- The voluntary Agricultural Producer Certification Option (APCO) program has been initiated to help dairy operators "increase air and water quality beyond what current regulations mandate." Endorsed by TCEQ, TSSWCB, BRA, USDA-NRCS, TIAER, TDA, TCE, and TAD, the APCO program uses trained technical service providers to review dairies for environmental compliance, obtain a TSSWCB-certified Comprehensive Nutrient Management Plan (CNMP), and provide oversight. (TSSWCB, 2003; USDA-NRCS, 2000)
- The Dairy Outreach Program Area (DOPA) waste management education program is conducted by TCE in cooperation with TCEQ and TSSWCB. It provides an initial 8-hour course on animal waste management within 12 months after permitting or being authorized to operate. An additional 8 hours of continuing education in animal waste management is required in each subsequent 24-month period. This is a valuable educational program that helps owner/operators integrate the different components of their waste management operations. (Sam Feagley, personal communication)
- TCE will soon begin to develop an online version of the Texas Nutrient Management Certification Short Course. Another component of this project will be the development and delivery of nutrient management and other management aspects for new CAFOs as specified by the new EPA CAFO regulations. (Sam Feagley, personal communication)
- The Dairy Manure Export Support Project (DMES) is administered by the TSSWCB and provides financial support to transport manure from dairies to composting facilities. Since 2000, the program has been responsible for transporting over 370,000 tons of manure from the North Bosque River watershed and over 280,000 tons from the Leon River watershed to approved composting facilities. (TIAER, 2003; Anonymous 2003)
- The Composted Manure Incentive Project (CMIP) is funded by TCEQ and administered by TWRI and TCE. Its goal is to educate the public and to develop markets for dairy compost, the CMIP provides financial support for purchase of composted dairy manure by public entities. The CMIP has helped establish the TxDOT market and will continue to be used to develop markets for surrounding cities and private entities through the Upper Leon Soil and Water Conservation District. By May 2003, over 150,000 tons of compost had been sold by approved composters, and TxDOT had let bids for over 300,000 tons of compost.(TIAER, 2003; Anonymous, 2003)
- The CMIP is complemented by a dairy compost marketing project. This Clean Water Act Section 319 (h) Nonpoint Source Grant Project is conducted by TWRI in close cooperation with TCE, TCEQ, TSSWCB, compost producers and others. It seeks to educate compost producers, improve the quality and uniformity of product, and obtain scientific data on the benefits and cost effectiveness of compost use. (Cecilia Gerngross, personal communication)
- The TSSWCB has developed a special project called "Technical and Financial Assistance to Dairy Producers and landowners of the North Bosque River Watershed." The project is administered by the Cross Timbers and the Upper

Leon Soil and Water Conservation Districts with funding from the EPA. This Clean Water Act Section 319(h) Nonpoint Source Grant Project provides $1,330,000 for the implementation of nonpoint source abatement measures from the TSSWCB-Approved Practice List on any agricultural operation land applying manure (or manure compost) or wastewater. Landowners and dairy producers must first develop a TSSWCB-Certified Water Quality Management Plan (WQMP) or a TSSWCB-Certified Comprehensive Nutrient Management Plan (CNMP) to qualify for funding. The funding is provided through a 75% (SWCD) / 25% (producer) cost-share system with a maximum of $10,000 per applicant. Unpermitted, nonpoint source animal feeding operations (AFOs) may use the funding for all practices on the TSSWCB-Approved Practice List. Permitted CAFOs must only use the funding for practices on the TSSWCB Approved Practice List that abate nonpoint source pollution, excluding the production area (milk barn, retention control structures, free-stall barns, drip sheds, open/covered lots, manure storage areas, etc.). Non AFO/CAFO farms may use the funding for all practices on the TSSWCB Approved Practice List. (John Foster, personal communication)

- Through the Water Quality Management Plan-Senate Bill 503 Cost-Share Program, the TSSWCB allocates approximately $180,000 annually for the implementation of nonpoint source abatement measures from the TSSWCB-Approved Practice List. Landowners must first develop a TSSWCB-Certified WQMP to qualify. The funding is provided through a 75% (SWCD) / 25% (producer) cost-share system with a maximum of $10,000 per applicant. Unpermitted, nonpoint source AFOs and non AFO/CAFO farms may use the funding for all practices on the TSSWCB-Approved Practice List. This funding is not applicable for permitted CAFOs. (John Foster, personal communication)
- The US Army Corps of Engineers (USACE) and Brazos River Authority (BRA) have begun the "Middle Brazos River Watershed, North Bosque River Sub-Basin Interim Feasibility Study." The study serves to protect and restore riparian, wetland, and aquatic habitats within the North Bosque River watershed. Individual restoration plans have been completed for twenty-one sites, and contracts were let for detailed surveys of proposed wetland and low water weir sites at eleven restoration sites. USACE and BRA have indicated a desire to expand the study to include sites on dairies, but no construction has begun. (USACE Fort Worth District, 2003)
- In 2003, over $2 million from the USDA-NRCS Environmental Quality Incentives Program (EQIP) has been allocated to develop CNMPs and implement management practices needed to reduce transport of soluble and sediment-attached phosphorus from WAFs in the North Bosque River watershed. Additional EQIP funding to implement best management practices is expected in future years. (Larry Butler, personal communication)
- The Lake Waco/North Bosque Wetlands project is a 180-acre functioning wetland. It is located near Lake Waco adjacent to the North Bosque River. There are significant water quality improvement advantages to having this marsh-type wetland. Approximately 20% of the base flow of the North Bosque River can be diverted under low flow conditions. The wetland will remove 99% of the sediment, 80% to 90% of the nitrogen and between 65% and 85% of the phosphorus from the water that flows through it. This project will cost about $1,000,000 with an annual operating cost of $75,000. (Rickey Garrett, personal communication)

- The Lake Waco Comprehensive Lake Management Study is a $2,000,000 project, involving participation from the EPA, TCEQ, USGS, Baylor University, and others. Many important characteristics of Lake Waco will be established, including: potential for internal loading of phosphorus, bathymetry or flow patterns in the lake, ecosystem status and viability, etc. The project manager is ENSR International, and the sponsor is the City of Waco. (Rickey Garrett, personal communication)
- In 1998, the City of Waco annexed several thousand acres and approximately 500 homes south and west of the City along Highway 84. The City will spend more than $7,000,000 to provide sewer service to this rapidly growing area. Already service has been provided to more than 50 homes, and homeowners will be given one year to connect to the sewer system with no charge once service becomes available. (Rickey Garrett, personal communication)
- The City of Waco has developed "North Bosque River Watershed CAFO Standards" for management of waste storage facilities and WAFs on dairies participating in cost-share programs funded by the City. Key elements of the Standards include: (1) maintenance of adequate empty volume in waste storage facilities to contain the 25-year, 10-day rainfall event (11.9 inches), (2) removal of at least 90% of collectible dry manure to "a TCEQ-permitted composting facility, other lawful waste reclamation or processing facility or for beneficial use outside the North Bosque River watershed," (3) the remaining 10% of dry manure can be applied to WAFs only if "extractable phosphorus in the uppermost two inches of soil is 200 ppm or less," (4) vegetated buffers of at least 150 feet between a WAF and a watercourse. The full text of the Standards is available from the City of Waco. (Wiley Stem, personal communication)
- The EPA (through TCEQ, TSSWCB, BRA, BRA, USDA/NRCS, TFB, Altria, an Electric Cooperative, a local dairy producer, TIAER, and Cascade Earth Sciences) have teamed to design, permit, build, and bring into operation a dairy waste management system that will include waste collection, anaerobic digestion, compost production, and marketing, CNMP development, phosphorus removal, and edge-of-field monitoring. This project utilizes both 319(h) grant funds, privte funds, and other means to support the approximately $1,300,000 project cost.
- The BRA is funding the site selection, permitting strategy, and preliminary engineering for construction of either an in-stream or off-channel wet pond or wetland o the main stem of the North Bosque River. The purpose of the project will be to remove nutrients and solids by physical and biological means. If this project proves successful, it may be desirable to build more such structures along the river.
- The TFB, EPA, TSSWCB, BRA, CW, TAMU, and Parsons Engineering have are cooperating to detemine the relative amounts of *E. coli* bacteria from different sources in Lake Waco, Lake Belton, and selected streams that contribute to the lakes.

Appendix IV

Management Practices for WAFs in the North Bosque River Watershed.
The subcommittee identified a number of promising management practices that may be used to reduce both phosphorus loading of WAFs and movement of phosphorus from those fields into streams. They are described below.

Reduction of Phosphorus Concentrations in Manure. Carefully matching dietary phosphorus inputs to dairy cow phosphorus requirements can reduce the amounts of phosphorus excreted by animals (Poulsen, 2000; Valk et al., 2000). For instance, in a two-year study, Wu et al., (2001) found a linear relationship between phosphorus intake and fecal excretion of lactating dairy cows. Based on research of this type, the National Research Council (2001) has published guidelines that reduce the recommended dietary phosphorus for lactating dairy cows to between 0.31% and 0.38%. Technical guidance developed by USDA-NRCS for CNMP development states that "Feed management can be an effective approach for addressing excess nutrient production and should be encouraged," though under the direction of a professional animal nutritionist. "Specific feed management activities to address nutrient reduction in manure may include phase feeding, amino acid supplemented low crude protein diets, and the use of low phytate phosphorus grain and enzymes, such as phytase and other additives." (TSSWCB, 2003; USDA-NRCS, 2000)

The North Bosque River watershed TMDL implementation plan specifies that the phosphorus content of dairy cow diets be reduced. Some dairy producers have responded by reducing the phosphorus content of rations. (Pete Schouten, personal communication)

Removal of Manure or Compost from the North Bosque River Watershed.
The North Bosque River watershed TMDL implementation plan specifies as a feasible measure, that half of the dairy-generated manure from the North Bosque River watershed be transported outside the watershed for use or disposal. In response to this need, the DMES and CMIP programs have facilitated the hauling of manure from dairies in the Bosque-Leon watershed to TCEQ-permitted composting facilities and the sale of composted dairy manure to TxDOT and other users. TCE and TWRI are conducting applied research focusing on possible uses on local agricultural lands. Agricultural producers within the watershed currently use chemical fertilizers and could benefit from dairy compost applications as an alternate nutrient source. Programs such as EQIP and the Upper Leon SWCD rebate program will provide economic incentives for the use of dairy compost within the agriculture industry. End users will be required to complete a CNMP ensuring environmentally sound compost applications to avoid potential phosphorus loading. Continuation of these projects is expected to reduce the amount of manure available for application to WAFs. (TIAER, 2003; McFarland and Bekele, 2003)

Removal of Phosphorus from Liquid Waste Stream. Several emerging technologies have been proposed to remove soluble and sediment-attached phosphorus from liquid dairy wastes. These include:

- Hydrocyclones are widely used by the petroleum and other industries to remove solids from contaminated waters. They can efficiently remove sediment-attached phosphorus from lagoon effluent, and they could be used in series with one of the technologies described below.

- Struvite (solid magnesium ammonium phosphate) is a crystalline material (Abbona & Boistelle, 1979) formed by reaction of soluble phosphorus with magnesium and ammonium ions under anaerobic conditions at high pH, just the conditions found in dairy lagoons. For several decades, struvite has been regarded as a nuisance material in clogging of sludge digesters (Rawn et al., 1939), municipal sewage/pumping systems, and recirculating effluent flush systems for livestock and poultry manure management systems (Booram et al., 1975; Roberto & Sweeten, 1985). Struvite forms at points of turbulence or roughness elements along with sufficient constituent concentrations in effluent. However, it is highly pH sensitive—highly soluble at 4.0-5.0 pH but with low solubility at pH 6.4-8.0 or greater. This reaction is well known (Abbona et al., 1982), and whereas acid treatment can be used effectively for struvite removal from piping and pumping systems (Roberto & Sweeten, 1985), elevated pH conditions have been proposed and developed for removal of both soluble phosphorus and ammonium in the form of struvite from municipal wastewater and animal wastewaters . Struvite formation can remove most (up to 80-90%) of the soluble phosphorus from liquid wastes (Bowers and Westerman, 2003), and it has been shown to be an excellent slow-release fertilizer. For application to dairy waste, limiting factors include an economical source of magnesium and a method of harvesting the struvite, which normally floats to the surface of the liquid (Burns and Moody, 2002).
- Electroflocculation is a process that uses electrolytic addition of coagulating metal (aluminum or iron) ions that react with phosphate and other ions in wastewater. The resulting metal phosphates float to the surface of the liquid, and up to 98% can be removed. This process is claimed to produce less sludge and residual salinity than precipitation of phosphorus by addition of alum and ferric chloride. Both batch and continuous processes are available. A critical issue appears to be the cost of electrodes, which are consumed as part of the process. A recent test performed by Ecoloclean, Inc. using liquids from a dairy lagoon demonstrated that the process can remove between 78% and 99% of the total phosphorus. (Robinson, 2003; Alan Hansen, personal communication)
- Adsorption of soluble phosphate and other ions on electrically charged surfaces.
- Chemical additions for flocculation/precipitation of phosphorus from liquid dairy manure (Kirk et al. 2003). Of three chemical additives tested in vitro—lime, alum, and ferric chloride—total P reductions were 30-82% after 1 hr of settling, compared to 24% in the control. Settling time of 24 hrs resulted in 57-100% total P removal. Alum performed better than the lime or ferric chloride treatments. (It may be noteworthy that a similar type of flocculation/precipitation system for P removal from feedlot runoff is being used at a large commercial feedyard in the Texas Panhandle.)

Several of these technologies are used routinely in other industries, but they have not been adopted by the dairy industry. If these technologies can be made cost effective, they could be used to remove phosphorus from wastewater applied to WAFs, reducing the build up of soil phosphorus levels and extending the useful life of the fields. Of course, residual high-phosphorus solids would need to be disposed of properly.

Minimizing Exposure of Freshly Applied Manure to Runoff.

A number of studies have demonstrated that the concentration of soluble phosphorus in runoff is inversely proportional to the time since manure has been applied to the soil surface. Practices that minimize the exposure of fresh manure to runoff will reduce phosphorus losses, including restricting manure application to periods of the year when runoff is less probable.

Minimizing Concentrations of Extractable Phosphorus On or Near the Soil Surface.
A number of studies have demonstrated that the concentration of soluble phosphorus in runoff is related to the concentration of extractable phosphorus in topsoil layers. The concentration of phosphorus in runoff can be reduced by practices that minimize the concentration of extractable phosphorus in the topsoil. These practices could include:

- Rates of waste application low enough to prevent build-up of high extractable phosphorus concentrations near the soil surface.
- Injection or incorporation of all or a large part of the wastes (and associated phosphorus) several inches below the soil surface to prevent contact of the phosphorus with runoff water.
- Incorporation of applied manure immediately after application to cultivated fields.
- Use of deep tillage in pasture areas to invert the soil, burying the high-phosphorus topsoil under low-phosphorus subsoil layers.
- Halt manure application in fields with high extractable phosphorus levels in the topsoil.
- Application of soil amendments to reduce the solubility of phosphorus in soil surface layers. Such amendments could include acidifying chemicals (such as alum), or amendments that increase soil pH or add calcium to the soil (such as agricultural limestone, water treatment residuals, fly ash, or gypsum. (Haustein et al., 2000)

Minimizing Runoff from WAFs.
Runoff is the principal means by which phosphorus moves from WAFs to streams. Minimizing runoff can protect stream water quality (Gburek and Sharpley, 1998). Practices that may be useful in the North Bosque River watershed include:

- Periodic deep ripping of WAFs to increase infiltration and reduce runoff.
- Construction of terraces in WAFs to slow runoff and increase infiltration.
- Construction of ponds or berms to intercept runoff before it reaches a stream.
- Use of impounded runoff water from WAFs for irrigation or process water.

Removing Phosphorus from Runoff Before It Reaches a Stream.
If runoff from WAFs cannot be prevented, vegetated filter strips, grassed water ways, and artificial wetlands can be used to filter out much of the sediment (with its adsorbed phosphorus) and adsorb some of the soluble phosphorus in the runoff. After the sediment has been filtered out, runoff can be allowed to flow slowly through a filter bed of crushed limestone, which will bind with soluble phosphorus.

Appendix V

Abbreviations.

AFO	Animal Feeding Operation
APCO	Agricultural Producer Certification Option
ARS	Agricultural Research Service
CAFO	Confined Animal Feeding Operation
CMIP	Composted Manure Incentive Project
CNMP	Comprehensive Nutrient Management Plan
CW	City of Waco
BRA	Brazos River Authority
DMES	Dairy Manure Export Support Project
EPA	US Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
NBRSAC	North Bosque River Scientific Advisory Committee
NRCS	USDA Natural Resources Conservation Service
SRP	Soluble Reactive Phosphorus
TAD	Texas Association of Dairymen
TAES	Texas Agricultural Experiment Station
TCFA	Texas Cattle Feeders Association
TCE	Texas Cooperative Extension
TCEQ	Texas Commission on Environmental Quality
TDA	Texas Department of Agriculture
TFB	Texas Farm Bureau
TIAER	Texas Institute for Applied Environmental Research
TNRCC	Texas Natural Resource Conservation Commission (changed to TCEQ on September 1, 2002)
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
TxDOT	Texas Department of Transportation
UA	University of Arkansas
USACE	US Army Corps of Engineers
USGS	US Geological Survey
WQMP	Water Quality Management Plan
WWTP	Waste Water Treatment Plant

Appendix VI

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 6
1445 ROSS AVENUE
DALLAS, TEXAS 75202-2733

July 16, 2002

MEMORANDUM

SUBJECT: Water Quality Standards Violations Caused by Wet Weather CAFO Lagoon Overflows

FROM: Kenneth Huffman (6WQ-PP) *(Signed)*

TO: Jack Ferguson
Chief, NPDES Permits Branch (6WQ-P)

The previous Region 6 CAFO permit that was issued in 1993 required permittees to sample containment facility waste overflows for biological oxygen demand (BOD5), fecal coliform bacteria and ammonia nitrogen. Those data, summarized in Table 1, show the waste overflow from these facilities to have very high concentrations of BOD5, ammonia nitrogen and fecal coliform bacteria, especially during overflows caused by chronic rainfall events. BOD5 concentrations ranged from 260 to 2486 mg/l (with a 99th percentile = 2393 mg/l), ammonia nitrogen concentrations ranged from 61 to 1640 mg/l (99th percentile = 1467 mg/l), and fecal coliform concentrations ranged from 920,000 to 260 million colonies/100 ml (99th percentile = 249 million colonies/100 ml). The 99th percentile is used to characterize the data, since this percentile of effluent data is normally used to determine daily maximum effluent limits. Estimated discharge volumes ranged from 155,000 to 7 million gallons. As discussed below, waste overflows having such high pollutant concentrations will violate a number of New Mexico and Oklahoma water quality standards. Although this analysis was done specifically for the water quality standards of New Mexico and Oklahoma, a similar conclusion could be reached in other states. It should be noted that both EPA's current and proposed CAFO regulations address only the technology-based requirements for CAFOs. These regulations do not address the requirements necessary to protect State water quality standards.

Both New Mexico and Oklahoma have water quality standards for fecal coliform bacteria. In New Mexico the fecal water quality standard (single sample not to exceed) ranges from 200 colonies/100 ml to 2000 colonies/100 ml depending on the designated use of the water body, whether that water body is impaired for fecal, and the requirements of the New Mexico Water Quality Management Plan. In Oklahoma, the fecal water quality standard for waters designated for primary body contact recreation requires that no more than 10% of the samples during a 30 day period can exceed 400/100ml, which the State (Oklahoma Department of Environmental Quality) incorporates in permits as a not-to-exceed daily maximum limit of 400/100ml. Likewise, New Mexico requires the fecal standard to be applied end-of-pipe as a permit limit. The fecal data from the containment facility waste overflows (99th percentile of 249 million colonies/100 ml) show that these fecal coliform water quality standards would obviously have been seriously violated as a result of all of these waste overflows caused by chronic rainfall events.

The high levels of ammonia nitrogen in the waste overflow from containment facilities caused by chronic rainfall events would violate the New Mexico Water Quality Standard for ammonia nitrogen for waters designated for fishery use. For warm water fishery designated waters, the acute ammonia nitrogen standard ranges from a high of 29 mg/l at a temperature of 0 C and pH of 6.5 to a low of 0.68 at 30 C and pH of 9.0. For cold water fisheries, the standard ranges from a high of 29 mg/l to a low of .48 mg/l at these temperatures and pH's. The New Mexico Water Quality Standards require the acute standards for ammonia nitrogen to be attained at the point of discharge. The ammonia nitrogen concentrations (99^{th} percentile of 1467 mg/l) in the containment facility waste overflows caused by chronic rainfall events would clearly violate these water quality standards.

Although Oklahoma does not have specific numeric water quality standards for ammonia nitrogen, the high levels of ammonia nitrogen in the waste overflow caused by chronic rainfall events would violate the Oklahoma narrative acute toxicity water quality standard for waters having a designated use of fish and wildlife protection. 40 CFR 122.44(d)(1)(vi) requires the permitting authority, where a State has not established a water quality standard for a specific chemical pollutant which may violate a narrative water quality standard, to establish effluent limits using criteria, such as those from EPA's 304(a) criteria document, which will achieve the narrative water quality standard and protect designated uses. EPA's 1999 update of Ambient Water Quality Criteria for Ammonia (EPA-822-R-99-014, December, 1999) provides such information on the direct toxic effects of ammonia on freshwater fish species. The acute criteria from this document range from 48.8 mg/l ammonia nitrogen at a pH of 6.5 down to 19.9 mg/l at a pH of 7.5 and 3.2 mg/l at a pH of 8.5, since ammonia toxicity increases as the pH increases. The high levels of ammonia nitrogen (99^{th} percentile of 1467 mg/l) in the containment facility waste overflow caused by chronic rainfall events would, therefore, cause a violation of the Oklahoma narrative acute toxicity standard.

Additionally, the high levels of nutrients, both nitrogen and phosphorus, in waste overflows from containment facilities caused by chronic rainfall events can contribute to violations of another Oklahoma water quality standard. Standard 785:45-5-19(b) and (c)(2) states that water must be free from noxious odors and tastes and, to protect this use, nutrients from point source discharges or other sources shall not cause excessive growth of periphyton, phytoplankton, or aquatic macrophyte communities (i.e., algae or aquatic plants) which impairs any existing or designated beneficial use. High levels of nutrients in waters used as drinking water supplies can stimulate algae growth, which can affect the taste and odor of drinking water.

The high BOD levels (99^{th} percentile of 2393 mg/l), in addition to the high levels of nutrients, in the containment facility waste overflows indicate potential significant impacts on dissolved oxygen in the receiving water body. These impacts on dissolved oxygen can have significant adverse impacts on aquatic organisms, as well as prey organisms.

All of the data in Table 1 were the result of waste overflows from containment facilities at dairies, and slaughter or feeder cattle operations. Manure-contaminated rainfall runoff can be a significant part of the waste water from dairy and cattle CAFO operations, since they typically have animals in open lot areas that can contain manure. Rainfall falling on these areas will become contaminated with the manure and will need to drain to the containment facilities, with the potential for waste overflows during heavy rain events if the containment facilities are not of sufficient holding capacity. Manure-contaminated rainfall runoff is of much less significance for other types of CAFOs, such as poultry and pork, since the animals in these operations are housed in enclosed structures. In addition to contaminated rainfall runoff, CAFO containment facilities may also have other highly contaminated wastes such as flushing or washdown water. As discussed above, the wastes in these containment facilities contain excessive amounts of nutrients, oxygen demanding organic matter and pathogens. In addition, these wastes contain pesticides, as well as antibiotics and hormones which are used in animal feeding operations and can appear in animal wastes, with the potential of having antibiotic resistant pathogens in these waste discharges. We do not, however, have data to evaluate what impact these latter pollutants may have on the receiving water bodies. For pork or poultry operations having wastewater containment facilities, overflows from such facilities would also be expected to cause violations of State water quality standards due to the high pollutant strength of the waste in those containment facilities.

40 CFR 122.44(d) requires NPDES permits to include any requirements, in addition to or more stringent than promulgated effluent limitations guidelines, which are necessary to achieve water quality standards established under section 303 of the Clean Water Act, including State narrative criteria for water quality. It should be noted that section 304 of the Clean Water Act requires that best available technology effluent limitations guidelines must consider the cost of achieving those limitations; whereas, for water quality standards, cost factors are taken into account by the State when determining the beneficial uses of the water body that the standards are designed to protect. The cost of achieving limits to protect State-established water quality standards is not, therefore, a factor to be considered. In order to comply with 40 CFR 122.44(d), the draft proposed Region 6 CAFO general NPDES permit for New Mexico and Oklahoma prohibits overflows of untreated CAFO wastes from containment facilities caused by chronic rainfall events. The draft permit allows existing CAFOs 3 years after the permit effective date to comply with this water quality-based requirement. During that 3 year period, the permit has the same requirements for containment facility overflows of untreated CAFO wastes that were in the expired Region 6 CAFO general permit. For CAFOs constructed after the proposed permit's effective date, the prohibition on overflows of untreated CAFO wastes caused by chronic rainfall events is effective immediately. These requirements, as well as the other requirements in the proposed permit, will also be protective of endangered species and their critical habitat.

Prohibiting waste overflows from containment facilities during chronic rainfall events is one way to address concerns over potential water quality standards violations. This can be achieved by increasing the containment facility's existing holding capacity, and/or by adding an additional holding lagoon(s). There may also be other equally effective ways of addressing this issue and, with this in mind, EPA Region 6 staff met with industry representatives several times over the past year to discuss our plans for reissuing the Region 6 CAFO general permit. In these discussions, EPA requested information and data on means, other than increasing holding lagoon capacity, to assure waste overflows from containment facilities do not violate water quality standards. Alternate treatment schemes discussed included treating the waste in the containment facility which might overflow during a chronic rainfall event to lower the concentration of pollutants of concern. For example, possible types of additional treatment might include constructed wetlands or anaerobic digesters. EPA will continue to request information and data on these or any other types of treatment that could be used, as well as the effectiveness of those treatment methods, to lower the concentration of the pollutants of concern to a level such that overflows during chronic rainfall events could be allowed, while assuring that water quality standards would not be violated by such overflows.

The above discussion shows that the high pollutant content of CAFO containment facility waste will cause the untreated overflows caused by chronic rainfall events to violate State water quality standards. If it can be demonstrated that the circumstances of overflows from a CAFO containment facility is of such a nature that overflows caused by chronic rainfall events will not violate State water quality standards, a CAFO may wish to apply for an individual NPDES permit instead of seeking coverage under the draft proposed general permit. By obtaining an individual permit, a CAFO's impact on water quality standards can be evaluated on a site-specific basis, instead of the state-wide basis which must be used in this general permit. A state-wide general permit must assure that water quality standards will not be violated by authorized discharges from any facility covered by that permit, including CAFOs located on small upstream tributaries. A general permit's water quality-based requirements must, therefore, be sufficiently conservative to assure that no authorized discharges anywhere in the State will violate water quality standards.

Table 1
CAFO Wastewater Holding Lagoon Overflow Data for authorized overflows (Monitoring required by Region 6 1993 CAFO General Permit)

	Chronic Rainfall Event (1)			Catastrophic Rainfall Event		
	BOD5 mg/l	NH3-N mg/l	Fecal col/100ml	BOD5 mg/l	NH3-N mg/l	Fecal col/100ml
Texas	260	67	-	119	6.8	1,400,000
	1628	200	1,540,000	300	28	6,200,000
	1594	130	4,580,000	930	86	11,700,000
	1575	130	7,100,000	1125	81	9,600,000
	160	100	7,000,000	210	14	1,800,000
				130	20	6,000,000
				42	<2	120,000
				311	53	5,900,000
Oklahoma	363	61	8,400,000	1147	35	3,300,000
	2486	137	260 million	691	4.6	-
	-	-	161 million	10	.4	14,000
	341	144	5,300,000	-	62	4,400,000
	307	126	1,950,000	310	86	3,400,000
	1715	1640	4,300,000	145	-	-
	578	84	5,200,000	738	121	17,000,000
	591	122	920,000	.		
New Mexico	300	150	To Numerous to Count			

(1) For Chronic rainfall event overflows, 99th percentile value for BOD5 = 2393 mg/l, for ammonia nitrogen = 1467 mg/l and for fecal coliform = 249 million colonies/100 ml.

MAR 1 8 2003

MEMORANDUM

SUBJECT: 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

FROM: Paulette Johnsey, Chief, Permits Section (6WQ-PP)
Kenneth Huffman (6WQ-PP)
Paul Kaspar (6WQ-PP)

TO: Jack Ferguson
Chief, NPDES Permits Branch (6WQ-P)

In proposing reissuance of the now expired general permit, Region 6 must evaluate the pollutant concentration, volume and frequency of the discharges in order to assess potential water quality impacts to receiving streams. In the absence of data, the now expired 1993 permit assumed authorized overflows would not violate water quality standards. As is common in permitting new facilities or industries with no data set or previous permitting history, the permit required monitoring and reporting of the discharged pollutants to evaluate water quality impacts to determine if further limitations would be needed to control the discharge in order that water quality standards would not be violated.

As you are aware, in September, 1999, Region 6 requested submission of analytical data for all reported CAFO manure/wastewater holding pond overflows that were authorized by Region 6's 1993 CAFO general permit. For the approximately 300 CAFOs which applied for coverage under the 1993 general permit, data on 29 overflows was submitted in response to this data submission request. We have no reason to believe that these data do not represent, in both volume and characteristics, CAFO discharges in Region 6; and have solicited any existing, additional data from several sources, including permittees and industry representatives. Without data to the contrary, our reasonable potential evaluations in the July 16, 2002, memo and here have been based on the data available. A discussion of frequency, volume, and concentration are provided below along with some examples and comparisons to show how the pollutants compare with other discharges.

Frequency of Overflow

In addressing those potential impacts Region 6 evaluated the data set with regard to frequency of reported discharges. The self reported data from the 1993 permit showed only 14 discharges resulting from rainfall buildup greater than the storage pond capacity (chronic build-up), out of more than 300 permitted facilities. If, as the reported data set indicates, discharges are very infrequent from properly designed and maintained facilities, water quality based restrictions in the permit allowing only 1 or 2 discharges in a 25 year period would not be burdensome to most facilities. Ninety five percent of all facilities did not report any discharge from 1993 to 1999, when the data was first requested, and most of those reporting a discharge had only one overflow. However, we believe the discharges are under reported and authorization of overflows in the permit must take into consideration that there is currently no restriction on the number of times a facility can discharge. Unrestricted, permitted overflows are not protective of water quality; and do not provide EPA or the public with any enforceable mechanism to prevent frequent discharges from violating water quality standards and are not consistent with the permitting regulations found at 40 CFR 122.44(d).

It is a common misconception that the CAFO technology regulations at 40 CFR 412 authorize overflows from CAFO holding ponds only when caused by a 25 year, 24 hour, or greater, rainfall event. That is not the case. Those regulations require holding ponds to be built to a certain size (to hold all manure, litter and process wastewater including the runoff and direct precipitation from a 25 year, 24 hour rainfall event) and to be properly operated and maintained. If these requirements are met, any rainfall, either chronic buildup or a single catastrophic, which causes an overflow from holding ponds is allowed by the technology regulation. These regulations do not specify the number or frequency of allowed overflows, nor do they place restrictions on the pollutant loadings in the overflows. In some areas, the impact of these overflows is compounded by having a substantial number of CAFOs located in close proximity in a watershed. An example is the 105 dairies located in the North Bosque River watershed in Texas. When heavy rainfalls, either chronic or catastrophic, cause a holding pond overflow from one CAFO, there is a high probability that rainfall will cause pond overflows from many of the adjacent CAFOs.

Volume of Pollutants Discharged in Overflows

As we explained in the July 16, 2002, memo the concentrations of the discharged pollutants are very high and clearly violate state standards which must be met at the discharge point i.e., without the benefit of dilution from the receiving water (Fecal Coliform) and likely violate the other standards instream.

Overflow Pollutants	99th Percentile Concentrations
BOD5	2393 mg/l
Ammonia Nitrogen	1467 mg/l
Fecal coliform	249 million colonies/100 ml

Considering the previously discussed pollutant concentrations and the reported volumes of overflows discharged, considerable dilution would be needed to protect water quality standards. The volume of the overflows caused by chronic rainfalls in this data set ranged from 155,000 to 7 million gallons and generally occurred over a day or less. A look at the receiving stream flow necessary for these overflows to meet a water quality standard which is required by be met at the edge of the instream mixing zone shows the significant impact these overflows can have. As an example, the fecal coliform standard in most Region 6 states requires no more than 200 colonies/100 ml to be met at the edge of the mixing zone. Assuming only one pond overflow of

1 million gallons in a day, this means the receiving stream would have to have a flow of about 200,000 cfs. Compare this with the peak stream flows in a number of the larger rivers in Region 6 for the period 1980 to 2000:

Rio Grande at Albuquerque, New Mexico = 10,000 cfs

San Juan River at Farmington, New Mexico = 12,000 cfs

Beaver River near Guymon, Oklahoma (in the Oklahoma Panhandle) = 55,400 cfs

Arkansas River near Ponca City, Oklahoma = 40,000 cfs

Arkansas river at Tulsa, Oklahoma = 310,000 cfs

Cimarron River near Guthrie, Oklahoma = 120,000 cfs

Illinois River at Tahlequah, Oklahoma = 65,000 cfs

Canadian river at Bridgeport, Oklahoma = 85,000 cfs

Canadian River at Canadian, Texas = 18,000 cfs

Sabine River at Wills Point, Texas = 21,000 cfs

Neches River near Diboll, Texas = 42,000 cfs

Trinity River at Trinidad, Texas = 98,000 cfs

Concentration of Pollutants Discharged in Overflows

As discussed above and in the July 16, 2002 memo the concentrations of pollutants reported was considerable, and significantly higher than originally considered by Region 6 in developing the 1993 permit. At the time, the permit writer considered the discharges to be roughly equivalent to that of raw sewage. The data shows that assumption to be in error. In order to illustrate how these discharges compare to the other "pollutant like" discharges, we have prepared a comparison between municipal sewage discharge and CAFO discharge characteristics based on information introduced in the July memo.

	Pollutant Concentration		
Discharge Type	BOD_5 (mg/l)	NH_3 (mg/l)	Fecal Coliform (colonies/100 ml)
Untreated CAFO (99th Percentile)	2393	1467	249 million
Untreated Sewage (Typical Maximum)	300	50	35 million
Treated Sewage (Typical Permitted Maximum)	45	6	400

Volumes of reported CAFO pond overflows caused by chronic rainfall events ranged from 155,000 to 7,000,000 gallons, as previously noted. Assuming a one million gallon one day discharge from a CAFO holding pond and equating this discharge to that of raw sewage and treated sewage from a Publically Owned Treatment Works results in the following comparative volumes. To further put into perspective, we have shown how these pollutant loads would be equal to municipalities with the populations indicated below, using a per capita water usage of 100 gallons per day, the Agency standard.

	Volume/Population Equivalent to one (1) million gallons of Untreated CAFO Discharge for Identified Pollutants		
Discharge Type	BOD_5	NH_3	Fecal Coliform
Equivalent Volume of Untreated Sewage	8 million gallons	29 million gallons	7 million gallons
Equivalent Volume of Treated Sewage	53 million gallons	245 million gallons	622,500 million gallons
Population to Produce Equivalent Volume of Untreated Sewage	80,000 people	290,000 people	70,000 people
Population to Produce Equivalent Volume of Treated Sewage	530,000 people	2.45 million people	6,225 million people

Summary

The reported monitoring data gathered per the requirements of the 1993 permit, and the analysis of reasonable potential of the overflow discharges to cause or contribute to a violation of water quality standards in the July, 16, 2002 memo, clearly indicate that further permitting controls or limitations are needed. While the technical guidelines provide treatment technology minimums, they do not place limits on numbers of pond overflows. In our water quality analysis we have demonstrated why further restrictions are necessary to meet the water quality protections required in 40 CFR 122.44(d).

As discussed in the July memo, a statewide general permit must assure that water quality standards will not be violated by authorized discharges from any facility covered by that permit, including CAFOs located on small upstream tributaries. The water quality-based requirements in a general permit must, therefore, be sufficiently conservative to assure that no authorized discharges anywhere in the State will violate water quality standards. If a CAFO can demonstrate that the circumstances of overflows from the manure/wastewater pond is of such a nature that overflows caused by chronic rainfall events will not violate water quality standards, a CAFO has the option of applying for an individual permit. By obtaining an individual permit, the impact of CAFO pond overflows on water quality standards can be evaluated on a site-specific basis.

Opinions Regarding Nutrient Loading to Lake Waco and Resultant Impacts

Offered by Kenneth J. Wagner, Ph.D., CLM
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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.

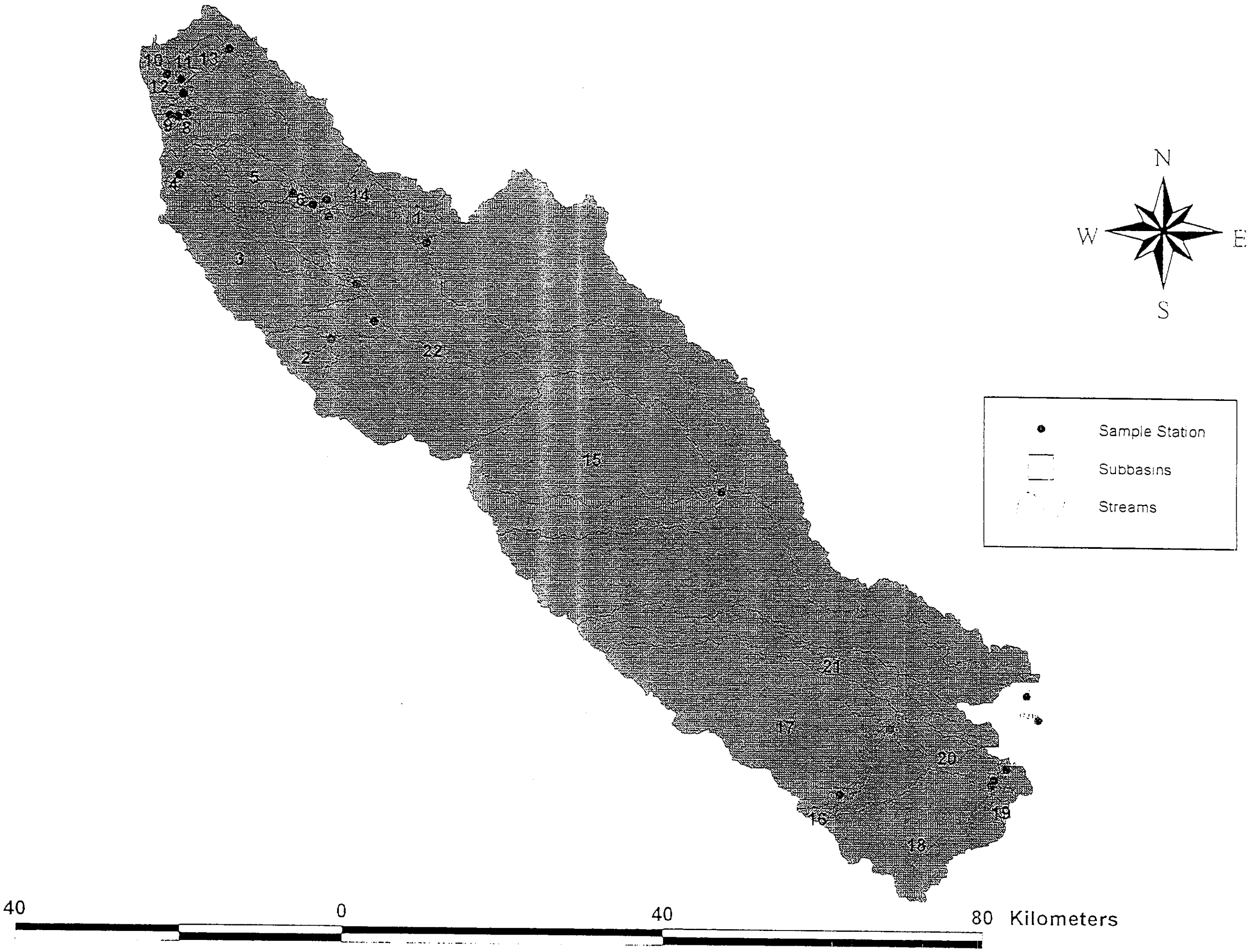

Figure 1. Lake Waco Watershed, Showing Sub-Watersheds Applied in Analysis.

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

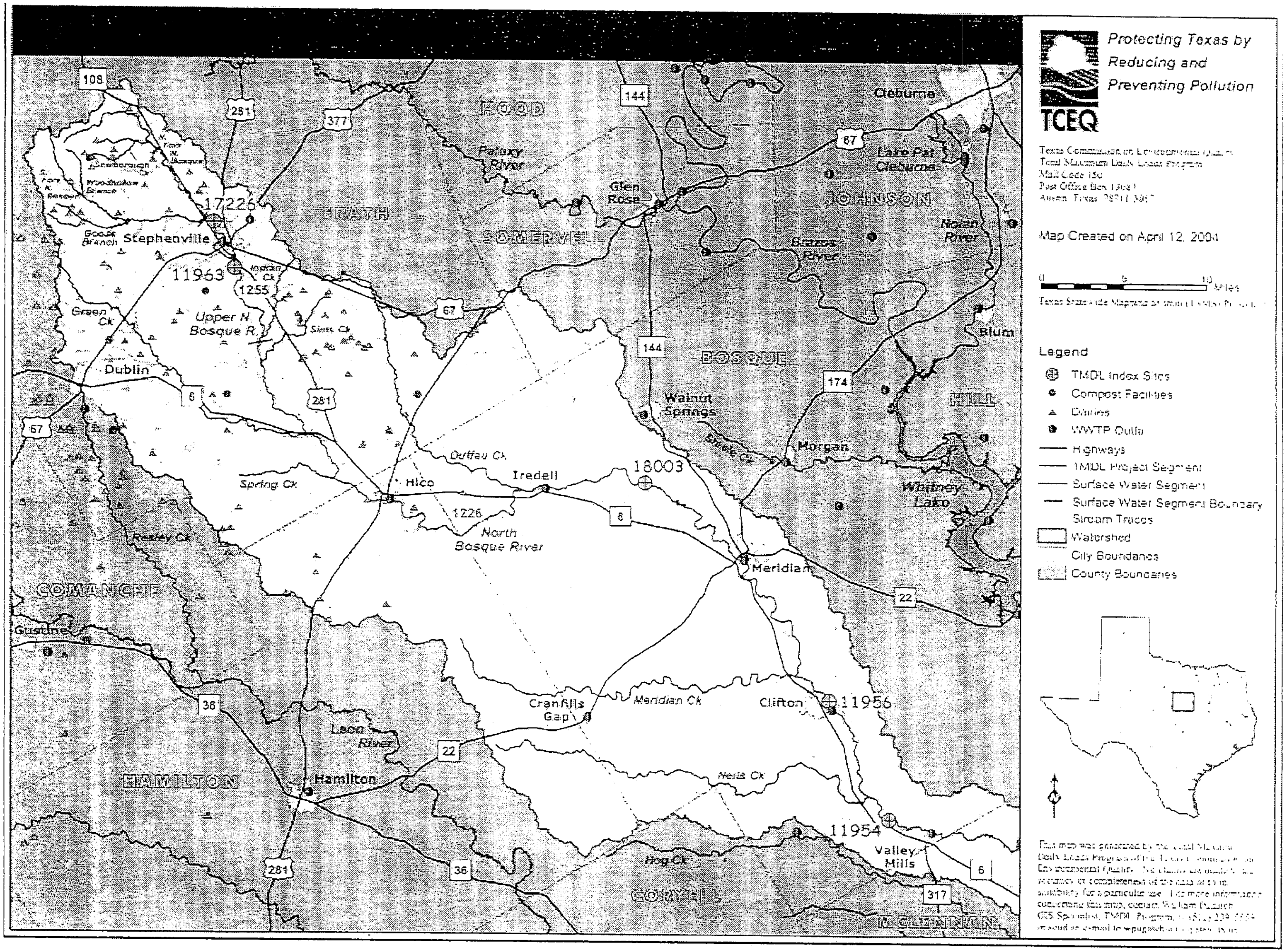

Figure 2. Location of Dairy Operations in the Lake Waco Watershed (after TCEQ 2005).

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, from 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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2002 Water Quality Inventory - Sources of Pollution for Water Bodies with Water Quality Concerns (October 1, 2002)

For each water quality concern identified in the 2002 Water Quality Inventory, TCEQ staff assigned possible sources of pollution and pollutants which contribute to the concern. TCEQ, River Authority, or other water quality staff provided the source information.

Water Body ID: **0101** Water Body Name: **Canadian River Below Lake Meredith**

Concern: **ammonia**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
portion in Hutchinson County	Concern	Ammonia (0600)	Agriculture (1000), Grazing-Related Sources (1350), Range Grazing--riparian and/or upland (1500)

Water Body ID: **0102** Water Body Name: **Lake Meredith**

Concern: **chloride**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Downstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)
Upstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)

Concern: **chloride in finished drinking water**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Downstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)
Upstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)

Concern: **sulfate**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Downstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)
Upstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)

Concern: **sulfate in finished drinking water**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Downstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)

Water Body ID: **1221** Water Body Name: **Leon River Below Proctor Lake**

Concern: **excessive algal growth**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Portion of segment west of US Hwy 281	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
Upstream portion of segment	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: **1221A** Water Body Name: **Resley Creek (unclassified water body)**

Concern: **nitrate+nitrite nitrogen**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Entire water body	Concern	Nitrogen (0920)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: **1225** Water Body Name: **Waco Lake**

Concern: **excessive algal growth**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Middle/South Bosque River arm of lake	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
North Bosque River arm of lake	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
Portion of lake near dam	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: **1225** Water Body Name: **Waco Lake**

Concern: **nitrate+nitrite nitrogen**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Middle/South Bosque River arm of lake	Concern	Nitrogen (0920)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
North Bosque River arm of lake	Concern	Nitrogen (0920)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
Portion of lake near dam	Concern	Nitrogen (0920)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: **1226** Water Body Name: **North Bosque River**

Concern: **excessive algal growth**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Portion of segment downstream of Clifton	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
Portion of segment downstream of Iredell	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
Upstream portion of segment	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: **1226B** Water Body Name: **Green Creek (unclassified water body)**

Concern: **excessive algal growth**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Entire water body	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: 1226E Water Body Name: Indian Creek (unclassified water body)

Concern: nitrate+nitrite nitrogen

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Entire water body	Concern	Nitrogen (0920)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: 1227 Water Body Name: Nolan River

Concern: nitrate+nitrite nitrogen

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Upper 8 miles	Concern	Nitrogen (0920)	Unknown Source (9000), Unknown Point Source (9001), Unknown Nonpoint Source (9002)

Concern: orthophosphorus

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Upper 8 miles	Concern	Phosphorus (0910)	Unknown Source (9000), Unknown Point Source (9001), Unknown Nonpoint Source (9002)

Water Body ID: 1232 Water Body Name: Clear Fork Brazos River

Concern: nitrate+nitrite nitrogen

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
25 miles downstream of Nugent	Concern	Nitrogen (0920)	Municipal Point Source (0200), Agriculture (1000)

Concern: orthophosphorus

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
25 miles downstream of Nugent	Concern	Phosphorus (0910)	Municipal Point Source (0200), Agriculture (1000)

2004 Water Quality Inventory - Sources of Pollution for Water Bodies with Water Quality Concerns (May 13, 2005)

For each water quality concern identified in the 2004 Water Quality Inventory, TCEQ staff assigned possible sources of pollution and pollutants which contribute to the concern. TCEQ, River Authority, or other water quality staff provided the source information.

Water Body ID: **0101** Water Body Name: **Canadian River Below Lake Meredith**

Concern: **ammonia**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
portion in Hutchinson County	Concern	Ammonia (0600)	Agriculture (1000), Grazing-Related Sources (1350), Range Grazing--riparian and/or upland (1500)

Water Body ID: **0102** Water Body Name: **Lake Meredith**

Concern: **chloride**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Downstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)
Upstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)

Concern: **chloride in finished drinking water**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Downstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)
Upstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)

Concern: **sulfate**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Downstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)
Upstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)

Concern: **sulfate in finished drinking water**

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Downstream half of lake	Concern	Salinity/TDS/Chloride/Sulfate (1300)	Groundwater Loadings (8910)

Water Body ID: 1221A Water Body Name: Resley Creek (unclassified water body)

Concern: nitrate+nitrite nitrogen

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Entire water body	Concern	Nitrogen (0920)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: 1225 Water Body Name: Waco Lake

Concern: excessive algal growth

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Middle/South Bosque River arm of lake	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
North Bosque River arm of lake	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
Portion of lake near dam	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Concern: nitrate+nitrite nitrogen

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Middle/South Bosque River arm of lake	Concern	Nitrogen (0920)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
North Bosque River arm of lake	Concern	Nitrogen (0920)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
Portion of lake near dam	Concern	Nitrogen (0920)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: 1226 Water Body Name: North Bosque River

Concern: excessive algal growth

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Portion of segment downstream of Clifton	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
Portion of segment downstream of Iredell	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)
Upstream portion of segment	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: 1226B Water Body Name: Green Creek (unclassified water body)

Concern: excessive algal growth

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Entire water body	Concern	Excessive Algal Growth (2800)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

Water Body ID: 1226E Water Body Name: Indian Creek (unclassified water body)

Concern: nitrate+nitrite nitrogen

Location of Water Quality Concern	Level of Concern	Cause Category (Cause Code)	Source Category (Source Code)
Entire water body	Concern	Nitrogen (0920)	Agriculture (1000), Intensive Animal Feeding Operations (1600), Confined Animal Feeding Operations Nonpoint Sources (1640)

AFFIDAVIT OF RICHARD B. GARRETT, P.E.

STATE OF TEXAS §

§

COUNTY OF MCLENNAN §

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

1. My name is Richard B. Garrett. 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. Currently, and since 1996, I have been Municipal Services Director of the Water Utility of the City of Waco, Texas (which I will usually refer to herein as "Waco" or "the City"). As Director of the Water Utility, I am responsible for the City's public water supply in Lake Waco and for the diversion and treatment of that "raw" water in the City's water treatment plants, where it is treated, filtered, and otherwise finished into water suitable for drinking. I am also responsible for the City's laboratory, where our raw and treated water is analyzed, for the distribution of the treated water to our customers, both inside and outside the City of Waco, and for the City wastewater system.

3. In 1985, I received a Bachelor's of Science degree in civil engineering from Texas A&M University, where I concentrated in the area of water resources. I have been a Texas Registered Professional Engineer since 1992. In 1986, I came to work for the City of Waco as an engineering project leader on water and wastewater and other public works design matters. In 1989, I was made Superintendent of the City's water treatment plants. In 1994, I was appointed acting Director of Utility Services, where my responsibilities included those that I now have for the City's public water supply. In 1996, my title became Municipal Services Director of the Water Utility.

4. For the 18 years that I have been responsible for Waco's public water supply, I have attended numerous conferences, seminars, and other programs concerned with protection, treatment, and maintenance of public water supply systems. I have attended various technology transfer conferences provided by the American Water Works Association Research Foundation (AWWARF), including the "Occurrence and Disinfection of Giardia and Cryptosporidium" (Oakland, California 1990); the annual Water Quality Technology Conference sponsored by the American Water Works Association (AWWA) (1990-1994); ASCE Wetlands Engineering & River Restoration Conference (1998); AWWA Sourcewater Protection Conference (San Francisco, California 1999); American Society of Agriculture Engineers TMDL Conference (2002 Fort Worth, Texas); and various other conferences sponsored by AWWA or AWWARF dealing with water quality, treatment, and protection. In August 2005, I attended the TCEQ Public Drinking Water Conference, and in June 2007, I attended the Water Environment Association of Texas Chapter 217 Rules Seminar. I completed my Surface Water II certification training in April 2007. From 1998 through 2001, I served on the Technical Work Group of the Bosque River Advisory Committee ("BRAC") that reviewed the work done by the Texas Institute for Applied Environmental Research ("TIAER") and the Blackland Research and

Extension Center in performing the studies and preparing the reports upon which the Texas Natural Resource Conservation Commission (TNRCC) based the *Two TMDLs for Phosphorus in the North Bosque River, Segments 1226 and 1255*, completed by the TNRCC in 2001.

5. All adjudicated and permitted rights to the water impounded in Lake Waco are owned by the City for public water supply, irrigation, recreation, and other municipal uses. The City is authorized to divert 78,970 acre-feet per year for municipal use, including consumption by over 160,000 people, including its citizens and the citizens of other smaller communities in the area. Tens of thousands of citizens of Waco fish, swim, sail, ski, and engage in other water recreation in and on Lake Waco every year.

6. As shown on the two attached maps, of the five tributaries that flow into Lake Waco, the largest by far is the North Bosque River, which contributes some 65% of the total inflow into Lake Waco. The North Bosque River comprises approximately 74% of the drainage area to Lake Waco, while the Middle and South Bosque Rivers together comprise 18% and Hog Creek comprises 5%.

7. Lake Waco is the sole source of supply of the public water supply system of the City of Waco, exclusive of emergency water connections. It is the only surface water source of the drinking water that the City treats and distributes to its 113,000 citizens and to approximately 45,000 residents of several small neighboring municipalities. Lake Waco has been designated by Texas Commission on Environmental Quality (TCEQ) rules for use as a public water supply.

8. TIAER studies overseen by the Technical Work Group on which I have served and a recent comprehensive study of Lake Waco prepared by ENSR, Inc., have shown that inflow from the North Bosque River accounts for approximately 72 – 80% of the soluble phosphorus loadings into Lake Waco, and that runoff from dairy-related waste application fields at concentrated animal feeding operations ("CAFOs") is the primary contributor of soluble phosphorus into both the North Bosque River and Lake Waco (comprising some 35% of the total amount of soluble phosphorus loadings in the Lake).

9. Over the course of the 22 years that I have been with the City of Waco, we have experienced increasing problems with excessive growth of algae in Lake Waco. The studies performed by TIAER and the Blackland Center that have been overseen by the Technical Work Groups on which I have served have concluded that the amount of soluble phosphorus is the controlling factor (the "limiting nutrient") for the increased algal growth that occurs in Lake Waco. In other words, limiting soluble phosphorus loadings to Lake Waco would reduce growths of algae in the Lake. The conclusion is inescapable, therefore, that the single greatest cause of algae growth in Lake Waco is the runoff from the waste application fields at the CAFOs in the watershed of the North Bosque River. This conclusion is supported by the draft reports that I have seen of the Lake Waco Comprehensive Management Program Report that is being prepared by ENSR, Inc., with participation by the City, the United States EPA, the U.S. Corps of Engineers, the U.S. Geological Survey, Texas Parks and Wildlife Department, and Baylor University. The sources of the loadings of soluble phosphorus (PO_4-P) in the North Bosque River at various locations above Lake Waco are illustrated in Figure 3 from the *Two TMDLs for Phosphorus in the North Bosque River* prepared and adopted by the TNRCC in 2001 (in which "WAF" stands for CAFO waste application fields) which is attached hereto.

10. Like most lakes in Texas, Lake Waco always has had a certain amount of algae in warm weather, and for many years Waco has had some complaints about the taste and odor of its drinking water. However, beginning in the 1980s, the Lake began to experience more frequent and longer durations of algae blooms, and the City experienced correspondingly more taste and odor problems with its drinking water. The source of the taste and odor problem has proven to be the *geosmin* that is a product of the decay of the blue-green algae that occurs in the Lake in warm weather.

11. The means that the City has employed thus far to address the offensive taste and odor caused by the algae-derived *geosmin* is increased use of powdered activated carbon in its water treatment process. In the year 2003, more than 45% of the total water treatment chemical costs were attributable to the additional activated carbon necessary to address the taste and odor problems, up from only 10% in 1995. The expense for activated carbon alone in the year 2003 was over $256,000. This cost did not include the costs of the equipment necessary to add the carbon, the labor necessary to maintain the carbon feeding equipment, or the labor devoted to cleaning carbon from the treatment basins. The use of powdered activated carbon has become a maintenance burden not only at the water treatment plants, but also in the City's wastewater collection system. One line-cleaning project resulted in the removal of 65 cubic yards of solids, which was primarily powdered activated carbon.

12. There is a definite threshold to the amount of activated carbon that we can use for treatment, no matter how high the *geosmin* level detected in the raw lake water that we must treat. We have reached this threshold many times recently, but have been forced to go ahead and deliver offensive tasting and smelling water to our customers. Not only does this cause me concern for the diminishment of the quality of an important component of the daily lives of our customers who must drink, cook with, and bathe in this water, it very much threatens the economic development of the City. Waco is home to several major industries that place a premium on the quality of the water that they use: Masterfoods, Minute Maid, and Allergan, to name a few. If these industrial customers or other industries that evaluate Waco as a site for their plants become dissatisfied enough with the taste, odor, and other qualities of the water that the City can provide them, they may well look elsewhere.

13. With the City at, and beyond, the limits of its capacity to address the algae-caused problems in its water, it has been forced to plan and budget for the installation of other, and much more expensive, treatment systems. Our investigation of available treatment options indicates that it will cost approximately $50 million for the dissolved air flotation (DAF), ozone addition, and other treatment combinations required to cope with the taste and odor problems caused by the excess algae in our lake. These and other expensive treatment systems also may be necessary to meet future requirements to address problems with microbes and disinfectant by-products associated with the algae and animal waste loads conveyed to the Lake from the North Bosque River watershed. Treatment of the high organic content of the raw water with traditional disinfectants such as chlorine causes elevated levels of disinfectant by-products that have been a source of recent health concerns. Pathogens that are associated with the wastes of warm-blooded animals, like the 45,000 dairy cattle in the North Bosque watershed, include E.coli, cryptosporidium, giardia, and naegleria fowleri amoeba. Naegleria cause amoebic meningitis and have been the cause of several deaths from contact recreation exposure over the past few years. Some of these pathogens, including cryptosporidium and giardia, cannot be destroyed by

traditional chlorine disinfection. Removal of these life-threatening pathogens would necessitate going to one of the multi-million dollar treatment options.

14. Even if these waste-associated pathogens do not make it into our drinking water, just the possibility (perhaps the near certainty) of their presence in the raw water in Lake Waco jeopardizes the enjoyment of the many aquatic recreational activities in which our citizens engage there. The pathogens conveyed to Lake Waco by the North Bosque River endanger the health of the City's many citizens who swim, fish, sail, ski, and engage in other water recreation in Lake Waco every year. In fact, the very possibility of their presence has dampened the ardor of many of our citizens for these aquatic activities in Lake Waco.

15. The City of Waco currently is investing a very considerable amount of time, money, and other resources in efforts to protect its water supply in Lake Waco from harm associated with animal waste. It has participated in the construction of a 174-acre wetland on the North Bosque River that removes significant amounts of nutrients and bacteria under normal flow conditions. The City is conducting extensive monitoring of Lake Waco and its tributaries as well as the area's marinas and golf courses. The City is spending millions of dollars to provide public sewer connections to alleviate potential impacts on the Lake from on-site septic facilities. However, the City's efforts alone are not going to solve the problem. Alleviation of the algae problems and health concerns in Lake Waco is going to require a reduction in the animal waste discharged into the streams that feed the Lake, particularly the North Bosque River.

16. In reliance on the opinion of Mr. Bruce Wiland, the City's consulting expert on water quality matters, as summarized in Mr. Wiland's Affidavit that he signed on April 4, 2008, which I have reviewed, I have concluded that, if the problems with the draft permit and incorporated application for P&L Dairy that are identified in Waco's public comment letter are not addressed to any greater extent than described in the Executive Director's Response to Comments, Lake Waco, the City's drinking water, the City's financial resources, and the health and welfare of its citizens will be adversely affected by the issuance of the proposed permit and by the runoff and other discharges of pollutants from P&L Dairy, in all of the ways that I describe in the preceding paragraphs of this Affidavit as resulting from the heavy algae growths and likely higher incidence of pathogens in the Lake.

Further, Affiant sayeth not.

Richard B. Garrett

Richard B. Garrett, P.E.

SUBSCRIBED AND SWORN to before me by the said Richard B. Garrett, P.E., on this the 4th day of April, 2008, to certify which witness my hand and seal of office.

KATHY A. KUNKEL
Notary Public
STATE OF TEXAS
My Commission
Expires 04/17/2010

Kathy A Kunkel

Notary Public in and for the
State of Texas

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30419.2

Brown McCarroll
L.L.P.

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direct (512) 479-9757 jbattle@mailbmc.com

November 9, 2007

Via Hand Delivery

Ms. LaDonna Castañuela
Office of the Chief Clerk/MC-105
Texas Commission on Environmental Quality
12100 Park 35 Circle, Building F
Austin, Texas 78753

Re: Peter Henry Schouten, Sr. and Nova Darlene Schouten, dba P&L Dairy
Draft Permit for Major Amendment
TPDES Permit No. WQ0003675000
Public Comment

Dear Ms. Castañuela:

The City of Waco ("City"), the mailing address of which is P.O. Box 2570, Waco, Texas 76702-2570, phone number (254) 750-5640, fax number (254) 750-5880, hereby submits the following public comments on behalf of the City and as *parens patriae* on behalf of its citizens. Communications regarding these matters may be made to the City's retained legal counsel, Jackson Battle, Brown McCarroll, L.L.P., Suite 1400, 111 Congress Avenue, Austin, Texas 78701, phone number (512) 479-9757, fax number (512) 479-1101.

PUBLIC COMMENTS.

The TCEQ should not issue the proposed Permit No. 3675 to Peter Henry Schouten, Sr. and Nova Darlene Schouten (hereinafter referred to by the name under which they are doing business, "P&L Dairy"), because to do so with no conditions other than those in the draft permit and without compliance with the substantive and procedural requirements of state and federal law that are identified herein would be illegal, as well as damaging to the North Bosque River, Lake Waco, the City's drinking water supply, and the health and welfare of its citizens. The specific legal requirements that would be violated by the issuance of this permit follow.

I. The draft permit fails to comply with the TMDLs for phosphorus in the North Bosque River or otherwise ensure attainment of the water quality standards for phosphorus in the river.

1. In the first place, P&L Dairy is a "new source" that has not demonstrated compliance with the specific requirements of 40 CFR § 122.4(i) as required by 30 TAC § 305.538.

As a matter of law, P&L Dairy is a "new source" within the literal terms of the state and federal definitions in 40 CFR § 122.2 and 30 TAC § 305.2(23), because construction of all sources at the site commenced after the first promulgation of the federal new source standards of performance for CAFOs on February 14, 1974. *See* 40 CFR § 412.15; 39 Fed. Reg. 5706 (February 14, 1974). The initial construction and operation of a dairy at the site commenced in 1993.

Beyond the matter of law that P&L Dairy has been a "new source" ever since it was constructed in 1993, the modifications of its two retention control structures ("RCSs") and the expansion of their total capacity, from 17.35 acre-feet to at least 27.24 acre-feet, creates a "new source" as the term is defined and explained in 40 CFR §§ 122.2, 122.29(a), (b) and 30 TAC §§ 305.2(24), 305.534(a), (b).

Also, the substantial expansion that P&L Dairy is seeking to have authorized under this permit is reason enough that the very specific water quality attainment demonstration required for a new source should be applied to it. If it is allowed to expand from 580 to 990 cows, its manure and wastewater production will, accordingly, increase more than 70%. Even if P&L Dairy were not otherwise a "new source," the 70% expansion that it is seeking authorization to undertake should make it a new source under the criteria for new source determination in 40 CFR § 122.29(b) and 30 TAC § 305.534(b), in that the resulting increase of the pollutant load is generated by processes that are "substantially independent" of existing sources – that is, the 410 additional cows that produce the additional manure and wastewater are sources that are quite independent of the existing 580 cows. Indeed, every one of these new cows is its own independent source of approximately 150 pounds of wet manure per day. By adding 410 new cows to the dairy, it will be increasing the amount of wet manure produced daily by over 30 tons (that is, by approximately 11,224 tons per year). Moreover, the expansions of the cow pens, milk barn, free stalls, and/or other animal confinement areas to accommodate the 410 additional cows constitute "new sources" as the term is defined and explained in 40 CFR §§ 122.2, 122.29(a), (b) and 30 TAC §§ 305.2(24), 305.534(a), (b).

All of these facts and circumstances, separately and collectively, add up to the need to classify P&L Dairy as a "new source" for purposes of holding it to the demonstration required by 40 CFR § 122.4(i):

- that pollutants load allocations have been performed for all pollutants causing violations of the state water quality standards;
- that there are sufficient remaining pollutant load allocations to allow for the discharge and still attain water quality standards; and
- that all existing dischargers into the segment are subject to compliance schedules designed to bring the segment into compliance with the applicable water quality standards.

The TCEQ may have made a global "load allocation" of sorts for soluble phosphorus loadings into Segments 1226 and 1255 of the North Bosque River when it accepted EPA's interpretation of its TMDLs for phosphorus in these two river segments. (*See* Table 1 in Mr. Cooke's 12/03/01 letter to Mr. Saitas, a copy of which is attached hereto as Attachment 1.)

There has been nothing even approaching, however, a demonstration that there are sufficient remaining pollutant load allocations of phosphorus discharged from CAFOs into these impaired segments to allow for the discharges from the P&L Dairy or any demonstration that the existing dischargers of phosphorus into the river are subject to compliance schedules. Most significantly to the present circumstance, as recognized by EPA in Footnote 2 to Table 1 in Mr. Cooke's 12/03/01 letter, the very general load allocation for phosphorus discharges performed by the TCEQ in the two TMDLs *did not include any allocation whatsoever for discharges from CAFO wastewater lagoons*. Also, no phosphorus load allocations were reserved for future CAFO expansions; all "Future Growth" was reserved for the municipal wastewater treatment plants discharging into the river.

2. The draft permit issued to P&L Dairy fails to meet the most basic requirement of Clean Water Act § 301(b)(1)(C), as implemented in 40 CFR §§ 122.4(a), (d) and 122.44(d), that attainment of the state water quality standards be ensured.

The several reasons for the failure of the draft permit to achieve the water quality standards for phosphorus are described below in subsections (a) – (d).

(a) The draft permit fails to require what was modeled in the TMDLs.

The key modeling assumptions for CAFOs in the TMDLs were as follows:

- watershed-wide waste production was limited to that from 40,450 dairy cows (the *actual* cow numbers in the mid-1990s);
- 50% of the solid manure (equating to 38% of the total manure and 89% of the solid collectible manure) from those 40,450 animals would be removed from the watershed;
- the amount of phosphorus in the animals' diet would be reduced to 0.4%;
- the phosphorus application rate would not exceed the "agronomic rate" on all fields in the watershed;
- the initial soil phosphorus concentrations in existing waste application fields were set at 200 ppm and, if the "agronomic" P application rate was intended to not exceed the crop removal rate, the soil P concentration in the existing fields would not climb above 200 ppm over time.
- the initial soil phosphorus concentrations in new waste application fields were set at 60 ppm and, if the "agronomic" P application rate was intended to not exceed the crop removal rate, the soil P concentration in any new field would not climb above 60 ppm over time.

The draft permit for P&L Dairy ignores all of these conditions that were modeled. Despite over 55,000 cattle currently permitted at CAFOs in the North Bosque River watershed, and approximately 9,600 more allowed at 48 unpermitted AFOs in the watershed (based on

TCEQ's January 2007 TMDL status report), the draft permit allows a 70% increase in the number of cows confined at the P&L Dairy without any offsetting decrease in the number of cows at CAFOs permitted elsewhere in the watershed. In fact, the CAFOs in the North Bosque River watershed are requesting that over 73,700 cows be authorized in issued permits and permit applications that are currently pending before the TCEQ. If all of these requested number of cows are authorized, this would result in an 82% increase over the number of cows modeled in the TMDL (not including AFOs).

This draft permit contains no limits whatsoever on the amount of phosphorus in the animal feed. As discussed later in these comments, it requires no removal of manure from the watershed.

The draft permit allows phosphorus to be applied (via wastewater application) at rates substantially beyond the "agronomic" phosphorus removal ("uptake") rate on all of the LMUs. This will cause the phosphorus concentrations in these fields to steadily increase (up to as high as 500 ppm), leading to increased phosphorus in the runoff from those fields.

Probably the most basic objection to this draft permit is that, by not requiring a NUP with a phosphorus *reduction* component until phosphorus concentrations in an LMU exceed 500 ppm [*See* Part VII.A.8(c)(4)], and by allowing phosphorus concentrations off-site in the watershed to build up to 200 ppm or higher, resulting in very substantial increases in phosphorus runoff from both on and off-site fields, this permit and any like it will work completely at cross purposes to any possible attainment of the TMDLs and water quality standards.

(b) The draft permit fails to implement in any way the TCEQ's commitment in its Implementation Plan for Phosphorus in the North Bosque River Watershed to facilitate establishment of commercial composting facilities in order to achieve the basic goal of the TMDLs "to remove from the North Bosque River watershed approximately 50% of the manure produced by dairies, and other facilities that manage large amounts of animal waste, within the watershed." (Implementation Plan, pp. 12-14)

In order to be consistent with this commitment in the Implementation Plan (based on the modeled haul-out of 50% of all *solid* manure produced by the number of confined cows existing in the watershed in the mid-1990s), the permit would have to require P&L Dairy to haul out of the watershed over 89% of the *collectible* manure produced by its 990 cows.

Instead, this permit purports to attain the state water quality standards for phosphorus by relying on NMPs and CNMPs (both of which were described in the Implementation Plan as *additional, not substitute*, measures necessary for attainment of the TMDLs) and on application of manure to third-party fields (which works as a *dis*incentive for a dairy CAFO to transport its waste to a compost facility or take it out of the watershed).

(c) By allowing all of the collectible manure from P&L Dairy's 990 dairy cows to be applied to third-party fields in the watershed, the Executive Director is drastically *increasing* the amount of phosphorus that will run off into the impaired river segments, not decreasing it.

Under P&L Dairy's existing permit and the incorporated provisions of the 1999 version of the Subchapter B rules, a substantial amount of the collectible manure from its 580 cows would, as a practical matter, have to have gone to a composting facility or out of the watershed. Now, with the open invitation to spread the manure and a portion of the wastewater from 990 cows over third-party fields, this would result in manure and wastewater containing over 320 tons of phosphorus (as P_2O_5), over the course of the five-year term of this permit, being spread over approximately 867 acres of minimally-regulated third-party fields, at application rates exceeding the agronomic needs of the crops and severely elevating soil phosphorus concentrations. This does not even include the additional phosphorus application and land requirements that will be necessary to accommodate the additional wastewater that will eventually need to be exported during the term of this permit. The runoff of tons of phosphorus into the river from these 867 acres of waste disposal fields will increase each year and be extremely counterproductive to attainment of the water quality standards for phosphorus in the North Bosque River.

(d) The Executive Director has provided no technical justification for his assertions that the measures recited in this permit will attain the water quality standards for phosphorus and implement the TMDLs.

In drafting this and other permits that have been published, the Executive Director effectively has thrown out the window all of the modeling, expertise, public participation, and other work invested over the course of the past ten years to prepare the phosphorus TMDLs and their Implementation Plan and instead resorted to little more than recitation of measures that, in virtually all instances, are little more than a paraphrase of the Subchapter B rules, which were never intended, nor previously represented by the TCEQ, to be enough to implement the TMDLs or attain water quality in the North Bosque River.

The Executive Director's conclusory statements in the Fact Sheet that the measures will ensure attainment of water quality standards and implement the TMDLs are supported by no modeling or any other technical analysis. No loading studies for the CAFO discharges into the River have been performed using these measures, nor has any load allocation been determined to remain for allocation to P&L Dairy. Indeed, all of the technically based requirements for formulation of a TMDL and an Implementation Plan to achieve water quality standards in an impaired receiving water that are contained in the Clean Water Act and in EPA's rules and guidance have been discarded in favor of the same kind of rough "let's try this and see what happens" approach that historically has brought water bodies like the North Bosque River to such sad conditions.

The third-party fields that will, inevitably, be relied on so heavily for waste disposal are not even identified. Neither the CNMP nor the Pollution Prevention Plan ("PPP") is part of the application. The TCEQ's rules do not require the Executive Director to have reviewed these critical documents prior to permitting. Without any access to such information that is vital to assessment of the effects of the BMPs that are at the heart of this draft permit, there is no possible way for the Executive Director to assess the impact on water quality of the issuance of this permit – except to the extent that, as demonstrated herein, all logic indicates that applying the waste produced by 410 more cows to hundreds more acres of land in the North Bosque River watershed can only make matters much worse.

II. The Executive Director has failed to make any "BPJ" determination that the "BCT" standards for the control of pathogens have been met by the limitations imposed on the P&L Dairy by this permit.

The United States Court of Appeals for the Second Circuit held in *Waterkeeper Alliance, Inc. v. Environmental Protection Agency*, 399 F.3d 486, 518-19 (2d Cir. 2005), that the federal effluent limitations for CAFOs were deficient for failing to include "best conventional pollutant control technology" ("BCT") based effluent limitations specifically designed to reduce the discharge of pathogens, including fecal coliform bacteria. Since EPA has not yet promulgated national effluent limitations for the pathogens discharged from CAFOs, the Clean Water Act commands the permit issuing authority, in this case the TCEQ, to employ its "best professional judgment" ("BPJ") to set the required technology-based limitations on a case-by-case basis when each permit is issued. *See* Clean Water Act § 402(a)(1)(B); 40 CFR § 125.3(a)(2)(ii)(B).

In the case of the e-coli, fecal coliform, and other bacteria and pathogens that are part of the "conventional" pollutant load discharged from CAFOs, this requires case-by-case consideration of the BCT criteria specified in the Clean Water Act and the federal NPDES rules:

> (d) In setting case-by-case limitations pursuant to § 125.3(c), the permit writer must consider the following factors:
>
> * * *
>
> (2) *For BCT requirements:* (i) The reasonableness of the relationship between the costs of attaining a reduction in effluent and the effluent reduction benefits derived;
>
> (ii) The comparison of the cost and level of reduction of such pollutants from the discharge from publicly owned treatment works to the cost and level of reduction of such pollutants from a class or category of industrial sources;
>
> (iii) The age of equipment and facilities involved;
>
> (iv) The process employed;
>
> (v) The engineering aspects of the application of various types of control techniques;
>
> (vi) Process changes; and
>
> (vii) Non-water quality environmental impact (including energy requirements).

40 CFR § 125.3(d)(2); Clean Water Act §§ 301(b)(2)(E), 304(b)(4)(B).

The TCEQ has considered none of these factors in evaluating any control technologies applied to P&L Dairy to control the bacteria and other pathogens that it discharges. Until it does so, and makes defensible record-based findings accordingly, no discharge permit can be issued to P&L Dairy.

III. The Executive Director fails to require any "third-party fields" that will be utilized by P&L Dairy for waste application to be identified in the application and fully regulated as LMUs.

Under both the federal and state CAFO rules, what makes land to which manure, litter, or wastewater is applied a "land management unit" ("LMU") (TCEQ rules) or a "land application area" (federal rules) is *control* of the waste application measures. *See* the TCEQ definition of "LMU" at 30 TAC § 321.32(25) and the EPA definition of "land application area" at 40 CFR § 412.2(e).

The draft permit issued to P&L Dairy requires it to exert very substantial control over the waste application process at any third-party field on which it might choose to allow its manure or wastewater to be applied. Most significantly, Part VII.A.8(e)(5)(i) of the permit requires that there be a *written contract* between the permittee and the operator of any third-party field that includes the following requirements:

> There must be a written contract between the permittee and the recipient that includes, but is not limited to, the following provisions:
>
> (A) All transferred manure, sludge, or wastewater shall be beneficially applied to third-party fields identified in the PPP in accordance with the applicable requirements in 30 TAC § 321.36 and § 321.40 at an agronomic rate based on soil test phosphorus. * * *
>
> (B) Manure or sludge must be incorporated on cultivated fields within forty-eight (48) hours after land application.
>
> (C) Land application rates shall not exceed the crop nitrogen requirement when soil phosphorus concentrations in zone 1 (0-6 inch incorporated; 0-2 or 2-6 inch not incorporated) depth is less than or equal to 50 ppm phosphorus.
>
> (D) Land application rates shall not exceed two times the phosphorus crop removal rate, not to exceed the crop nitrogen requirement, when soil phosphorus concentrations in zone 1 (0-6 inch incorporated; 0-2 or 2-6 inch not incorporated) depth is greater than 50 ppm phosphorus and less than or equal to 150 ppm phosphorus.
>
> (E) Land application rates shall not exceed one times the phosphorus crop removal rate, not to exceed the crop nitrogen requirement, when soil phosphorus concentrations in zone 1 (0-6 inch incorporated; 0-2 or 2-6 inch not

incorporated) depth is greater than 150 ppm phosphorus and less than or equal to 200 ppm phosphorus.

(F) Third-party fields which have had manure, sludge or wastewater applied during the preceding year must be sampled by a certified nutrient management specialist and the samples analyzed in accordance with 30 TAC § 321.36.

(G) A copy of the annual soil analyses shall be provided to the permittee within sixty (60) days of the date the samples were taken.

(H) Temporary storage of manure, sludge or wastewater is prohibited on third-party fields.

Not only does the permittee have to legally bind an operator of a third-party field to an enforceable contract that contains all such listed waste management provisions, the permit also makes sure that the permittee is motivated to enforce such contractual provisions by providing, in keeping with 30 TAC § 321.42(j), that "[t]he permittee will be subject to enforcement action for violations of the land application requirements on any third-party field under contract." Draft Permit, Part VII.A.8(e)(5)(iii).

It is difficult to imagine what greater control of manure, sludge, and wastewater management practices on someone else's waste application fields could be exerted by the permittee other than those contained in this permit, short of the permittee actually applying the waste itself, which is clearly not required to constitute "control." Thus, these contractual requirements and legal responsibility on the part of the permittee all add up to a level of control which makes any third-party field that would be used under this permit an LMU, subject to all the requirements that the Subchapter B rules impose on LMUs, including:

- identification of the exact location and boundaries of the land application area in the submitted application and in the permit itself;

- coverage of all waste application to the field within the required NMPs and CNMPs;

- adherence to all requirements for vegetative buffers and filter strips, etc.;

- prohibition of nighttime application of manure or wastewater;

- weekly inspections of all facilities and equipment used for land application of manure and wastewater;

- compliance with all land application recordkeeping and reporting requirements in 40 CFR § 412.37 and 30 TAC § 321.46.

Imposition of the same extent of control measures on "third-party fields" as on LMUs is precisely what should occur. It defies all logic and sound environmental policy to create second-class waste application fields, and to allow manure and wastewater to be applied to such fields throughout the watershed without NMPs, NUPs, CNMPs, and the full panoply of protections applicable to LMUs owned and operated by the permittees. To do otherwise, as this draft permit would allow, will simply, very counterproductively, expand enormously the land area in the watershed on which waste can be applied and from which pollutants will run off into the river, but without the accountability and management tools that existed even before Subchapter B was amended.

IV. This draft permit, and the process by which it was considered, violate the federal Clean Water Act, as interpreted in *Waterkeeper*, by not requiring all technical documents that demonstrate the methods by which the discharge of pollutants will be controlled at the CAFO to be submitted with the application, reviewed by the TCEQ, made available to the public, and incorporated into the permit.

In *Waterkeeper Alliance v. EPA*, 399 F.3d 486, 498-504 (2d Cir. 2005), the court held that the Clean Water Act required nutrient management plans ("NMPs") to be (1) reviewed by the permitting authority before issuing a permit that authorizes land application discharges; (2) included in the NPDES permits; and (3) made available to the public both before any NPDES issues (in order that the public may meaningfully participate in the permitting process) and after (in order for the public to assist in enforcement).

All sections of the federal Clean Water Act cited by the Second Circuit as bases of its opinion apply to states as well as to EPA if the states are administering the NPDES permit program:

- § 402(b)(1)(A), 33 USC § 1342(b)(1)(A). The permitting authority must review NMPs to ensure compliance with effluent limitations.
- § 301(a) and (b), 33 USC § 1311(a) and (b). Effluent limitations must be included in NPDES permits.
- § 502(11), 33 USC § 1362(11). The terms of NMPs are "effluent limitations."
- § 101(e), 33 USC § 1251(e). The public participation requirements apply to any state carrying out the NPDES program.
- § 402(b)(3), 33 USC § 1342(b)(3). Public hearings are required to be made available on permit applications.

Waterkeeper, 399 F.3d at 498-504.

All reasoning applied by the Second Circuit to hold that applicable sections of the Clean Water Act require NMPs to be reviewed by the permitting authority, incorporated into the permit, and made available to the public applies with the same force to the other site-specific technical plans and documented demonstrations of the methods by which the discharge of pollutants will be controlled at CAFOs permitted by the TCEQ, including:

- Comprehensive Nutrient Management Plans ("CNMPs") (in the North Bosque River watershed);

- Nutrient Utilization Plans ("NUPs");
- Pollution Prevention Plans ("PPPs");
- Retention Control Structure ("RCS") management plans (in the North Bosque River watershed);

Just as the NMPs required by the federal CAFO rule were found to be *effluent limitations* by the Second Circuit, so are each of these plans and documents required by Subchapter B "any restriction established by a State [or the Administrator] on quantities, rates, and concentrations of chemical, physical, biological, and other constituents which are discharged from point sources into navigable waters . . .." Clean Water Act § 502(11), 33 USC § 1362(11).

The Second Circuit's recognition that "the only restrictions actually imposed on land application discharges are those restrictions imposed by the various terms of the nutrient management plan," 399 F.3d at 502, is what caused the court to hold that the terms of the NMPs were effluent limitations that had to be reviewed by the permitting authority and included in any NPDES permit issue.

The State of Texas, however, goes further and imposes restrictions on land application discharges going beyond those in the federally required NMPs. The TCEQ protects against pollutant discharges from CAFOs by requiring, *inter alia*, NUPs (if LMUs are over 200 ppm phosphorous), CNMPs (if within the North Bosque River watershed), PPPs (which identify third-party fields), RCS management plans (in the North Bosque River watershed), additional RCS capacity (in the North Bosque River watershed), demonstration of no significant hydrologic connection between any RCS and water in the state, and additional buffer and filter strip requirements between LMUs and any water in the state.

By adopting these best management practice ("BMP") restrictions on CAFO waste management in order to reduce the discharge of pollutants, the TCEQ has created additional effluent limitations that must be reviewed by the agency, incorporated into the permit, and made available to the public so that it may participate effectively in the permitting and enforcement processes.

According to Clean Water Act § 402(b)(1)(A), state permit programs must ensure compliance with all applicable requirements of Section 301 of the Act, 33 USC 1311, including meeting the BPT, BCT, and BAT limits that were in issue in *Waterkeeper* [§§ 301(b)(1)(A), 301(b)(2)(A), and 301(b)(2)(E)] and achieving "any more stringent limitation, including those necessary to meet water quality standards, . . . established pursuant to any State law or regulations." Clean Water Act § 301(b)(1)(C), 33 USC § 1311(b)(1)(C).

Just as the Second Circuit concluded that EPA could not ensure compliance with an NMP without reviewing it and including it in the permit, TCEQ cannot ensure compliance with the CNMPs, PPPs, RCS capacity requirements and management plans, etc., without TCEQ's reviewing them and including them in the TPDES permits that it issues. The exact same statutory interpretations and legislative policies apply to the Clean Water Act provisions applicable to state permit programs as to those applicable to the federal permit program. The same is true of those Clean Water Act provisions that require public participation in the permitting process. Section 101(e) is expressly applicable to *state* implementation of *state standards*: "Public participation in the development, revision, and enforcement of any regulation, standard, effluent limitation, plan, or program established by the Administrator or any *State* under this chapter shall be provided for, encouraged, and assisted by the Administrator and the States." Clean Water Act § 101(e), 33 USC § 1251(e).

Once it is established that these documents must be included with any CAFO permit application and in any permit ultimately issued by the TCEQ, the Clean Water Act is explicit in its requirements that the state must make them available to the public for review prior to issuance of the permit and in order to obtain a public hearing on any contested aspect of them. Clean Water Act §§ 402(b)(3), 402(j), 33 USC §§ 1342(b)(3), 1342(j).

The draft permit for P&L Dairy, therefore, must be rescinded, and the technical review phase of the application reopened to require P&L Dairy to submit its current Pollution Prevention Plan, its CNMP, its RCS management plan, and any other technical documents missing from its application that would demonstrate how it intends to control the discharge of pollutants from the CAFO. Then the Executive Director must make all these documents available to the public, review them, and, if they are ultimately approved, incorporate them into the next draft permit, if any, for P&L Dairy.

V. The NMP and other parts of the permit application submitted by the P&L Dairy are replete with errors and deficiencies that make invalid the permit that incorporates the application.

These errors and deficiencies are described in the following 11 enumerations of "failures" in the application.

1. Failure to calculate realistic runoff amounts in the water balance.

The applicant is converting 24-hour Runoff Curve Numbers to 30-day Runoff Curve Numbers based on information in Texas Engineering Technical Note No. 210-18-TX3. Although the TCEQ has indicated that this Technical Note has been used by NRCS to predict average monthly runoff for use in the design of animal waste retention structures since 1990, this approach obviously has serious shortcomings and is not appropriate. This is demonstrated in the Water Balance Model provided in Tables 2.3a and 2.3b of the permit application. The water balance predicts that none (0.0 inches) of the rainfall that falls on the irrigation area will run off during seven of the months. Clearly, this is ridiculous and bears no semblance to reality. Does the TCEQ really believe that there will be no runoff from these fields during these seven months?

While the City acknowledges that the rainfall-runoff process involves many factors such as the initial abstraction and characteristics of the surface and that certain small rainfall events will not lead to any runoff, the point here is that, as clearly shown in the preceding water balance example, the use of 30-day curve numbers developed in Technical Note 210-18-TX3, are not appropriate for adjusting 1-day CN values in these small agricultural fields and production areas.

The adjustment process described in Texas Engineering Technical Note No. 210-18-TX3 was developed for a reservoir operation study. The reservoir operation study, as envisioned in this Technical Note, involved a much larger watershed area, probably on the order of thousands of acres, rather than the smaller watersheds of agricultural fields and production areas operated by CAFOs. These larger watersheds often contain many large depressions, small diversions, and other features (such as stock tanks) which reduce the runoff and were incorporated into the CN duration adjustment in the Technical Note. Even for these larger watersheds, the Technical Note has some reservations with using this adjustment procedure as shown on page 1-2 where it states "If this approach is used, however, the computed average annual runoff should be checked with gauged runoff from other areas of approximately the same size and located in similar climatic zones." The small agricultural fields and especially the production areas of CAFOs do not generally contain the large depressions and features which reduce runoff. In fact, 30 TAC § 321.40(e) and 30 TAC § 321.43(j)(5)(B) require CAFOs to minimize ponding or puddling. Because of this, the 30-day CN values used for CAFOs should be much higher than those used in Technical Note 210-18-TX3, and the current approach is useless in preparing a meaningful water balance. The City is not opposed to the concept of CN adjustments in the water balance when calculating runoff based on monthly rainfall values. However, the calculation of runoff needs to be based on more realistic CN adjustments rather than those from Figure 1 in Technical Note 210-18-TX3. Until more realistic CN adjustments can be made, the TCEQ should use the 1-day CN value for calculating monthly runoff from the production area.

2. Failure to provide a stage/storage table in order to properly calculate water balance.

A stage/storage table showing stage versus surface area and volume has not been provided in the permit application. This table is required in order to perform a water balance since the monthly evaporation from an RCS is based on the estimated surface area of the RCS which is a function of the monthly storage volume. The effective surface area for evaporation should be based on the average surface area during the month. The applicant has provided no information, such as a stage/storage table, to justify the effective surface area used in the water balance.

Even if the applicant has not constructed the enlarged RCS yet, a stage/storage table can and must be developed for the proposed structure. Specifications must be prepared showing what is planned for construction; otherwise, the contractor would not know how to construct it. The only way evaporation can be properly calculated is to use a stage/storage table based on the proposed structure. The purpose of as-built certifications is to provide assurances that the RCS has been constructed as designed and represented in the permit application, not as a justification for not providing the required information in the first place.

3. Failure to provide adequate information on settling ponds.

The applicant has indicated that settling ponds will remove 40% of the solids produced by the milking parlor based on estimates from the Midwest Plan Service Structures and Environment Handbook. The settling basins (weir notch or dewatering) described in this handbook have specific design requirements in order to achieve such removals. The applicant has provided no information at all concerning the type, design, or maintenance requirements for the settling pond. Just putting a hole in the ground will not meet the design criteria and is unlikely to achieve the projected removal rates. With the current information in the application, there is no way to determine if these settling ponds are adequately designed to meet the 40% solids removal rate or maintain this rate over the course of the permit. With a removal rate this high and its associated impact on RCS sizing, the TCEQ must require the design for these settling ponds to be submitted so it can be determined if they meet the criteria associated with the projected removal rates.

4. Failure to use proper RCS sludge accumulation rate for process-generated wastewater.

The applicant has calculated the required sludge accumulation rate resulting from process-generated wastewater based on a rate of 0.0729 cubic feet of storage capacity per pound of total solids. The accumulation rates in Table 10-4 of the USDA-NRCS Agricultural Waste Management Field Handbook are clearly based on the solids being decomposed in an anaerobic lagoon properly designed for adequate treatment. If adequate treatment volume is not provided, the solids will not be decomposed at the assumed rate. The assumed sludge accumulation rate would be acceptable if the minimum treatment volume were being provided. However, the applicant has no intention of providing adequate treatment as no minimum treatment level has been provided. Although a minimum treatment level may not be required for dairies with less than 1000 cows under the permit-by-rule air authorization in Chapter 106 Subchapter F, it must be required if the 0.0729 value for calculating sludge accumulation is to be used. Otherwise, a larger value should be used to calculate the sludge accumulation rate. If annual measurement of the sludge accumulation were required in the permit, the City's concern with respect to this comment would not be as important, and the City would consider the issue to have been adequately addressed.

5. Failure to use proper sludge accumulation rate from open lot runoff.

The applicant has calculated the sludge accumulation volume resulting from runoff based on 25% of the runoff from the 25-yr 10-day rainfall event. Even though the TCEQ may have accepted this since 1999, there is *no* technical basis or historical data (site-specific or otherwise) to justify this value. There is not even a logical or justifiable reason for using only the 25-yr 10-day event to calculate the sludge accumulation from runoff. All runoff events that occur at the facility will cause some portion of the manure to enter the lagoon and lead to sludge accumulation. The TCEQ cannot allow some arbitrary number in the calculation of sludge accumulation without providing some data or technical basis for using it. If annual measurement of the sludge accumulation were required in the permit, the City's concern with respect to this comment would not be as important, and the City would consider the issue to have been adequately addressed.

6. Failure to certify current RCS capacity and adequate sludge accumulation capacity.

Although capacity certifications were submitted with the permit application, these were made in 2003, about four years ago, and did not include any information concerning the accumulated sludge. More recent information has not been provided in the application, and there is nothing in the draft permit requiring that these RCSs be re-certified with respect to the existing sludge volume. It is quite possible that these RCSs are currently non-compliant with the capacity requirements of the existing permit.

7. Failure to provide adequate liner certifications.

The liner certification provided for RCS #1 is inadequate. Although not to scale and is not close to resembling the shape shown in the provided capacity certification, the samples appear to have been taken in the embankments with none being taken in the bottom of the RCS. Samples should have been taken in both the bottom and the embankments.

The liner certification provided for RCS #2 is inadequate. Although no locations are shown, the samples are reported to have been taken in the bottom with none being taken in the embankment of the RCS. Samples should have been taken in both the bottom and the embankments. Based on the engineer's language ("appears to meet the requirements", "should be no significant leakage", "should meet the requirements"), he is not completely certain that this RCS meets the requirements or that there will be no leakage. This is an unacceptable certification. The engineer should be able to definitively state that the RCS meets requirements. If he cannot, the certification is useless.

The liner certification provided for settling pond is inadequate. The diagram provided indicates that the samples were taken from the bottom of the settling pond with none being taken in the embankment of the pond. Samples should have been taken in both the bottom and the embankments.

8. Failure to address issues related to the enlargement of RCSs.

The applicant and the draft permit indicate that the requirements of the 25-yr 10-day design rainfall event will be met by enlarging RCS #1 and RCS #2. This will require enlarging RCS #1 by 31% from 9.81 ac-ft to 12.85 ac-ft and enlarging RCS #2 by 91% from 7.54 ac-ft to 14.39 ac-ft. There has been no information provided as to how these RCSs will be enlarged. RCS #2 is of particular concern. It will be almost doubling in size, and there is a drainageway and LMU immediately adjacent to it. There does not appear to be a way to enlarge this RCS without encroaching upon the drainageway or LMU.

There have been no plans submitted on how the applicant intends to operate while the RCSs are being enlarged. It appears that process wastewater would need to be stored, and runoff from any rainfall event, however unlikely, would need to be anticipated and stored if necessary during certain periods of construction while this embankment is removed and the disturbed area of the liner re-established. The permit should specifically indicate that the TCEQ is *not* granting approval to any construction activity that would allow process wastewater or contaminated runoff to flow into an RCS that is partially unlined even if only temporarily.

9. Failure to provide adequate description of structural controls.

The permit application does not provide an adequate description of structural controls, particularly the berms. The berms are an integral part of the facility necessary to prevent contaminated runoff from leaving the site. An inspector can observe whether berms are present or not and can judge the height and width, but the inspector does not generally have the expertise to determine whether the berms are adequate. The inspector certainly could not do this without making the necessary engineering calculations first, something that will not happen in the field. Therefore, some means must be given to the inspector to evaluate compliance. Additionally, if the operator is not given an adequate description of structural controls, the operator will not be able to determine their own compliance and how to make repairs if, for example, a berm deteriorates over time as a result of settling, some action of a careless worker, or runoff erosion. Simply pushing up a few inches of uncompacted dirt with a tractor blade is usually not adequate. The permit application and the draft permit should describe these berms in sufficient detail with respect to location, size, and construction so that TCEQ inspectors can determine if the facility is in compliance and the operator can make adequate repairs if necessary.

10. Failure to properly calculate agronomic rates.

The basic methodology being utilized in the NMP to calculate agronomic rates is flawed because the NMP fails to account for the nutrients available to plants in the root zone to satisfy the crop requirement. Instead, application of the annual crop requirement is allowed regardless of the actual soil nutrient content until the soil reaches a concentration of 200 ppm P. Even then, continued application of nutrients is allowed even though there is more than three times the amount of nutrients necessary for optimum growth.

As an analogy, the TCEQ more properly makes the agronomic rate calculations when determining agronomic rates for the application of biosolids. For biosolids permit applications, the TCEQ requires that the agronomic rate calculations take into account the nutrients in the soil by taking the crop requirement and subtracting the nutrients available in *both* the 0-6" and 6-24" soil depths for the most recent year. Only the amount of nutrients needed to satisfy the overall crop requirement for that year is allowed to be applied. If the amount of nutrients in the soil exceeds the crop requirement, no additional nutrients can be added during that year. The nutrients in biosolids are not fundamentally any different than the nutrients in dairy waste. There is no reason that the TCEQ should calculate the agronomic rate differently for CAFO permits. CAFO permits, including this one, should allow application of only that quantity of nutrients that will benefit optimum crop production (i.e., beneficial use), as required by the rules.

11. Failure of NMP to meet applicant's representation in permit application.

P&L Dairy has represented in the application (Application Section 6.2) that the dairy will be operated in a manner consistent with the TMDL . In item #1 and #2 of this section, the applicant indicates that it will implement a NUP that limits P application to crop requirement and incorporate a P reduction component on fields over 200 ppm P and that it will limit maximum P level in soils to 200 ppm. Setting aside the fact that NRCS Code 590 will not allow application of P at the crop requirement rate for fields over 200 ppm (it must be limited to the crop removal rate), the applicant is planning in its very first year (based on its submitted NMP) to cause LMUs #3 and #4 to reach projected soil P levels of 240 ppm and 233 ppm, respectively. LMUs #3 and #4 both currently have soil P levels of 198 ppm. The applicant is planning to apply at the crop P requirement rate on both. Considering the crop yield, this will result in a net P increase of 42 ppm in LMU #3 and 35 ppm in LMU #4 after the first year. As demonstrated by the City in part VI.13 of these comments, all of the LMUs are projected to have soil P levels above 200 ppm after four years. If the applicant really intended to limit maximum P level in soils to 200 ppm as it has represented, it would be applying no waste to its LMUs by end of the term of the permit . Does the TCEQ really believe it is being protective of water quality when it will likely have a dairy that is applying 100% of its waste to minimally regulated third-party fields?

VI. Numerous provisions in the draft permit are so defective that the permit cannot attain the phosphorus TMDLs for the North Bosque River, the state water quality standards, and the requirements for CAFOs in Subchapter B.

These technical permit deficiencies are described in the following 17 enumerations of "failures" in the draft permit.

1. Failure to require an RCS Management Plan until after the permit is issued.

The permit requires an RCS Management Plan to be prepared and placed in the PPP after the permit is issued, but no review of this plan by the TCEQ is required before the permit is issued or even before it is implemented after the permit is issued. This does not allow for any comment by the public on its adequacy. The water balance and RCS Management Plan are an integral part to properly sizing the RCS. This is not a trivial exercise. There are multiple factors to be considered. The water balance must be prepared in conjunction with an associated RCS Management Plan or it is meaningless. The water balance and RCS Management Plan must consider not only monthly rainfall runoff, but also the storage requirements and supplemental irrigation necessary to enable supplying sufficient water to the crops during the high water demand months of the summer. An RCS Management Plan should be required to be submitted before issuance of the permit.

Under the current draft permit, the only time the RCS Management Plan will be seen is when the inspectors see it on annual inspections. As a practical matter, there is not adequate time for inspectors in the field to properly evaluate the validity of such a plan. Additionally, it is unlikely that the TCEQ inspectors have the proper engineering background and expertise to make such an evaluation. If the TCEQ is intent on issuing the permit without reviewing an RCS Management Plan, the draft permit should require that the RCS Management Plan be submitted to the TCEQ permitting staff for review and approval.

2. Failure to adequately regulate settling ponds.

Permit Provision X.N indicates that the solids in the settling basin must be removed on a "regular and consistent basis." Since "regular and consistent" is a very subjective phrase and given the importance of removing solids to maintain the removal efficiency of the settling basin, the removal requirements must be more specific in the permit. For example, the Midwest Plan Service Structures and Environment Handbook referred to by the applicant recommends removing solids after every major rainfall event or 3 to 4 times a year depending on the type of settling basin. Since the applicant is relying on removal efficiencies described in this handbook, it should be held to the associated maintenance standards described in this handbook.

3. Failure to require adequate monitoring of sludge accumulation.

The buildup of sludge is one of the most common causes of reduced capacity in an RCS. The draft permit does not require measurement of the sludge volume in the lagoons until three years after the date of permit issuance. In the case of this dairy, the sludge accumulation has not been measured in at least four years and probably longer. Once a problem is discovered, it can take over a year to get it corrected and re-certified, especially since the TCEQ is reluctant to levy fines for such obvious violations. This permit should require that the sludge accumulation be determined annually, especially since the lagoon accumulation rates have been improperly calculated as indicated in previous comments.

4. Failure to adequately define capacity certification requirements.

The required RCS capacity certification under provision VII.A.3(a)(2) is ambiguous. It is not clear whether it refers to total as-built capacity or available capacity above the sludge. The permit language should make it clear that all capacity certifications require certification of both total as-built capacity and the volume of sludge accumulation. The available capacity is the difference between these two numbers.

5. Failure to provide adequate liner design specifications in the permit.

30 TAC §321.38(g) requires the permit to identify the required design specifications for all RCSs including procedures and minimum requirements for liner and embankment testing. Further, 30 TAC §321. 38(g)(3)(A) requires information on the "materials underlying and forming walls of the containment structure up to the wetted perimeter." While some of this information is provided in VII.A.3(f) of the permit, it is inadequate. Although the municipal solid waste rules in 30 TAC 330 do not apply to CAFOs, the permit should include information similar to that found in 330.339(c). Future liner certifications should meet a standard similar to other TCEQ programs.

The information provided to justify certification of liners at CAFOs in the past has been largely inadequate. Many previous certifications contained just a few samples with no information at all on the sample location. While design and construction standards of the past may have allowed such minimal information, the potential for significant water quality impacts today requires a significantly higher standard of practice. Although the permit does contain some procedures and requirements for liner and embankment construction (i.e., maximum lift depth and minimum Proctor density), it does not provide adequate procedures for testing. At a minimum, the TCEQ should 1) require the field density tests to be based on predetermined moisture-density compaction curves, Atterberg limits, and laboratory permeabilities of undisturbed field samples of the compacted soil liner, 2) define the frequency of testing (e.g., number of tests per specific area per lift) for both the bottom *and* sides, 3) require testing *during* the construction of the liner (*not* after completion of the liner), and 4) require continuous on-site inspection during construction. If these additional requirements are not placed in the permit, the TCEQ should explain why each of the preceding items is not necessary and by what other method it will ensure the public that the RCSs have been adequately constructed to protect water quality.

There is no reason to believe that simply providing a certification from a Licensed Professional Engineer can substitute for review of the supporting information by the TCEQ. Time and time again, Professional Engineers have submitted sealed documents to the TCEQ that are in error. The TCEQ must be able to review the soils testing results to make an independent verification of the certification.

6. Failure to require certification of structural controls prior to or upon issuance of permit.

Permit Provision VII.A.10(b) requires a licensed Texas professional engineer to complete a site evaluation of the structural controls once every five years and certify a report of findings. This type of evaluation should occur prior to issuance of the permit or at the very least immediately upon issuance of the permit. The structural controls, particularly the berms, are an integral part of the facility necessary to prevent contaminated runoff from leaving the site. If the berms are not sized properly, runoff will leave the facility during significant rainfall events. Without this certification, one cannot be sure that all berms are constructed and functioning properly to contain contaminated runoff and prevent it from leaving the site. If a certification has not been provided with the permit application, the City believes that the Five-year Evaluation should occur immediately upon issuance of the permit and then every five years thereafter.

7. Failure to require adequate sampling of wastewater and manure.

Only one annual sample is required to be collected for wastewater and for manure (one for wastewater and one for manure). The entire NMP and future application to third-party fields are based on these single annual samples. These single samples, if not representative, could and probably do drastically underestimate phosphorus loading to a field. Wastewater is typically sampled from the surface of RCSs. Taking a sample from the surface of a quiescent RCS will result in significantly different sample concentrations than taking it from the irrigation pipeline. When the irrigation pumps in the RCSs are operating, sludge in the bottom of the RCSs is agitated and becomes mixed with the wastewater. This sludge agitation has often been cited by the dairies as a reason that sludge removal may not be needed as often as predicted. Since this sludge contains high levels of phosphorus, the wastewater that is actually being used to irrigate the fields contains much higher levels of phosphorus than is measured in the single annual surface sample. This invalidates the assumptions used in the NMP. Additionally, the concentration of phosphorus in the RCS varies according to the antecedent rainfall or drought conditions which may cause varying degrees of dilution or concentration. RCS samples should be obtained from the irrigation pipeline following the pump rather than from the surface of the RCS to provide a more realistic estimate of what is actually being applied to the field.

RCS samples should be taken much more often (preferably at least once during each irrigation event). Wastewater treatment plants typically take samples weekly and often daily. There is no practical reason why one sample per irrigation event (which may often last for several days) should not be required. At the very least, at least one sample per week or month (when irrigating) should be required. Additionally, the City is not advocating updating the NMP after every irrigation event. An average of the sampling events over the year could be utilized in updating the NMP.

Similar problems arise with the manure and more than one annual sample of the manure should be performed (preferably one each month or one from each transport event). Taking only annual samples from manure can result in significant errors in calculating the amount of nutrients applied to the land. Moisture content plays an important role in calculating the amount of nutrients applied. If the sample is not taken concurrently with the application of the manure, significant errors may exist when calculating the application rates. If the manure is sampled while having a high moisture content and then applied much later when it has a much lower moisture content, the calculated nutrient application rate will be significantly underestimated.

8. Failure to require proper management of phosphorus production.

Table 2.1 p.10 (dated 11/20/2006) of the application indicates that the total phosphorus produced by the proposed 990 cows is 385 lb/day P2O5. This is equivalent to 140,525 lb/yr P2O5 (385 x 365).

The NMP (dated 6/12/07) indicates that the amount of wastewater to be irrigated is 301 ac-in/yr (25.1 ac-ft/yr). The NMP further indicates that, based on a lab analysis dated 4/26/2006, the wastewater contains 0.0102% P. Therefore, the nutrient availability from the wastewater is 16,012 lb/yr P2O5 (Table 1 of the NMP). Of the 301 ac-in/yr, 230 ac-in/yr will be applied to the four LMUs and the remaining 71 ac-in/yr will be applied offsite (Table 4 of the NMP). Therefore, with respect to wastewater, P&L Dairy plans to apply 12,235 lb/yr P2O5 (16,012 x 230 / 301) to its LMUs and send the remaining 3,777 lb/yr P2O5 offsite to third-party fields.

On the form "Manure, Litter, and Wastewater Handing" (p.6), the applicant has indicated that the sludge and solids will be disposed of either on-site or off-site. However, since the applicant does not have any capacity to provide for on-site application of sludge and solids, the sludge and solids will have to go off-site. Since the wastewater contains only 16,012 lb/yr P2O5, this leaves 124,513 lb/yr P2O5 in the sludge and solids that must be managed. Other than to say generally that the sludge and solids may be transferred to other persons, sent to third-party fields, or sent to composting, the application and the permit have given no specifics concerning the location of where these solids and sludges may be applied. Although listed as one of a number of possible options, there is no indication that *any* of the manure will actually be sent to composting or out of the watershed. This means that a total of 128,290 lb/yr P2O5 (91.3%) from wastewater, manure, and sludge will be potentially managed on third-party fields within the North Bosque River watershed in the first year *without any* nutrient management plan and very little regulation or oversight. As discussed elsewhere in the comments, the amount of exported wastewater will increase in year two and even more phosphorus will be managed on third-party fields. If all of the 128,290 lb/yr P2O5 from this wastewater and manure is applied to third-party fields in the watershed with soil concentrations less than 151 ppm P, approximately 867 additional acres (assuming 3-cut coastal) will have phosphorus applied at application rates ranging between the nitrogen crop requirement rate and 2 times the crop phosphorus removal rate. Assuming application at 2 times the crop phosphorus removal rate, this will result in an increase of the soil P in these additional acres of 16 ppm per year. The cumulative impact will be tremendous. Additionally, these additional acres will be virtually unseen (and hence unregulated) by TCEQ inspectors.

It is incredible that the TCEQ would allow 91.3% of the phosphorus (128,290 lb/yr P2O5) to be applied throughout the watershed with less oversight than the "regulated" LMUs that are located at the facility. Not only does this flout the goal of the TMDL to remove 50% of the collectable solids from the watershed, it does not even adequately regulate waste application within the watershed. Failure to plan for proper management of this phosphorus will lead to excess and unmanaged phosphorus distribution within the watershed resulting in further degradation of water quality in the North Bosque River and Lake Waco.

9. Failure to require removal of 50% of the solid manure from the watershed as modeled in the TMDL.

The TMDL for the North Bosque watershed recommends removal of 50% of the manure in order to meet the water quality goals. Based on the CDM Erath County Animal Waste Management Study performed for BRA in September 1998 and the SWAT modeling that was done in support of this TMDL, 50% of the solid manure (38.1% of the total manure production) was assumed to be removed from the watershed. For the proposed P&L Dairy permit, 53,540 lb/yr P2O5 would need to be removed from the watershed (or sent to composting). If this manure is not removed from the watershed, the water quality goal will not be met. The TCEQ has not provided any information to demonstrate how allowing 100% of the manure to be applied within the watershed will allow the water quality goals in the North Bosque River to be met.

10. Failure to prohibit waste and wastewater application to fields exceeding 200 ppm P.

The North Bosque River TMDL Implementation Plan dated December 2002 (p.16) states that formal enforcement action will result if CAFOs "apply waste or wastewater to a WAF that has been documented to have exceeded 200 parts per million phosphorus in Zone 1 of the soil horizon." Permit Provision VII.A.8(c)(2) negates this enforcement action by allowing application to continue as long as a NUP has been prepared and approved by the TCEQ. Soil phosphorus concentrations can continue to rise as long as they do not exceed 500 ppm. Even above 500 ppm, application can continue as long as the NUP contains a phosphorus reduction component. Application of waste and wastewater to fields in excess of 200 ppm (and especially 500 ppm) should be prohibited in order to be consistent with the language of the TMDL. At the very least, fields in excess of 200 ppm should be required to have a NUP containing a phosphorus reduction component subject to Permit Provision VII.A.8(c)(5).

Further, regardless of the language in the TMDL, the 200 ppm phosphorus is over seven times the amount of phosphorus needed for optimum growth of the proposed crops (i.e., seven times the agronomic need). The rules require NUPs to ensure the beneficial use of manure, litter, or wastewater. The definition of "beneficial use" in the rules is the "application of manure, litter, or wastewater to land in a manner that does not exceed the agronomic need or rate for a cover crop." Applying waste to soil that contains seven times the agronomic need cannot possibly be considered beneficial. No application should be allowed on fields which contain phosphorus exceeding the agronomic needs of the crop, much less on fields which contain more than seven times the agronomic needs of the crop. *The TCEQ needs to explain how there is an agronomic need for more phosphorus in fields which exceed the phosphorus requirement for the crop (almost always less than 60 ppm in the soil).*

11. Failure to adequately regulate and monitor third-party fields.

The language in Permit Provision VII.A.8(e)(5)(i)(E) allows land application to third-party fields when the phosphorus is "less than or equal to 200 ppm phosphorus". This is inconsistent with 30 TAC § 321.42(j)(2) of the rules which require application to cease if the phosphorus is greater than or equal to 200 ppm. The permit language should be changed to "less than 200 ppm phosphorus." Similarly, the language of Permit Provision VII.A.8(e)(5)(ii) should be changed to "greater than or equal to 200 ppm."

The language in Permit Provisions VII.A.8(e)(5)(i)(C-E) need to also include a statement that the application rate is not to exceed the requirements of NRCS Code 590. Although more restrictive in many instances, it is possible for third-party fields to meet the requirements of Permit Provisions VII.A.8(e)(5)(i)(C-E) and fail to meet the requirements of NRCS Code 590. For example, NRCS Code 590 requires that the application rate not exceed the annual crop P requirement in fields with a P-Index rated of "Very High." Permit Provision VII.A.8(e)(5)(i)(c) allows the nitrogen crop requirement rate if the field is less than 50 ppm irrespective of the P-Index. Adherence to NRCS Code 590 should be required if it is more restrictive. Contrary to previous assertions by the TCEQ, 30 TAC § 321.42(i)(5)(A) does not include third-party fields. Therefore, a specific permit provision must be added to require adherence to NRCS Code 590 for third-party fields if it is more restrictive.

According to Permit Provision VII.A.8(e)(5)(i)(A), no NMP is required for third-party fields. Without preparing an NMP, the requirements of Permit Provisions VII.A.8(e)(5)(i)(C-E) cannot be met since an NMP is the planning tool that is necessary to determine the appropriate application rates. An NMP must be required.

While 30 TAC §321.46(d)(8)(F) requires recording the actual yield of each harvested crop in the PPP, it does not require it to be reported. Similarly, Permit Provision VIII.B.7 does not require reporting of this information in the annual report. Permit Provision VII.A.8(e)(5)(iv) needs to include a requirement that records of crops and crop yields on third-party fields be submitted to the TCEQ quarterly. Permit Provision VIII.B.7 needs to include a requirement that records of crops and crop yields be submitted to the TCEQ in the annual report. Otherwise, the phosphorus crop removal rates cannot be calculated and compliance with the phosphorus application rate limitations cannot be determined.

12. Failure to adequately regulate sludge application.

Permit Provision VII.A.5(a)(7) is allowing sludge to be applied to third-party fields. Typical sludges contain extremely high levels of phosphorus. It is general knowledge that many of the fields in the Bosque watershed that exhibit very high levels of phosphorus (some in excess of 500 ppm) are the result of past applications of sludge from RCSs. Because of this, the City believes that the best management practice in the impaired Bosque watershed is for 100% of the sludge to be removed from the watershed or sent to composting. If this BMP is not implemented, the City believes that significantly greater oversight needs to be required by the TCEQ when sludge in being applied to third-party fields. The potential for significant adverse impacts from sludge application is enormous. Prior to application to third-party fields, the TCEQ should require 10-day notification as to the date and location of the planned application and an application plan prepared by a certified nutrient management specialist (based on current soil P levels and the measured sludge nutrient content) demonstrating that the requirements of Permit Provision VII.A.8(e)(5)(i) will be met. The notification of date and location will also allow the TCEQ to check compliance with the permit provision requiring incorporation within 48 hours of application. This is not an unreasonable requirement given past experience in the watershed and the potential for significant adverse impacts from sludge application; nor, is it an onerous requirement since sludge removal from an RCS is not a frequent occurrence.

13. Failure to require a demonstration of sustainability for the term of the permit.

The NMP provided in the proposed permit addresses only the first year of the permit. It fails to address the subsequent years of the five-year permit term. A 5-year NMP should be prepared that shows the impacts of all nutrient management issues over the five-year permit term and whether the operation is sustainable. The permit should establish an overall maximum application rate that allows the facility to operate in a sustainable manner over the five-year term of the permit. An annual NMP can then be used to fine-tune each years application schedule and adjust application to any individual field based on annual soil sampling and crop production. The Texas State Soil & Water Conservation Board requires that the smaller AFOs for which they prepare certified Water Quality Management Plans have *sustainable* operations and NMPs. The TCEQ should require no less of a standard for the much larger CAFOs.

The TCEQ has previously indicated that because an NMP is likely to change each year based on site-specific sampling, an NMP for the term of the permit would not be relevant. The City does not agree with this. While it is true that the NMP may change each year based on site-specific sampling results, an NMP for the term of the permit is far from irrelevant. If the NMP has any meaning, it must be considered to be a reasonably accurate predictor of what will occur in the fields assuming the wastewater and manure sampling is representative. The applicant should be required to demonstrate that, based on projected application rates, it has enough land to sustain its operation for the five-year term of the permit. If the applicant cannot demonstrate this on paper, it has little hope of sustaining its operation in reality.

The P&L application is a clear example of the need for 5-year NMP projections. P&L has four LMUs with a size of only 16 acres, 6 acres, 19 acres, and 2 acres. These four LMUs have a current soil P of 138 ppm, 95 ppm, 198 ppm, and 198 ppm, respectively. P&L will be applying the maximum allowable rates to their four LMUs. Even then, with no solids being applied onsite, only 76% of the wastewater can be applied onsite in the first year. The NMP indicates that in the first year, all of the solids and 24% of the wastewater must go offsite, presumably to third-party fields.

LMUs #3 & #4 will reach a soil P of 240 and 232, respectively, after the first year and then have to be cut back to 1xP removal rate. They will theoretically stay at 240 and 232 for the remaining four years of the permit. LMU #1 will reach a soil P of 221 after the second year and then have to be cut back to 1xP removal rate. It will theoretically stay at 221 for the remaining three years of the permit. LMU #2 will reach a soil P of 233 after the fourth year and then have to be cut back to 1xP removal rate. It will theoretically stay at 233 for the remaining year of the permit.

In summary, after only two years, three of the fields will have a soil P well over 200 ppm and 68% of the wastewater will be going offsite to third-party fields. After four years, all of the fields will have a soil P over 200 ppm and 73% of the wastewater will be going offsite to third-party fields. Even discounting where all of the solids will go (probably to third-party fields), after only two years, the majority of the wastewater is predicted to be going to third-party fields with none of the operational requirements of typical LMUs such as NMPs, vegetative buffers and filter strips, prohibition of nighttime application, inspections of equipment, etc. This is absurd, and the TCEQ should not allow it. This dairy should absolutely not be allowed to expand and probably should not be allowed to continue at its currently permitted size.

14. Failure to require designation of offsite LMUs in the permit.

It is almost impossible to economically truck significant quantities of wastewater, so P&L will have to obtain easements for pipelines to cross properties or obtain agreements to apply to adjacent fields. In order to implement the proposed NMP, P&L must already have a plan as to where the wastewater will go and have contracts in place. The dairy will have to have total control since only the dairy can determine pumping times from the RCSs, operate the pumps, and properly manage irrigation to avoid saturated soil conditions. The dairy has to be able to dewater the lagoons after significant rainfalls to avoid encroaching into the 25-year 10-day volume. How is the dairy going to do this if it does not have control of the fields? It is difficult to envision how irrigation fields could possibly be considered third-party fields rather than offsite LMUs. The applicant is making a mockery of the distinction between contracts and leases and third-party fields and LMUs. The TCEQ needs to explain how irrigation of wastewater to third-party fields is possible without them being considered LMUs and if EPA concurs with this reasoning.

15. Failure to provide a meaningful definition of vegetative buffers.

Permit Provision X.F of the draft permit requires that the permittee install and maintain buffers according to NRCS standards. While the NRCS does have practice standards for "filter strips" (Code 393), the NRCS has no practice standards for "vegetative buffers." The buffers specified in the permit contain both filter strips and a "vegatative [sic] buffer setback". Without a definition and standard for "vegetative buffer", the term is virtually meaningless. A single tree in the buffer area could be considered a "vegetative buffer."

The TCEQ has previously indicated that a vegetative buffer is commonly understood to mean vegetation that reduces shock due to contact and that the Riparian Forest Buffer (Code 391), which is referenced by Filter Strips (Code 393), qualifies in this respect. The TCEQ seems to indicate that it is defining "vegetative buffers" in the North Bosque River watershed to mean Filter Strips as defined by NRCS Practice Code 393 including Riparian Forest Buffers as defined by NRCS Practice Code 393. If the TCEQ is defining "vegetative buffers" to mean either Filter Strips as defined by NRCS Practice Code 393 or Riparian Forest Buffers as defined by NRCS Practice Code 393, then this definition should be placed in the permit to make it clear to the permittee.

16. Failure to clearly define the beginning of vegetative buffers and filter strips.

It is not clear where the measurement of the vegetative buffers and filter strips begin in relation to the streambed and the center of the stream. The measurement should be from the banks of the stream, not the centerline. The TCEQ has previously indicated that the vegetative buffers can only exist as close as the normal water line or at the top of the bank. The City accepts this definition, assuming the top of bank is used when the stream is intermittent or dry, but believes it would be clearer to the permittee if the language in the permit included this definition.

17. Failure to address discharge of bacteria and other pathogens.

No attempt has been made to demonstrate how the bacterial problems that exist in the North Bosque watershed will be addressed other than to say that controlling phosphorus will control bacteria. In previous responses to comments, the TCEQ has indicated that "management measures for controlling phosphorus will also have some corollary effect on reducing pathogen and bacteria loading, since non-point source nutrient and pathogen loads largely originate from the same sites and materials and are transported visa the same processes and pathways." This is not an adequate response to the City's comments for the following reasons: 1) There has been no demonstration by the TCEQ that the management measures for controlling phosphorus will have any effect on bacteria. 2) In using the term "some corollary effect", the TCEQ is acknowledging that they have no idea how much reduction might occur if it does occur. This is far short of demonstrating attainment with the bacteria water quality standards . 3) While the bacteria and pathogen loads originate from the same sites and materials and are transported via the same streams and rivers, the processes and removal mechanism for bacteria are far different than those for phosphorus. Much of the phosphorus from CAFOs is removed by harvesting growing crops to which it has been applied. There has been no demonstration that bacteria are removed by growing crops. There has been no demonstration to what extent bacteria might be captured by the soil or "filtered out" in grass. Bacteria undergo different processes in the streams and rivers. They are not removed by algae and have a potential for regrowth.

VII. The Executive Director has failed to prepare an accurate Fact Sheet.

Page 5 of the Fact Sheet states that "In determining the application rate, the nutrient management plan also evaluates the amount of nutrients needed for optimal crop production and then balances that need between the nutrients in the soils and nutrient source (i.e., wastewater)." This is factually incorrect. The nutrient management plan allows nutrients in the soil to far exceed what is needed for optimal crop production and to continue to apply nutrients in excess of this.

CONCLUSION

The City of Waco, on its own behalf and as *parens patriae* on behalf of its citizens, hereby requests the Executive Director to take the following actions:

1. Consider these comments in evaluating the draft permit by which the Executive Director has proposed to issue a permit to P&L Dairy;

2. Rescind the draft permit issued for P&L Dairy as without valid legal and technical basis.

The City appreciates very much the opportunity to submit these comments and the consideration that it knows the Executive Director and staff will give to them.

Respectfully submitted,

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Attachment 1

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
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DEC 0 3 2001

Mr. Jeffrey A. Saitas, P.E.
Executive Director
Texas Natural Resource Conservation Commission
P.O. Box 13087
Austin, Texas 78711-3087

Dear Mr. Saitas:

The Environmental Protection Agency (EPA) reviewed the final document *"Two Total Maximum Daily Loads for Phosphorus in the North Bosque River–for Segments 1226 and 1255"* submitted by the Texas Natural Resource Conservation Commission (TNRCC) on March 5, 2001. Based on this review, EPA requested supplemental supporting information, which was furnished by TNRCC.

This letter defines EPA's understanding of these total maximum daily loads (TMDLs) based on our review of the submitted TMDL document, modeling information, and the supplemental information provided by TNRCC. Table 1 summarizes the actual TMDLs, including waste load allocations (WLAs), load allocations (LAs), allowance for future growth (FG), and an implicit margin of safety (MOS). EPA recognizes that this TMDL modeling information represents "net" TMDL values at the five river index stations and therefore, the non-point source LAs are net loading values while WLAs are expressed as "gross" loads. It would be consistent with these TMDLs to express the net LA value as a gross LA value for the purpose of developing nonpoint load reductions.

Table 2 includes a scenario for individual WLAs for soluble reactive phosphorus. These WLAs were calculated from the TMDL document, modeling scenario information obtained directly from the Blacklands Agricultural Research Center, and the supplemental information provided by TNRCC. As established in the August 14, 2001, TMDL process agreement between EPA and TNRCC, these individual WLAs may be different from actual effluent limits established as a part of the Texas Pollutant Discharge Elimination System permitting process, and TNRCC will document how actual permit limitations are consistent with these TMDLs.

We request that TNRCC review and provide written concurrence with our interpretations of the enclosed tables. As you are aware, in May 2001, EPA Region 6 held listening sessions with key stakeholders of the North Bosque River Watershed, including cities, dairymen, and environmental groups. The results of these sessions revealed a number of key issues that I feel need further study. My staff and I have shared this information with you and your staff. We look forward to working with you and your staff to complete the review process for the North Bosque River TMDLs. If further discussion is required, please contact me or have your staff contact Sam Becker at (214) 665-8133.

Sincerely,

Gregg A. Cooke

Gregg A. Cooke
Regional Administrator

Enclosure

TABLE 1-North Bosque River TMDL (Segments 1226 and 1255) for Soluble Reactive Phosphorus (SRP)

Column	1	2	3	4	5	6
River Index Stations	TMDL - e for SRP (lbs/day)	LA for SRP (lbs/day)	WLA for SRP (lbs/day)	FG for SRP (lbs/day)	MOS for SRP (lbs/day)	Comments
Above Stephenville	9.34	9.34	0.000	0.00	Implicit	No PS discharge
Below Stephenville	25.18	0.94	24.24	0.00	Implicit	Stephenville discharge
Above Meridian	63.23	34.92	27.06	1.25	Implicit	Stephenville, Hico, and Iredell discharges
Clifton	93.52	61.29	30.98	1.25	Implicit	Stephenville, Hico, Iredell, & Meridian discharges
Valley Mills	106.35	69.78	35.32	1.25	Implicit	Stephenville, Hico, Iredell, Meridian, & Clifton discharges
End of Segment 1226	>106.35	>69.78	37.57	0.00	Implicit	Stephenville, Hico, Iredell, Meridian, Clifton, & Valley Mills discharges

TMDL (Total Maximum Daily Load), WLA (Wasteload Allocation), LA (Load Allocation), FG (Future Growth), MOS (Margin of Safety)

1 Represents net TMDL, which is equivalent to stream loading capacity for the "existing" scenario and incorporates best management practices (BMPs) for waste application fields (WAFs) and wastewater treatment plants (WWTPs). Represents anticipated in-stream effect at the five river index stations, which are the compliance points for the mainstem of the North Bosque River Segments 1226 and 1255.

2 LA at a given river index station is equal to the sum of all nonpoint sources at or above that location with the exception of manure/wastewater holding lagoons. LA allocation does not include any allocations for manure/wastewater holding lagoons.

3 WLA at a given river index station is equal to the sum of all individual point source dischargers at or above that location. For example, at river index station "Above Meridian" the WLA (27.06 lbs/day) = WLA for Stephenville (24.24 lbs/day) + WLA for Hico (2.30 lbs/day) + WLA for Iredell (0.52 lbs/day). These individual WLAs are presented in Table 2.

4 FG at a given river index station is allocated between that location and the one above it. For example, at "Above Meridian" the FG (1.25 lbs/day) is allocated between "Below Stephenville" and "Above Meridian."

5 MOS is based on conservative assumptions and is implicit for this TMDL.

6 These dischargers are located at or above the five river index stations.

TABLE 2- North Bosque River Intial Wasteload Allocations (WLAs) for Soluble Reactive Phosphorus (SRP)

City/Town	Segment Number	Design Flow (MGD)	Individual Point Source Concentrations (ug/l)	Individual Point Source WLA (lbs/day)
Stephenville	1255	3.00	969.00	24.24
Hico	1226	0.20	1378.00	2.30
Iredell	1226	0.05	1244.00	0.52
Meredian	1226	0.45	1045.00	3.92
Clifton (new)	1226	0.65	801.00	4.34
Valley Mills	1226	0.36	748.00	2.25
Future Growth (FG)	1226	0.60	750.00	3.75
TOTAL		**5.31**		**41.32**

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 6
1445 ROSS AVENUE, SUITE 1200
DALLAS, TX 75202-2733

DEC 0 3 2001

Mr. Jeffrey A. Saitas, P.E.
Executive Director
Texas Natural Resource Conservation Commission
P.O. Box 13087
Austin, Texas 78711-3087

Dear Mr. Saitas:

The Environmental Protection Agency (EPA) reviewed the final document *"Two Total Maximum Daily Loads for Phosphorus in the North Bosque River–for Segments 1226 and 1255"* submitted by the Texas Natural Resource Conservation Commission (TNRCC) on March 5, 2001. Based on this review, EPA requested supplemental supporting information, which was furnished by TNRCC.

This letter defines EPA's understanding of these total maximum daily loads (TMDLs) based on our review of the submitted TMDL document, modeling information, and the supplemental information provided by TNRCC. Table 1 summarizes the actual TMDLs, including waste load allocations (WLAs), load allocations (LAs), allowance for future growth (FG), and an implicit margin of safety (MOS). EPA recognizes that this TMDL modeling information represents "net" TMDL values at the five river index stations and therefore, the non-point source LAs are net loading values while WLAs are expressed as "gross" loads. It would be consistent with these TMDLs to express the net LA value as a gross LA value for the purpose of developing nonpoint load reductions.

Table 2 includes a scenario for individual WLAs for soluble reactive phosphorus. These WLAs were calculated from the TMDL document, modeling scenario information obtained directly from the Blacklands Agricultural Research Center, and the supplemental information provided by TNRCC. As established in the August 14, 2001, TMDL process agreement between EPA and TNRCC, these individual WLAs may be different from actual effluent limits established as a part of the Texas Pollutant Discharge Elimination System permitting process, and TNRCC will document how actual permit limitations are consistent with these TMDLs.

We request that TNRCC review and provide written concurrence with our interpretations of the enclosed tables. As you are aware, in May 2001, EPA Region 6 held listening sessions with key stakeholders of the North Bosque River Watershed, including cities, dairymen, and environmental groups. The results of these sessions revealed a number of key issues that I feel need further study. My staff and I have shared this information with you and your staff. We look forward to working with you and your staff to complete the review process for the North Bosque River TMDLs. If further discussion is required, please contact me or have your staff contact Sam Becker at (214) 665-8133.

Sincerely,

Gregg A. Cooke

Gregg A. Cooke
Regional Administrator

Enclosure

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2 LA at a given river index station is equal to the sum of all nonpoint sources at or above that location with the exception of manure/wastewater holding lagoons. LA allocation does not include any allocations for manure/wastewater holding lagoons.

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TOTAL		**5.31**		**41.32**

TEXAS NATURAL RESOURCE CONSERVATION COMMISSION

Protecting Texas by Reducing and Preventing Pollution

December 7, 2001

Mr. Gregg A. Cooke
Regional Administrator
Environmental Protection Agency, Region 6
1445 Ross Avenue, Suite 1200
Dallas, Texas 75202-2733

Dear Mr. Cooke:

Thank you for your letter setting out the Environmental Protection Agency's (EPA's) understanding of our TMDL document *"Two Total Maximum Daily Loads for Phosphorus in the North Bosque River–for Segments 1226 and 1255"* and supplemental supporting information. We concur with your interpretations and request that you proceed with final approval of the Bosque TMDLs. Thank you also for the information that you and your staff provided to the Texas Natural Resource Conservation Commission (TNRCC) as a result of the May 2001 listening sessions held by EPA Region 6 for the stakeholders of the North Bosque River Watershed. As we have discussed, I share your view that the stakeholders raised a number of important issues concerning the North Bosque River total maximum daily loads (TMDLs), and we at TNRCC have developed a plan of action that we believe will address their concerns and help to ensure the improvement of water quality in the North Bosque River Segments 1226 and 1255.

Our plan of action includes implementation of a monitoring program and reexamination of the water quality modeling as well as a mid-course evaluation of the TMDLs and possible revisions to the TMDLs. The following is a description of the specific tasks.

1. Develop and implement a long-term monitoring program to evaluate water quality improvements and the preliminary targets for the Bosque River watershed. This monitoring program should provide continuity with historical monitoring, but must provide more specific monitoring data. This monitoring effort will:

    a. provide data useful in refining the initial modeling efforts, and verifying modeling assumptions;
    b. include both wet weather and low flow conditions to better characterize the contributions of point and nonpoint sources; and
    c. expand monitoring to provide information for identifying tributaries with significant load contributions, especially in the Upper North Bosque River (Segment 1255).

Mr. Gregg A. Cooke
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2. Review and evaluate additional scientific studies such as edge of field studies, characterizations of dairy lagoon wastes and the effects of permitted discharges from dairy lagoons.

3. Improve modeling results by:

    a. increasing model resolution by reducing model cell sizes in the SWAT model. This effort will result in a more thorough analysis or assessment of additional sources such as additional tributaries and PL-566 reservoirs, as well as establishing more reliable estimates of the net to gross ratios of soluble reactive phosphorus at the watershed index points; and

    b. incorporating any applicable and appropriate results discovered from the review of data in item 2.

4. TNRCC will re-evaluate TMDL allocations and make any appropriate revised recommendations based on results from additional monitoring data and improved modeling information.

The overall goal of the mid-course evaluation will be to determine if it is appropriate to refine the TMDLs to more accurately predict the loads and address stakeholder concerns. This approach allows TNRCC to move forward with pollution reductions without waiting for additional data collection and analysis. TNRCC will revise the North Bosque River TMDLs if necessary based on the results of the additional study, and submit any revised TMDLs to EPA by the end of calendar year 2006.

Please contact me if you or your staff have questions or additional concerns.

Sincerely,

Jeffrey A. Saitas, P.E., Executive Director
Texas Natural Resource Conservation Commission

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 6
1445 ROSS AVENUE, SUITE 1200
DALLAS, TX 75202-2733

DEC 13 2001

Mr. Jeffrey A. Saitas, P.E.
Executive Director
Texas Natural Resource Conservation Commission
P.O. Box 13087
Austin, Texas 78711-3087

Dear Mr. Saitas:

Thank you for your letter confirming our interpretation of the total maximum daily load (TMDL) document *"Two Total Maximum Daily Loads for Phosphorus in the North Bosque River–for Segments 1226 and 1255"* and supplemental information provided by the Texas Natural Resources Conservation Commission. Based on our review, detailed in the enclosed document, we conclude that the TMDL document listed above meets the requirements found in Section 303 of the Clean Water Act and the implementing regulations at 40 CFR Section 130.7. The Environmental Protection Agency (EPA) is therefore pleased to approve the TMDLs for phosphorus for the North Bosque River. EPA also acknowledges that these TMDLs will be incorporated as updates to the Texas Water Quality Management Plan.

Thank you also for sharing your plan of action for the North Bosque watershed, which includes implementation of a monitoring program, re-evaluation of the water quality modeling, and a mid-course evaluation of the TMDLs. My staff has reviewed your plan of action and agree that it is a positive step forward to address stakeholder issues and concerns. This continues to demonstrate your commitment to ensure that all regulatory decisions are based on the best available science.

We commend your staff for the considerable effort that went into developing and establishing these TMDLs. If you would like to discuss this approval, please contact Sam Becker at (214) 665-8133.

Sincerely yours,

Gregg Cooke
Regional Administrator
EPA Region 6

Enclosure

The Texas Natural Resource Conservation Commission (TNRCC) adopted "Two Total Maximum Daily Loads for Phosphorus in the North Bosque River—for Segments 1226 and 1255" on February 9, 2001. The North Bosque TMDLs call for 50% reduction in the average concentration of soluble reactive phosphorus at the river index station, "Above Meridian." In order to achieve this goal, both point sources and non-point sources are expected to reduce their phosphorus loadings by approximately 50%.

The Environmental Protection Agency's (EPA's) approval of the North Bosque River TMDLs is based on a technical review of the modeling completed by Blackland Agricultural Research Center and supplemental information provided by TNRCC. EPA also considered critical issues raised by the North Bosque River Watershed stakeholders, which included the legislature, cities, dairies, and environmental organizations. Stakeholders had an opportunity to express their concerns during listening sessions held by EPA in April 2001. EPA responded by working closely with TNRCC to develop a plan for future actions, which will ultimately address their major concerns.

The plan for future actions will lead to a mid-course evaluation and submittal of any necessary revisions of the North Bosque River TMDLs to EPA. The overall goal of the mid-course evaluation will be to determine if it is appropriate to refine the TMDLs to more accurately predict the loads and address stakeholder concerns. This approach allows TNRCC to move forward with pollution reductions to move forward in establishing a process that moves forward in meeting water quality standards without waiting for additional data collection and analysis.

TNRCC's key future actions include the following:

1. Develop and implement a long-term monitoring program to better characterize water quality in the North Bosque River Watershed;

2. Review and evaluate additional scientific studies such as edge of field studies, characterizations of dairy lagoon wastes and the affects of permitted discharges from dairy lagoons;

3. Increase model resolution by reducing model cell sizes in the SWAT model; and

4. Re-evaluate TMDL allocations and make any appropriate recommendations based on results from additional monitoring data and improved modeling information.

EPA's approval of the North Bosque River TMDLs is the first step in the TMDL Process. The next step is implementation. TNRCC has committed to completing an implementation plan for the North Bosque River TMDLs. The plan for future actions agreed upon by both agencies ensures that the necessary actions are taken to meet applicable water quality standards for the North Bosque River.

EPA commends TNRCC along with the Texas Institute for Applied Environmental Research, the Bosque River Advisory Committee, the Texas State Soil and Water Conservation Board, and the Blackland Research and Extension Center for working together to complete these TMDLs.