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TNRCC

Two Total Maximum Daily Loads for Phosphorus in the North Bosque River

For Segments 1226 and 1255

Prepared by:
The Strategic Assessment Division, TNRCC

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TEXAS NATURAL RESOURCE CONSERVATION COMMISSION

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Introduction

Section 303(d) of the Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. For each listed water body that does not meet a standard, states must develop a total maximum daily load (TMDL) for each pollutant that has been identified as contributing to the impairment of water quality in that water body. The Texas Natural Resource Conservation Commission (TNRCC) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

In simple terms, a TMDL is a quantitative plan that determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. In other words, TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load, with units of mass per time period, but may be expressed in other ways also. TMDLs must also estimate how much the pollutant load needs to be reduced from current levels in order to achieve water quality standards.

The Total Maximum Daily Load Program, a major component of Texas' statewide watershed management approach, addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in or bordering the state of Texas. The primary objective of the TMDL Program is to restore and maintain the beneficial uses (such as drinking water, recreation, support of aquatic life, or fishing) of impaired or threatened water bodies.

These TMDLs are meant to achieve significant reductions in the annual-average concentration and total-annual loading of soluble phosphorus in the North Bosque River.

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA) implementing regulations (40 Code of Federal Regulations, Part 130) describe the statutory and regulatory requirements for acceptable TMDLs. The TNRCC guidance document, *Developing Total Maximum Daily Load Projects in Texas* (GI-250), further refines the process for Texas. Following these guidelines, this TMDL document describes six elements which are summarized in the following sections:

- Problem Definition
- Endpoint Identification
- Source Analysis
- Linkage Between Sources and Receiving Waters
- Margin of Safety
- Pollutant Load Allocation

These TMDLs were prepared by:

- the TMDL Team in the Strategic Assessment Division of the Office of Environmental Policy, Analysis, and Assessment of the Texas Natural Resource Conservation Commission.

Significant assistance was provided by:

- the Texas Institute for Applied Environmental Research (TIAER) at Tarleton State University in Stephenville, Texas
- the Bosque River Advisory Committee (BRAC)
- the Texas State Soil and Water Conservation Board (TSSWCB)
- the Blackland Research and Extension Center (Blackland)

The two TMDLs described in this document were adopted by the Texas Natural Resource Conservation Commission on February 9, 2001. Upon adoption, the TMDLs became part of the Texas Water Quality Management Plan. The Texas Natural Resource Conservation Commission will use this document and the Texas Water Quality Management Plan in reviewing and making determinations on applications for wastewater discharge permits and in its nonpoint source pollution abatement programs.

Background Information

The North Bosque River (Segments 1226 and 1255) was included in the 1998 Texas CWA § 303(d) List and deemed impaired under narrative water quality standards related to nutrients and aquatic plant growth. Recent studies have indicated that under most conditions phosphorus is the limiting nutrient in the North Bosque River basin (Kiesling et. al., draft), and that dairy waste application fields and municipal wastewater treatment plants are the major controllable sources of phosphorus (McFarland and Hauck 1995, 1997, 1998, 1999a, 1999b). Watershed modeling for the North Bosque River TMDL assessed source categories of urban stormwater runoff, municipal wastewater treatment plants, wood/range land, pasture, row crops, non-row crops, and dairy waste application fields (Santhi et al 2000a, 2000b). The wood/range land use approximates the natural background condition of the watershed prior to development.

Evaluation of water quality conditions in the North Bosque River cannot be expressed exclusively in quantitative terms because the bases for including these segments on the impaired water body list are not related to violations of specific numeric criteria, but rather to narrative standards concerning nutrients and excessive algal growth. The Texas Surface Water Quality Standards [30 TAC, Chapter 307.4 (e)] say:

> "Nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use. Site-specific nutrient criteria, nutrient permit limitations, and/or separate rules to control nutrients in individual watersheds will be established where appropriate after notice and opportunity for public participation and proper hearing."

While there is little debate that nutrients in excessive amounts can create a situation conducive to the proliferation of algae and other aquatic plants, the quantification of what constitutes excessive algal and aquatic plant growth and the most effective means to control that growth is more elusive. Determination that a narrative standard has been violated is inherently a subjective exercise, so determination of desired endpoints and allowable loading is also largely subjective. Objective science may establish linkages between nutrient loading and water body trophic status, but subjective human values then determine or influence selection of the desired trophic level for a particular water body. Natural waters exhibit a range of trophic levels, that may vary geographically at any moment or may vary through time at any location. Natural sources often provide sufficient nutrients to support algal communities or blooms when other environmental conditions are favorable. The algae and aquatic plant growth supported by nutrients constitute the basal level of the aquatic food chain, so entirely depleting a water body or system of nutrients would undermine its ecology. Selection of appropriate nutrient endpoints must balance consideration of what is ecologically and technologically feasible against the subjective conditions favored by humans at any particular site.

When nutrients are the primary limiting factor for aquatic plants in a flowing stream, the most controllable nutrient is usually phosphorus. In the case of the North Bosque River segments, instream algal growth potential evaluations provided strong evidence that phosphorus is a controlling factor in the growth of aquatic plants (Matlock et. al. 1999a, 1999b). Evaluation of in-stream water quality data provided an estimate of the annual-average soluble phosphorus concentrations that are likely to limit the growth of aquatic plants in portions of the river (Kiesling et. al., draft). However, it must be noted that a number of other factors such as temperature, stream flow, light availability, and seasonal variations influence and may control the growth of aquatic plants in a river system. The ecologic interplay of the numerous limiting factors, combined with the subjective nature of nutrient standards or goals, makes determination of precise nutrient limits very difficult.

Local stakeholder participation in TMDL development was coordinated through the Bosque River Advisory Committee (BRAC), which was initially formed in 1996 to address some of the social and political issues associated with delineation and mitigation of regional water quality issues. The committee membership included elected officials (state senator and representatives, county judges and commissioners, city mayors), watershed residents representing dairies (large and small), row crop farmers, non-agricultural industry, and citizens with general interest in water quality. Representatives of several agencies involved in local TMDL or Concentrated Animal Feeding Operation (CAFO) issues served as resources to support the stakeholder process. Advisors and staff for the committee members also participated. The stakeholder committee was also supported by a Technical Work Group consisting of professionals from universities, institutes, and state and federal agencies. The Technical Work Group provided peer review of and consultation for the technical analyses performed for the TMDL.

The endpoint for this TMDL is a significant reduction in soluble reactive phosphorus (SRP) average total-annual loading and annual-average concentrations, as measured in the river at various sites. The goal is expressed as a “percent reduction” relative to the initial (i.e. current or existing) condition at the respective sites. The numeric statement of the goal of these North Bosque River TMDLs is to reduce average total-annual loading of

SRP by approximately 50% for the entire North Bosque River watershed. That is predicted to reduce annual-average SRP concentrations in the river by approximately 47%, as a long-term watershed average and with some local variation that reflects location within the watershed and along the river.

Problem Definition

The Bosque River is located in north central Texas, northwest of the City of Waco, and is a tributary of the Brazos River. The Bosque River is impounded at Waco, near its confluence with the Brazos River, to form Waco Lake (Segment 1225), which provides water for approximately 150,000 people. The North Bosque River is the longest arm of the Bosque system, draining approximately 75% of the Waco Lake watershed, while the Middle and South Bosque Rivers and Hog Creek drain most of the remaining area (Figure 1).

Topographically and historically, the Bosque River watershed is representative of the heart of Texas. The upper watershed has medium-sized hills, carved into a limestone plateau, with relatively shallow, rocky soils and areas of moderate to steep slope. The upper watershed has long been utilized for ranching, dairies, and other animal production agriculture. The lower watershed, drained by the Middle and South Bosque Rivers, has rolling blackland prairie with deep soils, and row crop production is the predominant form of agriculture. The distribution of these and other land uses within the watershed is depicted on Figure 2.

The North Bosque River is administratively divided between two designated water quality segments (see Figure 1):

- <u>Segment 1226, North Bosque River</u> – extends from a point 100 meters upstream of FM Road 185 in McLennan County to a point immediately upstream of the confluence of Indian Creek in Erath County
- <u>Segment 1255, Upper North Bosque River</u> – extends from a point immediately upstream of the confluence of Indian Creek in Erath County to the confluence of the North Fork and South Fork of the North Bosque River in Erath County

Designated uses for both segments of the North Bosque River are established in the Texas Surface Water Quality Standards (30 TAC Chapter 307). The 1998 Texas 303(d) List identified the North Bosque River segments as "impaired" by high levels of nutrients, based on exceedance of screening criteria used to assess support of narrative standards. These total maximum daily load (TMDL) allocations were developed to address nutrient loading and algal growth, and to support plans for attaining and maintaining water quality standards in the North Bosque River. Actions that reduce nutrient loading in the North Bosque River watershed will also improve or protect water quality in downstream water bodies.

Recent studies have indicated that phosphorus is the limiting nutrient in the watershed under most conditions (Matlock et. al. 1999a, 1999b). Studies also indicated that soluble phosphorus, which was analytically measured as soluble reactive phosphorus (or orthophosphate phosphorus), was a major form of phosphorus in the North Bosque River and statiscally better correlated to algal levels than total phosphorus (Kiesling et. al., draft). These TMDLs focus on controlling soluble phosphorus loading and stream concentrations to attain and protect designated uses.

Endpoint Identification

The water quality standard that was the basis for including the North Bosque River segments on the 303(d) List is narrative in nature. There are currently no established numeric criteria for nutrients in Texas.

Studies in the North Bosque River watershed to support development of these TMDLs included biological experiments and chemical analyses to estimate critical nutrient species and concentrations for the local streams. Instream periphytometers were used to assess algal productivity (measured as periphytic chlorophyll-α production) relative to nitrogen and phosphorus concentrations, which led to the determination that phosphorus is the limiting nutrient under most conditions (Matlock et. al. 1999). Analyses of stream nutrient and chlorophyll-α data then supported estimation of an annual-average soluble phosphorus concentration likely to exert some limitation on algal growth potential (Kiesling et. al., draft). Scientific techniques and statistical approaches used to develop preliminary phosphorus targets were discussed extensively by the Technical Work Group. The conclusion was that annual-average soluble reactive phosphorus (SRP) concentrations of 50 micrograms per liter (µg/L) or less would have a limiting effect on stream algal communities. As a lower bound for a target range of annual-average phosphorus concentrations, data from the least-disturbed reference stream in the watershed (Neils Creek) were assessed. That assessment indicated that an annual-average SRP concentration of 15 µg/L approximates least-disturbed natural conditions. Thus, biological and chemical data established that achieving annual-average phosphorus concentrations between 15 and 50 µg/L would probably have a significant limiting effect on algal growth. A "preliminary target" concentration within that range, i.e. 30 µg/L, was estimated for a monitoring station immediately upstream of Meridian, and related to a monitored mid-1990s average concentration at the same site of 60 µg/L. As a gross estimate, a 50% reduction in loading was presumed needed to attain a 50% reduction in average concentration in the vicinity of Meridian.

Parts of the upper reaches of the North Bosque River (i.e. Segment 1255 and the upper part of Segment 1226, or generally upstream from Iredell), and many tributary streams in that area, are intermittent in natural flow. In a section of the Upper North Bosque (Segment 1255), some dry weather flow is maintained primarily by wastewater treatment plant (WWTP) discharge from the City of Stephenville – but the length of that section varies due to the effect of weather conditions. As a result, there is effectively a technological lower limit on feasibly attainable nutrient concentrations within the zone affected by the Stephenville discharge. The upper-reach nutrient concentrations vary widely over time because storm runoff provides most flow other than the WWTP discharge, with relatively little baseflow from groundwater to buffer or limit the variability. Intermittent sections of stream channels, whether in tributaries or in the main stem river, typically contain terrestrial or wetland plant growth that can provide natural nutrient loading sufficient to support algal growth during wet periods. Consequently, algal growth in the upper reaches is probably more likely to be limited by light and/or water availability than by nutrient availability or temperature (i.e. when water and light are available, algae can grow; temperature and nutrients would seldom be limiting factors). For these reasons, nutrient concentration targets to assure control of aquatic plants are even more difficult to establish for intermittent stream reaches, and less certain to be ecologically meaningful.

The North Bosque River TMDLs are meant to achieve significant reductions in the total-annual loading and annual-average concentration of soluble phosphorus in the North Bosque River. Compared to existing conditions, the TMDLs are recommending average total-annual load reductions ranging from about 39% to about 62%, depending on the site monitored, with an average overall reduction of approximately 50% in soluble phosphorus average total-annual loading. Those load reductions are expected to reduce the average annual-average concentrations of soluble phosphorus by about 33% to 60%, depending on the site monitored. Because of the inherent natural variability of nutrient loading, "average" conditions or targets will be exceeded on occasion. Post-TMDL monitoring of soluble phosphorus concentrations in the North Bosque River will utilize probability curves developed from model analyses to determine if the long-term response of the system meets expectations.

Soluble phosphorus reductions of that magnitude (i.e. around 40% to 60%, loading or concentration) will reduce the potential for problematic algae growth in the North Bosque River and downstream waters, and should reduce the actual occurrence of algal blooms. Model simulations predict that the annual-average soluble phosphorus concentration in the North Bosque River at Valley Mills will be low enough to limit algal growth during 90 to 95% of the years following implementation (see Figure 4). Algal growth potential will also be significantly reduced at the upstream stations, although to a lesser degree than at Valley Mills (Figures 5 through 8). However, algae and nutrient interactions are extremely dynamic, and very much influenced by weather conditions and other environmental factors. Human efforts to control nutrient loading can reduce or limit the occurrence of algal blooms, but cannot totally prevent them in living water bodies. The model analyses predict, as shown in Figures 4-8, that these TMDLs will improve water quality conditions (i.e. reduce nutrient loads and concentrations) every year, but that some years will still exceed the most desirable range of annual-average soluble phosphorus concentrations.

Source Analysis

During the 1980s, the dairy industry expanded very rapidly in the North Bosque River and adjacent watersheds, to the extent that Erath County became the leading county for milk production in the state. The total number of milk cows in the watershed grew tremendously, with the current total in the neighborhood of 41,000 head. In keeping with current trends in the dairy industry, operations in this watershed also shifted from relatively small dairies dispersed over the landscape, to large dairies that tend to cluster together for economic and cooperative reasons. At the time data were collected to support this evaluation, 104 of the 105 dairies operating in the Bosque River Basin were located in the watershed of Segments 1226 and 1255 of the North Bosque River. The majority of those 104 dairies are in the upper half of the North Bosque River watershed, with the primary concentration within Erath County. Portions of Erath County that are not in the Bosque River watershed (see Figure 1) also contain numerous dairy operations, such that Erath County alone contains more dairy cattle than the entire Bosque River watershed.

Extensive data collection and scientific studies were performed during the 1990s, primarily in the Upper North Bosque River watershed, to assess the water quality effects of dairy practices. Those studies characterized nutrient loading from sources categorized as urban stormwater runoff, municipal wastewater discharges, wood/range land, pasture, non-row crops, row crops, and dairy waste application fields (McFarland and Hauck 1998, 1999a, 1999b). The percentage of gross annual loading provided by each of these sources depends on the location at which loading is summarized, since land uses and wastewater discharge are not evenly distributed across all subwatersheds (see Figures 2 and 3; McFarland and Hauck 1999a). Citizen stakeholders and technical experts involved in development of the North Bosque River TMDL agreed that the data indicate the major controllable sources of nutrients in the North Bosque River basin to be municipal wastewater treatment plants (WWTPs) and dairy waste application fields (WAFs). Of the other sources, only urban stormwater is controllable via an existing regulatory program. Loading contributed by urban stormwater is relatively small compared to other storm-event-driven loading within the watershed. However, if needed later to achieve the goals of these TMDLs, urban stormwater management to reduce phosphorus loading could be required by stormwater permits.

WWTPs are classic *point sources*, long regulated by state and federal permitting programs. WWTP discharges have been analyzed (modeled) as distinct point sources, and will be controlled as needed via the existing permit programs. Urban stormwater is also legally defined as a point source subject to permit requirements, but the hydrologic occurrence of urban runoff and geographic distribution of discharge points are more similar to nonpoint sources from a modeling perspective. The areas in which cattle are fed or confined at dairy operations are subject to Concentrated Animal Feeding Operation (CAFO) permits because they are legally considered point sources. Runoff from areas such as lots, feed lanes, and milking areas is regulated as point source, but runoff from dairy WAFs is not covered by CAFO permits and is treated as a nonpoint source. There are also dairies that are small enough to not require CAFO permits, but are considered to be small Animal Feeding Operations (AFO) and required to operate in compliance with Texas State Soil and Water Conservation Board (TSSWCB) guidance or TNRCC rules. Small AFOs are considered to be nonpoint sources, and regulated as such. Measures to control nutrient loading from WAFs may include a combination of CAFO permit conditions regulating land application of CAFO wastes, watershed rules that affect all AFO operations, and voluntary programs.

The source categories of urban stormwater, wood/range land, pasture, non-row crops, row crops, and dairy waste application fields (WAFs) were analyzed (modeled) as *nonpoint sources*. Of these, only the urban stormwater and WAFs are associated with activities that may require permits. Among these nonpoint categories, the largest sources of phosphorus loading in the North Bosque River basin are wood/range land and WAFs (Figure 3). The wood/range land use is considered to be the *background* condition of the watershed, because those areas are relatively natural in character and contribute a large percentile to the loading summary only because that land use occupies a large amount of the watershed area. On the other hand, the WAFs occupy a relatively small area of the watershed, but contribute a disproportionately large share of the nutrient loading.

Figure 2 illustrates the distribution of land use within the Bosque River watershed. Municipalities with permitted WWTP discharges are listed in Table 1.

Table 1. Municipal WWTP Flows (daily average in Million Gallons per Day – MGD)

City	Permitted Flow	Recent Flow	Estimated Yr 2020 Flow **
Clifton (old)	0.400	0.303	NA
Clifton (new)	0.650	NA	0.372
Hico	0.200	0.086	0.089
Iredell	0.050	0.024	0.033
Meridian	0.450	0.157	0.251
Stephenville	3.000	1.939	2.629
Valley Mills	0.360	0.101	0.103
Total *	4.710	2.610	3.477

(* Total permitted flow uses new Clifton facility) (** from Easterling 2000)

Population projections for 20 years in the future for each of the municipalities with permitted WWTPs were prepared for assessing future growth conditions (Table 2; Easterling 2000).

There are 104 dairies operating or authorized within the North Bosque River watershed. Of those, 66 are CAFOs operating under individual or general permits, while 38 are AFOs that are not required to obtain permits but must operate such that they do not cause water quality problems.

Table 2. Estimated Urban Population Growth within the North Bosque River Watershed		
City	**Year 2000**	**Year 2020**
Clifton	3,557	4,268
Hico	1,380	1,417
Iredell	433	581
Meridian	1,504	1,791
Stephenville	16,060	21,103
Valley Mills	1,090	1,118
Total	24,024	30,278

The existing gross annual loadings above (upstream of) each of the five North Bosque River index stations were estimated using water quality analyses and land use information (McFarland and Hauck 1999a). This served to establish approximate percentile contributions to the gross loading by each source or land use type. Those gross annual loads, and the percent contributions by source type, are shown in Figure 3. The percent contributions by source category are also shown in Table 3.

Table 3. Estimated Percent of Total Gross Annual Load by Source Type					
Source	**Above Stephenville**	**Below Stephenville**	**Above Meridian**	**Clifton**	**Valley Mills**
urban runoff	2 %	6 %	6 %	6 %	6 %
row crop	0 %	0 %	2 %	4 %	5 %
non-row crop	2 %	2 %	2 %	1 %	1 %
pasture	9 %	5 %	7 %	8 %	9 %
wood/range	7 %	5 %	18 %	22 %	24 %
WWTP	0 %	28 %	10 %	9 %	10 %
WAF	80 %	54 %	55 %	50 %	45 %
Column totals (%)	100 %	100 %	100 %	100 %	100 %

Linkage Between Sources and Receiving Water

Data collected during the 1990s were used to develop and calibrate a watershed model of the Bosque River basin. The model program used was the Soil and Water Assessment Tool, or SWAT (Arnold et al 1998; Arnold et al 1999; USDA-ARS 1999), which is designed for assessing large-scale agricultural management and water quality issues, and is supported by the U.S. Department of Agriculture - Agriculture Research Service. Preparation of a Bosque River application of SWAT was a joint effort by the Texas Institute for Applied Environmental Research (TIAER) and the Blackland Research and Extension Center (Blackland), with TIAER providing some of the input data and Blackland staff operating the model (Santhi et al 2000). The Bosque River application of SWAT is the primary technical tool for linking watershed sources, land use, and management practices to receiving water responses.

The SWAT model is dynamic, or time-variable, using a one-day time step and capable of simulating periods ranging from a few weeks to many years. Model inputs define subwatersheds within which management measures (i.e. crops, timing of irrigation or fertilizer applications, etc.), soil types and topography, and weather conditions can be stipulated. For each day of simulation, the model uses the weather input, subwatershed characteristics and management practices, crop growth effects, and other physical processes approximated by the model algorithms, to calculate the amount of water and associated constituents leaving the subwatershed outlet. Constituents simulated may include sediment, particulate and soluble forms of nutrients, and pesticides. A flow routing component of the model transports flow and loading from each subwatershed across the subsequent subwatersheds while accumulating the subwatershed contributions. First-order decay kinetics were calibrated to allow the flow routing component of SWAT to also account for assimilation of soluble phosphorus (i.e. via conversion to biomass or adsorbtion to soil particles).

Initial steps towards the Bosque River application of SWAT involved definition and characterization of the modeled watershed. Land use, soils and topographic information were used to determine subwatersheds and their individual characteristics. Precipitation and temperature data were collected and formatted to drive model simulations of recent historical periods.

Water quality data were collected and analyzed to characterize the river response during a monitoring period in the mid-1990s. Then, the model was calibrated by simulating a period of time during which input factors (i.e. rainfall, land uses and management, etc.) and output factors (i.e. water quality, nutrient concentrations in stream) were known, and adjusting model kinetics or input parameters until the observed (i.e. real life) conditions were reproduced as closely as possible by the model output. Once calibrated, the model was ready for use in TMDL analyses (Santhi et. al. 2000a, 2000b).

In order that the model simulations should account for the variability in nutrient concentrations or loading that occur due to normal variations in weather, the SWAT runs simulated a 39-year period using actual records of daily rainfall and temperature for the years 1960 through 1998. For predictive purposes, those years are assumed to represent the usual range of weather conditions that are likely to occur – although future weather cannot be expected to occur in precisely the same sequence.

If plotted directly, the raw model output produces a time series of SRP concentrations that reflect temporal variability, which appears erratic and very difficult to interpret. So, review of model output focused on predicted annual-average SRP concentrations, which was justified because of both model calibration and TMDL implementation considerations. In calibration, model-predicted monthly-average and annual-average SRP concentrations compared well to observed concentrations, but predicted daily concentrations compared less well. Other nutrient TMDLs have used long-term averages as targets rather than daily concentrations. These considerations supported defining annual-average SRP concentration as an appropriate parameter for post-TMDL monitoring.

In order to enhance model output interpretation and target evaluation, the SWAT-predicted annual-average SRP concentrations for the 39 simulated years were developed into exceedance probability graphs by ranking the annual results from highest to lowest and plotting exceedance probabilities for each annual value. The SWAT simulations kept land uses and management measures constant while weather conditions were dynamically simulated for a representative 39-yr period, so the resulting variation in the model output represents the effect of hydrologic variability. The resulting figures (see Figs. 4 through 9) can thus be read as indicating the probability that a particular annual-average concentration (or total-annual load) will be equaled or exceeded during any random year, or as the frequency at which a particular annual-average concentration will be equaled or exceeded during any group of years. For instance, in Figure 4, looking at the line representing the "TMDL-e" case in the concentration-based graphs, above the 0.2 exceedance probability marker, one reads the figure as predicting that the annual-average concentration would be greater than or equal to (approximately) 29 parts per billion (ppb) in 20% of future years, and less than or equal to 29 ppb in 80% of future years. For the purposes of these TMDL analyses and discussions, parts per billion (ppb) and micrograms per liter (µg/L) are considered to be equivalent units, and are used interchangeably.

Numerous predictive model scenarios were simulated to provide insights concerning the linkage between watershed conditions, management practices, and instream water quality. Scenarios represented in this report include:

Existing – represents conditions extant during the mid-1990s; uses actual flows and concentrations of WWTPs, actual dairy cow numbers (40,450) and WAF areas, etc., as measured during the monitoring/calibration period

Future – represents "full permitted" conditions for WWTPs and dairies, and projected urban populations and areas 20 years in the future; uses maximum number of dairy cows (66,930) allowable under existing permits with corresponding WAF area, and maximum permitted WWTP flows with phosphorus concentrations as measured during monitoring period; includes hypothetical 0.6 million gallons per day (MGD) discharge to represent new point sources

TMDL-e – incorporates management measures for WAFs and WWTPs, using populations, WWTP flows, dairy cow numbers and WAF area corresponding to mid-1990s monitoring period; represents anticipated effect of TMDL under "existing conditions"

TMDL-f – incorporates management measures for WAFs and WWTPs, using populations, WWTP flows, dairy cow numbers and WAF area corresponding to 20 years growth and full permitted limits; represents anticipated effect of TMDL under "future growth" conditions; includes hypothetical 0.6 million gallons per day (MGD) discharge to represent new point sources

Nonpoint only – same as TMDL cases except that WWTPs remain at "existing" conditions; provides a way to estimate how much load or concentration reduction at the river index sites was due to nonpoint source management practices on WAFs only, which also provides estimates for the amount of reduction due to WWTP measures.

The "existing condition" model scenario provides the initial or reference values for calculating percent reductions, and the "TMDL-e" model scenario defines the amount of reduction possible if a hypothetical suite of management measures is imposed on existing conditions. Similarly, the "future growth" model scenario provides the reference values, and the "TMDL-f" scenario estimates the amount of reduction, for calculating percent reductions that would occur under full-permitted and 20-year growth conditions.

Discussion of percent reduction targets are based on long-term averages derived from the model results. Each model run produced 39 total-annual loads and 39 annual-average concentrations representing each year included in the simulation. Plotting those sets of 39 values produced the model output figures shown in Figures 4-9. The long-term averages used for target discussions were determined by calculating the arithmetic mean for each set of 39 values. The calculated long-term averages are depicted as horizontal lines crossing the "existing" and "TMDL-e" plots for concentration and load in Figures 4-8.

Results from the model runs, as illustrated in Figures 4 through 8, indicate that the management measures simulated can significantly reduce total-annual loading and annual-average concentration of SRP throughout the North Bosque River watershed, and thus in downstream water bodies as well. The model results also indicate that lower soluble phosphorus loads and concentrations will occur every year, although the natural variation caused by weather and other environmental conditions will cause some years to still exceed the most desirable levels. Stated another way, "better conditions" will occur every year at all locations, "desirable conditions" will occur more often and at more locations, and "undesirable conditions" will occur less often at fewer locations. In particular, annual-average concentrations in the lower river reaches (i.e. at Clifton and Valley Mills) are predicted to be less than the 50 µg/L biological limitation concentration derived from periphytometer studies and in-stream water quality data analyses, in most years.

Model results from "Above Stephenville" (Fig. 8) characterize a subwatershed that contains no permitted WWTP discharges, but does contain numerous dairy operations and WAFs. Annual load and concentration reductions predicted for that subwatershed area are considered to be representative of how the simulated management measures would affect phosphorus loading and water quality in other dairy-dominated subwatersheds. This result demonstrates that the simulated suite of management measures would also cause significant improvement to water quality conditions in unclassified tributary streams that have no point source discharges and contain dairy operations.

By performing an intermediate model run that incorporated only the nonpoint source (i.e. WAF) management measures, leaving WWTPs at their "existing" condition, and comparing that to the "TMDL-e" model run, it is possible to estimate the "Nonpoint only" portion of reductions in annual-average concentration and total-annual loading. Figure 9 shows model output profiles that depict this process for two river stations, and also shows the net percent reductions then calculated as being achieved by the WWTP and WAF sources upstream from the stations.

Figure 9 also illustrates an important but sometimes confusing relationship between loading and instream concentrations. When concentration output is reviewed, point source reduction causes the most change. When loading output is reviewed, nonpoint source reduction causes the most change. For the purposes of this TMDL, the most important point to be gained from Figure 9 is that both point (WWTP) and nonpoint (WAF) sources are significant contributors.

Margin of Safety

This TMDL includes an *implicit* margin of safety that is significant but not specifically quantifiable. The margin of safety is embodied in two major aspects of the technical analyses and modeling performed to develop the TMDL.

First, a very large amount of data and information concerning nutrient sources and conditions in the North Bosque River watershed has been collected and assessed. Few watersheds in the United States have been studied as extensively with regard to nutrient issues and agricultural management practices. The data were thoroughly analyzed and peer-reviewed by experienced professionals at TIAER and in the technical work group that assisted in the project. Because of these factors, uncertainty associated with the study conclusions is minimized, and should be significantly less than the uncertainty associated with nutrient loading analyses in general.

Second, the SWAT model used for assessing alternatives is generally conservative. This is evident by comparing the "existing" model scenario output (exceedance probability curves) to the monitored phosphorus data from corresponding stations. Most notably in the lower river stations (i.e. Clifton and Valley Mills), the "existing" model scenario output tends to predict higher annual-average phosphorus concentrations than were recorded during the mid- to late-1990s. The model was calibrated to data from a period that included two major flood events, which probably maximized watershed nonpoint source loading and stream transport of phosphorus to the lower watershed. Since the calibration period, severe drought conditions have occurred, with minimal watershed loading and more loss of stream flow to evaporation or bank storage than the model calibration conditions. So, recently observed river concentrations have been significantly lower than the model predicts would occur. Calibration to maximal loading conditions means that the model tends to overpredict loading and transport under more average or low-flow conditions, and is thus environmentally conservative. Basically, this means that management measures are likely to be more effective, in the long-term average context of TMDL targets, than the model results predict.

Pollutant Load Allocations

TMDLs establish the allowable pollutant loading for each water body, distributed among the source categories that contribute the pollutant. The TMDLs described in this section will result in compliance with water quality standards. Implementation plans to achieve the recommended reductions may select a phased approach that achieves initial loading reductions from a subset of the source categories. A phased approach would allow for development or refinement of technologies that enhance the effectiveness of certain management measures. Periodic and repeated evaluations of the effectiveness of implementation measures will assure that progress is occurring, and may show that the original distribution of loading among sources can be modified to increase efficiency, while maintaining the objective of compliance with water quality standards.

The phosphorus sources addressed by these TMDLs include urban stormwater runoff, municipal wastewater discharges, wood/range land, pasture, non-row crops, row crops, and dairy waste application fields. Estimates of the existing (circa 1997) gross soluble phosphorus loading from each of those source types were derived from land use data, water quality data, phosphorus export coefficients (McFarland and Hauck 1998), and permit records (for municipal wastewater discharges), at several index stations along the North Bosque River (McFarland and Hauck 1999a). Those estimates are presented in Fig. 3, which shows both the percent contribution by each source type, and the total accumulated load during the 29-month monitoring period, by source type.

Those estimates are not directly comparable to the model output values or figures. The gross loading estimates predict how much phosphorus leaves a relatively small site (i.e. per acre) during an average year, and do not account for any loss or assimilation between the source site and the water quality site some distance downstream. Thus the estimates represent the gross average movement of phosphorus within a subwatershed, but stream data would measure the net unassimilated loading that passes the monitoring site (which must always be less than the gross export). However, the percent contributions by source type derived from these estimates can be assumed to be reasonably consistent and applicable to net soluble phosphorus loading. The percentile contributions, together with land use area information, can then be used to determine which subcategories of point and nonpoint sources should be targeted for reduction efforts.

Management measures ultimately implemented as a result of these TMDLs should lead to reducing average total-annual net SRP load by approximately 50%, and average annual-average SRP concentrations by approximately 47%. Stated another way, following implementation of management practices to meet the recommended reductions, the amount of soluble phosphorus that passes Meridian each year should be approximately half as much as would have passed there under similar environmental conditions before TMDL implementation.

Model scenarios represented existing conditions prior to TMDL implementation and predicted future conditions following TMDL implementation. Table 4 summarizes before and after model results, from the "Existing" and "TMDL-e" scenarios respectively, showing predicted average total-annual loading for each of the river index stations. These values represent net loading predicted to pass each site, which is different from (less than) the gross loading generated by sources upstream from the sites.

Table 4. Predicted Net Average Total-Annual Soluble Phosphorus Loading

Loading is expressed in units of kilograms per year, **kg/yr**	**Above Stephenville**	**Below Stephenville**	**Above Meridian**	**Clifton**	**Valley Mills**
Predicted average total-annual load from 'Existing' scenario	4,061	10,068	22,117	26,990	28,832
Predicted average total-annual load from 'TMDL-e' scenario	1,556	4,173	10,479	15,498	17,625

Both point and nonpoint sources are expected to reduce their aggregate (i.e. sum of all individual sources) loading by approximately 50% compared to their respective existing aggregate loading. Table 5 presents estimates of the percent reductions needed above each river index station.

Similar comparison of model simulations indicates that average annual-average SRP concentrations will also be significantly reduced. Table 6 illustrates that overall annual-average concentration reductions ranging from 33% to 61% are predicted by the model, as the average response over multi-year periods, depending on where in the watershed the reductions are calculated. Most of the reduction in annual-average concentration is expected to occur in the middle watershed.

The "preliminary target" established from biological data and analyses was to reduce soluble phosphorus loading above Meridian approximately 50%, in order to attain a similar reduction in annual-average concentration. Tables 4 and 6 show that average total-annual load and average annual-average concentration can both be reduced by approximately 50% at the model output station "Above Meridian," which is the nearest

Table 5. Estimated Gross Loading Reductions Needed To Achieve Target

Percentages below are calculated relative to existing gross loading, and estimate the anticipated average % reductions within watersheds where gross loading originates.

	Above Stephenville	Below Stephenville	Above Meridian	Clifton	Valley Mills
Estimated % reduction of nonpoint source loading	61.68 %	55.31 %	51.50 %	41.10 %	37.54 %
Estimated % reduction of point source loading	0.00 %	66.90 %	62.70 %	57.50 %	50.80 %

The decimal places shown in this table are artifacts of the estimation process, and should not be considered significant.

Table 6. Average Annual-Average Soluble Phosphorus Concentration

	Above Stephenville	Below Stephenville	Above Meridian	Clifton	Valley Mills
From 'Existing' scenario (ppb)	203.3	1,143.2	117.0	52.2	41.3
From 'TMDL-e' scenario (ppb)	114.2	448.1	54.5	30.3	27.5
% reduction	43.83 %	60.80 %	53.42 %	41.95 %	33.41 %

The decimal places shown in this table are artifacts of the estimation process, and should not be considered significant.

to the original monitoring station for which preliminary targets were discussed. This means that the amount of soluble phosphorus that passes Meridian each year after TMDL implementation should be approximately half as much as would have passed there under similar environmental conditions before TMDL implementation.

Some allowance for future growth (AFG) is embodied in these TMDLs. The "future growth" model scenarios incorporated full permitted discharge from WWTPs, the maximum number of dairy cows allowable under current permits and rules with corresponding WAF area, and included a hypothetical 0.6 million gallons per day (MGD) of wastewater discharge to represent potential new industry or municipal growth beyond the capacity of current permits. In addition, the "future" scenarios used human population projections to estimate urban areas 20 years in the future and adjusted urban runoff accordingly. As shown in Figures 4 through 8, TMDL implementation is expected to achieve annual-average SRP concentrations and total-annual net SRP loading that are significantly less than the existing condition, with 20 years of growth and full permitted discharges included.

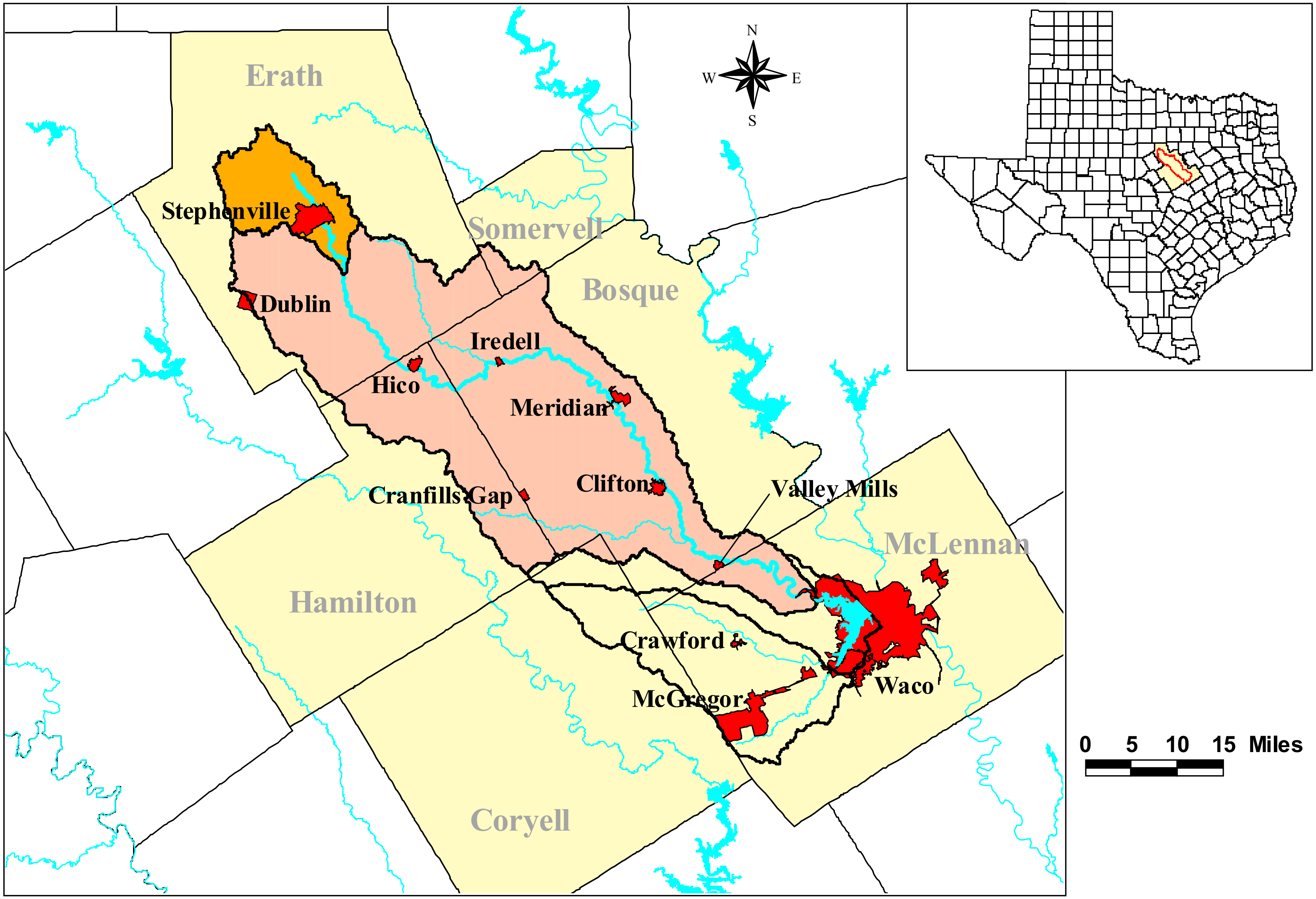
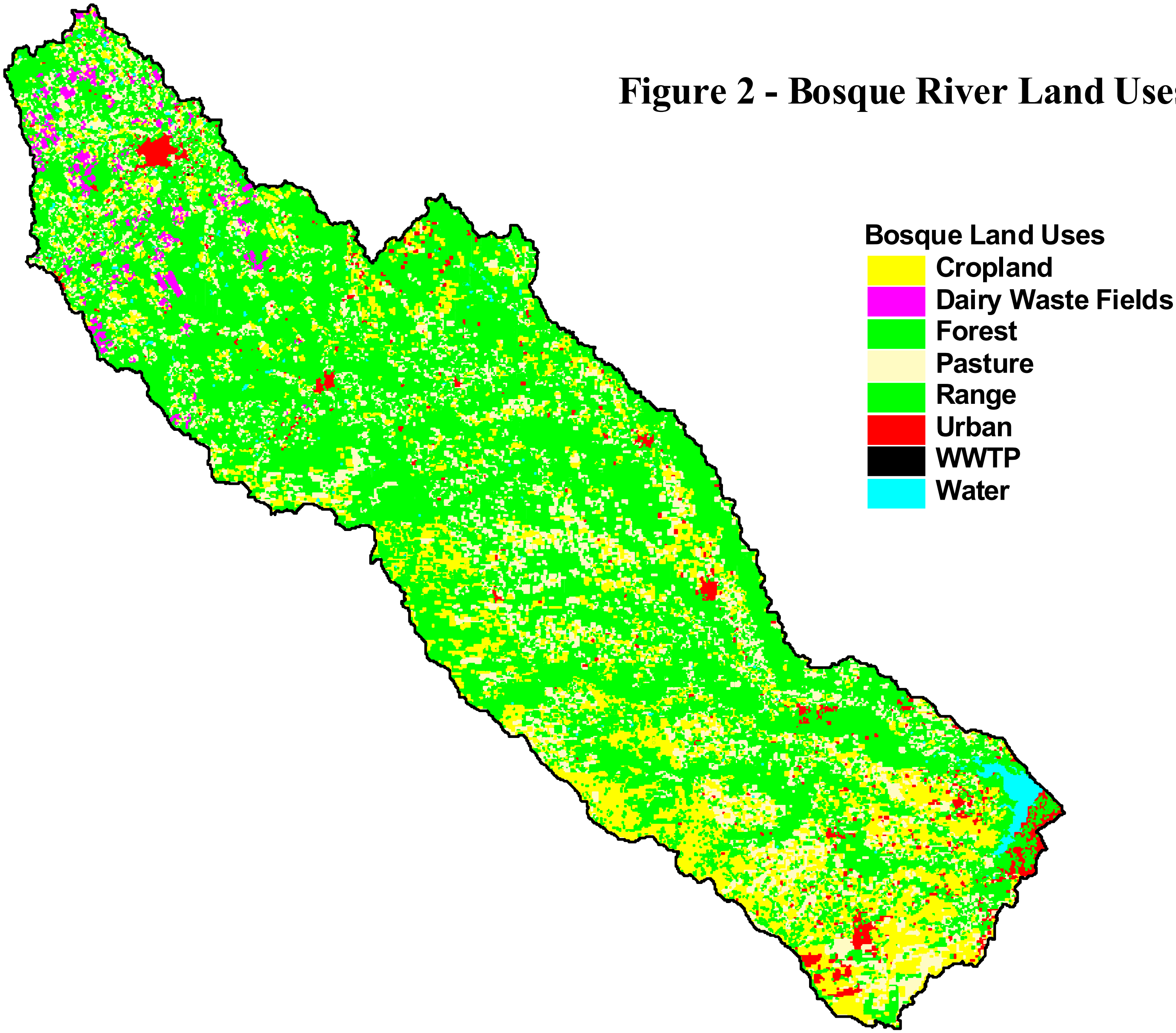
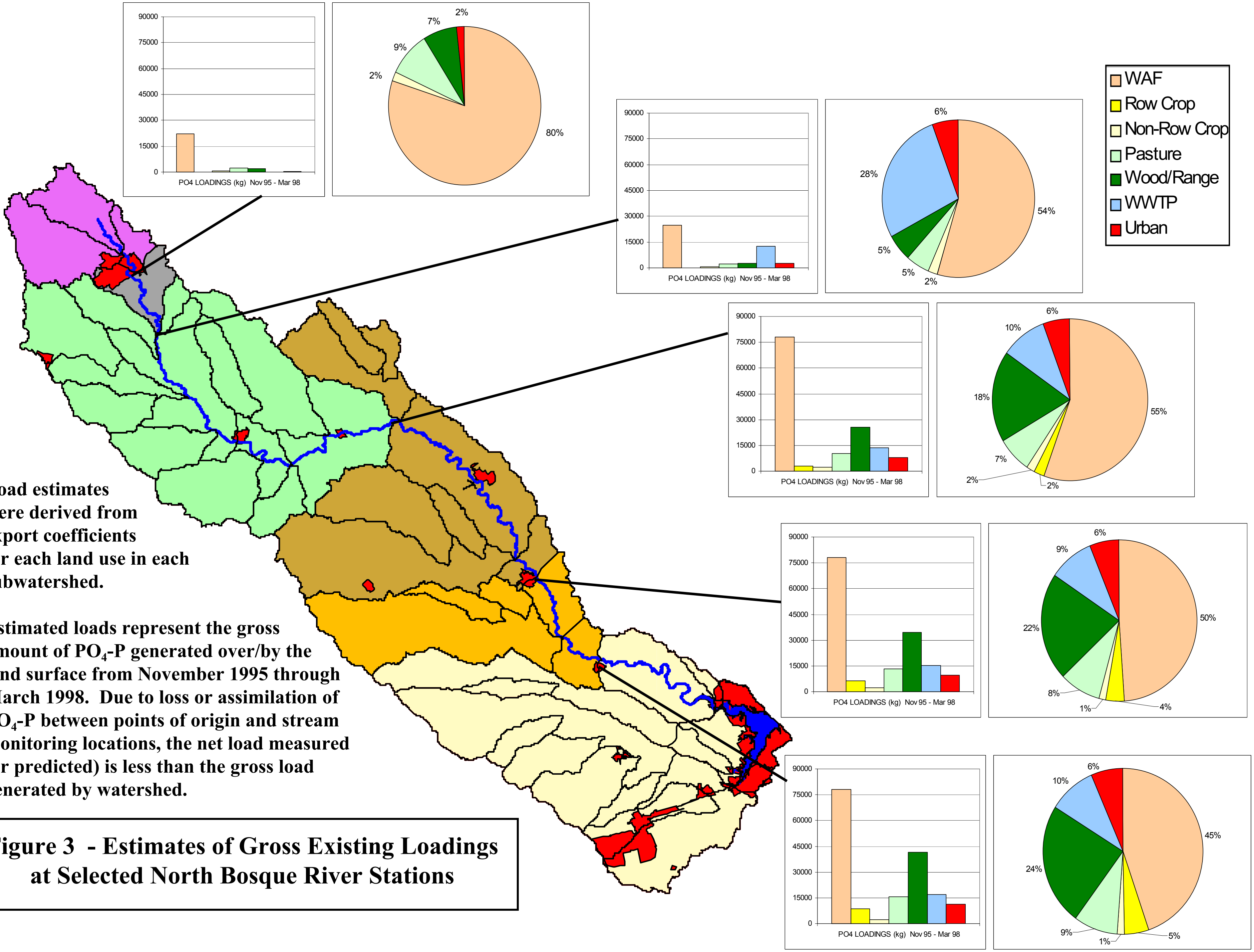


Figure 1 - North Bosque River Watershed

Figure 2 - Bosque River Land Uses





Load estimates were derived from export coefficients for each land use in each subwatershed.

Estimated loads represent the gross amount of PO_4-P generated over/by the land surface from November 1995 through March 1998. Due to loss or assimilation of PO_4-P between points of origin and stream monitoring locations, the net load measured (or predicted) is less than the gross load generated by watershed.

Figure 3 - Estimates of Gross Existing Loadings at Selected North Bosque River Stations

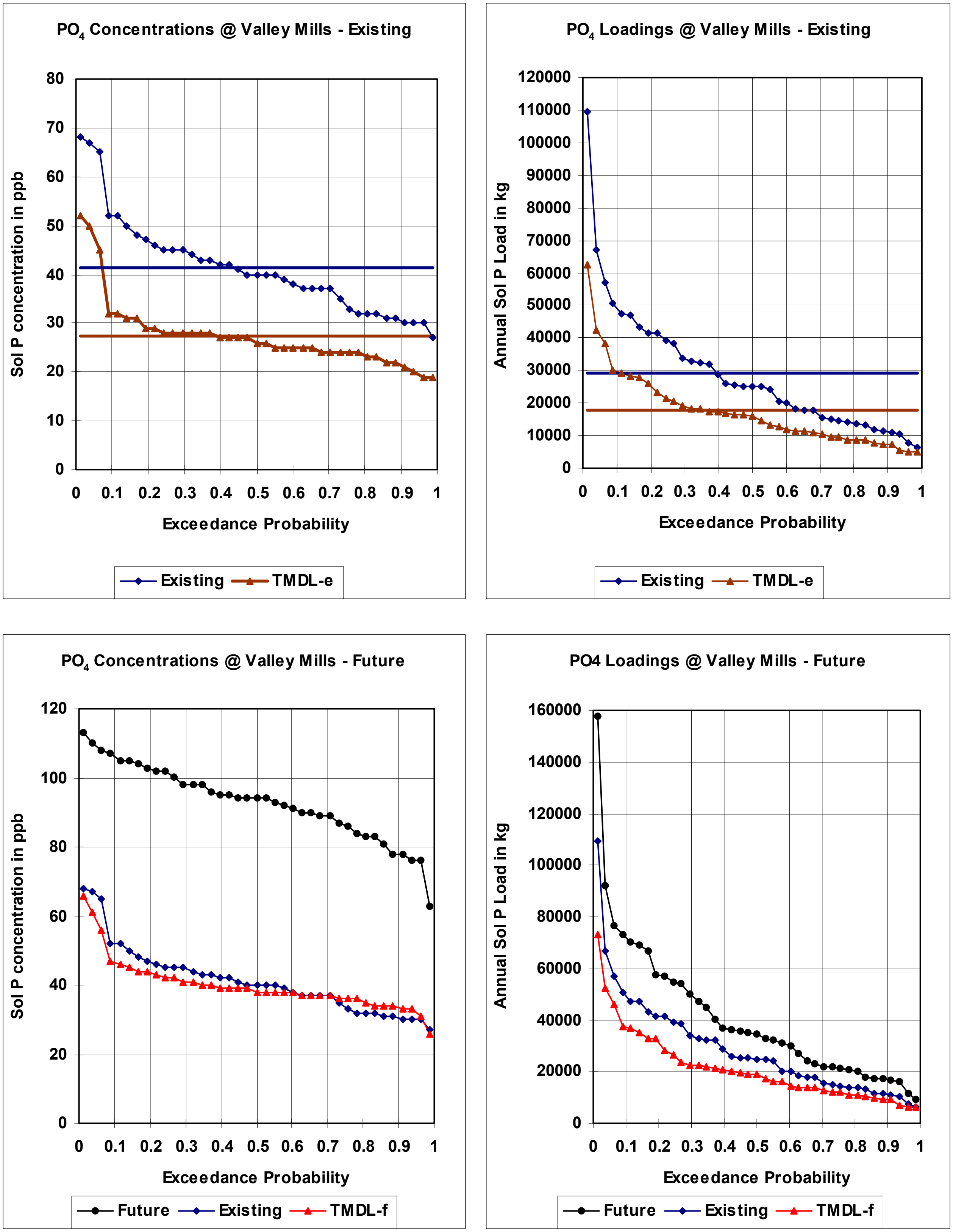


Figure 4 - SWAT Model results at Valley Mills

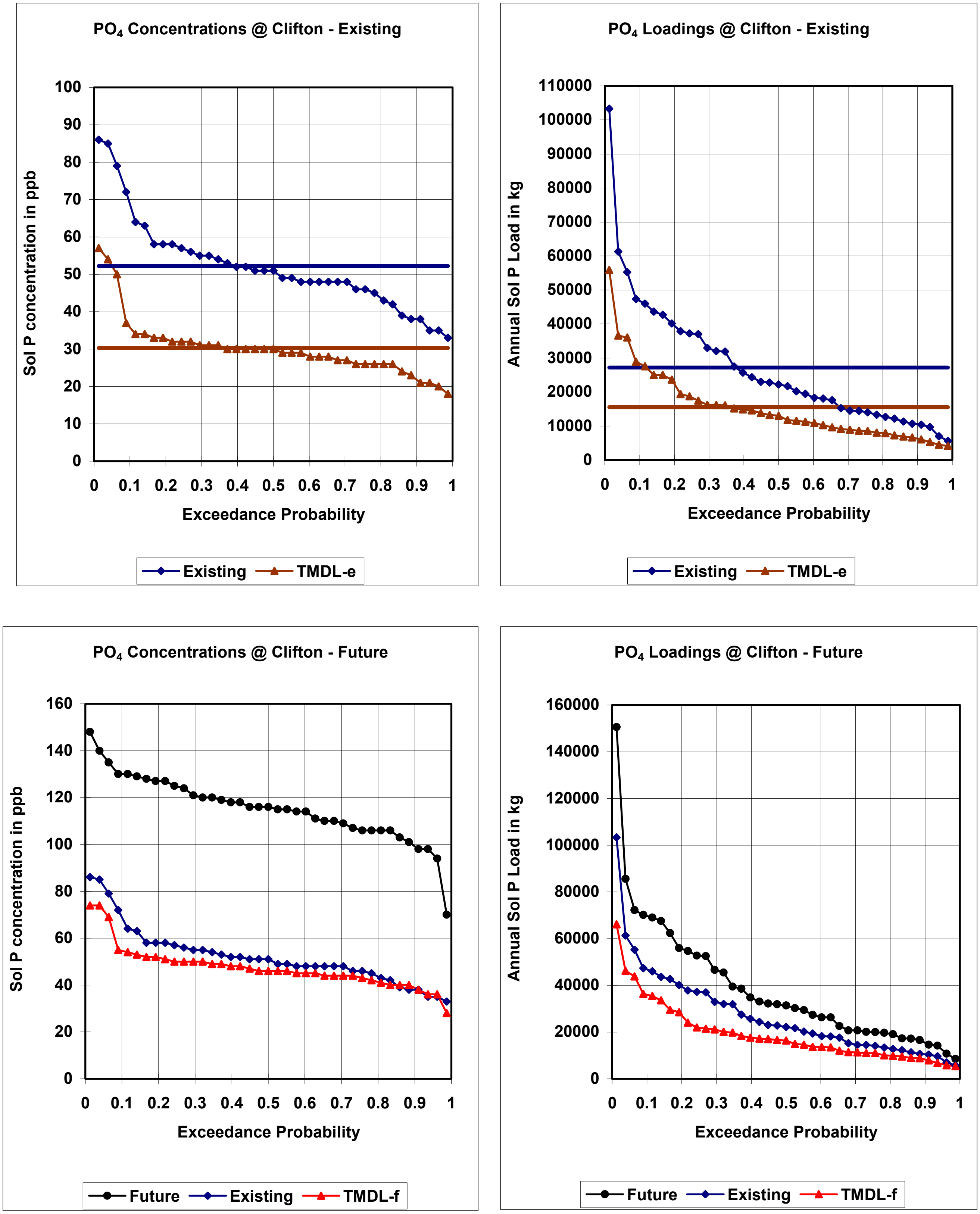


Figure 5 - SWAT Model results at Clifton

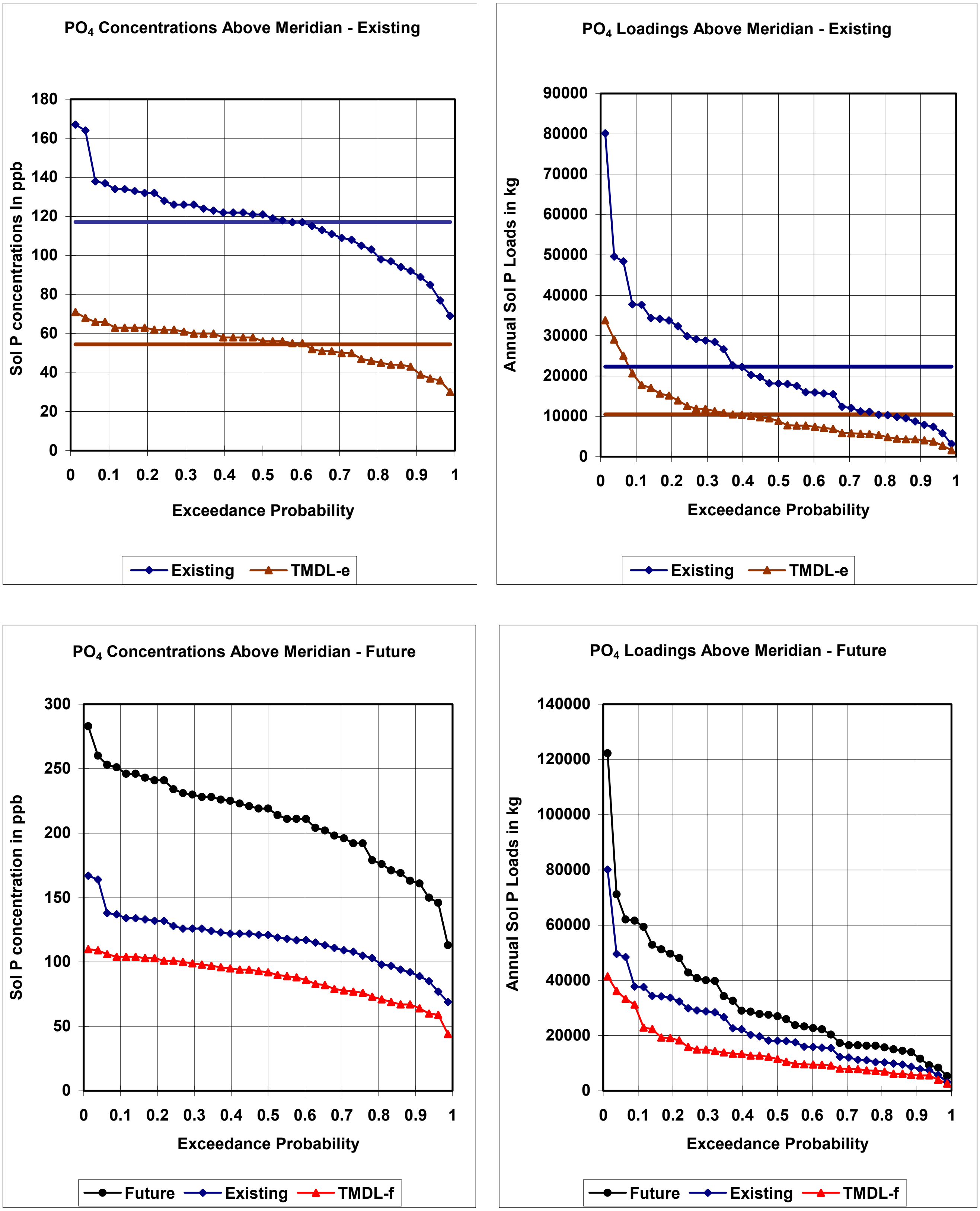


Figure 6 - SWAT Model results Above Meridian

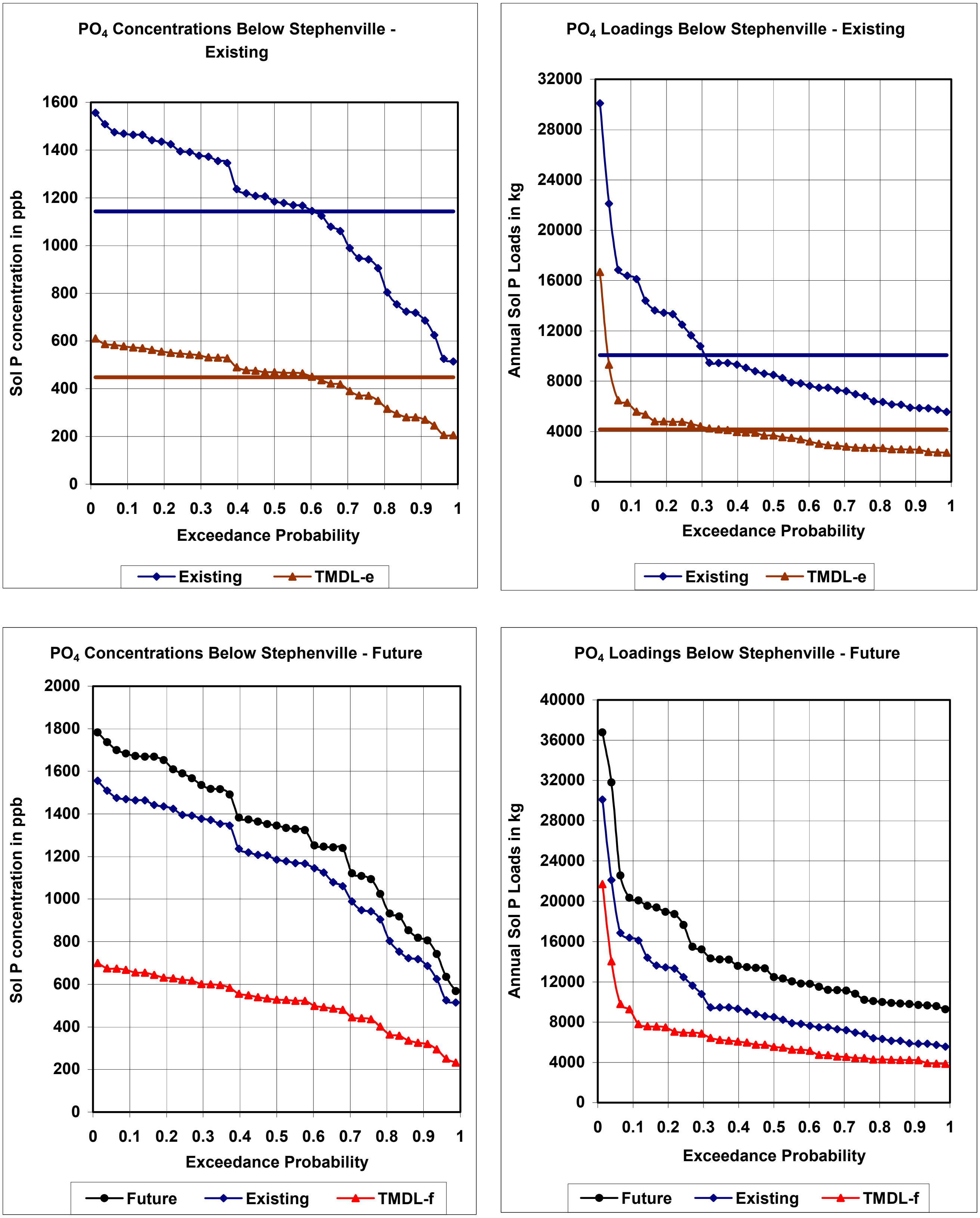


Figure 7 - SWAT Model results Below Stephenville

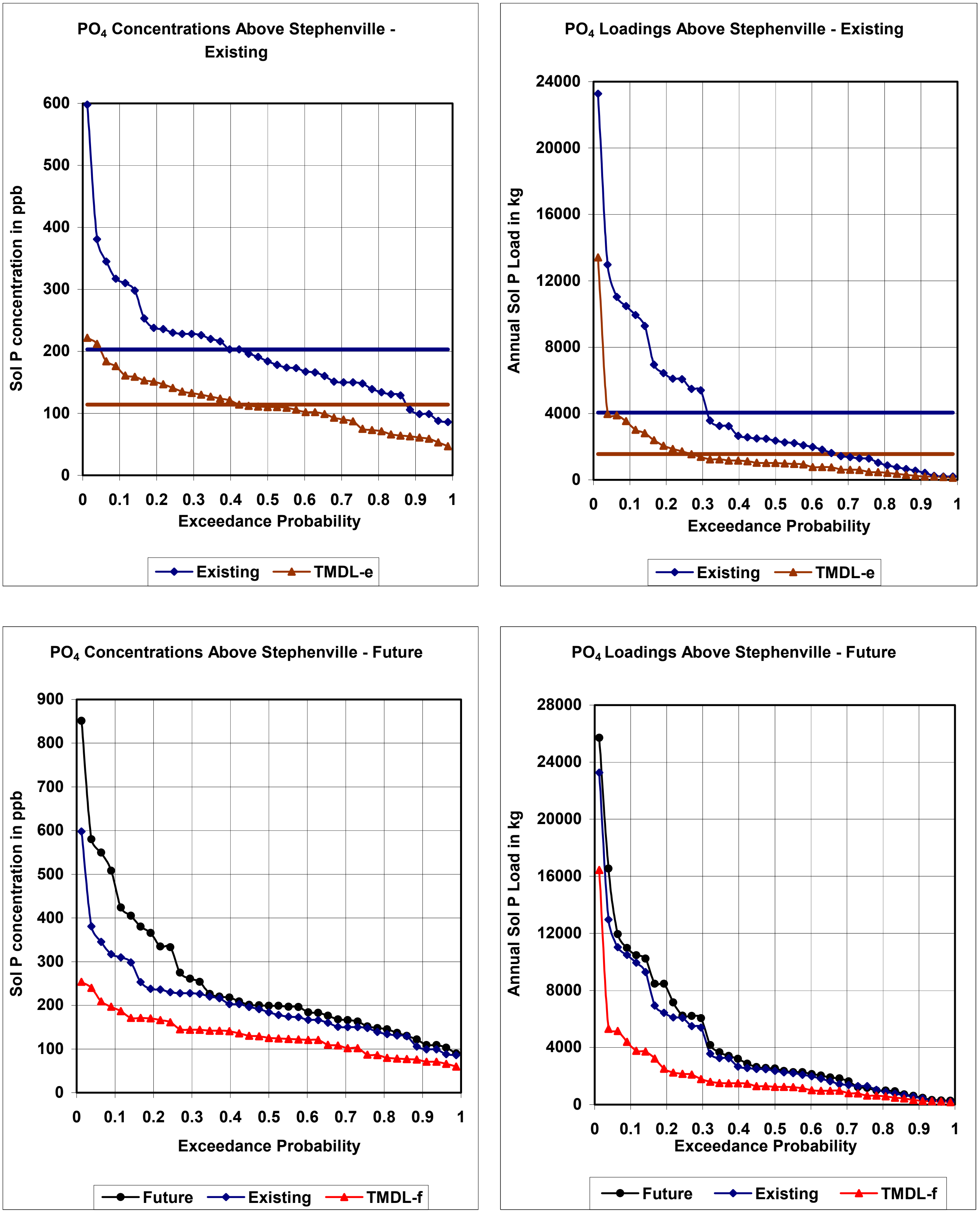


Figure 8 - SWAT Model results Above Stephenville

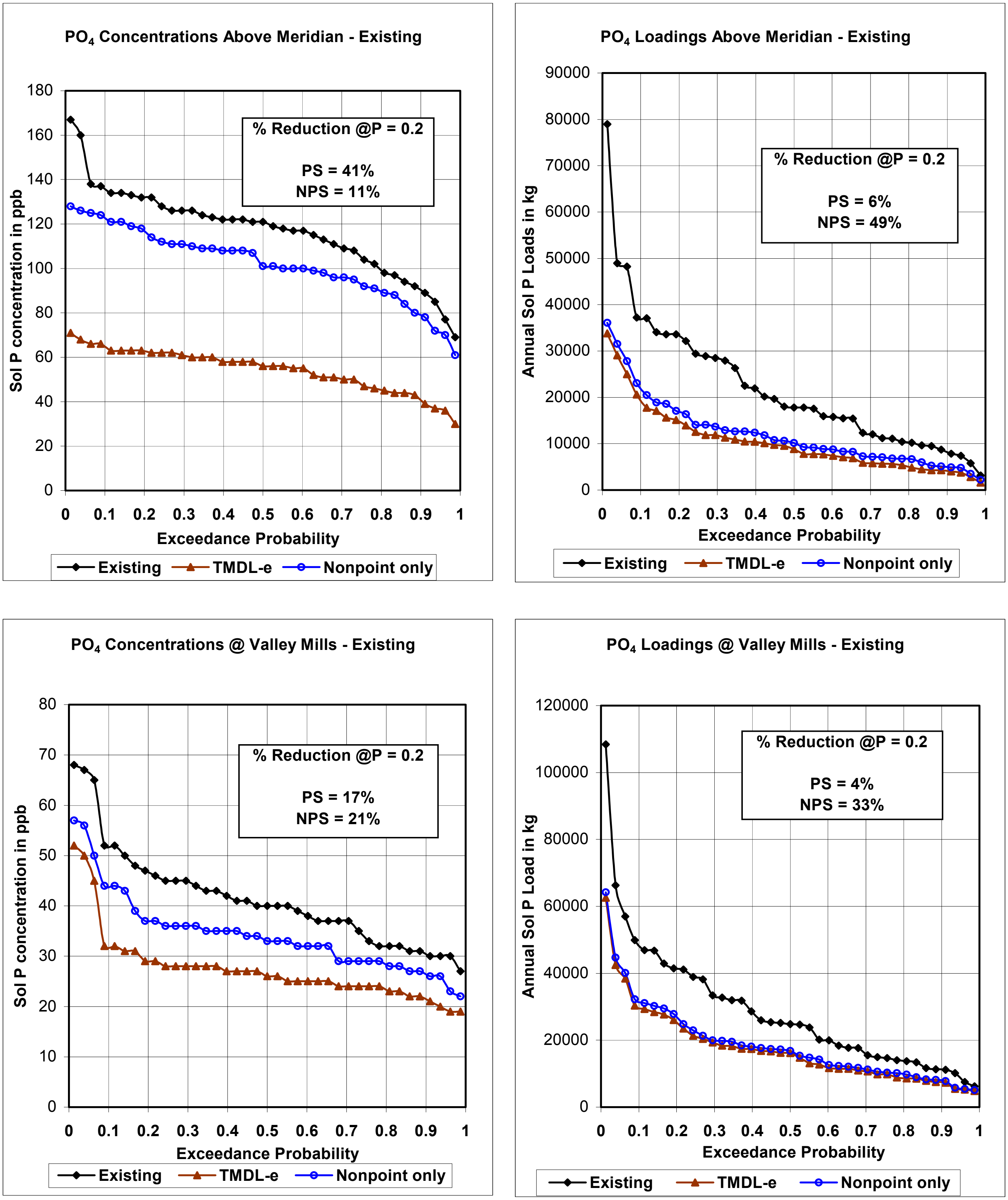


Figure 9 - SWAT Model results for Nonpoint Sources

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