Concho River Watershed Protection Plan

Developed by the Upper Colorado River Authority

Revised May 2011

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LIST OF ACRONYMS

AFO	Animal Feeding Operation
AFY	acre feet per year
AU	Assessment Unit
BMP	Best Management Practice
CAFO	Concentrated Animal Feeding Operation
COSA	City of San Angelo
CRP	Texas Clean Rivers Program
CWA	Clean Water Act
CWQM	Continuous Water Quality Monitoring
DEM	digital elevation model
DO	dissolved oxygen
E&P	exploration and production
EPA	United States Environmental Protection Agency
EQIP	USDA NRCS Environmental Quality Incentives Program
GCD	Groundwater Conservation District
LCRA	Lower Colorado River Authority
LDC	load duration curve
NPS	nonpoint source
NRCS	USDA Natural Resources Conservation Service
OSSF	on-site sewage facility
QAPP	Quality Assurance Project Plan
RRC	Railroad Commission of Texas
SAMFA	San Angelo Museum of Fine Arts
STATSGO	State Soil Geographic Database
SWAT	Soil and Water Assessment Tool
SWCD	Soil and Water Conservation District
SWQM	Surface Water Quality Monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TIAER	Texas Institute for Applied Environmental Research
TMDL	Total Maximum Daily Load
TPWD	Texas Parks and Wildlife Department
TSS	total suspended solids
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
UCRA	Upper Colorado River Authority
USACE	United States Army Corp of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WPP	watershed protection plan

EXECUTIVE SUMMARY

The Concho River Watershed consists of approximately 4.2 million acres located in all or parts of fourteen arid and semi-arid counties in west central Texas. A total of 12 TCEQ designated stream segments, 27 assessment units, and 40 active and/or historic sampling stations are located within its boundary.

In August 2004, the Texas State Soil and Water Conservation Board (TSSWCB) and the Upper Colorado River Authority (UCRA) entered into an agreement regarding a voluntary effort to assess water quality in the Concho River Watershed, primarily through the continuation of existing monitoring that was being conducted by UCRA in its affiliation with the Texas Clean Rivers Program and monitoring and research that UCRA was conducting in conjunction with the North Concho Pilot Brush Control Project.

From this genesis, an advisory committee, composed of local stakeholders, and state and local agency personnel was formed to ensure that the planning and development of the Concho River Watershed Protection Plan would be a locally driven process.

Status of 303(d) and 305(b) Listings

When this process began, one assessment unit, 1421_07, was included on the 303(d) list of impaired water bodies. It is an approximately 3 mile stretch of the Concho River located immediately west of the City of San Angelo. The listing was due to an impaired macrobenthic community. Based on a recent study by USGS, although there has been modest improvement, it still fails to meet the criteria for delisting.

In 2008 assessment unit 1421_08 was placed on the 303(d) list for bacteria and depressed oxygen levels. It consists of the North Concho River from Bell Street Lake to O.C. Fisher Dam in the City of San Angelo. Based on evaluation of monitoring data conducted for the WPP, the bacteria impairment has been attributed to avian causes. The depressed oxygen levels are attributable to urban runoff and low flows. One of the BMPs recommended in the WPP, dredging of the river channel and bank stabilization, is currently being implemented. Additional data in the form of bacterial source tracking needs to be performed to verify the attribution to avian sources.

Also in 2008, Assessment Unit 1425_01, which consists of O.C. Fisher Lake, was placed on the 303(d) list for elevated chlorides. Because the elevated chlorides are attributable to extremely low lake levels that serve to concentrate chlorides, it has since been de-listed.

With the exception of Kickapoo Creek and Lipan Creek, the entire Concho River from Paint Rock to the Lake Nasworthy and O.C. Fisher dams is included on the 305(b) list of water quality concerns. These listings are mostly for excess nutrients and chlorophyll-a and low dissolved oxygen levels which are associated with excess nutrients and low flows. Based on monitoring data, it is considered likely that Lipan Creek will be listed in the future as a concern for nitrates.

No regulatory water quality stream standards for nutrients currently exist, but are currently in the development process. Based on the evaluation of existing data and watershed characteristics, when regulatory standards are enacted for nutrients, it is likely that this stretch of the Concho River will be listed as impaired. BMPs recommended in the WPP are aimed at increasing base flows and reducing nitrate contributions, both of which are needed remedies to improve the excess nutrient and low dissolved oxygen and associated concerns.

Both Twin Buttes Reservoir and O.C. Fisher Lake are also on the list of concerns for nutrients. The data acquisition and evaluation performed during development of the WPP failed to attribute a cause. Dove Creek and the North Concho River at the Sterling County line are each listed for depressed oxygen levels. Each of these is likely attributable to low flows. The cause of the bacteria concern at the North Concho River at the Sterling County line was not determined.

Water Quality Assessment Results Elsewhere in the Watershed

Evaluation of water quality in the remainder of the watershed is good to excellent, except for low base flows.

The prevalent concerns voiced by local stakeholders were worries over potential saltwater contamination, low stream flows, private landowner rights, and the condition of the river through San Angelo. There is a common concern that voluntary efforts could turn into regulator heavy handedness.

Many of the BMPs focus on enhancing stream flows and protecting them not only from potential saltwater contamination, but also from contamination caused by urban runoff.

Education and Outreach

The Water Education Center continues to reach large numbers of not only school age youth, but also adults. Virtually all stakeholders recognized the extreme value of education efforts. By serving as a vehicle for implementation of the recommended BMPs and continual education programs, the Center is a key component of the Concho River Watershed Protection Plan.

Final Thoughts

Several data gaps and data needs were identified during the WPP planning process. Undoubtedly, the use of modeling tools would have been useful for providing better predictions of the efficacy and cost analysis of recommended BMPs.

It is encouraging that implementation of some of the BMPs is progressing. Also, the stakeholder group continues to be actively engaged and motivated in the pursuit of implementation of the remaining recommended BMPs. The ultimate goal is for complete implementation of the WPP and the continued evaluation of data acquired through existing programs to not only make progress on recommended BMPs, but also to identify and deal with new water quality challenges as they become know.

1.0 INTRODUCTION

The purpose of the Concho River Watershed Protection Plan is to identify and evaluate existing and potential sources of nonpoint source pollution and to develop a set of best management practices (BMPs) that have the highest likelihood for voluntary implementation.

Significant keys to the generation of an effective watershed protection plan are the solicitation and acquisition of public input early in the planning process, the aggregation of that input for use in defining the scope of the assessment effort, and the integration of it into the final plan. Upper Colorado River Authority (UCRA) staff identified interested parties and stakeholders and formed a stakeholder advisory group. The stakeholder group is comprised of individuals from local governmental agencies, local citizens, landowners, local business people, academia, and members of the Upper Colorado River Basin Steering Committee of the Texas Clean Rivers Program (CRP). The scope of the watershed planning effort was defined with inputs from the stakeholder advisory group based on their knowledge, experience, and concerns.

The Texas Commission on Environmental Quality (TCEQ) has designated the state's rivers and water bodies into various stream segments. Stream segment numbers refer to streams and water bodies that have been individually defined by the TCEQ and assigned unique identification numbers. Some stream segments are further divided into assessment units (AUs). Each segment designation is intended to have relatively homogeneous chemical, physical, and hydrological characteristics and provides the basic unit for assigning site-specific standards and for applying water quality management programs of the TCEQ. Classified waters include most rivers and their major tributaries, major reservoirs and lakes, and estuaries. Unclassified waters are those smaller water bodies and streams that typically do not have site-specific water quality standards assigned to them, but instead are protected by general standards that apply to all surface waters in the state. The Concho River Watershed stream segment designations and descriptions are included in Table 1.

Table 1. Concho River Watershed Designated Stream Segments

Concho River Watershed TCEQ Designated Stream Segments		
Segment ID	**Name**	**Segment Description**
1421	Concho River	From a point 2 km (1.2 miles) above the confluence of Fuzzy Creek in Concho County to San Angelo Dam on the North Concho River in Tom Green County and to Nasworthy Dam on the South Concho River in Tom Green County
1421A	Dry Hollow Creek	From the confluence with the Concho River west of Paint Rock in Concho County to the headwaters at US 87
1421B	Kickapoo Creek	From the confluence with the Concho River west of Paint Rock in Concho County to the headwaters northwest of Eden
1421C	Lipan Creek	From the confluence with the Concho River west of Paint Rock in Concho County to the headwaters near RR 1223 in Tom Green County

Concho River Watershed TCEQ Designated Stream Segments		
Segment ID	**Name**	**Segment Description**
1422	Lake Nasworthy	From Nasworthy Dam in Tom Green County to Twin Buttes Dam in Tom Green County, up to the normal pool elevation of 1872.2 feet (impounds South Concho River); From a point 2 km (1.2 miles) above the confluence of Fuzzy Creek in Concho County to San Angelo Dam on the North Concho River in Tom Green County and to Nasworthy Dam on the South Concho River in Tom Green County
1423	Twin Buttes Reservoir	From Twin Buttes Dam in Tom Green County to a point 100 meters (110 yards) upstream of US 67 on the Middle Concho River Arm in Tom Green County and to a point 4.0 km (2.5 miles) downstream of FM 2335 on the South Concho River Arm in Tom Green County, up to the normal pool elevation of 1940.2 feet (impounds the Middle Concho River and the South Concho River)
1423A	Spring Creek	From the confluence of Twin Buttes Reservoir south of Tankersley in Tom Green County to the upstream perennial portion of the stream northeast of Ozona in Crockett County
1423B	Dove Creek	From the confluence with Spring Creek above Twin Buttes Reservoir to the headwaters near FM 1828 in Schleicher County
1424	Middle Concho/South Concho River	From a point 4.0 km (2.5 miles) downstream of FM 2335 in Tom Green County, and from a point 100 meters (110 yards) upstream of US 67 in Tom Green County to the confluence of Three Bluff Draw and Indian Creek on the Middle Concho River in Reagan County
1424A	West Rocky Creek	From the confluence of Middle Concho River to the upstream perennial portion of the stream north of Mertzon in Irion County
1425	O.C. Fisher Lake	From San Angelo Dam in Tom Green County up to normal pool elevation of 1908 feet (impounds North Concho River)
1425A	North Concho River	From the headwaters of O.C. Fisher Lake near San Angelo in Tom Green County upstream to the Glasscock/Howard County Line

To satisfy the requirements of federal Clean Water Act Sections 303(d) and 305(b), the Texas Commission on Environmental Quality assesses Texas surface water quality every two years and reports their findings to the U.S. Environmental Protection Agency. The assessment is derived from routine water quality monitoring conducted throughout the state. The report contains the 303(d) list (impaired water bodies) and the 305(b) list (water bodies with water quality concerns). The water bodies located in the Concho River Watershed included in the 2008 assessment, for which impairments or concerns have been identified, are included in Tables 2 and 3 below.

Table 2. Concho River Watershed 2008 303(d) List of Water Quality Impairments

Concho River Watershed 2008 303(d) List of Water Quality Impairments				
Name	**Assessment Unit**	**Parameter of Concern**	**Category**	**Yr Listed**
Concho River	1421_07	impaired macrobenthic community	5c	2002
Concho River	1241_08	bacteria	5c	2008
		depressed oxygen levels	5c	2008
O.C. Fisher Lake	1425_01	chloride	5c	2008
5c - Indicates Additional data and information will be collected before a TMDL is scheduled				

Table 3. Concho River Watershed 2008 305(b) List of Water Quality Concerns

Concho River Watershed 2008 305(b) List of Water Quality Concerns			
Name	**Assessment Unit**	**Parameter of Concern**	**Category**
Concho River	1421_01	chlorophyll-a	CS
Concho River	1421_02	nitrate	CS
		orthophosphorus	CS
Concho River	1421_03	orthophosphorus	CS
		chlorophyll-a	CS
		depressed oxygen levels	CS
		nitrate	CS
Concho River	1421_04	nitrate	CS
		chlorophyll-a	CS
Concho River	1421_05	nitrate	CS
Concho River	1421_06	depressed oxygen levels	CS
		nitrate	CS
		orthophosphorus	CS
Concho River	1421_07	chlorophyll-a	CS
		depressed oxygen levels	CS
Concho River	1421_08	chlorophyll-a	CS
Concho River	1421_09	depressed oxygen levels	CS
Dry Hollow Creek	1421A_01	nitrate	CS
Twin Buttes Reservoir	1423_01	nitrate	CS
		orthophosphorus	CS
Twin Buttes Reservoir	1423_02	orthophosphorus	CS
Dove Creek	1423B_01	depressed oxygen levels	CS
O.C. Fisher Lake	1425_01	ammonia	CS
		chlorophyll-a	CS
		orthophosphorus	CS
		total phosphorus	CS
North Concho River	1425A_02	bacteria	CN
		depressed oxygen levels	CS
CS - indicates concern for near non-attainment of water quality standard CN - indicates concern for screening level standard			

These listed impairments and concerns are addressed in the relevant assessment area evaluations included in Section 5 of the Watershed Protection Plan as described below.

Because of the size of the Concho River watershed and the hydrologic partitioning created by the emplacement of various dams, the watershed was divided into six assessment areas designated A, B, C, D, E, and F (Figure 9). The assessment areas were delineated based on logical divisions of the watershed according to hydrologic function and land use. The known and identified water quality issues and threats determined the amount and type of investigative work and analysis performed in each assessment area.

Where applicable, load duration curves were constructed and analyzed for determining load reduction goals. Load duration curves provide an effective graphical analytical tool that illustrates the relationship between stream flow and water quality relative to a particular parameter. They may also provide information to differentiate between nonpoint source and point source pollution. In some cases the seasonality of when problems are occurring may also be discerned. Probably the most meaningful use of load duration curves is the ability to calculate percent reduction goals needed to meet water quality standards.

In areas where availability of meaningful flow data from which to construct useful load duration curves was lacking, various graphical charts were generated. These illustrate pollutant concentrations and the relevant water quality standard or screening level (and in some cases, other parameters) to discern possible relationships between certain parameters and water quality.

Some water quality issues occur in all or almost all assessment areas while others are confined to individual areas. Each assessment area was individually evaluated using the best available data sources for analysis.

Data sources used in the development of the Concho River Watershed Protection Plan include:

- Hydrologic modeling results from Texas State Soil and Water Conservation Board (TSSWCB) funded brush control feasibility studies
- Various pertinent papers and publications
- Stream flow data from U.S. Geological Survey gaging stations,
- CRP water quality and stream flow data
- TCEQ Surface Water Quality Monitoring Information System (SWQMIS) database
- Water quality data from U.S. Environmental Protection Agency (EPA) funded urban NPS pollution BMP effectiveness monitoring
- Groundwater elevation and water quality data from groundwater conservation districts
- OSSF Permitting Records of Tom Green County
- Texas Railroad Commission data and records, TCEQ complaint, enforcement and permit records

- TSSWCB brush treatment certification records
- TSSWCB Water Supply Enhancement Program hydrologic response monitoring data
- UCRA complaint data and records

The Watershed Protection Plan development process entailed the integration of existing databases with newly acquired data collected from the extension and expansion of existing hydrologic monitoring programs and the origination of data collection projects designed specifically for the Watershed Protection Plan.

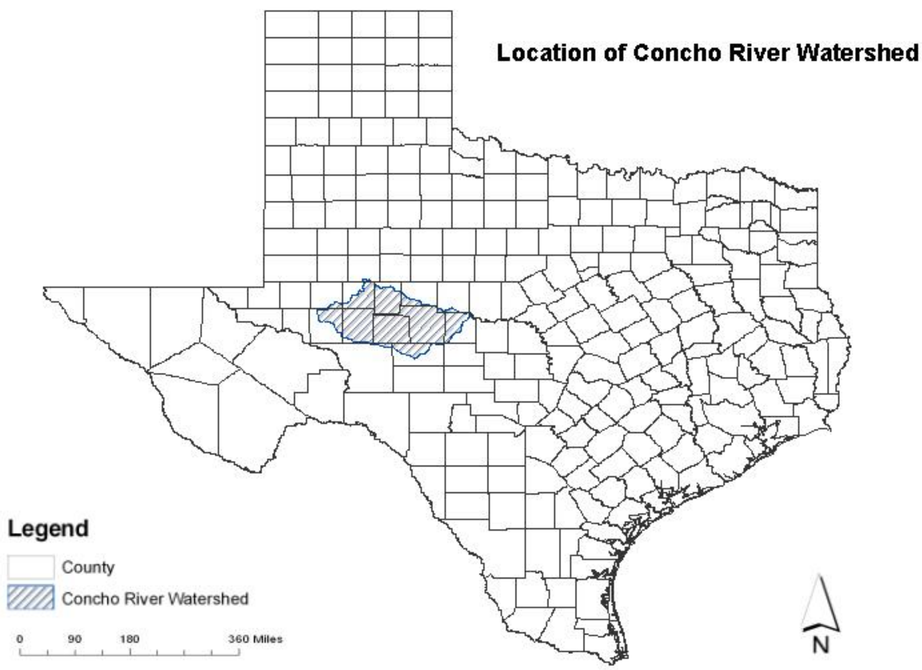
The location of impacts and problems were identified not only from the analyses of these data, but also from observational information, knowledge of the investigators and input of the stakeholders. Where applicable, pollutant loadings were estimated and pollutant load reduction goals were determined. From these efforts, various management strategies to address identified issues were considered and BMPs were developed.

Specific BMPs or groups of BMPs selected for each assessment area were arrived at through a process of comparative analysis. In most cases, for each nonpoint source pollution issue, a set of several potential BMPs was conceptually developed. Subsequently, they were comparatively analyzed to arrive at the final selection(s). The set of analysis and selection criteria included construction and/or maintenance costs, likelihood of implementation, environmental effects, efficacy in dealing with the problem, public acceptability, availability of willing project sponsors and/or managers, etc.

2.0 WATERSHED DESCRIPTION

The Concho River watershed is located northwest of the geographical center of Texas. It encompasses all of Tom Green and Irion Counties and portions of twelve surrounding counties. It is approximately 4.2 million acres in size (Figure 1).

Figure 1. Watershed Location Map



2.1 HISTORY

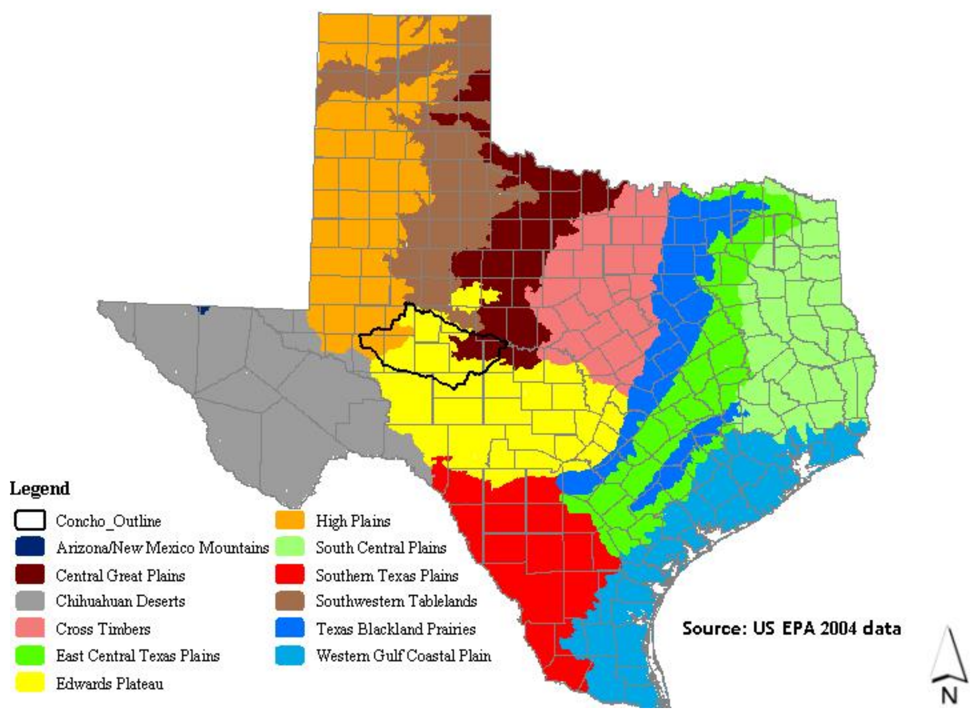
“For thousands of years the land and water of Concho River Watershed has responded to human influence. Until the mid-nineteenth century, Native Americans and the buffalo they hunted, dominated the hills and valleys of the Concho River. Over the course of two decades, roughly 1860 to 1880, the U.S. Army occupied forts along the West Texas frontier, hide hunters decimated the great southern buffalo herd, and the Texas Rangers, in cooperation with ranchers and the U.S. Army, drove the Native Americans from the region. During the late 1800’s, cattle and sheep ranching became a major industry in the Concho River watershed and surrounding areas. By the early 1900’s irrigation companies began to divert water from the rivers to grow crops, and windmills began to tap the watersheds shallow ground water for livestock and human consumption”. (Jones, 2005)

Archives of the early Texas Almanac describe the counties of the watershed and cited the abundant surface and ground water along with the agricultural and recreational value of that water resource. Cities and towns emerged throughout the basin, with San Angelo located at the confluence of the North and South Concho Rivers. This community was (and is) the largest and has had the greatest impact on the water resources of the Concho River basin. In the early to mid-twentieth century, Tom Green County residents could boast of living in the county with the most miles of running water in the state. This included the South Concho, which has the distinction of being the only river in Texas that flows due North. Historic overgrazing of the range and suppression of range fires ultimately led to dramatic ecological changes within the watershed as the area changed from predominately grassland prairies to brush infested rangeland. Many springs dried up and once perennial creeks and streams ceased to flow. Urban development and agricultural utilization throughout the 20th Century has resulted in various environmental threats and/or concerns described in this Watershed Protection Plan.

2.2 HYDROGRAPHIC DESCRIPTION

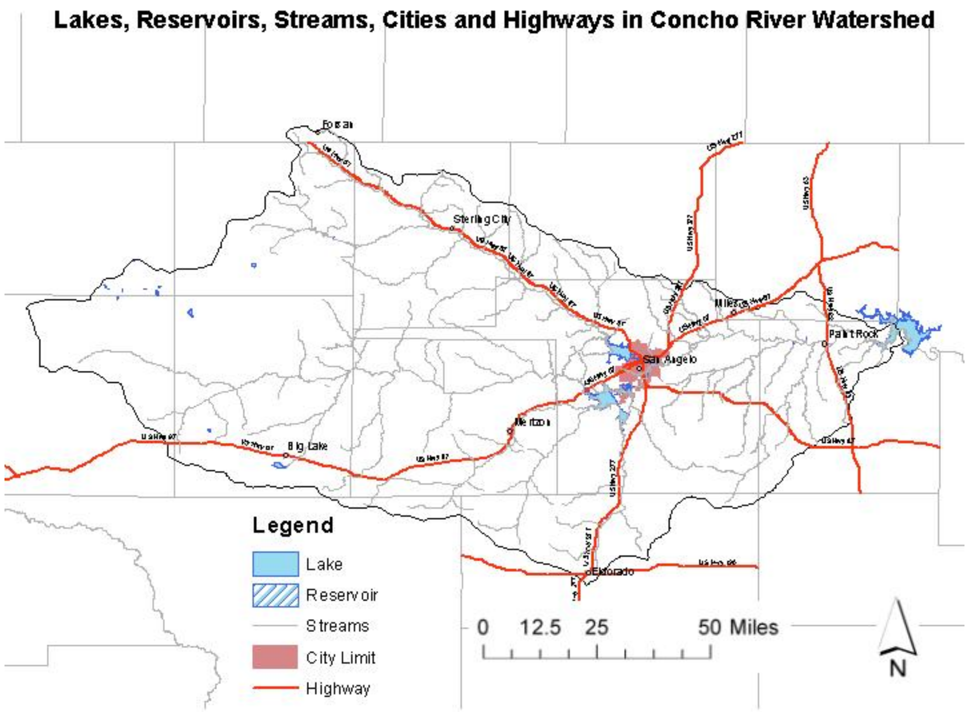
The Concho River watershed is situated at the convergence of the High Plains, the Rolling Plains and Edwards Plateau regions of Texas (Figure 2). It is bordered on its west by the Trans Pecos region.

Figure 2. Texas EcoRegions Map



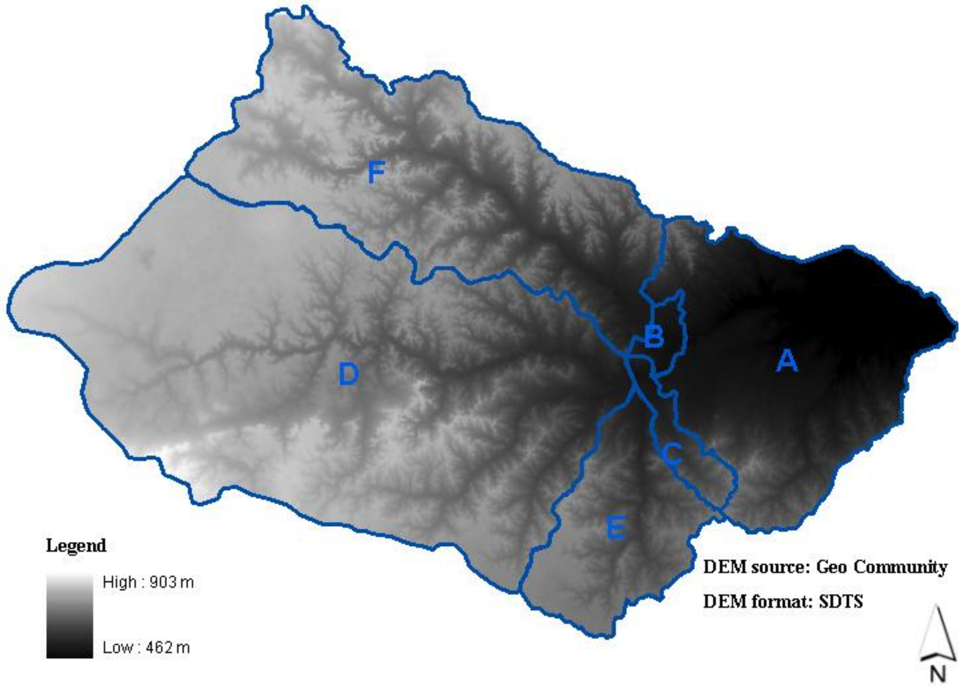
The Concho River, a tributary of the Colorado River flows generally west to east and its watershed encompasses all of Irion County, almost all of Tom Green County, large portions of Reagan and Sterling Counties, over half of Glasscock County, and smaller portions of Concho, Runnels, Coke, Schleicher, Howard, Midland, Upton, and Crockett Counties, and a very small area of the northwest corner of Menard County, fourteen counties in all (Figure 3).

Figure 3. Watershed Geography Map



The highest point of the watershed is located at its northernmost boundary in Howard County (2,900 ft) and the lowest point is at the watershed's drainage outlet, O.H. Ivie Reservoir in Concho County (1,550 ft). This is an elevation differential of over 1300 ft (Figure 4). The areal extent of the watershed is approximately 4.2 million acres.

Figure 4. Watershed DEM Map



The principal rivers in the watershed consist of the North Concho River (northwest to southeast flow), the Middle Concho River (west to east flow), the South Concho River (south to north flow) and the main Concho River (west to east flow). The confluence of the Middle Concho River with the South Concho River is located at Lake Nasworthy in west San Angelo. The South Concho River continues below Lake Nasworthy to its confluence with the North Concho River above Bell Street Dam in east San Angelo forming the Concho River, which continues east to O.H. Ivie Reservoir.

Significant drainage features and tributaries of the North Concho River include Lacy Draw, Sterling Creek, and Mulberry Creek on the south side of the river and Walnut Creek, Chalk Creek and Grape Creek on the north side of the river.

Centralia Draw and several other drainage features join in east Reagan County to form the Middle Concho River. The principal drainage features and tributaries of the Middle Concho River include Indian Creek, Kiowa Creek, West Rocky Creek and Rocky Creek on the north side of the river and Spring Creek and Dove Creek on its south side.

The main drainage features and tributaries of the South Concho River are Bois D'Arc Draw on its west side and Dry Creek and Pecan Creek on its east side.

The principal drainage features and tributaries of the main Concho River on its north side include Red Creek, Crow's Nest Creek, Willow Creek, Little Concho Creek and Fuzzy Creek.

South of the river, the main drainage features and tributaries are Lipan Creek, Dry Creek, Kickapoo Creek, Hog Creek and Duck Creek.

Three major reservoirs are located within the North Concho River watershed. They consist of O.C. Fisher Lake, Twin Buttes Reservoir and Lake Nasworthy.

O.C. Fisher Lake impounds the North Concho River and is located adjacent to the northwest city limit of San Angelo.

Twin Buttes Reservoir is located southwest of San Angelo's city limit. It consists of the North Pool and the South Pool and an equalization channel between the two. The North Pool impounds the Middle Concho River and its two main tributaries, Spring Creek and Dove Creek. The South Pool impounds the South Concho River.

Lake Nasworthy is a commercially and residentially developed lake located immediately below the Twin Buttes Reservoir dam within the city limits of San Angelo. It is operated as a constant level lake through controlled releases from Twin Buttes Reservoir and uncontrolled stream flow from Pecan Creek.

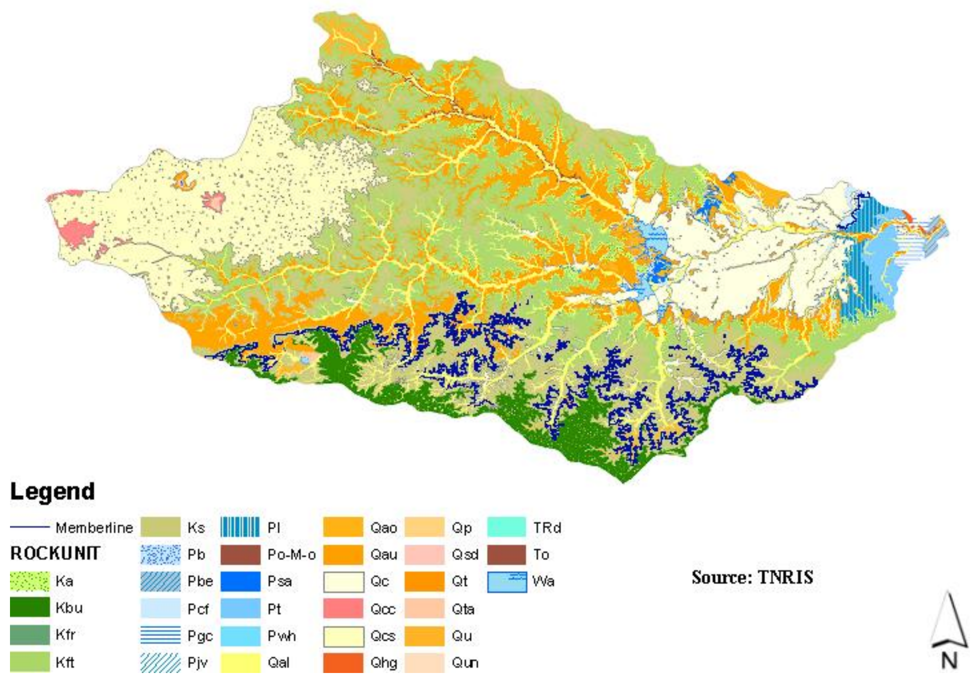
O.H. Ivie Reservoir is located at the drainage outlet and downstream terminus of the watershed near the community of Paint Rock in Concho County. It is a major public water supply reservoir operated by the Colorado River Municipal Water District, which supplies water to its member cities of Odessa, Snyder, and Big Spring and to the contract cities of Midland, San Angelo, and Abilene. Together, these four reservoirs comprise a significant public water supply for approximately one half million West Texas residents.

2.3 GEOLOGY

Geological Description

The geologic formations exposed at the surface within the Concho River Watershed predominantly consist of approximately equal areal extents of Quaternary and Cretaceous sedimentary deposits and less extensive areas of Permian sedimentary deposits (Figure 5).

Figure 5. Watershed Surface Geology Map



Large areas of predominantly Quaternary deposits are located at the westernmost and easternmost portions of the watershed. In the west portion of the watershed, which is located near the margins of the High Plains (Llano Estacado) and the Edwards Plateau, a thin veneer of eolian deposited Quaternary sands overlie Cretaceous limestones. East of San Angelo, Quaternary alluvial deposits are exposed over a broad floodplain known as the Lipan Flats. In the central portion of the watershed, Quaternary Alluvium is deposited along the major rivers, tributaries and drainage features.

The Quaternary alluvial deposits in the Lipan Flats east of San Angelo area are known as the Leona Formation. This formation is composed of up to approximately 100 ft of primarily caliche, gravel, fine sands and clays. The Lipan Aquifer, a designated Minor Aquifer of Texas, consists of the Leona Formation and the underlying Permian aged Clear Fork Group.

The Quaternary Alluvium in the central portion of the watershed consists of mainly floodplain and terrace deposits of sands, silts, gravels, and caliche. These alluvial floodplain deposits overlie and are in contact with Cretaceous rocks and to a lesser extent, Permian rocks at locals where paleo-highs existed on the erosional, undulated Permian surface. These floodplain and terrace deposits are present in the broad erosional valleys that have been incised into Cretaceous deposits by the major rivers and tributaries of the watershed. Quaternary alluvial deposits are also present in the form of gently sloping alluvial fans situated along the margins of the limestone hills.

The Cretaceous rocks in the central portion of the watershed consist of the Edwards Group (mostly limestones) and the Antlers Formation (mostly clastic sediments). Lithologically, the Edwards Group consists of light to dark gray, grayish brown, massive to thinly bedded limestones and dolomites interbedded with clays, shales, and irregularly bedded nodular chert layers throughout. Minor amounts of sand exist in the lower beds. The hills and mesas that form the margins of the watershed are composed primarily of the Edwards Group and can be as thick as 350 ft. The Antlers Formation is commonly referred to as the Antlers Sand and conformably underlies the Edwards limestones. The Antlers Sand is composed of up to approximately 100 ft of fine to coarse grain unconsolidated sands, fine to coarse grain friable to well cemented sandstones, and fine to coarse grain quartzites with a conglomeratic base. The Antlers Sand outcrops at the base of the hills in the lower elevations of the erosional valleys of the North Concho, Middle Concho, South Concho, Spring Creek, Dove Creek and Pecan Creek. The Cretaceous beds dip gently toward the southeast.

The exposed Permian rocks are unconformably overlain by Cretaceous rocks, and dip west in the subsurface toward the Midland Basin. In the subsurface western portion of the watershed, the Dockum Group (Triassic) is sandwiched between the Cretaceous and Permian aged rocks. The Permian aged San Angelo Formation crops out in an area from Lake Nasworthy to O.C. Fisher Reservoir, primarily within the city limits of San Angelo, and in a narrow band northeast of San Angelo. It consists of thinly bedded to massive, cross-bedded, red, brown, yellow and gray sandstones and indistinctly bedded red clay and shale deposits. Small outcroppings of members of the Permian aged Clear Fork Group are exposed in the Lipan Flats area along stream and river channels where the Leona deposits are absent by erosion. Lithologically, the Clear Fork is predominantly dolomites, shales and sands. Along the extreme eastern edge of the watershed, the Concho River and its tributaries, primarily Duck Creek, Fuzzy Creek, Hog Creek and the lower reaches of Kickapoo Creek, traverse the upper members of the exposed Permian aged Wichita-Albany Group. Lithologically, members in this group are mostly limestones and shales.

Hydrogeological Systems and Hydrological Function

In the Concho River watershed, the existent surface and near-surface geologic and physiographic attributes, and, to a lesser extent, soil attributes are the primary physical features that make up the hydrogeological systems that govern hydrological function. The interactions of surface water and ground water with these physical features define how the systems function. Ultimately, the rate and volume of water inputs to the systems and water withdrawals from the systems are the overriding processes that impact hydrologic function.

The major subwatersheds of the Concho River watershed are characterized by two types of hydrogeological systems.

The North Concho River, Middle Concho River, and the main Concho River erosional valleys are characterized by broad floodplains. These floodplains contain fluvially deposited clastic material, primarily gravels, sands and clays. These shallow alluvial deposits form aquifers that perform two important functions, i.e. a storage function and a conduit function. Groundwater flows under the local hydraulic gradient from the recharge areas at higher elevations to discharge areas along the rivers. The recharge areas of these floodplains are located in the limestone hills at the margins of the erosional valleys and on the floodplains themselves. In this type of geologic setting, as long as the alluvial aquifers located near the river channels remain charged and do not become depleted, they serve to store groundwater, support base stream flows and impede channel transmission losses during runoff events.

The typical hydrologic characteristics of a watershed in this geologic setting include perennial rivers and tributaries, sustained by recharged aquifers that support viable and stable fisheries. Historically, large volumes of storm generated surface runoff, without significant channel transmission losses, would be delivered downriver during storm events. This was the historical norm for most of the North Concho River, Middle Concho River, and the main Concho River portions of the Concho River Watershed.

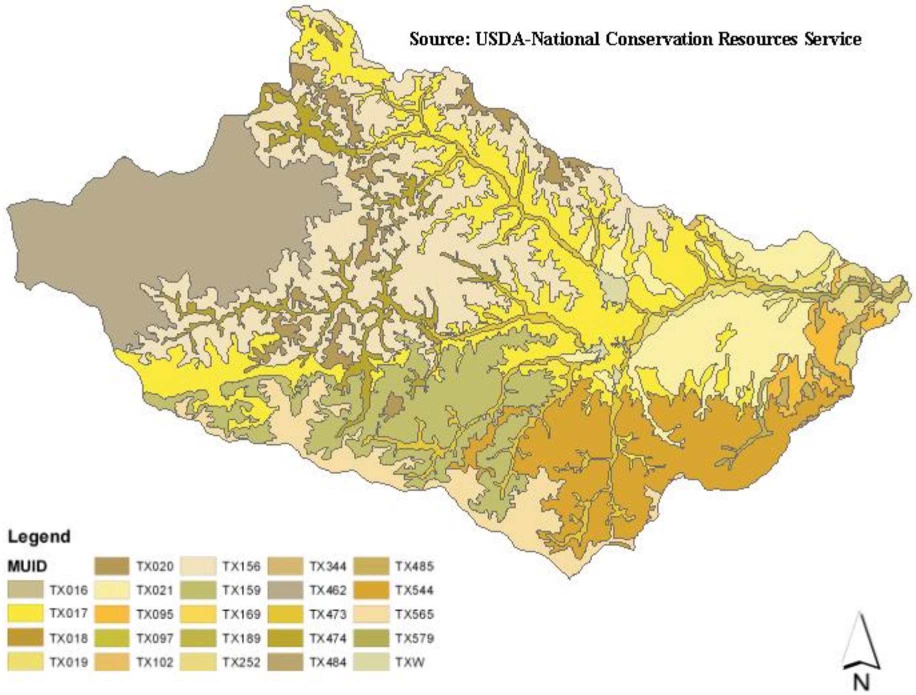
However, hydrologic function of the watershed changes if the alluvial aquifers become depleted. As depleted aquifers continuously rob the rivers to recharge themselves, the rivers and tributaries become intermittent or ephemeral in nature, gaining-streams become losing streams, fisheries perish, and channel transmission losses impede the delivery of runoff downstream. Such were the recent conditions observed in the North Concho River, Middle Concho River, and the main Concho River.

The other main subwatersheds, i.e. Spring Creek, Dove Creek and South Concho River are characterized by much narrower and steeper erosional canyons than are the aforementioned subwatersheds. These waterways are fed by springs located in their mid to upper reaches that issue forth from Edwards Group limestones that serve to de-water the northern edge of the Edwards-Trinity Plateau Aquifer. The groundwater conditions in the northern extents of the Edwards-Trinity Plateau Aquifer are the primary drivers of the volume and rate of base flows in these waterways. However, in their lower reaches, where their floodplains broaden and more alluvial deposits are located, their hydrogeological function is similar to the previously described hydrogeological systems of the North Concho River, Middle Concho River, and main Concho River subwatersheds.

2.4 SOILS

Many different soil profiles are present throughout the Concho River watershed. The following average soil compositions of the Concho River watershed are taken from “An Integrated Stream Classification System for the State of Texas” (Hersh, 2007), which reported average soil compositions for watersheds. The data in that publication was derived from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) State Soil Geographic Database (STATSGO), (Figure 6).

Figure 6. Watershed Soils Map



Hersh reported average textural soil composition of the Concho River watershed as 20-40 percent clay, 30-40 percent silt and 20-40 percent sand. From this information it is deduced that the average USDA textural classification of soils in the watershed range between a clay loam and a loam.

Of primary concern regarding nonpoint source pollution issues is the intrinsic propensity of a particular soil type to erode. This is known as the soil-erodibility factor, designated the K factor. Factor K is a numerical measurement of both the susceptibility of soil to erosion and the rate of runoff under standard conditions in standardized tests. The numerical values range from a minimum of about 0.05 in high clay content soils (low erodibility soils), to a maximum in excess of 0.4 in highly erodible soils.

Soils that have high clay content are typically more resistant to detachment and thus, less susceptible to erosion and less likely to create inordinate sediment loading during storm water runoff events. Obviously, many other factors, i.e. specific soil attributes, slope-length factors, land cover, land use, land management, etc. influence erosion and sediment loading, but in general terms, the average soils of the Concho River watershed are only moderately susceptible to erosion and are not considered to be a significant nonpoint source pollution issue. In certain instances, soil erosion is considered to be a concern, and those occurrences are discussed in Section 5 under the relevant assessment area section.

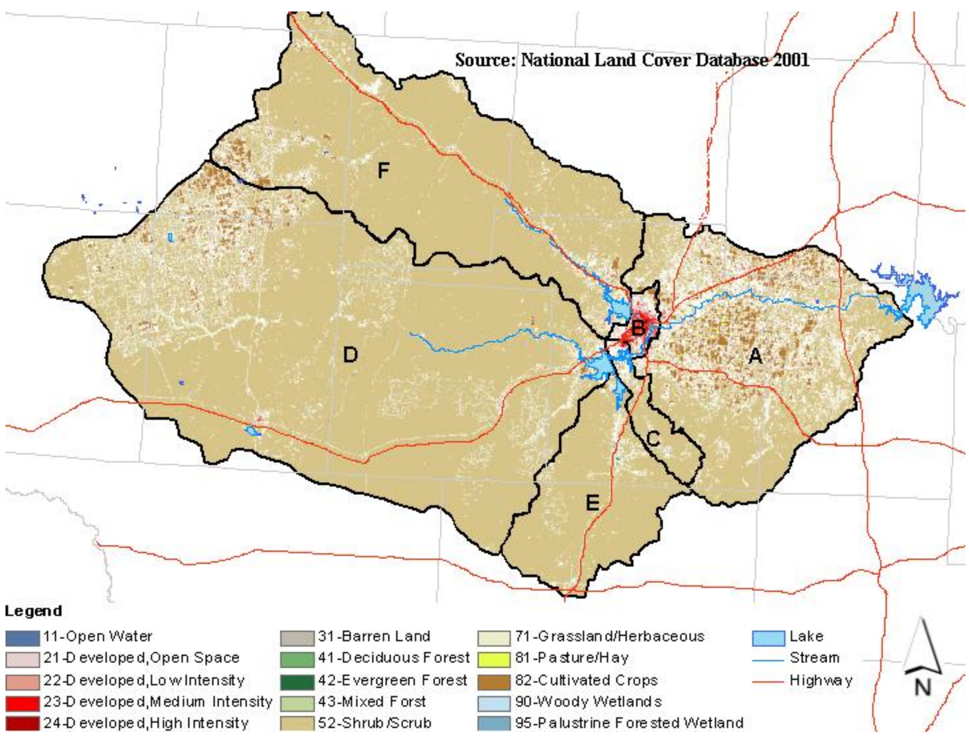
2.5 CLIMATOLOGY

The climate of the Concho River watershed varies from arid conditions at its western margins to semi-arid conditions in its central and eastern portions. Annual average precipitation ranges from less than 14 inches in its western portion to approximately 25 inches in its eastern portion. A large percentage of the annual rainfall received throughout the watershed occurs in short duration, high intensity storm events. Multi-year drought conditions occur periodically. Prevailing wind is from the south-southwest. Winters are mild and the summers hot and dry. The mean annual temperature for San Angelo is 64.5° F with first frost occurring in late October to mid-November and last frost occurring in late March to mid-April.

2.6 LAND USE

Land use in the Concho River watershed includes rangeland utilized for livestock grazing (predominately upstream of San Angelo), a very large area of farming and crop irrigation (east of San Angelo), concentrated animal feeding operations, extensive rural subdivision development, and residential, commercial and industrial development in and around the City of San Angelo (Figure 7). Each of these land uses has been implicated as effecting regional water resources. Specific land uses, as they relate to the nonpoint source pollution issues and concerns of each Assessment Area, are addressed in Section 5.

Figure 7. Watershed Land Use Map



3.0 PUBLIC PARTICIPATION

3.1 WATERSHED PROTECTION PLAN DEVELOPMENT PHASE

It is a recognized principal that having the involvement of interested parties and stakeholders throughout the watershed planning process is a requisite for the successful development of a well-structured and useful Watershed Protection Plan. To this end, UCRA staff identified potential stakeholders and interested parties and invited them to become partners in the development of the Watershed Protection Plan through accepting membership in a stakeholder advisory group. Stakeholders included interested individuals, local business people, City of San Angelo, Tom Green County, Lower Colorado River Authority (LCRA), Colorado River Municipal Water District, Texas Railroad Commission, Texas Commission on Environmental Quality, Texas State Soil and Water Conservation Board, and U.S. Environmental Protection Agency. Several members of the Concho River Watershed Stakeholder Advisory Group also serve as members of the Upper Colorado River Basin Steering Committee, which is associated with the Texas Clean Rivers Program.

The Stakeholder Advisory Group held meetings on September 28, 2005, June 01, 2006, September 26, 2006, July 12, 2007, September 27, 2007, July 01, 2008, October 23, 2008, and May 23, 2009. Drawing on the varied backgrounds, knowledge, expertise, and experience of group members, the focus of the initial meetings was on reaching consensus on the specific components to include in the watershed plan. At subsequent meetings, presentations were given to update the members on the progress of watershed planning efforts. Typically, reports were delivered by the lead investigative team and others, ideas from various group members were interjected, issues were discussed, and if necessary, the planning process and investigative tasks were modified.

A Public Water Forum was held in October 2006 to garner additional public input to supplement the efforts of the Stakeholder Advisory Group. The forum was advertised in advance, held in the San Angelo Convention Center and attended by approximately 80 people, many of who supplied input by voicing their ideas and concerns. The event was widely covered by the San Angelo media, including television, radio and print media.

It should be recognized that the Concho River Watershed Protection Plan is a living document. That is, it will change through time as the recommended voluntary BMPs are implemented and nonpoint source pollution problems respond, and/or as future monitoring efforts expose new issues and problems that need to be addressed to restore and preserve the Concho River watershed.

3.2 EDUCATION AND OUTREACH STRATEGY

One of the recommended BMPs of the Watershed Protection Plan that has been implemented is the construction and operation of the Concho River Basin Aquatic Education & Research Center. It is located in a highly visible area on the North Concho River in downtown San Angelo.

In 2007, the UCRA was in the process of completing two converging CWA §319(h)-funded projects, the Concho River Basin Watershed Protection Plan, funded through the TSSWCB, and a final BMP Demonstration Project for San Angelo on the North Concho River, funded through TCEQ. The Demonstration BMP included a series of aesthetically pleasing storm water filtration ponds in a highly visible area located in close proximity to the river, the UCRA office, the San Angelo River Stage, and the San Angelo Museum of Fine Arts (SAMFA). One of the goals of this project was to offer the public a hands-on look at the benefits of nonpoint source abatement, by providing a living laboratory full of native aquatic plants and a thriving ecosystem. Concurrently, the UCRA was concluding work on the Watershed Protection Plan. A best management practice was conceived by the stakeholder group for the purpose of implementing the Watershed Protection Plan. The stakeholder group envisioned an aquatic research and education facility that would dually serve as a venue from which to systematically implement the provisions of the Watershed Protection Plan and as a regional focal point for water education and public outreach. The facility and its operation is the implementation BMP of the Watershed Protection Plan.

This concept resulted in the first implementation of a best management practice of the Concho River Watershed Protection Plan, i.e. the acquisition and renovation of an older building located adjacent to the SAMFA (a UCRA partner), transforming it into the Concho River Basin Aquatic Research & Education Center (the Water Education Center). Grant financing for the project was secured by UCRA from TCEQ through EPA 319(h) funds with the local match dollars coming from SAMFA, UCRA, and Walmart's Water for Texas Initiative. The vision ultimately became a reality with completion of the construction phase in the fall of 2008, and the Water Education Center has been fully operational and meeting the needs of the community since then.

As a platform for implementation of the Concho River Watershed Protection Plan, several BMPs have been implemented, with others in progress. These are discussed elsewhere herein.

Regarding the Water Education Center's education and outreach endeavors, thousands of youth and adults have been involved in public meetings & forums, special events, and other educational and outreach experiences held in and around the Water Education Center (Figure 8). Some statistics follow:

- 1,560 students & 85 adult sponsors participated in tours of not only the living laboratory storm water treatment ponds, but also tours of other nonpoint source BMPs constructed San Angelo during and since the 1900s; also participated in tours of the Water Education Center with its educational displays and interactive stations.

- 5,800 citizens (youth and adult) have walked through the Water Education Center during Family Days, the annual Eco-Fair and general public hours.
- 5,900 youth and adults have participated in off-site outreach programs.
- 60 elementary & secondary educators have participated in annual Teacher Workshops.
- 200 professionals attended stakeholder meetings, public forums and grant planning meetings.
- 135 presentations have been made off-site to various Boards and professional and civic organizations.
- 20 applicators and 20 students have participated in pesticide/herbicide chemical use workshops.

The Water Education Center will continue to provide educational opportunities for area schools and the communities of the Concho River Basin. The following programs and events will continue to be sponsored by the center.

- Annual Eco Fair in partnership with SAMFA
- Annual Teacher Workshops
- Water Forums
- Stormwater education
- School programs (rural and urban)
- Summer camps
- Field trips for area students
- Presentations to Civic Groups and other organizations
- Continued Watershed Protection Plan stakeholder involvement
- Continued implementation of the BMPs of the Watershed Protection Plan

Figure 8. Water Education Center Utilization

Topics that are regularly taught at the Center include the following:

- Importance of water to our lives
- Limited amount of water actually available for humans
- Human population growth
- Watersheds
- Groundwater and surface water
- Local watersheds: Colorado River and Concho River (or as particular to their area)
- Local sources of water (particular to their area)
- Point source pollution and the Clean Water Act
- Nonpoint source pollution
    - Fertilizers
    - Pesticides and herbicides
    - Motor oil and gas
    - Sedimentation - what this is and how it harms a river
    - Pet waste, cattle waste, etc.... feedlots
    - Grass clippings and leaves
    - Low dissolved oxygen - what causes this?
- Solutions
    - Limited use of fertilizers, pesticides and herbicides
    - Fixing oil and gas leaks, cleaning up spills
    - Importance of vegetation for natural filtration and erosion control
    - Pervious vs. impervious surfaces
    - Picking up pet waste...what to do with it
    - Bagging or mulching grass and leaves
    - Using carwashes instead of washing in driveway
    - Trash pick-up/recycling
    - Local solutions
    - Projects UCRA and the City of San Angelo are doing.... monitoring, structural improvements, education
    - What they can do as citizens

In addition to the Water Education Center's existing programs, new outreach and education programs and materials can be made available to advance the different management strategies recommended in the Watershed Protection Plan. Outreach and education efforts can initially be targeted to support landowners, ranchers/farmers, and municipal and county governments. Several existing programs can be utilized as follows.

TEXAS Watershed Steward

Texas Watershed Steward Program: The Texas Watershed Steward Program was initiated to provide science-based, watershed education to help citizens identify and take local action to address local water quality problems. At these one-day workshops, Texas Watershed Stewards learn about the nature and function of watersheds, potential impairments, steps that can be taken to help improve and protect water quality in their watershed, and how to get involved in community-driven watershed protection and management. The Texas Watershed Steward Program is implemented through a partnership between the Texas AgriLife Extension Service and the TSSWCB. The Program is supported through CWA §319(h) nonpoint source grants from TSSWCB and USEPA to AgriLife Extension. More information on the Texas Watershed Steward Program is available at http://tws.tamu.edu/.

Lone Star Healthy Steams Program: The Lone Star Healthy Streams Program is the State's mechanism to provide a coordinated and comprehensive education program designed to increase awareness of the water quality issues associated with grazing and dairy cattle, poultry, horses, and feral hogs; and encourage voluntary implementation of BMPs to reduce the runoff of pollutants which will ultimately lead to improved water quality. The Program will build on recent research and demonstration projects, conducted and funded by a variety of entities, which evaluated the effectiveness of BMPs to improve water quality impacted by grazing and dairy cattle, poultry, horses, and feral hogs. The Program will be implemented through workshops utilizing Resource Manuals focused on each of the five animal groups. Implementation of the Lone Star Healthy Streams Program is designed to increase the utilization of technical assistance and financial incentives available to landowners to implement BMPs targeted to manage the impact of these five animal groups. The Lone Star Healthy Streams Program is implemented through a partnership between the Texas AgriLife Extension Service, the Texas Water Resources Institute, and the TSSWCB. The Program is supported through CWA §319(h) nonpoint source grants from TSSWCB and USEPA to TWRI. More information on the Lone Star Healthy Streams Program is available at http://lshs.tamu.edu/.

Watershed Signage: Contingent upon funding, signs can be developed and posted along major roads notifying travelers that they are entering the Concho River watershed. Signs to discourage illegal dumping can also be placed at bridges to the extent funding is available.

Texas Stream Team: Texas Stream Team is a network of trained volunteers and supportive partners working together to gather information about the natural resources of Texas and to ensure that information is available to all Texans. Volunteers are trained to collect quality-assured information that can be used to make environmentally sound decisions. The Texas Stream Team can be called upon to improve communication and facilitate environmental stewardship by empowering a network of concerned volunteers and partners within the Concho River watershed.

4.0 METHODS

The watershed planning process used in the development of the Concho River Watershed Protection Plan generally followed the steps outlined in the USEPA *Handbook for Developing Watershed Plans to Restore and Protect Our Waters*. After the initial step of building partnerships through the creation of the Stakeholder Advisory Group, the next step was to characterize the watershed. In order to characterize the watershed, existing data sources and resources were identified, data gaps were recognized and plans were designed and implemented to collect additional data, nonpoint source threats were assessed, management strategies were developed, and a mechanism for implementation was recommended.

The activities undertaken in preparing the Watershed Protection Plan were performed in adherence to the Quality Assurance Project Plan approved by EPA. The Quality Assurance Project Plan governed the technical aspects of the project, specifically sampling procedures and laboratory analysis methodologies, to ensure data of known and acceptable quality was generated and used.

The assessment process entailed the integration of existing monitoring efforts and programs with surface and ground water monitoring activities developed specifically for the Watershed Protection Plan, and the coordination of project assessment activities with other entities in the region. The project has involved coordinating program elements with other entities, such as the Texas State Soil and Water Conservation Board, Texas Water Development Board, Sterling County Underground Water Conservation District, U.S Geological Survey, Texas Institute for Applied Environmental Research and the City of San Angelo.

As previously mentioned, the Watershed Protection Plan was developed through an iterative process performed by the Stakeholder Advisory Group. Input from group members was critical in identifying the nonpoint source pollution issues of concern. From this input a data acquisition and analysis plan from which to develop best management practices was designed. Also as previously mentioned, to facilitate such a large scale assessment process, it was decided to partition the watershed into six assessment areas. Assessment Area boundaries were chosen based on logical divisions according to their hydrologic function (Figure 9).

Each Assessment Area was assessed using information garnered from pertinent papers and publications, USGS stream flow data, SWQM water quality and stream flow data, urban nonpoint pollution best management practice effectiveness monitoring data, ground water elevation and water quality data from underground water districts, TCEQ complaint, enforcement and permit records, TSSWCB Water Supply Enhancement Program records, hydrologic response monitoring data and observations, UCRA complaint data and records, project data collections, results data from on-going research projects, and project investigational observations. The data assessment process included the following elements:

- The TCEQ Texas 2008 303(d) list and other water quality and impairment publications were reviewed and integrated into the watershed assessment.

- Load duration curves (LDCs) were developed for sites with enough available historic flow data to construct meaningful flow duration curves. The LDCs were used to help classify potential pollutant sources, characterize hydrologic condition classes under which water quality standard exceedances occur, and to develop percent reduction goals for various pollutants and parameters.

- The lack of a sufficient flow data set, precluded development of meaningful flow duration curves at many locations. At these sites, graphs were constructed to illustrate various pollutants/parameters and their relationship to water quality standards and trends through time. Most of these include analytical results of samples collected subsequent to publication of the TCEQ's 2008 303(d) list and other of their water quality and impairment reports.

- Analysis of historical and project water quality monitoring data – trend analysis, comparative analysis, and spatial analysis based on water quality standards and/or best professional judgment.

- Identification of water quality impairments using SWQM water quality data for trend analyses, comparative analysis and spatial analysis.

- Analysis of historical and project hydrologic data for identification of trends, patterns, spatial relationships, temporal relationships and the identification of mechanisms and interactions applicable to the watershed's water resources.

- Determination and delineation of land uses and related potential water quality implications.

- Determination of the geologic, topographic and geomorphologic features of the watershed and associated water quality implications.

- Assessment of the water quality threats based on local knowledge, experience and expertise, public input, and project stakeholder advisory group participation.

- Identification of water quality threats based on extrapolation of assessment results and observations from one assessment area to others with similar characteristics and conditions.

In assessing environmental threats and water quality impairments within the Concho River Watershed, certain standards or criteria were employed as follows:

- Texas Surface Water Quality Standards
- U.S. Environmental Protection Agency Drinking Water Standards

- Historical water quality norms
- Historical stream flow norms
- Historical land cover/land use norms

A load duration curve is essentially a flow duration curve combined with a water quality criterion, i.e. either a water quality standard, screening level or target level criterion. It provides a visual and mathematical representation of the maximum load of a particular pollutant or parameter that a stream can carry and remain protective of a desired target level or in compliance with water quality standards. In some cases LDCs can provide information to help differentiate between point and nonpoint source issues, show seasonal water quality effects, address frequency and magnitude of water quality criterion exceedances, and identify the magnitude of reduction required to meet water quality criteria (EPA, 2006).

In Assessment Areas A, B, and F, following the methods described in *An Approach for Using Load Duration Curves in Developing TMDLs* (EPA, 2006), load duration curves were constructed with a 10% explicit margin of safety and analyzed. In cases where existing loadings exceeded the applicable water quality standard or screening level, hydrologic condition classes were identified and percent reduction goals were calculated. The hydrologic condition class with the highest percent load reduction needed to meet the water quality standard was defined as the critical flow condition and was chosen as the load reduction goal for that particular assessed area. It is assumed that if water quality standards are achieved in the critical hydrologic condition class, then the water quality standard will be attained in the other flow conditions where a lower percent reduction was calculated.

For various reasons, at many sampling stations there was no available flow data, nor could any meaningful surrogate flow data be generated. For that reason no useful load duration curves could be constructed at those sampling stations. At these sites various graphical charts were generated. These illustrate pollutant concentrations and the relevant water quality standard or screening level, and in some cases, other parameters. A comparative analysis of these was conducted to discern possible relationships between various parameters of interest and water quality.

5.0 WATERSHED ASSESSMENT

The TCEQ divides the stream segment designations presented in Table 1 in Section 1 into assessment units. These are assigned unique assessment unit identification numbers and typically have at least one sampling station and in some cases several sampling stations located within their boundaries. The assessment units (AUs) in the Concho River watershed are presented in Table 4, below. The sampling station identification numbers located in each assessment are also included.

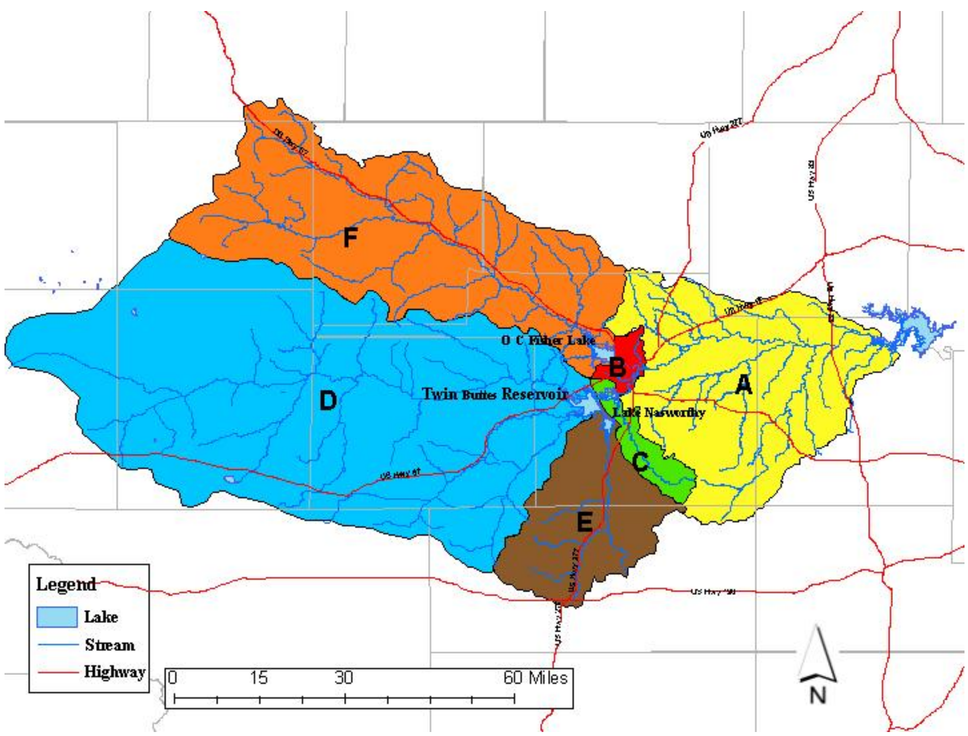
Table 4. Concho River Watershed Assessment Unit Designations

Concho River Watershed TCEQ Assessment Unit Designations			
Name	**AU ID**	**Assessment Unit Description**	**Station ID**
Concho River	1421_01	Downstream end to Chandler Lake confluence	12401
Concho River	1421_02	From Chandler Lake confluence upstream to confluence of Puddle Creek	12402
Concho River	1421_03	From the confluence of Puddle Creek upstream to the confluence of Willow Creek	12403
Concho River	1421_04	From the confluence of Willow Creek upstream to the confluence of an unnamed tributary near Chandler Road	12404
Concho River	1421_05	From the confluence of an unnamed tributary near Chandler Rd. upstream to the confluence of Red Creek	12405
Concho River	1421_06	From the confluence of Red Creek upstream to the dam near Vines Rd.	12407
Concho River	1421_07	From the dam near Vines Road upstream to the confluence of the North Concho River and the South Concho River	12408 12409
Concho River	1421_08	North Concho River, From the confluence with the South Concho River upstream to OC Fisher Dam	12412 12414 15886 20324
Concho River	1421_09	South Concho River, from the confluence with the North Concho River upstream to Nasworthy Dam	12416 17348
Dry Hollow Ck	1421A_01	Entire water body	12257
Kickapoo Creek	1421B_01	From the confluence with the Concho River west of Paint Rock in Concho County to the headwaters northwest of Eden	12255
Lipan Creek	1421C_01	Lower 25 miles of creek	12254
Lake Nasworthy	1422_01	Lower half of lake	12418 12421
Lake Nasworthy	1422_02	Upper half of lake	12419
Twin Buttes Res	1423_01	North Pool	12422
Twin Buttes Res	1423_02	South Pool	12425
Spring Creek	1423A_01	From the confluence of Twin Buttes Reservoir upstream to Duncan Avenue crossing in Mertzon	12161
Spring Creek	1423A_02	From Duncan Avenue crossing in Mertzon upstream to the upstream perennial portion of the stream northeast of Ozona in Crockett County	17346
Dove Creek	1423B_01	From the confluence of Spring Creek upstream to RR 915	12166
Middle/South Concho River	1424_01	South Concho River from a point 4 km (2.5 miles) upstream of FM 2335 upstream to the confluence of Bois D'Arc Draw in Tom Green County	12427 17349 18712 18869
Middle/South Concho River	1424_02	Middle Concho River from a point 100m upstream of US 67 in Tom Green County upstream to the confluence of Big Hollow Draw in Irion County	12428 16903

Concho River Watershed TCEQ Assessment Unit Designations			
Name	**AU ID**	**Assessment Unit Description**	**Station ID**
Middle/South Concho River	1424_03	From the confluence of Big Hollow Draw in Irion county upstream to the confluence of Three Bluff Draw and Indian Creek on the Middle Concho River in Reagan County	No Stations
West Rocky Ck	1424A_01	Entire water body	12165
OC Fisher Lake	1425_01	Entire water body	12429
North Concho River	1425A_01	Lower end of water body to Sterling County line	12170 12171 17245 17350 17351
North Concho	1425A_02	Sterling County line to SH 163	16779
North Concho	1425A_03	SH 163 to US 87	16780

To facilitate the assessment process, it was deemed prudent to partition the watershed into six assessment areas based on logical divisions of the watershed according to hydrologic function. These were designated Assessment Areas A-F (Figure 9). A brief geographic description of each assessment area and the associated stream segment designation(s) is presented below. (They do not geographically conform to the stream segment numbers assigned by the TCEQ in every case.) The stream segments and assessment units located in each assessment area are presented in tables in each assessment area's section.

Figure 9. Assessment Areas Boundary Map



- Assessment Area A (Stream Segment 1421 Concho River (rural portion)): Includes the drainage area of the Concho River and its tributaries extending from Bell Street Reservoir in East San Angelo to O.H. Ivie Reservoir, a distance in excess of 50 river miles with an areal extent of approximately 778,500 acres.

- Assessment Area B (Stream Segment 1421 North and South Concho Rivers (urban portion)): Includes the watersheds of the North and South Concho Rivers from Bell Street Reservoir upstream to the O.C. Fisher Reservoir dam and the Lake Nasworthy dam respectively, plus the drainage area of Pulliam Draw located north of San Angelo. The total areal extent is approximately 33,600 acres.

- Assessment Area C (Stream Segment 1422 Lake Nasworthy): Comprised of a small municipal constant level reservoir (10,108 ac. ft. in size), located immediately below Twin Buttes Reservoir, plus the Pecan Creek Watershed. The total areal extent is approximately 70,500 acres.

- Assessment Area D (Stream Segments 1423 and 1424 Twin Buttes North Pool and Watershed): An extremely large sub-basin which contains the Middle Concho River, Spring Creek and Dove Creek watersheds plus the Twin Buttes Reservoir North Pool. The total areal extent is approximately 1,972,000 acres.

- Assessment Area E (Stream Segments 1423 and 1424 Twin Buttes South Pool and Watershed): A large sub-basin that includes the Twin Buttes Reservoir South Pool and the South Concho River Watershed. Its areal extent is approximately 339,000 acres.

- Assessment Area F (Stream Segment 1425 O.C. Fisher Lake and Watershed): Comprised of the North Concho River Watershed and O.C. Fisher Lake. The total areal extent is approximately 985,000 acres.

Some nonpoint source pollution threats and/or existing nonpoint source pollution problems pertain to all or almost all assessment areas. A discussion of these broadly prevalent nonpoint source pollution issues is included prior to the discussion of individual assessment areas. These broadly prevalent issues include petroleum exploration and production (E&P) activities, abandoned and/or unused water wells, and intensive development of rural areas. Each is discussed below.

Petroleum Exploration and Production Activities Located in the Concho River Watershed

The most significant threat, and the main constituent of concern from petroleum E&P activities, is highly saline brine water intrusion into useable groundwater and ultimately into surface water. Petroleum E&P Activities hold many potential avenues of contamination. These include improperly or inadequately cemented producing wells, improperly plugged wells, pipeline leaks, improperly operated injection wells, improperly completed and/or operated saltwater disposal wells, corroded well casings, corroded pipelines, etc. In actuality, pollution from petroleum E&P activities originates from a point source. However, by the time the leak presents in water wells or in a seep or spring, the specific source is typically not easily identified (or impossible to identify) and it has effectively become a nonpoint source pollution issue. Locating the source of a leak or leaks can be a very difficult task, especially when it (they) may originate several hundred or even several thousand feet below ground level and spread laterally through several layers of permeable rock before showing up in an aquifer or at the surface in a seep. Evidence of underground brine flows may only present themselves extremely long distances from the actual source. It is virtually impossible to identify point sources when multiple leaking wells are located in a large oil field or in a densely drilled area and contamination plumes have intermingled.

Included in each assessment area discussion (except for Assessment Area B which consists primarily of the area within the San Angelo city limit), well counts from the Texas Railroad Commission's Active Well Counts Reports are provided. Active well counts are categorized by county and obviously, not all wells reported for a county are included in the assessment area's boundaries. The publicly available internet interface to the RRC's database does not allow for large scale spatial analysis of well information. Consequently, the exact numbers of wells located within each assessment area were not determined for the Concho River Watershed Protection Plan. The county level data are provided to give the reader an idea of the scope of the potential threat that exists. Active wells consist of producing wells, temporarily abandoned wells, shut-in wells, injection wells and miscellaneous wells. For every currently active well, there are many more wells that are plugged and abandoned dry holes, plugged and abandoned depleted producers or unplugged orphan wells, i.e. wells for which there are no operators of record.

The Texas Railroad Commission has jurisdictional authority over oil and gas matters and engages in the plugging of unplugged orphan wells and also performs remediation at petroleum contaminated oil field sites through its Oil Field Cleanup Program. This program is primarily funded through fees imposed on the oil and gas industry. Since 1984, the Texas Railroad Commission has plugged over 26,000 wells and cleaned up, assessed, or investigated 3,382 sites statewide (RRC, 2006). No map is provided for orphaned wells as the list of current orphan wells is in constant flux, because of plugging activities and discoveries of previously unknown orphaned wells.

Abandoned and/or Unused Water Wells Located in the Concho River Watershed

Administrative personnel of area groundwater conservation districts estimate that hundreds of abandoned and/or unused water wells exist within the Concho River Watershed. Many of these wells remain open to the atmosphere and represent direct contaminant pathways to groundwater aquifers. The potential for contamination exists and is considered a legitimate water quality threat by the managers of groundwater conservation districts.

Intensive Development of Rural Areas Located in the Concho River Watershed

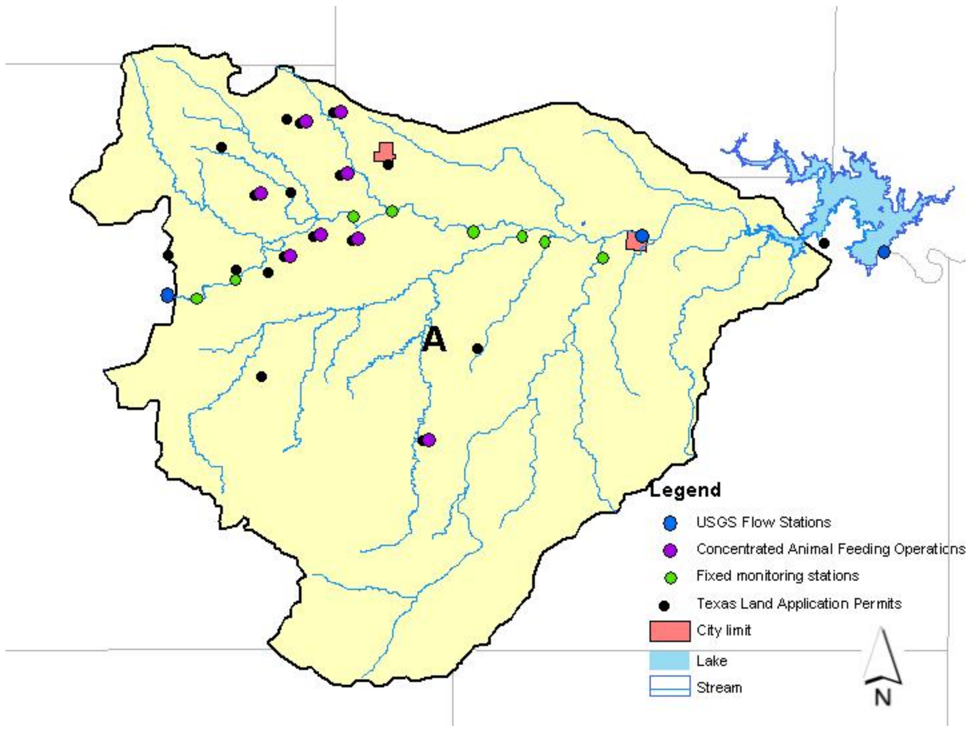
In the rural areas of the Concho River Watershed, small-acreage, single-family residential developments are situated along and near the rivers and creeks and many more such developments have been proposed. Several unincorporated communities that range in population from a few hundred to several thousand exist within the watershed. The proliferation and expansion of these developments are likely driven by various perceived attributes including desires to live in aesthetically pleasing country settings near to water, real estate investment based considerations, avoidance of municipal taxes, and/or school district preferences. The communities are typically served by a public water supply system (and/or private water wells), but rely on on-site sewage facilities for sewage effluent treatment. A potential threat of shallow groundwater bacterial contamination exists from densely sited on-site sewage facilities, especially from facilities that were installed prior to passage of current comprehensive regulatory standards.

In the more densely developed areas and proposed developments located near rivers or creeks, the density of impervious surfaces, i.e. rooftops, roads, etc. and the potential misuse of fertilizers and pesticides on home lawns increase the potential for stormwater runoff water quality impacts, especially in areas with significant slopes.

5.1 ASSESSMENT AREA A

Assessment Area A consists of Stream Segment 1421 of the Concho River east of San Angelo, an area known as Lipan Flats. Assessment Area A includes the drainage area of the Concho River and its tributaries extending from Bell Street Lake in East San Angelo to O.H. Ivie Reservoir, a distance in excess of 50 river miles with an areal extent of approximately 778,500 acres (Figure 10).

Figure 10. Assessment Area A Boundary Map



Several Concentrated Animal Feeding Operations, Texas Land Application Permitted facilities and the City of San Angelo's wastewater treatment plant are located in this assessment area. Effluent from the wastewater treatment plant is land applied primarily by row flooding by farmers belonging to the Tom Green Water Control and Improvement District #1. There are no permitted wastewater discharges in Assessment Area A and the only identified point sources include the City of San Angelo's stormwater (MS4) discharge and illegal discharges from concentrated animal feeding operations.

The TCEQ assessment units located within Assessment Area A are included in Table 5, below.

Table 5. Assessment Area A TCEQ Assessment Unit Designations

Assessment Area A TCEQ Assessment Unit Designations			
Name	**AU ID**	**Assessment Unit Description**	**Station ID**
Concho River	1421_01	Downstream end to Chandler Lake confluence	12401
Concho River	1421_02	From Chandler Lake confluence upstream to confluence of Puddle Creek	12402
Concho River	1421_03	From the confluence of Puddle Creek upstream to the confluence of Willow Creek	12403
Concho River	1421_04	From the confluence of Willow Creek upstream to the confluence of an unnamed tributary near Chandler Road	12404
Concho River	1421_05	From the confluence of an unnamed tributary near Chandler Rd. upstream to the confluence of Red Creek	12405
Concho River	1421_06	From the confluence of Red Creek upstream to the dam near Vines Rd.	12407
Concho River	1421_07	From the dam near Vines Road upstream to the confluence of the North Concho River and the South Concho River	12408 12409

The water bodies located in Assessment Area A that are included in the 2008 Texas Water Quality Inventory and 303(d) list are displayed in Tables 6 and 7 below.

Table 6. Assessment Area A 2008 303(d) List of Water Quality Impairments

Assessment Area A 2008 303(d) List of Water Quality Impairments				
Name	**Assessment Unit**	**Parameter of Concern**	**Category**	**Yr Listed**
Concho River	1421_07	impaired macrobenthic community	5c	2002
5c - Indicates Additional data and information will be collected before a TMDL is scheduled				

Table 7. Assessment Area A 2008 305(b) List of Water Quality Concerns

Assessment Area A 2008 305(b) List of Water Quality Concerns			
Name	**Assessment Unit**	**Parameter of Concern**	**Category**
Concho River	1421_01	chlorophyll-a	CS
Concho River	1421_02	nitrate	CS
		orthophosphorus	CS
Concho River	1421_03	orthophosphorus	CS
		chlorophyll-a	CS
		depressed oxygen levels	CS
		nitrate	CS
Concho River	1421_04	nitrate	CS
		chlorophyll-a	CS

Assessment Area A 2008 305(b) List of Water Quality Concerns			
Name	**Assessment Unit**	**Parameter of Concern**	**Category**
Concho River	1421_05	nitrate	CS
Concho River	1421_06	depressed oxygen levels	CS
		nitrate	CS
		orthophosphorus	CS
Concho River	1421_07	chlorophyll-a	CS
		depressed oxygen levels	CS
Dry Hollow Creek	1421A_01	nitrate	CS
CS - indicates concern for near non-attainment of water quality standard			

Area A 303(d) Impairments - Impaired Macrobenthic Community

Assessment Unit 1421_07 was first identified on the 2002 303(d) list for not supporting its designated aquatic life use based on an impaired benthic community. Four monitoring events performed by UCRA at Station 12409 between March 1, 1996, and February 28, 2001, were assessed by TCEQ. The average Index of Biological Integrity (IBI) score was 18. A score of 29 is required to meet a high aquatic life use. The segment has remained on subsequent 303(d) lists because there has not been sufficient data to re-evaluate the impairment. The category 5c assignment means that the water body does not meet applicable water quality standards or is threatened for one or more designated uses by one or more pollutants and that additional data and information will be collected before a TMDL is scheduled.

The TCEQ retained the USGS in 2008 to perform biological and other monitoring within the Assessment Unit. Preliminary data from two sample events indicate a mean benthic IBI score of 25.5, which does not meet the standard for high aquatic life use.

Assessment Unit 1421_07 is located immediately downstream of Assessment Area B and receives urban storm water runoff from the City of San Angelo. Although the cause of the impaired macrobenthic community cannot be directly linked to this source, it is likely responsible or at a minimum, a significant contributor. In the intervening years between the monitoring events conducted by the UCRA from 1996 to 2001 and those conducted by the USGS since 2008, the IBI scores have shown improvement. This improvement may partially relate to the structural nonpoint source best management practices that were installed in San Angelo between 1998 and 2002 that have improved the water quality of storm water flows from the Concho River above the Bell Street dam.

Area A 305(b) Concerns - Chlorophyll-a, Nitrate, Orthophosphorus, Depressed Oxygen

The pollutants of concern on the 305(b) list area are all interrelated and attributable to excessive nutrient influxes combined with low flows.

To evaluate the reach of the Concho River in Assessment Area A, load duration curves were constructed using flow data from USGS gaging station 08136500 located at the community of Paint Rock and water quality data collected at AU_1421_01 Station 12401. This station is the downstream of AU_07, 06, 05, 04, 03, and 02. As such it is the downstream outlet for not only Assessment Area A, but also the entire Concho River watershed. Parameters for which LDCs were developed include chloride, E. coli, dissolved oxygen, nitrite+nitrate, chlorophyll-a, total phosphorus, and orthophosphate phosphorus.

The load duration curve developed for nitrite+nitrate exhibited significant exceedances of the Texas surface water quality monitoring screening level for nitrate (Figure 11).

Figure 11. Assessment Area A, Paint Rock Station Nitrogen LDC

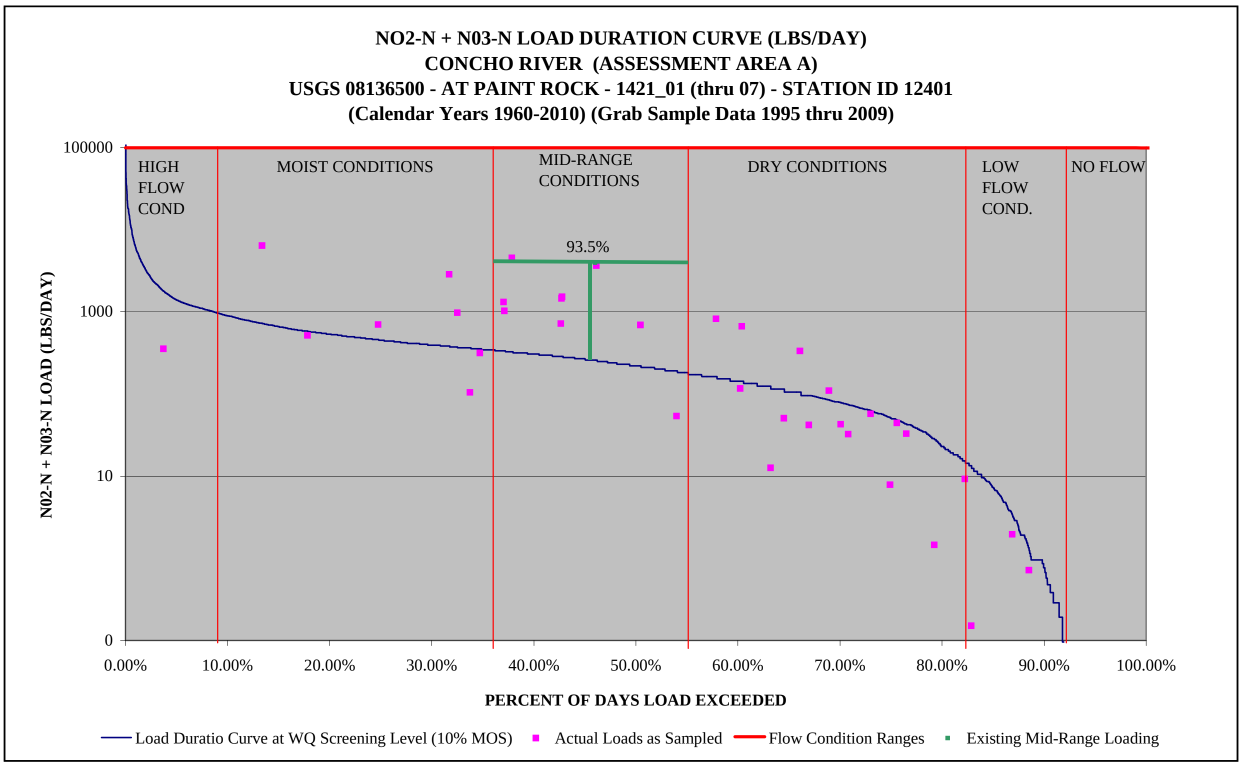


Figure 11 shows that the measured nitrite+nitrate levels from samples collected at the Paint Rock monitoring station consistently exceed TCEQ water quality screening level for nitrate. Exceedances are not concentrated in any particular hydrologic (or flow) condition class, but instead persist throughout the moist, mid-range and dry flow conditions. Combined, these three hydrologic condition classes encompass 80% of the total flows, while low flows and high flows represent 20% of total flows with no exceedances. The mid-range condition exhibits the highest existing loading calculated at the 90th percentile of measured nitrite+nitrate. The difference between existing loading and the water quality criterion (measured at the midpoint of hydrologic condition class) is used to calculate the loading reduction required to meet the criterion. The calculated percent reduction in loading needed at the Paint Rock monitoring station to meet the water quality screening level is 93.5%.

The annual load at Paint Rock was calculated using mean daily flows from the period 1960-2010 and mean concentrations of actual samples taken at the site. This resulted in a total annual load estimate of 384,179 lbs of nitrate nutrients. Using the percent reduction goal as indicated from the load duration curve calculations, a total load reduction of 359,207 lbs needs to be accomplished to meet the TCEQ's screening level for nitrate. That places the annual target load at 24,972 lbs.

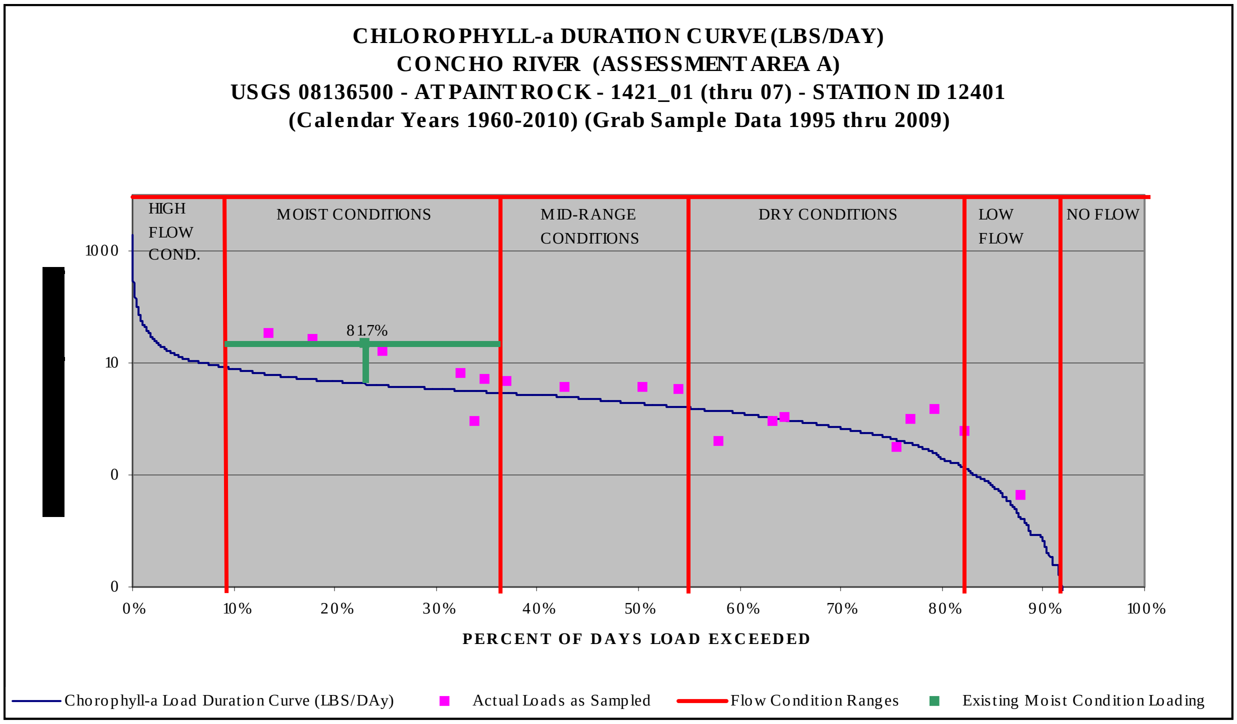
Nitrate exceedances are distributed over all flow conditions except the extreme low and high flow conditions, and because they are, little information regarding the attribution of sources can be gleaned from the load duration curve. There exist numerous contributors to the nitrate loading in this portion of the Concho River watershed.

As discussed in Section 2, historically the Concho River is a gaining stream through this section (Figure 14). When the Lipan Aquifer is charged and operating according to historical norms, it provides groundwater to the Concho River and Dry Hollow Creek, Lipan Creek, and Kickapoo Creek, all of which are major tributaries to the river. It has been know for a long time that shallow groundwater in the Lipan Flats area carries high concentrations of nitrates, and when these tributaries are flowing they typically deliver high loads of nitrates to the Concho River. The source of nitrates in the groundwater is not certain.

However, the groundwater is not the only source of nitrates impacting the Concho River. Other probable or potential sources have also been identified, such as storm water discharges from the City of San Angelo, concentrated animal feeding operations, illegal discharges from concentrated animal feeding operations, agricultural nutrient management practices, and failing on-site sewage facilities (septic systems). These potential sources are discussed in more detail in the following segments of the Concho River Watershed Protection Plan.

Chlorophyll-a is another constituent listed as a concern on the 305(b) list. The load duration curve constructed for chlorophyll-a is displayed below (Figure 12).

Figure 12. Assessment Area A Paint Rock Station Chlorophyll-a LDC

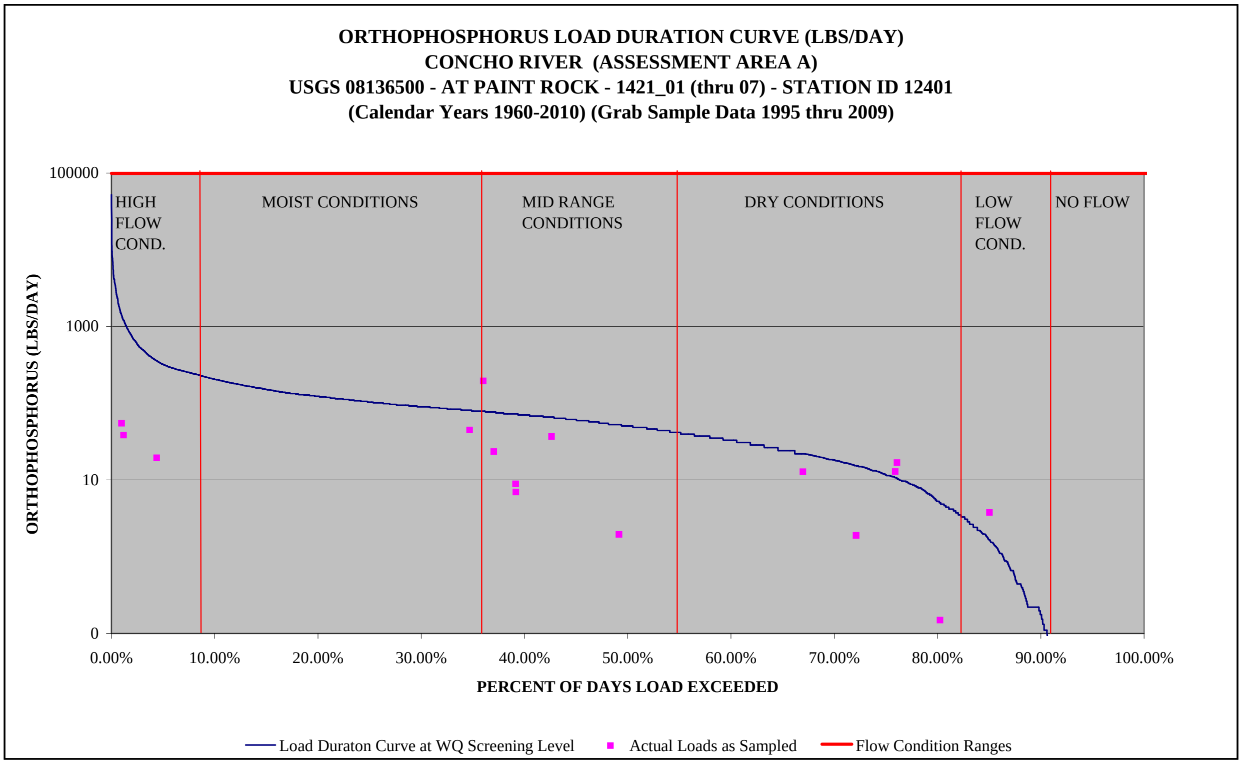


Under the right conditions nitrates and orthophosphorus are nutrients that stimulate algal growth. Chlorophyll-a is an indicator of algal biomass concentrations in water. Increases in chlorophyll-a concentrations indicate the occurrence of algal blooms, which can harm other aquatic organisms and lead to the potential eutrophication of the system. As long as algae are engaged in photosynthesis they increase oxygen levels in the water. However when an influx of nutrients causes rapid growth and multiplication of algae, an algal bloom occurs. Their numbers quickly multiply until they deplete the nutrient supply then they die in mass. Once this happens they start to decompose and this process uses oxygen and has a depressive effect on dissolved oxygen levels. Typically, algal growth is more of a concern in standing bodies of water such as lakes and ponds. However, the decreases to only minimal flow (or no flow) in various segments of the Concho River between San Angelo and Paint Rock during recent years periodically creates environments conducive to algal growth.

The chlorophyll-a load duration curve (Figure 12) exhibits similar characteristics to the nitrate curve. Again, as with nitrates, the distribution of chlorophyll-a exceedances is across all flow conditions except for extreme high and low flows. The moist condition class exhibits the highest exceedance values. The calculated percent reduction needed to meet water quality standards is 81.7%, again a very large number. An annual load of 3,894 lbs was calculated from the data, which places the total load reduction at 3,181 lbs and the target load at 713 lbs.

The orthophosphorus load duration curve exhibited a few exceedances, but most of the sample data points plot below the water quality based curve. Loading capacity is the greatest amount of loading for a pollutant or constituent that a water body can receive without exceeding water standards or screening levels. Based on analysis of the load duration curve, the Concho River at Paint Rock still has not reached its loading capacity for orthophosphorus (Figure 13).

Figure 13. Assessment Area A Paint Rock Station Orthophosporus LDC



Assessment Area A Other Identified Threats and/or Known Water Quality Problems

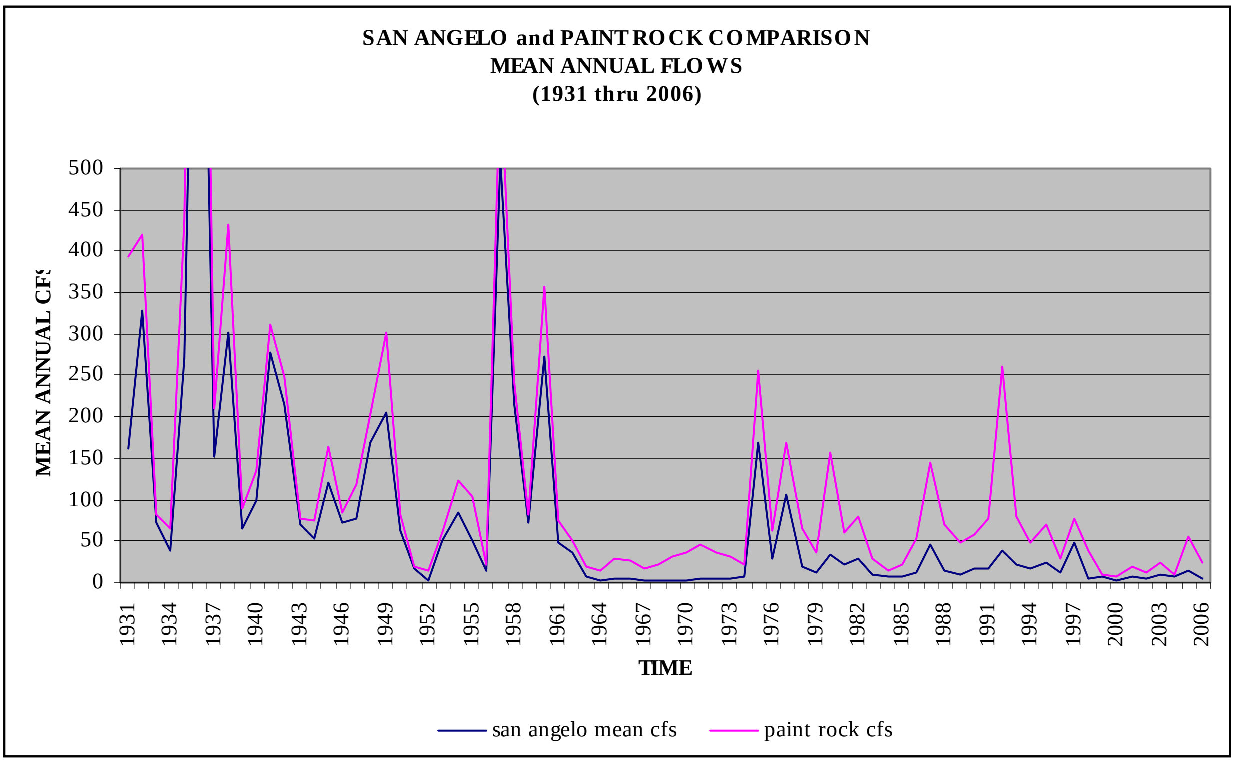
- Identified Base Stream Flow Impacts
- Identified Water Quality Impacts from Non-Compliant CAFOs
- Identified Water Quality Impacts from Farming Operations
- Potential Water Quality Impacts from Urban Runoff
- Potential Water Quality Impacts from Petroleum E&P Activities
- Potential Water Quality Impacts from Abandoned/Unused Water Wells
- Potential Water Quality Impacts from Development of Rural Areas

These other identified threats and/or known problems included in the investigative scope of the watershed planning process for this assessment area are discussed below or in Section 5.0.

Identified Base Stream Flow Impacts

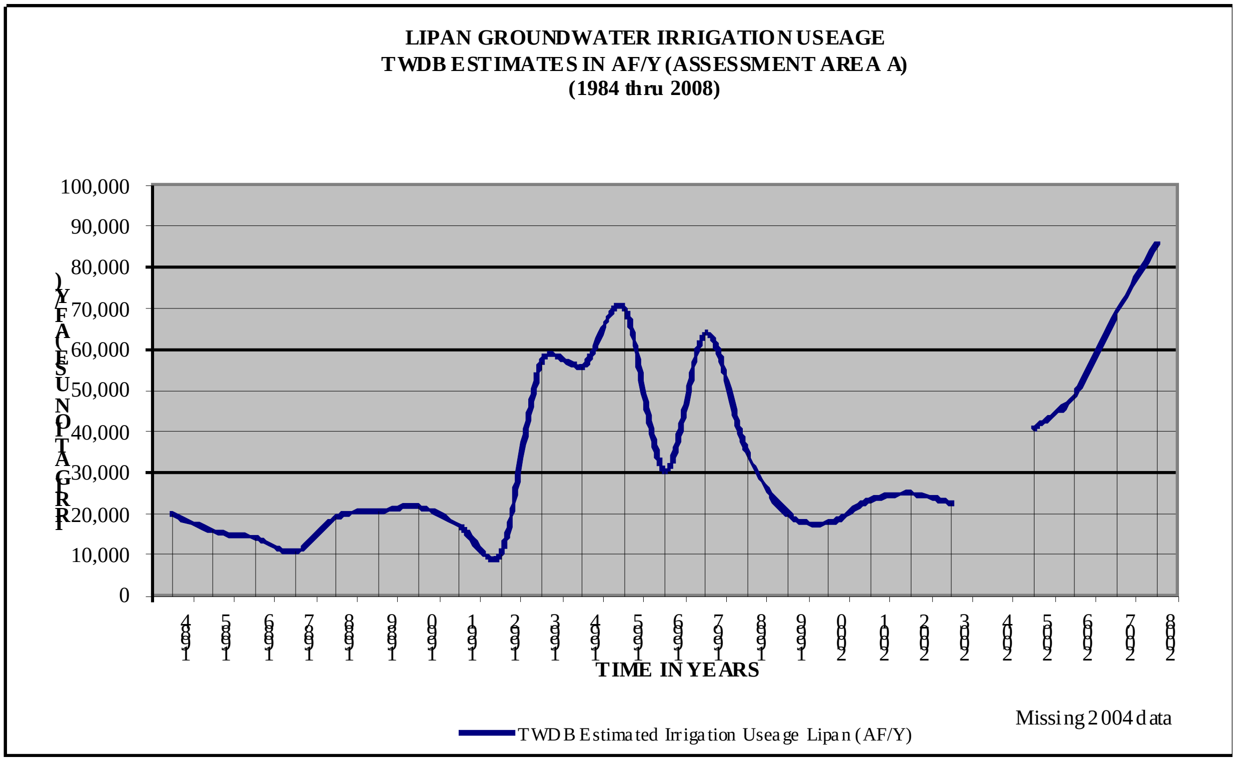
USGS stream flow records indicate that the Concho River is a gaining stream between USGS Gaging Stations 08136000 at San Angelo and 08136500 at Paint Rock (Figure 14). Texas Clean Rivers Program records show that during the period from 1998-2002, the river intermittently ceased to flow while many holes of water completely dried-up. This resulted in massive fish kills, thousands of native pecan tree deaths, and forced the City of Paint Rock, which uses the Concho River for its public water supply, to seek alternative supplies. While it is true that stream flow impairments that are taking place in Assessment Area A are in response to climatological factors, i.e. drought, other factors also likely contribute significantly to measured base flow diminishment.

Figure 14. Concho River Flow Comparison (San Angelo and Paint Rock Stations)



One possible factor is the increase in the amount of irrigation pumping from the Lipan Aquifer. As reported in the Texas Water Development Board (TWDB) report 360, *Aquifers of the Edwards Plateau*, well records indicate that from 1990 to 2000, the number of irrigation wells in this area increased from approximately 200 to over 1,000. According to this report, irrigation pumping increased from about 15,000 acre feet per year (AFY) in the late 1980s to over 65,000 acre feet per year by the late 1990s (TWDB, 2006). The TWDB's irrigation estimates from the Lipan Aquifer have sharply risen since 2003 (Figure15). The 85,811 acre feet pumped in 2008 is the most ever pumped from the aquifer. It surpasses the 70,158 acre feet pumped in 1995 (the previous high mark) by more than 22%.

Figure 15. Lipan Groundwater Irrigation Usage 1984 -2008



The increases in irrigation pumping have been partially mitigated by state and federal cost share programs that have improved irrigation efficiency on land where the programs have been implemented. These programs provide incentives for the conversion of less efficient sprinkler and flood irrigation systems to more efficient pivot and drip irrigation systems.

Another factor contributing to decreased base flows is the impoundment of river flows in the reservoirs located upstream of Assessment Area A. This has been partially alleviated by the Concho River Watermaster Program that, on occasion, requires releases from Lake Nasworthy.

Also contributing to diminished base flows of the Concho River in Assessment Area A is the occurrence of approximately 285,000 acres of moderate to heavy density brush infestations within this subwatershed. In the *Concho River & Upper Colorado River Basins Brush Control Feasibility Study* (UCRA, 2000), modelers, using the Soil and Water Assessment Tool (SWAT) model, determined that water yields could be increased by over 48,000 acre feet per year, assuming treatment of all moderate and heavy brush in the main Concho River watershed. This represents lost water that is being consumed by deep-rooted mesquites and/or intercepted by dense canopies of juniper. The implementation of brush control water supply enhancement projects would improve water quality, support base flows, aquatic life, wildlife, and other uses in this and other watersheds of the Concho River and its major tributaries.

Surface water rights holders also withdraw water directly from the Concho River. Because of the recent lack of base flow conditions existent on this portion of the Concho River, the water rights holders petitioned the TCEQ to implement a Watermaster Program, which is now in operation. The TCEQ's Watermaster Programs ensure compliance with water rights by monitoring stream flows, reservoir levels, and water use. By curtailing excessive surface water pumping and fairly distributing surface water resources, this program should help to address this component of the base flow impairment issue.

Water Quality Impacts from Concentrated Animal Feeding Operations

As defined by the TCEQ, an animal feeding operation (AFO) is a lot or facility, other than an aquatic animal production facility, where animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period, and in which the animal confinement areas do not sustain crops, vegetation, forage growth, or post-harvest residues in the normal growing season over any portion of the lot or facility. When the number of confined animals reaches certain levels (varies by animal type), the term concentrated animal feeding operation (CAFO) is used (Table 8). An AFO categorized as a small AFO does not require a TCEQ permit unless it is designated a small CAFO by the executive director. All medium and large CAFOs are required to have either a general permit or an individual TCEQ Water Quality Permit.

Table 8. TCEQ Animal Feeding Operations Categorizations

Generalized CAFO Categories		
Category	Animal Type	Animal Numbers
Small AFO	Veal Calves or Cattle	<300
	Mature Dairy Cattle	<200
	Sheep	<3,000
Medium CAFO	Veal Calves or Cattle	300-999
	Mature Dairy Cattle	200-699
	Sheep	3,000-9,999
Large CAFO	Veal Calves or Cattle	1,000 or More
	Mature Dairy Cattle	700 or More
	Sheep	10,000 or More

In the North Concho River Watershed, the types of CAFOs are cattle feeding operations, sheep feeding operations and dairies. The type and number of animals on site determine how a CAFO is categorized. Table 8 illustrates the categorization criteria used by the TCEQ.

Through the middle reach of this segment, there are eight CAFOs and several smaller AFOs located adjacent to or near tributaries that flow into the Concho River. Particularly impacted is

Willow Creek, near which several of these CAFOs and AFOs are located (Figure 10). TCEQ complaint and enforcement records and UCRA complaint investigation records attest to many documented unauthorized discharges from CAFOs during recent years. These discharges have degraded water quality with high organic loads, nutrients and bacteria. Associated with the operation of CAFOs is the generation of large quantities of manure that is typically disposed on area farmer's fields. If agronomic application rates are not strictly adhered to and the manure not plowed into the soil in a timely manner, this practice represents a potential nonpoint source pollution threat from runoff and from nutrients leaching into the groundwater.

Willow Creek Subwatershed Special Study

As previously mentioned, the Willow Creek Subwatershed is a watershed on which several large permitted CAFOs and also several smaller, un-permitted AFOs are located. The presence of these facilities, concentrated on one subwatershed, in and of itself is considered to represent a potential threat to surface and groundwater. TCEQ records reveal that one of the CAFOs, a dairy, has an extensive history of compliance violations. Combined, these facts led to the selection of Willow Creek as a special study site.

Willow Creek Discharge Investigation Results

From March 2005 thru April 2007, UCRA received four complaints regarding illegal discharges from a CAFO located north of Miles in southwest Runnels County, near the Tom Green County line. The receiving stream for these discharges is Willow Creek. In each case, UCRA staff notified TCEQ's Region 3 Office in Abilene of the citizen complaint, then conducted field investigations. The field investigations included photographically documenting the event, taking flow measurements, measuring field parameters, and collecting grab samples for laboratory analysis. The following loadings were calculated using the values obtained from analytical results of samples collected during all discharge investigations during the two year period, and assuming a twenty-four hour flow interval (Table 9). (This particular CAFO, a dairy, ceased operation with the final dispersal of its milk cow herd in April of 2010.)

Table 9. Willow Creek Discharge Loadings

Willow Creek Discharge Total Loadings		
Parameter	**Total Amount**	**Units**
Discharge Amount	861,470	Gallons
BOD	715	lbs.
NH_3N (Ammonia Nitrogen)	280	lbs.
TSS	2,342	lbs.

Willow Creek Storm Event Monitoring

The original goal of this component of the Willow Creek Special Study was to monitor three storm events. However, only one event was successfully monitored. On some occasions when storm event monitoring could have been performed, the sampling equipment was unavailable, as it was deployed at other sites. Other times when weather conditions appeared conducive to producing storm water flows on Willow Creek, the equipment was deployed there, but either precipitation did not occur in the right places, or in sufficient quantities to produce runoff.

Loadings were calculated for this single small event, which lasted for 10 hours (Table 10).

Table 10. Willow Creek Storm Event Loadings

Willow Creek Storm Event Loadings		
Parameter	**Total Amount**	**Units**
Runoff Quantity	≈ 3	Ac Ft
BOD	40	Lbs
NH_3-N	7	Lbs
NO_3-N	70	Lbs
TPO	3.5	Lbs
TSS	1050	Lbs

Willow Creek Subwatershed Base Flows

Through the winter months, Willow Creek typically exhibits base flows. Table 11 below illustrates average values and loadings for 2005 and 2006.

Table 11. Willow Creek Average Annual Base Flows

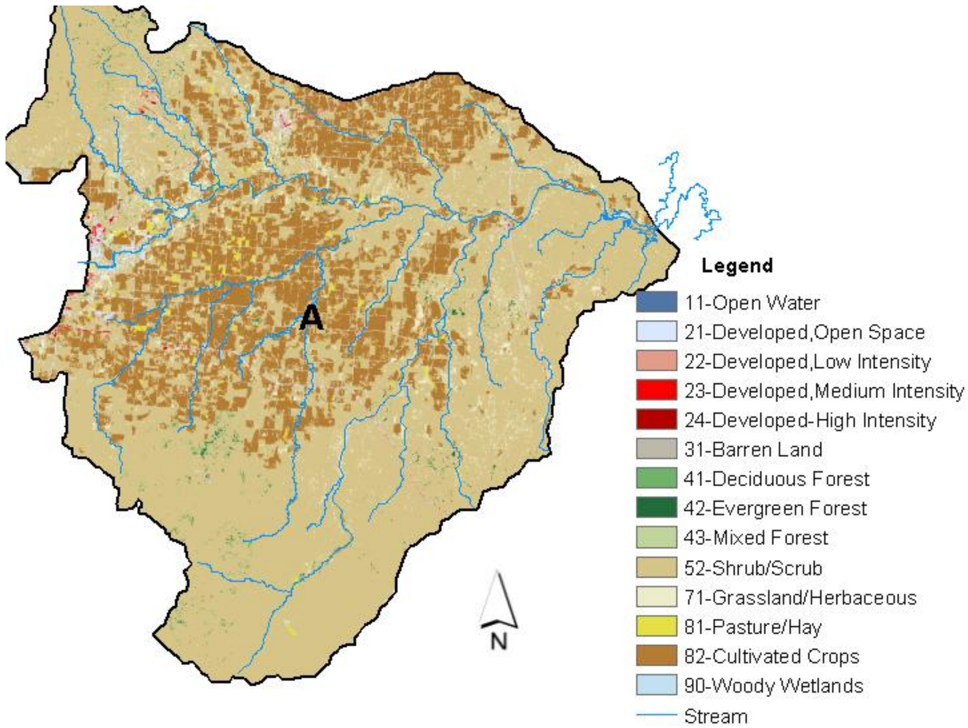
Willow Creek Average Annual Base Flows		
Parameter	**Total Annual Average**	**Units**
Base Flow	≈150	AFY
NH_3-N	290	Lbs
NO_3-N	775	Lbs

Although the desired outcomes of the Willow Creek subwatershed special study were not fully realized, this subwatershed remains a potential treat of water quality impacts because of its location proximal to concentrated animal feeding operations.

Water Quality Impacts from Farming Operations

According to the land use determinations made in the *Concho River & Upper Colorado River Basins Brush Control Feasibility Study* (UCRA, 2000), over 25% of the total acreage of Assessment Area A is used for farming purposes. According to the National Land Cover Database, 2001 (Figure 16) the percentage of cultivated cropland in this subwatershed is 21.4%.

Figure 16. Assessment Area A Land Use Map



The Lipan Aquifer is a resource that has been utilized for farmland irrigation purposes since at least the 1940s, and for dry land farming since the 1800s. As mentioned before, high nitrate levels are common in groundwater pumped from the Lipan Aquifer and have been since at least the 1940s (Bulletin 5411, Groundwater Resources of Tom Green County, US Dept of the Interior, 1954). When irrigation practices first began on the Lipan Flats, row flooding was the method most widely utilized and it is considered likely that over-watering was not uncommon. It is considered likely that the practice of over application of fertilizer and over watering leached highly soluble nitrates into the soils, past the rooting depth of crops and into the shallow alluvial portion of the Lipan Aquifer. It is recognized, that as a group farmers adhere to better management practices than in years past, and considering the cost of fertilizer and irrigation pumping, it is likely that if such practices occur now, it is only infrequently and unintentionally.

Moreover, the source(s) of nitrates in the Lipan Aquifer is unknown with certainty, and it is not clear that farming activities have contributed to the problem. An EPA study published in 1973 attributed the high levels of nitrates in groundwater in Runnels County to high levels of naturally occurring organic material in the soil and specifically excluded activities of man as an attributable cause (An Investigation of the Nitrate Problem in Runnels County, Texas, EPA, 1973).

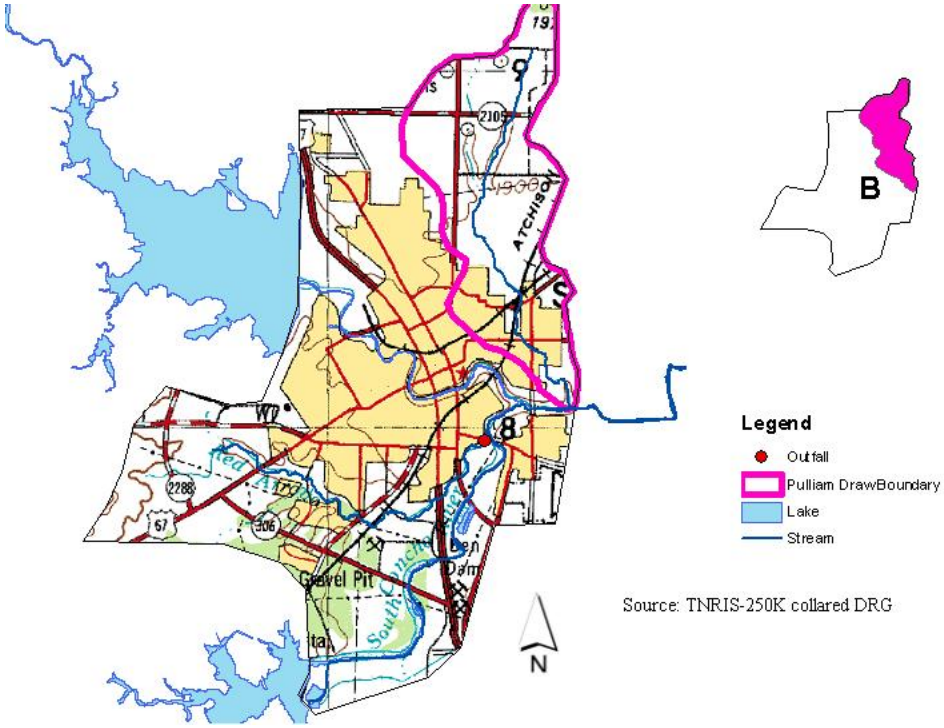
Most irrigation wells are drilled through the Quaternary aged alluvial deposits (Leona Formation) and into the Permian aged limestones, dolomites and shales of the Clear Fork Group, and are open-hole completed in both units. Prior to the practice of completing wells in both units there existed two distinct groundwater chemical signatures. The shallow water from the Leona was of good chemical quality except for the previously described nitrogen content while the deeper Clear Fork water contained higher levels of chlorides and sulfates. The two formations were minimally hydraulically connected but the proliferation of wells completed in both units has caused a commingling of the groundwater from both aquifers and the TWDB has designated the combined Leona and Clear Fork Formations to be the Lipan Aquifer, a designated Minor Aquifer of Texas. The chemical quality of the water is now high in nitrates, chlorides and sulfates, and when it dewaters into the Concho River and its tributaries, it contributes dissolved solids and nutrients.

Water Quality Impacts from Urban Runoff

The Concho River downstream of San Angelo has been significantly impacted over the last 50 years by urban runoff. Reservoirs constructed above San Angelo have minimized scouring flows within the upper reaches of Assessment Area A. Most of the water that exits the City of San Angelo's city limit at the Bell Street dam is urban stormwater runoff produced from San Angelo's impervious cover. The Assessment Area B section of the Watershed Protection Plan contains a thorough discussion of the impact that urban runoff has inside San Angelo. Much of that discussion is pertinent to Assessment Area A as well. However, the impacts to the Concho River are not as overwhelming because a hydrologically functioning river, even a minimally functioning one, can better handle storm water flows than the closely spaced, contiguous impoundments in the City of San Angelo. This is due to the dispersion of storm flows throughout its reach and the gaining nature of its hydrology.

In addition to the flows passing the Bell Street dam, Pulliam Draw is an uncontrolled wet weather waterway that also supplies urban runoff flows to the Concho River. The confluence of Pulliam Draw and the Concho River is located approximately 4,000 ft downstream from Bell Street dam. It is mostly located in Assessment Area B and is considered a significant threat to Assessment Area A. It drains an approximately 7,500 acre subwatershed located in east San Angelo and north of the city limit of San Angelo (Figure 17).

Figure 17. Pulliam Draw Location Map



The draw runs through an area of San Angelo zoned for Heavy Manufacturing, Light Manufacturing, Heavy Commercial, General Commercial, and Residential. Several industrial TCEQ permit holders are located in the watershed of this draw. Much of the area around and adjacent to the urban portion of the draw was used years ago to dispose of slag waste generated by foundries formerly located in San Angelo. Foundry slag is a partially vitreous, ferrous waste material derived from the removal of fluxing agents and impurities from molten metal prior to casting. TCEQ enforcement records document several instances of industrial solid waste and wastewater violations. From TCEQ complaint and enforcement records, known contamination issues include heavy metals, and PCBs in soil and groundwater, and CAFO violations from a former dairy. Based on field observations, slag was used as base material for construction foundations, as fill material and otherwise dumped along the draw before regulations governing such activities were in-place (Figure 18). The dark brown material in the photographs is slag.

Figure 18 Pictures of Exposed Foundry Waste Slag

Based on prior contamination cases, the observed wastes dumped near or adjacent to this drainage feature, the types of industries located adjacent to it, and the water quality data collected and analyzed for this assessment, runoff from Pulliam Draw is considered to represent a potentially significant threat to the waters of the Concho River in Assessment Area A. (Loadings, calculated from storm event water quality monitoring of Pulliam Draw, are included in the Assessment Area B section).

Assessment Area A Water Quality Impacts from Petroleum E&P Activities

Assessment Area A includes portions of Concho, Runnels, Menard and Tom Green Counties. Active well counts are categorized by county and obviously, not all wells reported for a county are included in the assessment area boundaries. The counts are from RRC active well counts reports and are provided to give the reader an idea of the scope of the potential threat that exists (Table 12).

Table 12.Texas Railroad Commission Active Counts Reports

Texas Railroad Commission Active Counts Reports			
County	**# Active oil wells**	**# Active gas wells**	**Total**
Concho	403	93	496
Runnels	877	62	939
Tom Green	939	107	1046
Totals	2219	262	2481

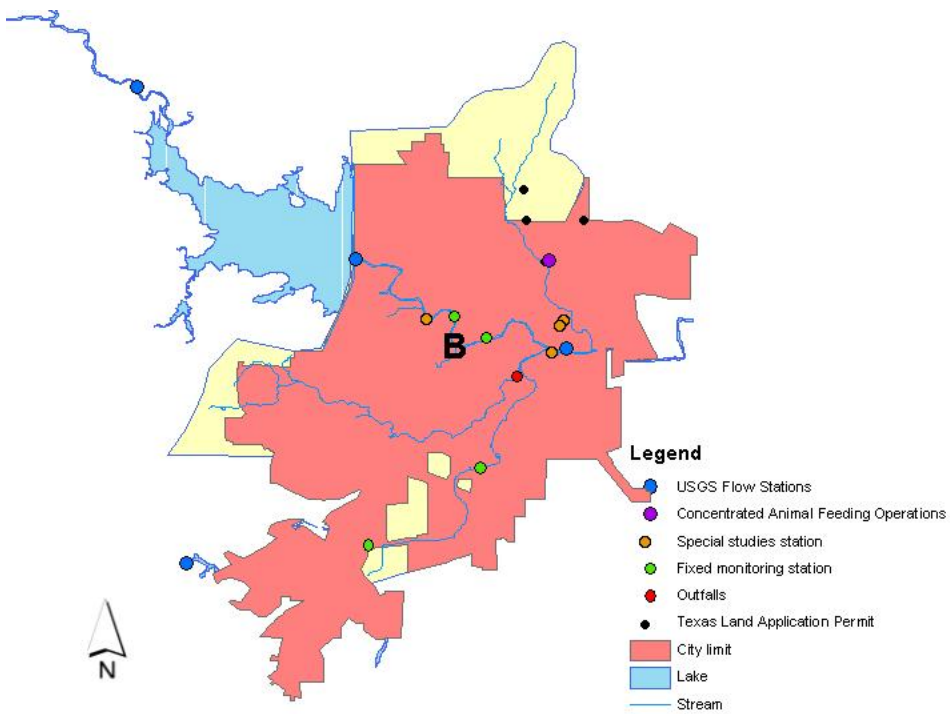
A very small portion of Menard County is included in Assessment Area A; however, no oil or gas wells or dry holes have been drilled in the applicable portion of the county.

(Other load duration curves, analytical charts, materials and maps developed for and used in the analysis and evaluation of Assessment Area A, but not included in the text of the Watershed Protection Plan are included in Appendix A.)

5.2 ASSESSMENT AREA B

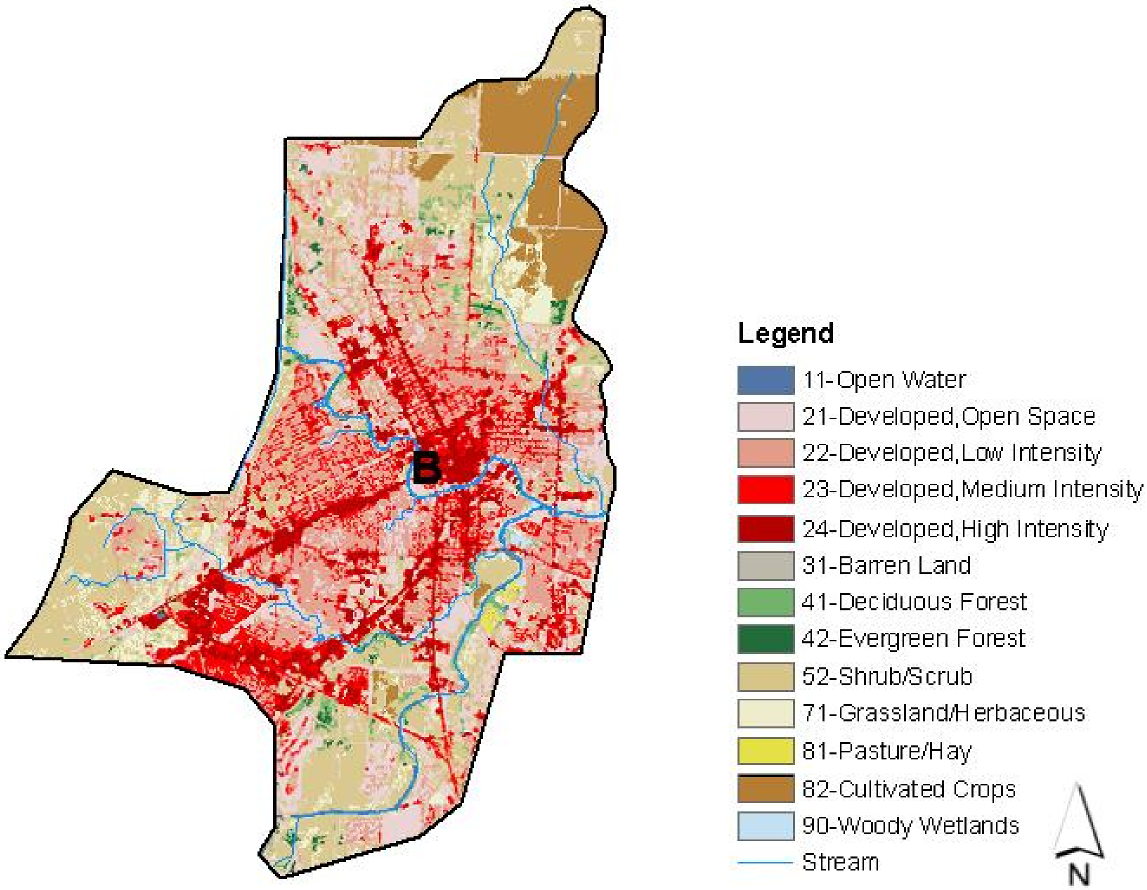
Assessment Area B includes urban portions of Stream Segment 1421, which includes the North Concho and South Concho Rivers from Bell Street Lake upstream to O.C. Fisher Lake dam and Lake Nasworthy dam respectively, plus the drainage area of Pulliam Draw located north of San Angelo and in east San Angelo (Figure 17). Pulliam Draw's confluence with the Concho River is located in Assessment Area A. The total areal extent of Assessment Area B is approximately 33,600 acres (Figure 19).

Figure 19. Assessment Area B Boundary Map



Because most of Assessment Area B is located within the city limits of the City of San Angelo, most of the land use is either low intensity developed, medium intensity developed, or high intensity developed (Figure 20).

Figure 20. Assessment Area B Land Use Map



The Assessment Units and associated Station IDs included in Assessment Area B are presented in Table 13 below.

Table 13. Assessment Area B TCEQ Assessment Unit Designations

Assessment Area B TCEQ Assessment Unit Designations			
Name	**AU ID**	**Assessment Unit Description**	**Station ID**
Concho River	1421_08	North Concho River, From the confluence with the South Concho River upstream to OC Fisher Dam	12412 12414 15886 20324
Concho River	1421_09	South Concho River, from the confluence with the North Concho River upstream to Nasworthy Dam	12416 17348

The water bodies located in Assessment Area B that are included in the 2008 Texas Water Quality Inventory and 303(d) list are displayed in Tables 14 and 15 below.

Table 14. Assessment Area B 2008 303(d) List of Water Quality Impairments

Assessment Area B 2008 303(d) List of Water Quality Impairments				
Name	**Assessment Unit**	**Parameter of Concern**	**Category**	**Yr Listed**
Concho River	1241_08	bacteria	5c	2008
		depressed oxygen levels	5c	2008
5c - Indicates Additional data and information will be collected before a TMDL is scheduled				

Table 15. Assessment Area B 2008 305 (b) List of Water Quality Concerns

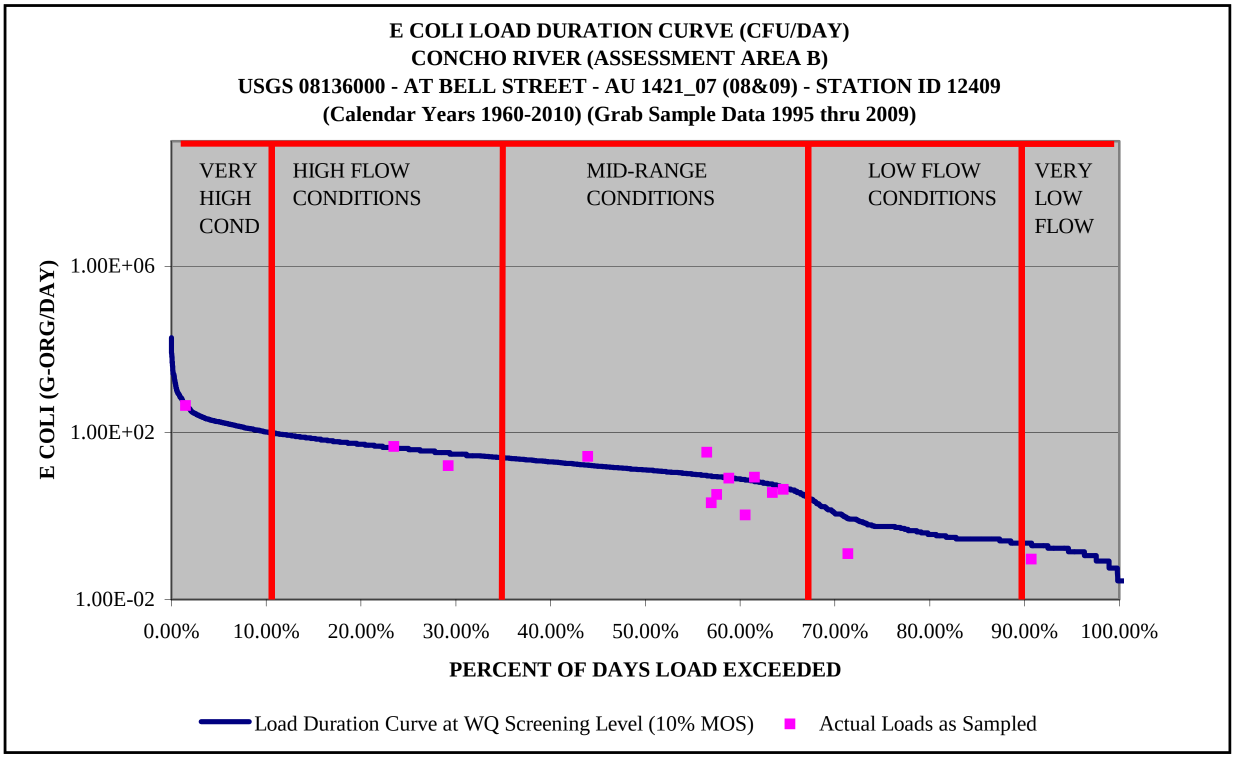
Assessment Area B 2008 305(b) List of Water Quality Concerns			
Name	**Assessment Unit**	**Parameter of Concern**	**Category**
Concho River	1421_08	chlorophyll-a	CS
Concho River	1421_09	depressed oxygen levels	CS
CS - indicates concern for near non-attainment of water quality standard			

Assessment Unit 1241-08 is included on the 2008 303(d) list for two impairments, bacteria and depressed oxygen levels. Because of man-made impoundments located in Assessment Unit 1421_08, continuous low flows and the unavailability of useful flow data, it was not feasible to develop meaningful load duration curves for the section of river. Load duration curves for dissolved oxygen, chlorides, nitrates, E. coli, total phosphates and chlorophyll-a were developed using flow data from the USGS 8136000 flow station and sample data from the Bell Street Station 12409. These stations are technically located in Assessment Area A and in the TCEQ's Assessment Unit 1421_07. However, they are positioned immediately downstream of Bell Street Lake and, except for the Pulliam Draw watershed, serve as the drainage outlet for almost all of the City of San Angelo and Assessment Area B. As such they measure flows leaving San Angelo and water quality from Assessment Area B.

Assessment Area B 303(d) Impairments – Bacteria

Although the load duration curve for E. coli (Figure 21) did not indicate an overall exceedance above the loading capacity, the water quality screening level did calculate near the loading capacity at the Bell Street Station.

Figure 21. Assessment Area B, Bell Street Station E. coli LDC



For Figure 21, typical hydrologic condition class divisions are not meaningful. The divisions displayed on the E. coli load duration curve were subjectively determined from the shape of the flow curve and standard interpretations of their meaning cannot be made. Most of the samples cluster at the lower end of the mid-range condition class, which represent flows that occur approximately 30% of the time.

Although the E. coli load duration curve shows that the loading capacity of the river below Bell Street dam has not been exceeded, Assessment Unit 1420_08 is included on the 303(d) list as impaired for bacteria. To evaluate this portion of the river for the bacteria impairment, a series of charts were generated for comparative analysis. Charts that display grab sample concentrations, the E. Coli grab sample geomean water quality standard and the E. Coli single grab sample water quality standard plotted against time were generated for Station 12412 (Figure 22) and Station 15886 (Figure 23).

Figure 22. Assessment Area B, Irving St. Dam Station E. coli Grab Concentration vs. Time

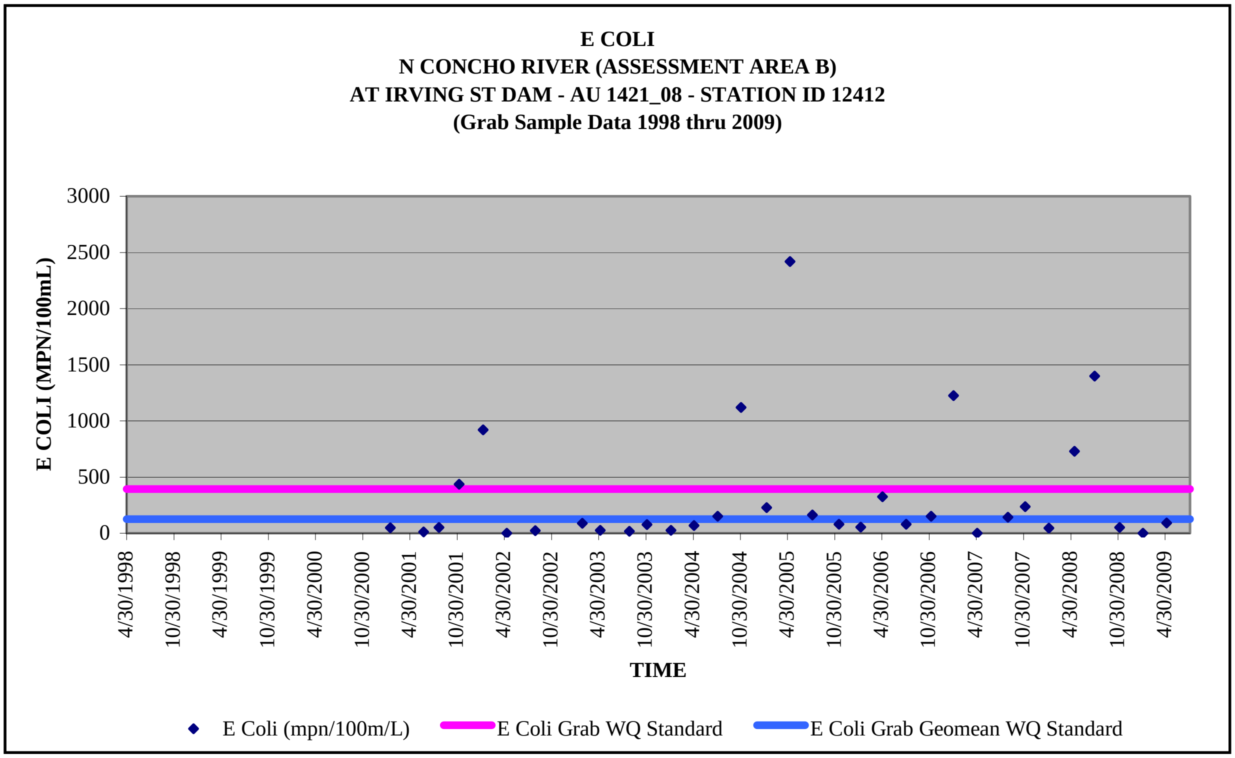
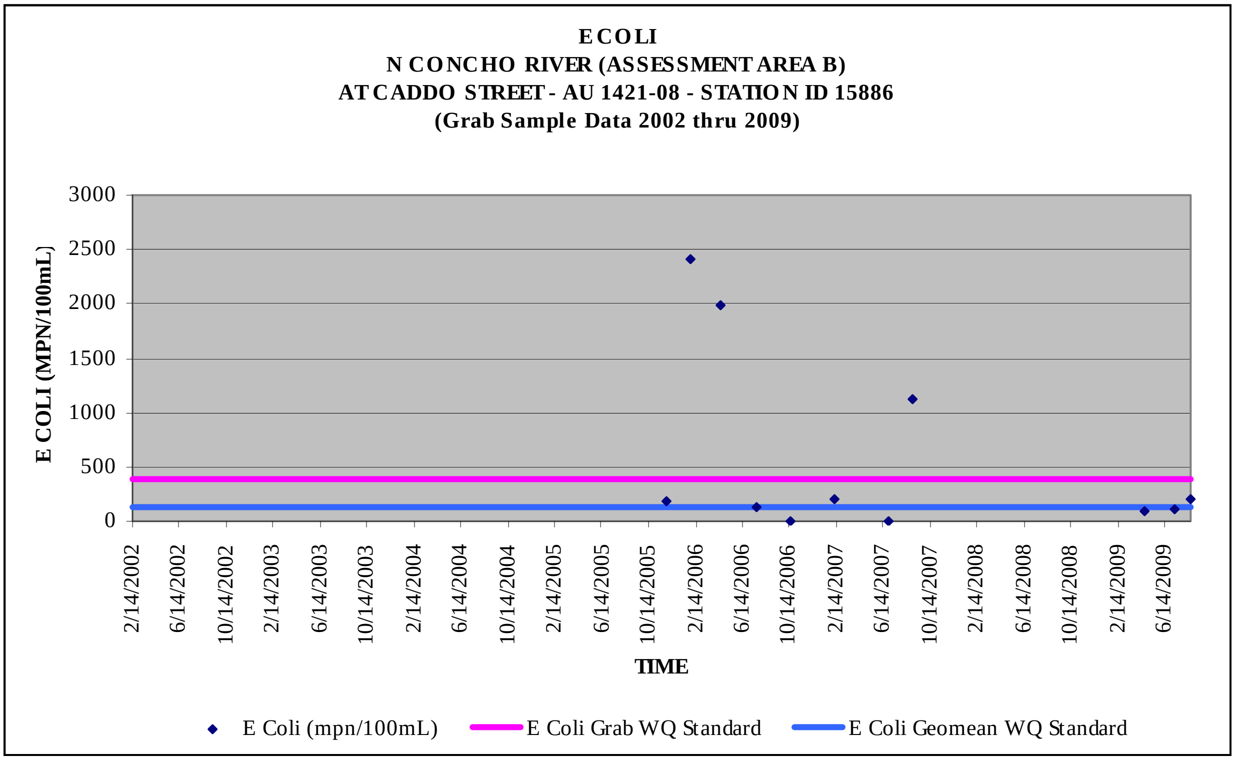
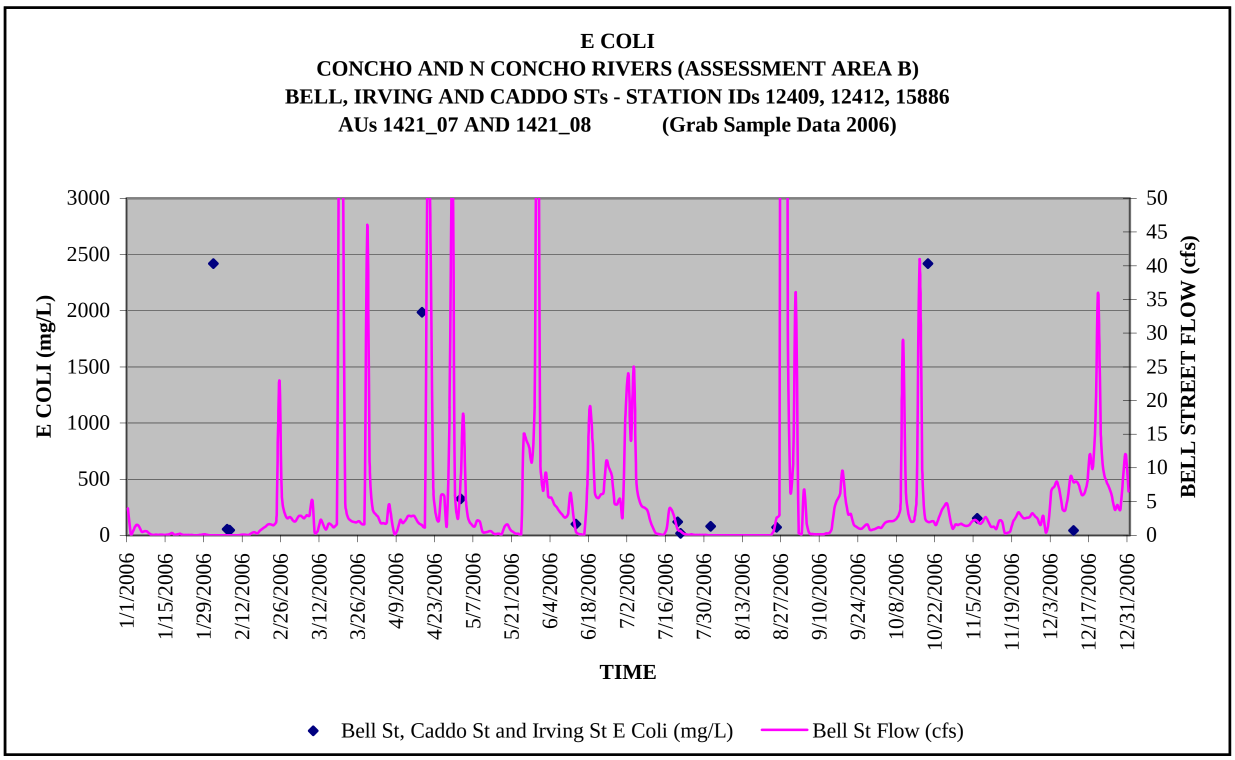


Figure 23. Assessment Area B, Caddo St. Station E. Coli Grab Concentration vs Time



These charts show low levels of E. coli interspersed with sporadic very high exceedances of water quality standards. No patterns could be discerned from the data. The exceedances are unrelated to seasons or identifiable specific periods of time. Bacteria sampling was not included in the sampling protocol for storm event monitoring conducted in Assessment Area B and could provide no information regarding the bacteria exceedances. To assess whether there may be a relationship between the exceedances and occurrence of storm event flows, nine charts (one each for years 2001 – 2009) were generated. The data plotted on these include the data from the previous two charts plus E. coli grab sample data and flow data at the Bell Street Station. (The flow data has been inserted to provide a time marker of storm events only, and is not useful for relating the concentrations to specific levels of flow). These charts were evaluated to discern any pattern to the timing of bacteria exceedances and no meaningful correlations were discovered. The exceedances occur before storm events, immediately after storm events, and during long and short periods of low to moderate flow between storm events. The 2006 chart is included below and is representative of the entire set of nine (Figure 24).

Figure 24. Assessment Area B E. Coli Grab Sample Concentration vs. Flow



These observations lead to the conclusion that bacteria loading is not specifically related to storm events nor is it related to dry weather sources or wet weather sources.

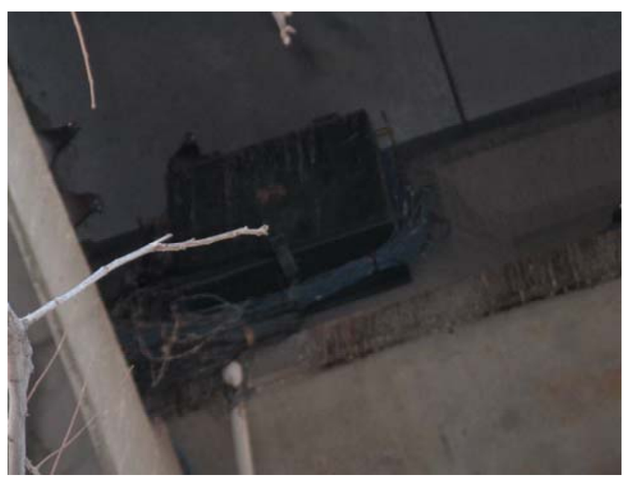
The American Veterinary Medical Association estimates that the average Texas household owns 0.8 dogs (AVMA 2002). Based on this estimation and the estimated number of households located in the contributing drainage area of Assessment Unit 1421_08, as many as 10,000 dogs may live in the impaired drainage area. Therefore pet waste is considered a potential contributor. However, the sporadic nature of the bacteria exceedances coupled with the observation that exceedances are not correlative to storm event timing, lead to the inference that pet waste is at most, a minor contributor. If pet waste in storm runoff were a significant contributor, the exceedances would be more likely to occur in a regular pattern shortly after storm events when the waste would be washed into the river. Other factors that mitigate against the significance of excessive pet waste loading is the fact that the City of San Angelo, in 2005, began installing and maintaining pet waste stations in its public parks. Interviews with city personnel indicate that the stations have a high level of use. They estimate that more than 2000 bags are used on an annual basis. The heaviest concentration of these waste stations is located in the park areas along and adjacent to the river in Assessment Unit 1421-08. The city monitors usage and adds capacity when needed and upon expansion of public areas. Moreover, pet waste, as a nonpoint source pollutant and solutions to deal with it, is a regularly taught topic in the education programs conducted by the Water Education Center (see Section 3).

Bacterial source tracking studies performed in the development of TMDLs elsewhere have determined that birds can be a significant source of bacteria loading. Birds that roost under and build nests under bridges are of particular concern because they can and do contribute fecal matter directly into the water. Fourteen traffic bridges and one railroad bridge cross the North Concho River in Assessment Unit 1421_08. In addition to pigeon roosting sites and nesting areas for swallows, waterfowl also use the river. Not only do domestic waterfowl reside in the parks along this stretch of river, but river use by wild waterfowl is also prevalent. Wild waterfowl use the waterway during migrations and winter months, swallows nest under the bridges, pigeons roost under the bridges, and the area has a sizeable population of cormorants and sea gulls for many months of the year.

Given the limited data available for this analysis, it is considered most likely that waterfowl and birds that use bridges for roosting and nesting are responsible for the sporadic E. coli exceedances that occur in Assessment Area B (Figure 25).

Figure 25. Assessment Area B, Photographic Evidence of Avian Influence on Bacteria Concentrations

(Bird feces on concrete, and swallow nests)



(Roosting pigeons)

(Swallow nests) (Domestic ducks and geese)

Assessment Area B 303(d) Impairments – Depressed Dissolved Oxygen Levels

The cause of the dissolved oxygen listing for Assessment Unit 1421_08 is related to low flows and urban runoff. Since completion of O.C. Fisher Reservoir in 1952, flow has been seriously reduced in the river and desirable scouring flood flows have been completely eliminated. Low water levels in O.C. Fisher Reservoir generally prevent any significant downstream releases. Existing stream flows consist of minor reservoir seepage, spring flow and stormwater runoff. The drainage system in this area consists primarily of natural surface drainage features and a minor system of constructed storm sewers located almost exclusively in the downtown area. Several small dams impound water in this section of river. These dams have effectively created a series of urban storm water impoundments characterized by very low flows except during storm events. A major portion of the residential, industrial and commercial development in the city lies within the contributing watershed of this section of river.

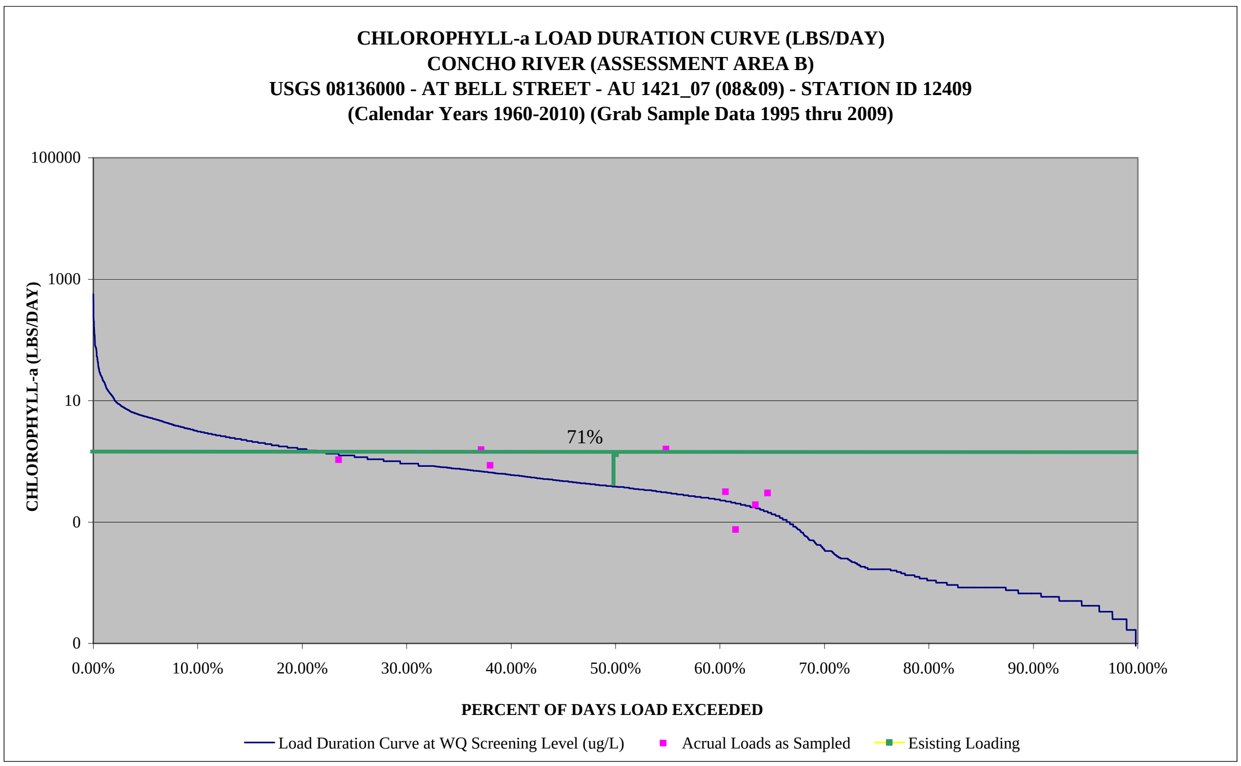
During storm events urban runoff enters the North Concho River at man-made and natural drainage outlets. The storm water typically carries with it heavy loads of organic materials, i.e. dead plants, grass clippings, leaves, animal excrement, etc., and nutrients. Upon entering the river, aerobic bacteria quickly begin to decompose the organic materials. This process consumes oxygen causing a steep increase in biological oxygen demand. As the bacteria continue this process, more and more biological oxygen demand is created and the process continues until the organic wastes are consumed or dispersed. At some point in this cycle, provided there is adequate sunlight, algae begin to feed on the nutrients and a repeating cycle of algal blooms begin. During the day, algae engage in photosynthesis and produce oxygen and dissolved oxygen levels increase but at night photosynthesis stops, all the while bacteria are decomposing remaining stores of organic materials and the algae have died and sunk to the bottom. Because of the low flows into the system at this point, water is not agitated, oxygen is not replenished and recovery of the system is slowed. These cycles can continue for many days after a storm event until the system gradually achieves a balance and dissolved oxygen can recover.

To mitigate the depressed dissolved oxygen levels in the North Concho River, organic loadings need to be significantly reduced to suppress the oxygen robbing bacteria activity and nutrients, nitrates and phosphates, need to be reduced to control the algal blooms.

Assessment Area B 305(b) Concern - Chlorophyll-a

The load duration curve developed for chlorophyll-a exhibited significant exceedances of the Texas surface water quality monitoring screening level for chlorophyll-a (Figure 26).

Figure 26. Assessment Area B, Bell Street Station Chlorophyll-a LDC



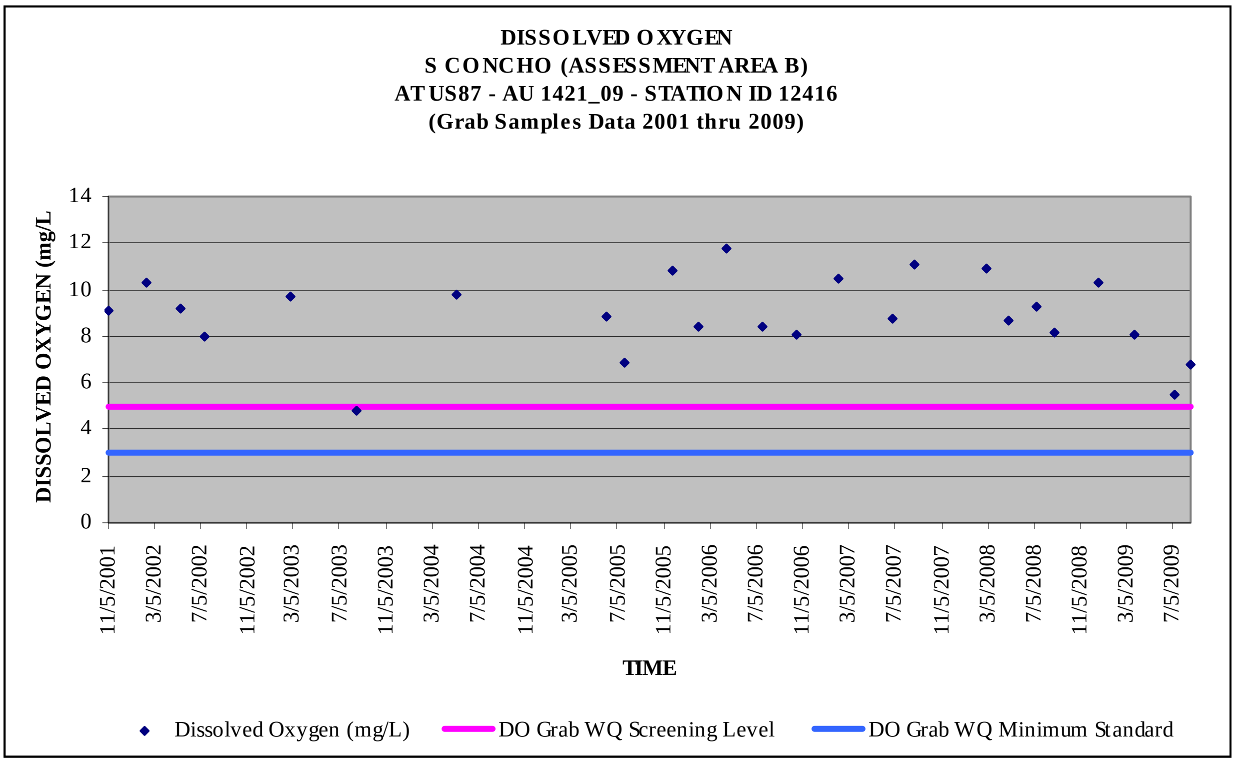
Because of the hydrologic function of the North and South Concho Rivers in Assessment Area B the flows do not correspond to normal hydrologic condition classes. The measured flows are not related to the dynamics of typical stream flows, but instead reflect periodic releases from Lake Nasworthy and occasional infrequent releases from O.C. Fisher Lake. Consequently, dividing the graph into normal hydrologic condition classes is not meaningful.

Because all but one of the samples plot near the mid-range of measured flows, the entire data set was used in calculating existing loads. The calculated percent reduction needed to meet water quality standards is 71%. An annual load of 2.7 lbs was calculated from the data, which places the total load reduction needed to achieve the water quality screening level standard for chlorophyll-a at 1.91 lbs. The target load is 0.79 lbs. The seemingly low numbers in absolute terms for chlorophyll-a is explained by the fact that the unit of measure is micrograms per liter (ug/L) and not mg/L.

Assessment Area B 305(b) Concern – Depressed Dissolved Oxygen Levels

The dissolved oxygen concern in Assessment Unit 1421_09 has essentially been corrected with the water releases from Lake Nasworthy. Data collected years ago during a sustained period of low flows led to the listing of this Assessment Unit. Data collected from 2001 through 2009 show dissolved oxygen levels mostly in the range 8 to 10 mg/L (Figure 27). As long as the releases from Lake Nasworthy continue, oxygen levels in Assessment Unit 1421_09 should remain high and will eventually be removed from the 305(b) list of concerns.

Figure 27. Assessment Area B, S Concho River DO Grab Concentrations vs. Time



Assessment Area B Other Identified Threats and/or Known Water Quality Problems

- Identified Urban Runoff Water Quality Impacts from the North Concho subwatershed (Urban Portion)
- Identified Urban Runoff Water Quality Impacts from Pulliam Draw
- Identified Urban Runoff Water Quality Impacts from the Red Arroyo subwatershed
- Identified Excessive Erosion and Sedimentation in the North Concho River downtown area

- Potential Water Quality Impacts from Unused and/or Abandoned Water Wells

These other identified threats and/or known problems included in the investigative scope of the watershed planning process for this assessment area are discussed below or in Section 5.0.

Urban Runoff Water Quality Impacts from the North Concho River Subwatershed

In the early 1990's, Texas Clean Rivers Program Water Quality Assessment reports identified the urban portion of the North Concho River as one of the most heavily impacted streams within the state regarding urban runoff nonpoint source pollution. Nonpoint source pollution measured in the area included oxygen demanding substances, suspended solids, nutrients and fecal coliform. Numerous periodic fish kills have occurred historically and unsightly conditions continuously existed due to prolific planktonic algae blooms and extreme eutrophic characteristics. This segment of the river receives no base flows due to the impoundment of the North Concho River, which created O.C. Fisher Lake. The only water received by the river in this segment is from urban runoff.

Implementation of a master plan for the 6.75 miles stream reach of the North Concho River through San Angelo resulted in a series of Clean Water Act (CWA) 319(h) construction projects, implemented by the UCRA and City of San Angelo. (UCRA 1999, 2001, 2002, 2008) Expenditures on these projects totaled $2,495,000, $1,266,150 from CWA 319(h) grants and $1,228,850 in local matching funds.

As evidenced by the results of BMP effectiveness monitoring, the installation of structural BMPs has mitigated some of the nonpoint source pollution problems. Prior to their construction, fish kill events were a regular occurrence on the urban portion of the North Concho River. Beginning in the late 1960's, the existence and frequency of fish kills was documented by the TCEQ (and its predecessor agencies), Texas Parks and Wildlife Department (TPWD) and since 1992, by the UCRA. Additional documentation is provided in numerous newspaper articles spanning the period. Now, fish kills are an extremely rare event. However, as previously mentioned, the North Concho River within San Angelo remains significantly impacted by urban runoff nonpoint source pollution.

Bell Street Lake Storm Event Monitoring

On August 27-28, 2006, January 20, 2007, and August 17-18, 2007 storm water monitoring events were conducted at the dam at Bell Street Lake. During each of these events an automatic sampler was deployed that collected samples at one hour intervals. Individual samples from each event were combined to produce a flow-weighted composite sample that was analyzed for water quality. Flows were periodically measured throughout the event. Table 16 presents the calculated loadings of various parameters and the measured flow values obtained from the three storm water monitoring events conducted.

Table 16. Bell Street Lake Storm Event Loadings and Flows

Bell Street Lake Storm Event Loadings and Flows			
Date	**Parameter**	**Amount**	**Units**
08/27-28/06	BOD	14,173	lbs.
	NH_3-N	587	lbs.
	NO_3-N	<140	lbs.
	TPO_4	<200	lbs.
	TSS	56,690	lbs.
	Total Flow	745	ac ft
01/20/07	BOD	1,184	lbs.
	NH_3-N	85	lbs.
	NO_3-N	159	lbs.
	TPO_4	31	lbs.
	TSS	4,737	lbs.
	Total Flow	87.1	ac ft
08/17-18/07	BOD	45,203	lbs.
	NH_3-N	2,712	lbs.
	NO_3-N	4,972	lbs.
	TPO_4	995	lbs.
	TSS	940,223	lbs.
	Total Flow	3,327	ac ft

Houston Harte Outfall Storm Event Monitoring

On April 20, 2006, August 27, 2006, and June15-16, 2007 storm water monitoring events were conducted at the Houston Harte Outfall. During each of these events an automatic sampler was deployed that collected samples at one hour or one half hour intervals. Individual samples from each event were combined to produce a flow-weighted composite sample that was analyzed for water quality. Flows were periodically measured throughout the event. Table 17 below presents the calculated loadings of various parameters and the measured flow values obtained from the three storm water monitoring events conducted.

Table 17. Houston Harte Outfall Storm Event Loadings and Flows

Houston Harte Outfall Storm Event Loadings and Flows			
Date	**Parameter**	**Amount**	**Units**
04/20/06	BOD	55	lbs.
	NH_3-N	5.2	lbs.
	NO_3-N	2.8	lbs.
	TPO_4	0.75	lbs.
	TSS	236	lbs.
	TPH	Non Detect	NA
	Flow	262,082	Gallons
08/27/06	BOD	136	lbs.
	NH_3-N	3.5	lbs.
	NO_3-N	6.5	lbs.
	TPO_4	1.4	lbs.
	TSS	3,440	lbs.
	TPH	Non Detect	NA
	Flow	1,484,000	Gallons
06/15-16/07	BOD	130	lbs.
	NH_3-N	17	lbs.
	NO_3-N	41.6	lbs.
	TPO_4	5.7	lbs.
	TSS	832	lbs.
	TPH	Non Detect	NA
	Flow	3,118,000	Gallons

Urban Runoff Water Quality Impacts from Pulliam Draw Subwatershed

Urban runoff from the Pulliam Draw subwatershed impacts the Concho River in Assessment Area A and is discussed in the Assessment Area A section. Loadings from storm water monitoring events conducted on Pulliam Draw are presented below.

Pulliam Draw Storm Event Monitoring

On April 20, 2006, August 27, 2006, and June 15-16, 2007 storm water monitoring events were conducted on Pulliam Draw. During each of these events an automatic sampler was deployed that collected samples at one hour intervals or one half hour intervals. Individual samples from each event were combined to produce a flow-weighted composite sample that was analyzed for water quality. Flows were periodically measured throughout the event. Table 18 below presents the calculated loadings of various parameters and the measured flow values obtained from the two storm water monitoring events conducted.

Table 18. Pulliam Draw Storm Event Loadings and Flows

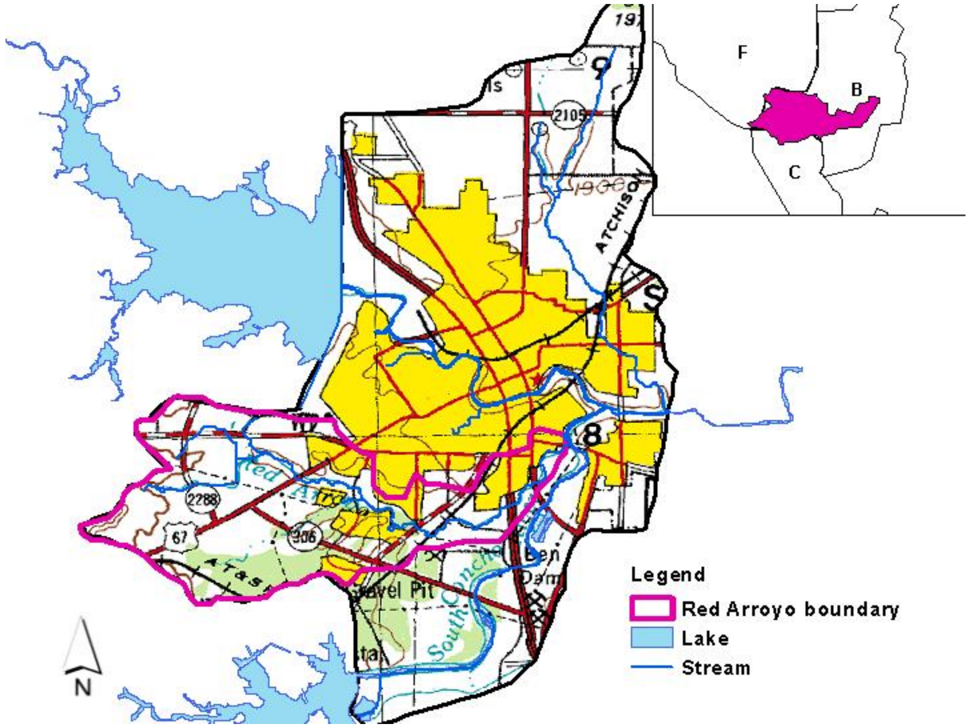
Pulliam Draw Storm Event Loadings and Flows			
Date	**Parameter**	**Amount**	**Units**
04/20/06	BOD	152	lbs.
	NH_3-N	13.4	lbs.
	NO_3-N	3	lbs.
	TPO_4	2	lbs.
	TSS	1,090	lbs.
	TPH	Non Detect	NA
	Flow	413,300	Gallons
06/03-04/07	BOD	140	lbs.
	NH_3-N	14	lbs.
	NO_3-N	63	lbs.
	TPO_4	0.9	lbs.
	TSS	700	lbs.
	TPH	Non Detect	NA
	Flow	2,100,000	Gallons

Although the water quality measured in these storm events is relatively good, this is attributable to the minor nature of the storms and the small amount of storm runoff generated. Based on land use and TCEQ compliance records Pulliam Draw is considered a potential threat to Assessment Area A.

Urban Runoff Water Quality Impacts from the Red Arroyo Subwatershed

The South Concho River within Assessment Area A is impacted by urbanization, but differently than the North Concho River. Red Arroyo is a major tributary to the South Concho River (Figure 28).

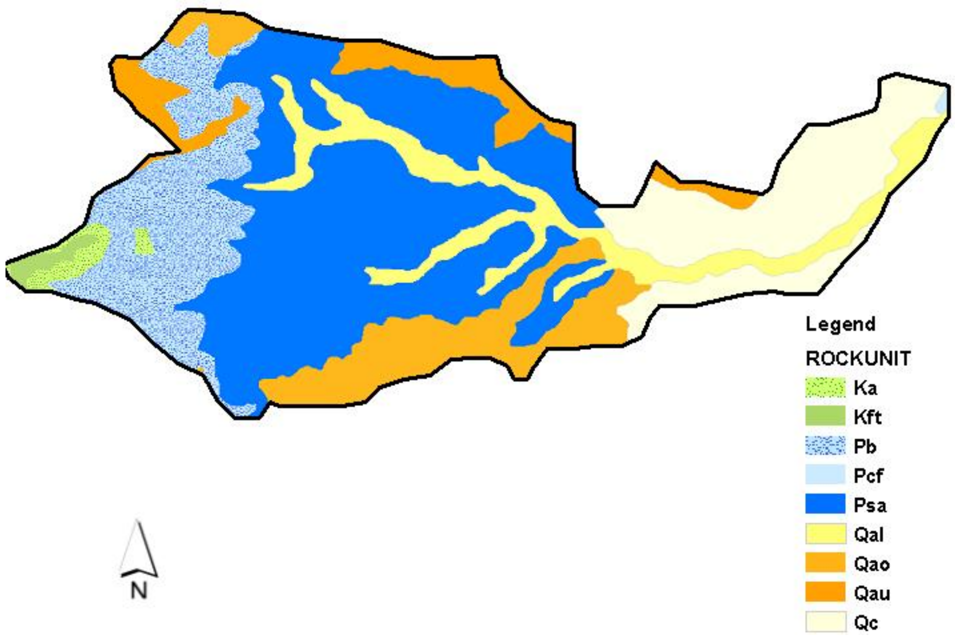
Figure 28. Red Arroyo Boundary Map



The confluence of Red Arroyo and the South Concho River is located just below Metcalfe Dam. The City of San Angelo's intake to its water treatment plant is located just above Metcalfe Dam. Red Arroyo's natural confluence with the South Concho River is also located above Metcalfe Dam. However, the City of San Angelo long ago diverted the stream channel to drain into the South Concho River downstream of the dam. This was done to avoid sediment loading from Red Arroyo during storm events that was responsible for the repeated fouling of intake pump filters. The Red Arroyo subwatershed is located almost entirely within the San Angelo city limit. There are no existing nonpoint source abatement structures on Red Arroyo, only a few small dams situated throughout its reach constructed for aesthetic purposes. The waterway is bounded by a relatively wide, mostly grassy, but in some areas only sparsely vegetated floodplain.

Most of Red Arroyo's flow path traverses the exposed Permian aged San Angelo Formation (Figure 29). This formation in the Red Arroyo drainage area consists mainly of indistinctly bedded friable sandstones, sandy shale and shale.

Figure 29. Assessment Area B Surface Geology Map



On both sides of its stream channel is located dense urban residential and commercial development. During storm events, runoff from these areas is channeled to the Red Arroyo where it erodes the reddish colored clay soils and transports the suspended sediment downstream. The sediment is typically deposited near its confluence with the South Concho River and/or in Bell Street Lake, where the sediment settles out of suspension in the lower energy environment.

Red Arroyo Storm Event Monitoring

On 10/28/05 and 10/16/06 storm water monitoring events were conducted on Red Arroyo. During each of these events an automatic sampler was deployed that collected samples at one hour intervals. Individual samples from each event were combined to produce a flow-weighted composite sample that was analyzed for water quality. Flows, from which peak flow values and total flow values were obtained, were periodically measured throughout the event. A flow rating-curve for the sampling station site was developed specifically for the project. A third monitoring event was attempted on 08/20/07, but was aborted when excessive flow threatened to wash away the sampling equipment. Table 19 below presents the calculated loadings of various parameters and the measured flow values obtained from the two storm water monitoring events conducted.

Table 19. Red Arroyo Storm Event Loadings and Flows

Red Arroyo Storm Event Loadings and Flows			
Event Date	**Parameters**	**Amount**	**Units**
10/28/05	TPO_4	115	lbs.
	BOD	6,942	lbs.
	TSS	68,654	lbs.
	NH_3-N	277	lbs.
	NO_3-N	486	lbs.
	Peak Flow	425	CFS
	Total Flow	233.88	Ac. Ft.
10/16/06	TPO_4	38	lbs.
	BOD	1,446	lbs.
	TSS	11,570	lbs.
	NH_3-N	104	lbs.
	NO_3-N	160	lbs.
	Peak Flow	120	CFS
	Total Flow	106.4	Ac. Ft.

Excessive Erosion and Sedimentation in the North Concho Downtown Area

Visual observation of the banks of the urban portion of the North Concho River indicates that urban runoff has led to bank erosion, bank undercutting and the slumping of trees located on the banks of the river (Figure 30). During storm events, accumulations of sludge in upstream impoundments are exported hydraulically downstream. Turbulence generated by urban runoff inflows and to a lesser extent, wave action, re-suspends sediments located on the channel bottom and transports them downstream. This reintroduction of nutrients to the aquatic environment coupled with the loading of additional nutrients likely leads to the downstream deposition of reworked sludge and contributes to the development of eutrophic conditions, which enhances depression of oxygen levels.

Figure 30. Assessment Area B, Example of Bank Erosion and Undercutting

The sediment and sludge also serve as a continuous reservoir for bacteria that generate high biological oxygen demand when organic materials are introduced in storm water runoff. The processes and cycles that take place when this occurs are previously discussed in detail in the 303(d) List Impairments portion of this section of the Watershed Protection Plan.

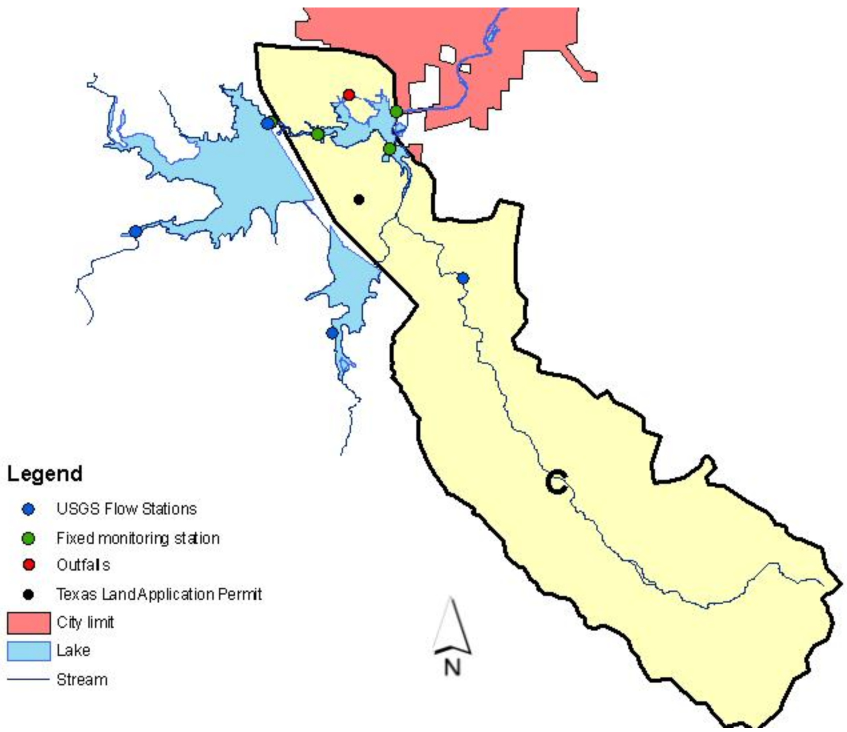
One of the major contributors of this sediment is erosion and bank/tree collapse within the project area. The City of San Angelo's consulting engineering firm identified and delineated areas in need of bank stabilization in a report to the city. They also measured and produced a map of sediment thickness in the river channel, and developed a channel dredging and bank stabilization project plan. The City of San Angelo has contracted with a local architect to revise and finish the project.

(Other load duration curves, analytical charts, materials and maps developed for and used in the analysis and evaluation of Assessment Area B, but not included in the text of the Watershed Protection Plan are included in Appendix B.)

5.3 ASSESSMENT AREA C

Assessment Area C is comprised of a small municipal constant level reservoir, Lake Nasworthy (approximately 10,000 ac. ft. in size), plus the Pecan Creek Watershed. The lake is located immediately downstream and adjacent to Twin Buttes dam. The total areal extent is approximately 70,500 acres (Figure 31). Lake Nasworthy is operated as a constant level lake. It uses water from Twin Buttes Reservoir for lake level management. Pecan Creek contributes uncontrolled flows into the lake.

Figure 31. Assessment Area C Boundary Map



The Assessment Units and associated Station IDs included in Assessment Area C are presented in Table 20.

Table 20. Assessment Area C TCEQ Assessment Unit Designations

Assessment Area C TCEQ Assessment Unit Designations			
Name	**AU ID**	**Assessment Unit Description**	**Station ID**
Lake Nasworthy	1422_01	Lower half of lake	12418 12421
Lake Nasworthy	1422_02	Upper half of lake	12419

Water quality within the lake is dependent upon releases from Twin Buttes Reservoir located immediately upstream, and water quality in Twin Buttes Reservoir is typically good. There is likely some seepage from the San Angelo Formation that adds minimal amounts of dissolved solids to the water body, but the lake is not listed for any impairments. Lake Nasworthy is neither included on the 303(d) list of impairments nor on the 305(b) list of concerns. Water quality measurements indicate that there are no nutrient problems and dissolved solids are typically below 1,000mg/L. Water quality is exceptional in Pecan Creek and there are no listed impairments or concerns for the creek.

Assessment Area C Other Identified Threats and/or Known Water Quality Problems

- Identified Base Flow Impacts (Pecan Creek subwatershed)
- Potential Water Quality Impacts from Existing Lakeshore Developments (Lake Nasworthy)
- Potential Water Quality Impacts from Petroleum E&P Activities
- Potential Water Quality Impacts from Abandoned/Unused Water Wells
- Potential Water Quality Impacts from Development of Rural Areas

These other identified threats and/or known problems included in the investigative scope of the watershed planning process for this assessment area are discussed below or in Section 5.0.

Pecan Creek Subwatershed Base Flow Impacts

In the *Concho River & Upper Colorado River Basins Brush Control Feasibility Study,* (UCRA, 2000), modelers, using the Soil and Water Assessment Tool (SWAT) model, determined that water yields could be increased by over 4,500 AFY assuming treatment of all moderate and heavy brush in the main Pecan Creek subwatershed. This represents lost water that would support base flows, aquatic life, wildlife and other uses in the watershed of Pecan Creek if it was not being consumed by deep-rooted mesquites and/or intercepted by dense canopies of juniper. Since Pecan Creek is an uncontrolled waterway to Lake Nasworthy, any net base flows generated by brush control will provide water contributions to the lake and support aquatic life use.

Potential Water Quality Impacts from Existing Developments (Lake Nasworthy)

Over 80% of the shoreline of Lake Nasworthy is residentially or commercially developed. A power generation plant that has not been in operation for several years is located on the lake. When in operation, the power plant used lake water for cooling purposes. Recently, the City of San Angelo installed collection lines and pump stations, providing public wastewater service to shoreline residential and commercial developments, and the San Angelo Regional Airport located nearby. This action has significantly reduced the threat of impacts from existing lakeshore developments. Although potential misuse of fertilizers and pesticides on lawns is a potential nonpoint source issue, due to the small areal extent, stormwater runoff from these same areas is considered only a minor water quality concern for the lake.

Assessment Area C Potential Water Quality Impacts from Petroleum E&P Activities

The entire subwatershed of Pecan Creek is located in Tom Green County. Active well counts are categorized by county and obviously, not all wells reported for a county are included in the assessment area's boundaries. The counts are from RRC active well counts reports and provided to give the reader an idea of the scope of the potential threat that exists. (See Section 5.0)

Table 21. Texas Railroad Active Counts Reports

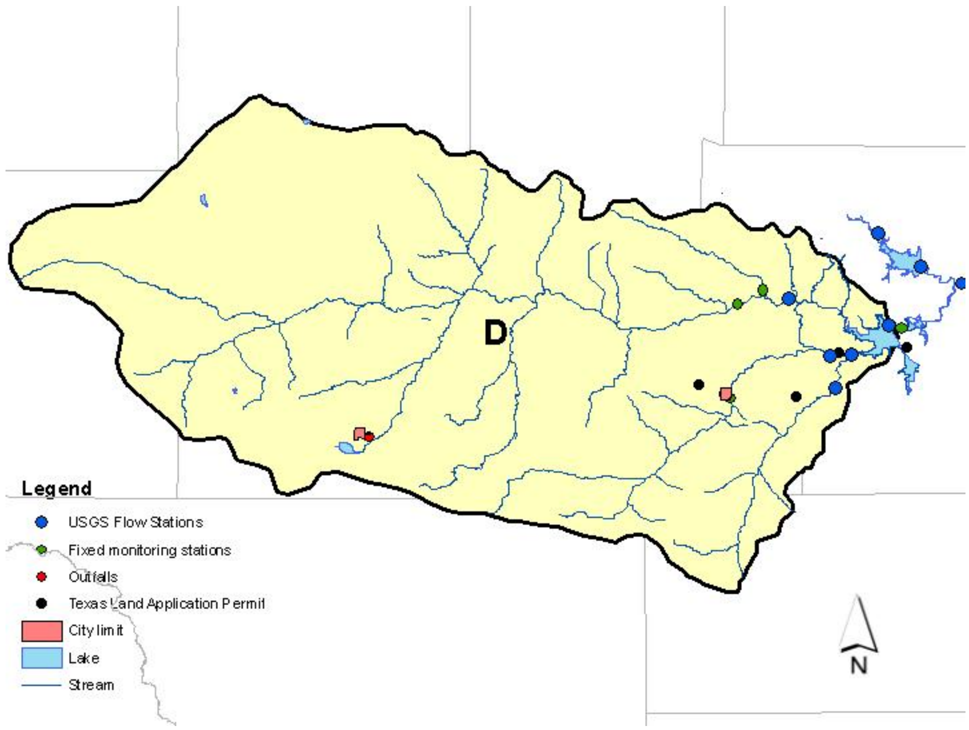
Texas Railroad Commission Active Counts Reports			
County	**# Active oil wells**	**# Active gas wells**	**Total**
Tom Green	939	107	1046

(Other load duration curves, analytical charts, materials and maps developed for and used in the analysis and evaluation of Assessment Area C, but not included in the text of the Watershed Protection Plan are included in Appendix C.)

5.4 ASSESSMENT AREA D

Assessment Area D consists of the Middle Concho River, Spring Creek and Dove Creek subwatersheds plus the Twin Buttes Reservoir North Pool. It encompasses an area of approximately 1.9 million acres (Figure 32).

Figure 32. Assessment Area D Boundary Map



The Assessment Units and associated Station IDs included in Assessment Area D are presented in Table 22.

Table 22. Assessment Area D TCEQ Assessment Unit Descriptions

Assessment Area D TCEQ Assessment Unit Designations			
Name	**AU ID**	**Assessment Unit Description**	**Station ID**
Twin Buttes Reservoir	1423_01	North Pool	12422
Spring Creek	1423A_01	From the confluence of Twin Buttes Reservoir upstream to Duncan Avenue crossing in Mertzon	12161
Spring Creek	1423A_02	From Duncan Avenue crossing in Mertzon upstream to the upstream perennial portion of the stream northeast of Ozona in Crockett County	17346
Dove Creek	1423B_01	From the confluence of Spring Creek upstream to RR 915	12166
Middle/South Concho River	1424_02	Middle Concho River from a point 100m upstream of US 67 in Tom Green County upstream to the confluence of Big Hollow Draw in Irion	12428 16903

Assessment Area D TCEQ Assessment Unit Designations			
Name	AU ID	Assessment Unit Description	Station ID
		County	
Middle/South Concho River	1424_03	From the confluence of Big Hollow Draw in Irion county upstream to the confluence of Three Bluff Draw and Indian Creek on the Middle Concho River in Reagan County	No Stations
West Rocky Creek	1424A_01	Entire water body	12165

Assessment Area D 2008 305(b) Listed Concerns

None of the Assessment Units in this Assessment Area D are included on the 303(d) list of impaired water bodies. The Assessment Units included on the 305(b) list of concerns are included in Table 23 below.

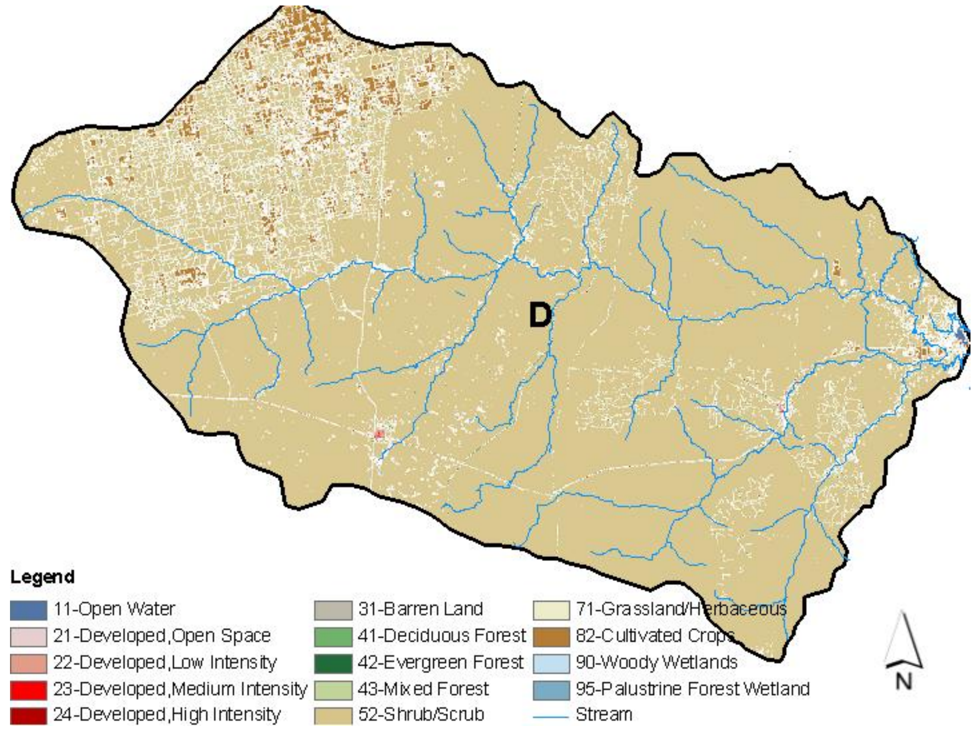
Table 23. Assessment Area D 2008 305(b) List of Water Quality Concerns

Basement Area D 2008 305(b) List of Water Quality Concerns			
Name	Assessment Unit	Parameter of Concern	Category
Twin Buttes Reservoir	1423_01	nitrate	CS
North Pool		orthophosphorus	CS
Dove Creek	1423B_01	depressed oxygen levels	CS
CS - indicates concern for near non-attainment of water quality standard			

Nutrients, nitrate and orthophosphorus are listed concerns in Twin Buttes Reservoir North Pool portion of Assessment Area D. Load duration curves were not developed for Assessment Area D due to a lack of acceptable flow data sets. Charts were constructed for Twin Buttes Reservoir Station 12422, Spring Creek Station 12161, Dove Creek Station 12166, Middle Concho River Station 16903 and West Rocky Creek Station 12165 (see Appendix D). These charts reflect samples for Total Phosphorus and Nitrite+Nitrate. The nitrate and phosphorus data were derived from samples collected from 2005 through 2009 at each of the stations mentioned above. Only one exceedance of total phosphorus occurred during this time period. No exceedances of nitrate occurred during this time period.

Most of the land in Assessment Area D is comprised of rangeland used for ranching purposes and hunting, but about ten percent, approximately 192,000 acres, is used as farmland, most of which is located at the northwesternmost margin of the watershed and contributes runoff only sporadically to the watershed's lower portions (Figure 33).

Figure 33. Assessment Area D Land Use Map



However, approximately 4,000 acres of land located between Spring Creek and Dove Creek and very near Twin Buttes Reservoir is farmed. About 500 to 600 acres of it is irrigated with groundwater sources. The irrigated land is positioned between the Spring Creek Arm and the Middle Concho Arm of Twin Buttes Reservoir, less than a mile from the reservoir's shoreline. The edges of dry land farm fields for about two river miles are located within 100 to 200 feet along the northern bank of the Spring Creek (Figure 33). There is no evidence, other than proximity, to suggest that the farming activity along Spring and Dove Creeks nor the farmland located near the reservoir is a nonpoint source of the nutrients of concern. However, it does hold the potential to be a contributor. The cause(s) of the nitrate and orthophosphorus concerns have not been determined.

Significant springs exist at the head of both Spring Creek and Dove Creek and both tributaries contribute base flows to the Twin Buttes Reservoir North Pool. Other than two small parks with boat ramps, the shoreline of Twin Buttes Reservoir North Pool has not been developed.

Other than the listed nutrient concerns, water quality in Middle Concho River, Spring Creek and Dove Creek subwatersheds is excellent. Measured total dissolved solids (TDS) levels in each tributary are typically 500 mg/L and water clarity is generally greater than three feet of depth.

Water quality in the reservoir is also exceptional, mirroring the tributaries from which it receives inflows. Measured TDS levels are typically less than 500 mg/L and water clarity at times is as great as 10 feet deep.

The segment of Dove Creek, AU 1423B_01 (from its confluence with Spring Creek upstream to Rural Road 915), that is included on the TCEQ 305(b) inventory of concerns for impaired dissolved oxygen levels is likely attributable to samples being collected during times of low flows.

Assessment Area D Other Identified Threats and/or Known Water Quality Problems

- Identified Base Flow Impacts
- Potential Water Quality Impacts from Petroleum E&P Activities
- Potential Water Quality Impacts from Abandoned/Unused Water Wells
- Potential Water Quality Impacts from Intensive Development of Rural Areas

These other identified threats and/or known problems included in the investigative scope of the watershed planning process for this assessment area are discussed below or in Section 5.0.

Base Flow Impacts

In the *Concho River & Upper Colorado River Basins Brush Control Feasibility Study* (UCRA, 2000), modelers, using the Soil and Water Assessment Tool (SWAT) model, determined that water yields could be increased by over 51,000 AFY assuming treatment of all moderate and heavy brush in the Middle Concho River, Spring Creek, and Dove Creek subwatersheds. This represents lost water that would support base flows, aquatic life, wildlife and other uses if it was not being consumed by deep-rooted mesquites and/or intercepted by dense canopies of juniper.

Assessment Area D Water Quality Impacts from Petroleum E&P Activities

Assessment Area D covers parts of nine counties. Active well counts are categorized by county and obviously, not all wells reported for a county are included in the assessment area's boundaries. The counts are from RRC active well counts reports and are provided to give the reader an idea of the scope of the potential threat that exists.

Table 24. Texas Railroad Commission Active Counts Reports

Texas Railroad Commission Active Counts Reports			
County	**# Active oil wells**	**# Active gas wells**	**Total**
Crockett	3119	5957	9076
Glasscock	1608	148	1756
Irion	1823	50	1873
Midland	5503	343	5846
Reagan	4430	82	4512

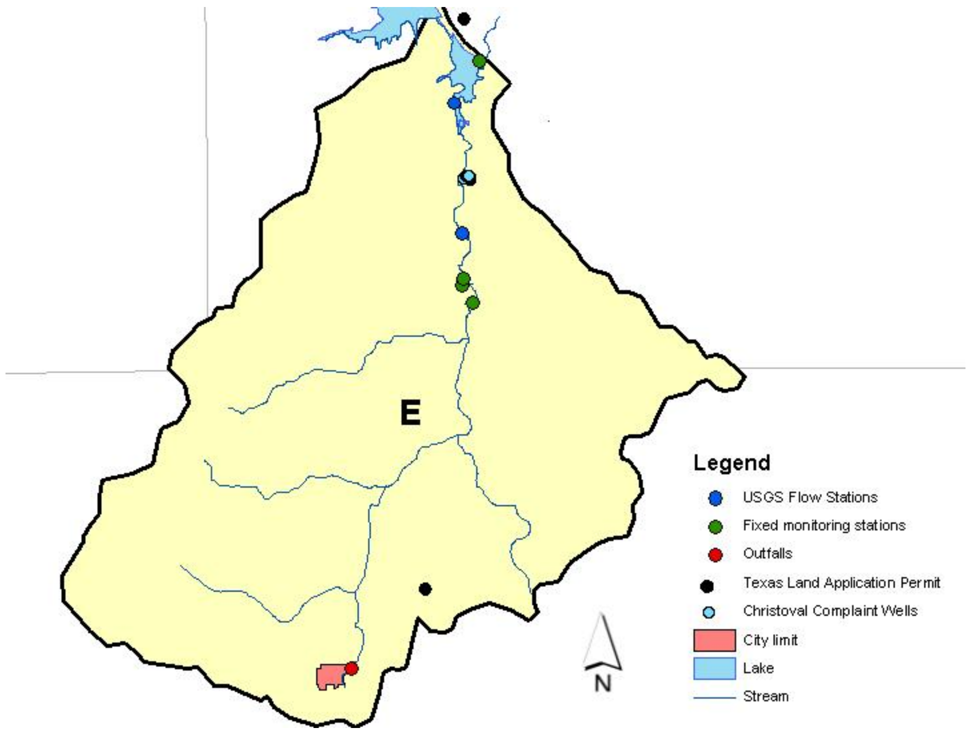
Texas Railroad Commission Active Counts Reports			
County	**# Active oil wells**	**# Active gas wells**	**Total**
Schleicher	435	799	1234
Sterling	1672	791	2463
Tom Green	939	107	1046
Upton	4088	466	4554
Totals	23617	8743	32360

Other analytical charts, materials and maps developed for and used in the analysis and evaluation of Assessment Area D, are included in Appendix D.

5.5 ASSESSMENT AREA E

Assessment Area E consists of the South Concho River watershed and the Twin Buttes Reservoir South Pool. It encompasses and area of approximately 300,000 acres (Figure 34).

Figure 34. Assessment Area E Boundary Map



The Assessment Units and associated Station IDs included in Assessment Area D are presented in Table 25.

Table 25. Assessment Area E TCEQ Assessment Unit Designations

Assessment Area E TCEQ Assessment Unit Designations			
Name	**AU ID**	**Assessment Unit Description**	**Station ID**
Twin Buttes Reservoir	1423_02	South Pool	12425
Middle/South Concho River	1424_01	South Concho River from a point 4 km (2.5 miles) upstream of FM 2335 upstream to the confluence of Bois D'Arc Draw in Tom Green County	12427 17349 18712 18869

Assessment Area E 2008 305 (b) Listed Concerns

None of the Assessment Units in Assessment Area E are included on the 303(d) list or impaired water bodies. The Assessment Units included on the 2008 305(b) list of concerns are included in Table 26 below.

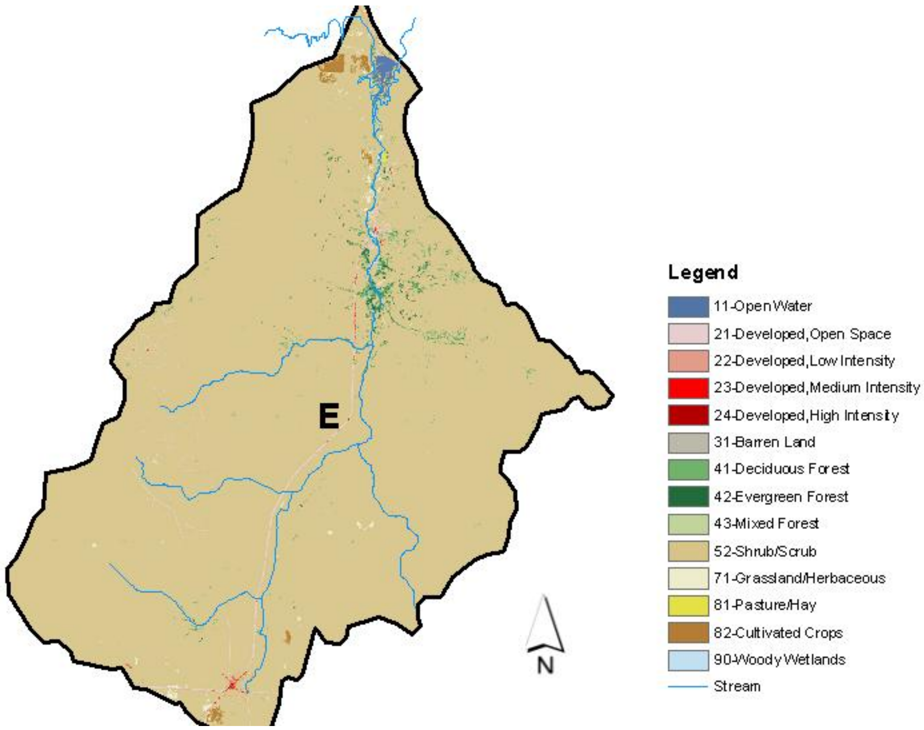
Table 26. Assessment Area E 2008 305(b) List of Water Quality Concerns

Assessment Area E 2008 305(b) List of Water Quality Concerns			
Name	**Assessment Unit**	**Parameter of Concern**	**Category**
Twin Buttes Reservoir South Pool	1423_02	orthophosphorus	CS
CS - indicates concern for near non-attainment of water quality standard			

Approximately 1800 acres of farm land is located between Spring Creek and the Twin Buttes Reservoir South Pool. Over half of it is irrigated (Figure 35). Other than proximity, there is no evidence to suggest that this farming activity is a nonpoint source of orthophosphorus. However, it does hold the potential to be a contributor. The origin of the orthophosphorus has not been identified.

Major rural subdivision development along the South Concho River has accelerated in recent years, but the dominant land use continues to be ranching (Figure 35).

Figure 35. Assessment Area E Land Use Map



Rising from Anson Springs and Cold Creek Springs located approximately four miles south of Christoval, the South Concho River dewaters the northeastern edge of the Edwards-Trinity Plateau Aquifer and contributes significant base flows to the Twin Buttes Reservoir South Pool. One point source (municipal wastewater) exists within the watershed and another permit is pending, and will likely be issued. Neither is considered a significant threat. The shoreline of the Twin Buttes Reservoir South Pool is not developed.

With the exception of the listed orthophosphorus concern, water quality within the entire assessment area is exceptionally good. Measured TDS levels are below 400mg/L and water clarity is typically five feet of depth. The South Concho River watershed is the most pristine hydrologic system within the entire Concho River watershed.

Assessment Area E Other Identified Threats and/or Known Water Quality Problems

- Identified Base Flow Impacts
- Identified Water Quality Impacts from Petroleum E&P Activities
- Potential Water Quality Impacts from Abandoned/Unused Water Wells
- Potential Water Quality Impacts from Intensive Development of Rural Areas

These other identified threats and/or known problems included in the investigative scope of the watershed planning process for this assessment area are discussed below or in Section 5.0.

Base Flow Impacts

In the *Concho River & Upper Colorado River Basins Brush Control Feasibility Study*, (UCRA, 2000), modelers, using the Soil and Water Assessment Tool (SWAT) model, determined that water yields could be increased by over 22,000 AFY assuming treatment of all moderate and heavy brush in the South Concho River watershed. This represents lost water that would supplement existing base flows and support aquatic life, wildlife, and other uses if it was not being consumed by deep-rooted mesquites and/or intercepted by dense canopies of juniper.

Assessment Area E Water Quality Impacts from Petroleum E&P Activities

Most of Assessment Area E lies in Tom Green and Schleicher Counties with a very small portion in the southeast corner of Irion County. Active well counts are categorized by county and obviously, not all wells reported for a county are included in the assessment area's boundaries. The counts are from RRC active well counts reports and are provided to give the reader an idea of the scope of the potential threat that exists.

Table 27 Texas Railroad Active Counts Reports

Texas Railroad Active Counts Reports			
County	**# Active oil wells**	**# Active gas wells**	**Total**
Tom Green	939	107	1046
Schleicher	435	799	1234
Irion	1823	50	1873
Totals	3197	956	4153

Special Study Conducted in Assessment Area E

Christoval Complaint Investigation

The UCRA has conducted groundwater monitoring on a saltwater complaint located approximately two miles north of Christoval. The initial complaint was brought in 1986. The complainant stated that salt water showed up in a private well shortly following the occurrence of nearby road construction activities that included powerful dynamite blasting. The RRC investigated the complaint and determined that an improperly plugged well, located a few hundred feet from the affected wells, was under sufficient pressure to flow brine water to the surface and had likely been flowing brine water into the shallow groundwater aquifer for up to thirty years. They estimated that the well created a plume of saltwater around the well that was mobilized by the blasting. They re-plugged the well, stopping the flows. After this action, the Texas Railroad Commission continued to test area wells and over time the water returned to more normal levels of chlorides.

However, in 2001, saltwater again showed up in wells located west and northwest of the wells from which the original complaint was filed. It was at this time that the UCRA began monitoring field parameters including specific conductance in area water wells. UCRA monitored the situation quarterly or sometimes semi-annually. The Texas Railroad Commission was contacted at the beginning of the UCRA's involvement. The Railroad Commission provided their complaint records, but stated that they had done all they could do in the area. The Railroad Commission investigated several wells located within a few miles of the complaint and re-plugged a total of twelve wells. However, most of the wells that were re-plugged were situated downdip on the water gradient and were unlikely contributors to this local issue.

During development of the Watershed Protection Plan, laboratory samples were collected and analyzed from several wells in the immediate area. Analysis of the field data and laboratory data collected by the UCRA indicates that there is a plume of saltwater that continues to move through the area. Whereas the highest concentrations of chlorides were initially indicated in the southernmost affected wells, the highest concentrations at the last sampling event existed in the northernmost affected wells (Figure 36).

Table 28. Average Chloride Levels (7 Monitoring Events, 2005-2007)

Well	Average Chloride Level
M	28.5
P	84.0
HB	47.0
DF	45.6
G1	738.8
G2	261.0
CH	126.5
W	107.6
10A	57.8

* Well names were changed to protect the privacy of individual landowners.

The levels of concentration fluctuate through time. This is most likely attributable to the raising and lowering of the shallow water table in response to recharge from precipitation and discharge to the river and water wells.

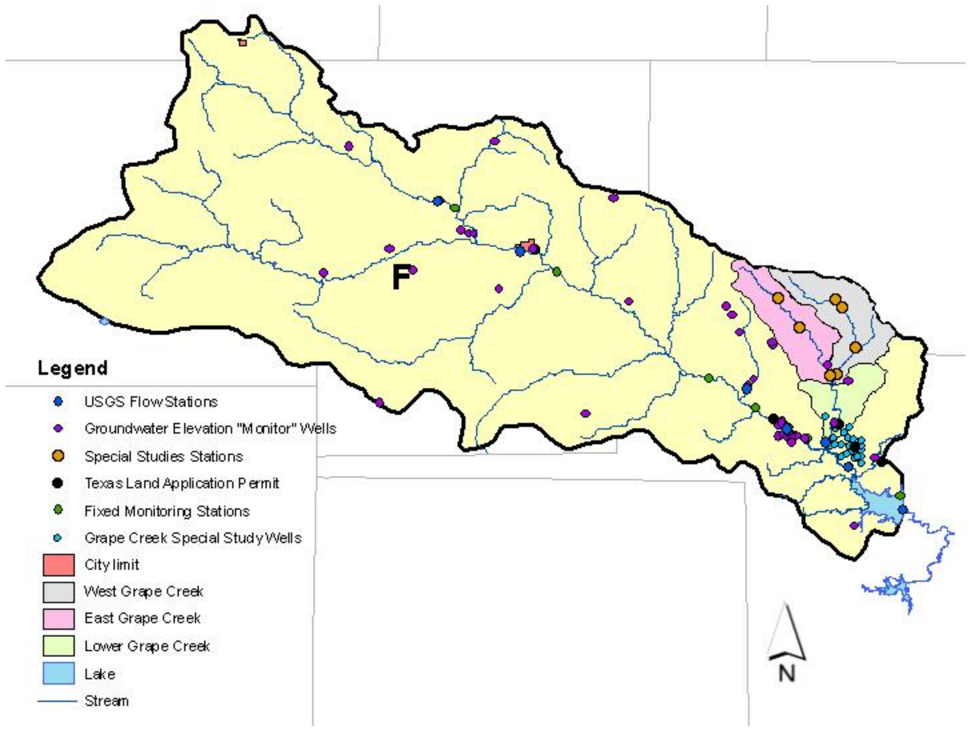
If the source of the chlorides currently being measured is the well identified by the Texas Railroad Commission, it is unclear why the plume would not affect the wells for a period of fifteen years and then reappear with no apparent cause. Since there exists no feasible way to remediate the problem and the water quality is improving through time, the recommended course of action is to respond to any future complaints. If, in the future, measured field parameters again increase, additional efforts may be required.

Other analytical charts, materials and maps developed for and used in the analysis and evaluation of Assessment Area E, are included in Appendix E.

5.6 ASSESSMENT AREA F

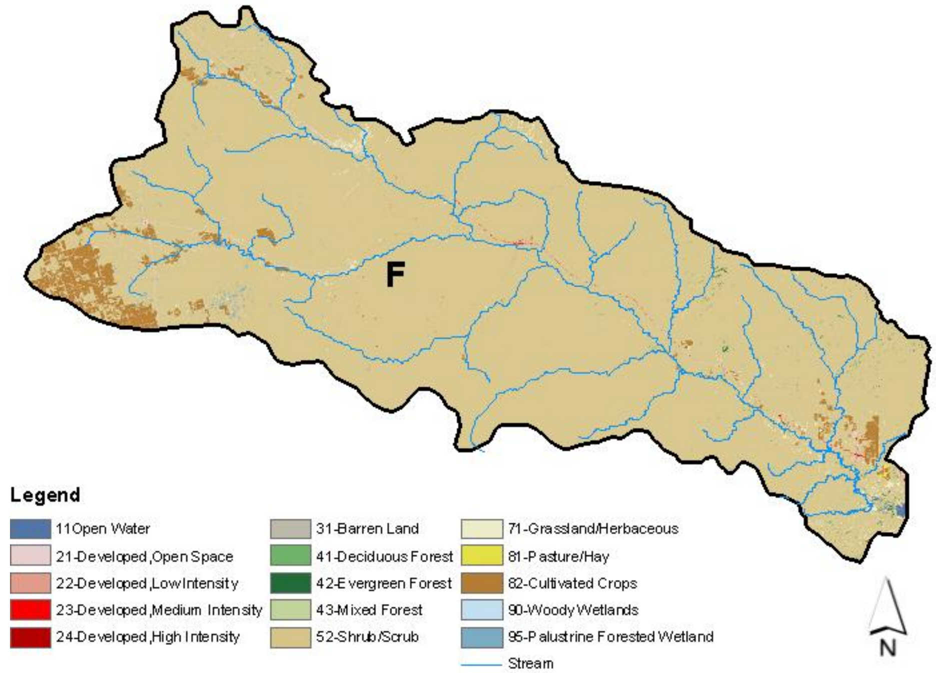
Assessment Area F consists of the North Concho River Watershed and O.C. Fisher Lake. It encompasses an area of more than 900,000 acres. It includes portions of five (5) counties, Tom Green, Coke, Sterling, Glasscock and Howard (Figure 36).

Figure 36. Assessment Area F Boundary Map



Considerable rural subdivision development has occurred along the lower reaches of the North Concho River, most of which is located in Tom Green County. The dominant land use for the watershed is ranching (Figure 37).

Figure 37. Assessment Area F Land Use Map



Dissolved solids along the reach average 800mg/L, clarity is greater than two feet of depth, and there are no nutrient impairments.

The Assessment Units and associated Station IDs included in Assessment Area D are presented in Table 29.

Table 29. Assessment Area F TCEQ Assessment Unit Designations

Assessment Area F TCEQ Assessment Unit Designations			
Name	**AU ID**	**Assessment Unit Description**	**Station ID**
OC Fisher Lake	1425-01	Entire water body	12429
North Concho River	1425A_01	Lower end of water body to Sterling County line	12170 12171 17245 17350 17351
North Concho	1425A-02	Sterling County line to SH 163	16779
North Concho	1425A_03	SH 163 to US 87	16780

Assessment Area F 2008 303(d) and 305(b) Listed Impairments and Concerns

The water bodies located in Assessment Area F that are included in the 2008 Texas Water Quality Inventory and 303(d) list are displayed in Tables 30 and 31 below. O.C. Fisher Lake, AU 1425_01, is included on the 2008 303(d) list for impaired chlorides as Category 5c. Category 5c denotes that additional data and information will be collected before a TMDL or review of the water quality standard is scheduled.

Table 30. Assessment Area F 2008 303(d) List of Water Quality Impairments

Assessment Area F 2008 303(d) List of Water Quality Impairments				
Name	**Assessment Unit**	**Parameter of Concern**	**Category**	**Yr Listed**
OC Fisher Lake	1425_01	chloride	5c	2002
5c - Indicates Additional data and information will be collected before a TMDL is scheduled				

O.C. Fisher Reservoir was first identified as impaired on the 2002 303(d) list for not meeting the general use standard due to elevated levels of chlorides. It remained listed through the 2008 assessment. However, from about 2000 through 2008 the chloride levels in the lake exhibited a decreasing trend. The TCEQ commissioned a study by the Texas Institute for Applied Environmental Research to investigate the chloride issue of chloride concentrations in O.C. Fisher Lake. That study concluded that the chloride concentrations increased with decreasing lake levels. The study also noted that in recent years the chloride concentrations were trending downward even though lake levels remained fairly constant. This was attributed to dilution from fresh water inflows with only relatively small increases in reservoir volume under drier conditions (TIAER 2008). As a result of the decreasing trend in chlorides and the conclusion of the study, the chloride impairment in O.C. Fisher Lake has been de-listed in the Draft 2010 303(d) list.

O.C. Fisher Lake is included on the 2008 305(b) list of concerns for nutrients Table 31).

Table 31. Assessment Area F 2008 303(b) List of Water Quality Concerns

Assessment Area F 2008 305(b) List of Water Quality Concerns			
Name	**Assessment Unit**	**Parameter of Concern**	**Category**
OC Fisher Lake	1425_01	Ammonia	CS
		chlorophyll-a	CS
		Orthophosphorus	CS
		total phosphorus	CS
North Concho River	1425A_02	Bacteria	CN
		depressed oxygen levels	CS
CS - indicates concern for near non-attainment of water quality standard CN - indicates concern for screening level standard			

The investigative activities conducted for the Watershed Protection Plan did not include an evaluation for nutrient levels in O.C. Fisher Lake, Assessment Unit 1425_01. The San Angelo State Park utilizes onsite sewage facilities and properly maintains them on a regular schedule. Some farmed acreage, irrigated and dry land, is located north of O.C. Fisher. However, other than proximity, there is nothing to suggest that either of these potential sources contribute to nutrient levels in the lake. No other potential sources have been identified. The nutrient concerns may also be related to the low lake levels mentioned in the above discussion about the chloride impairment.

The concerns for bacteria and depressed oxygen levels in the North Concho River in segment 1425A_02 were not investigated during development of the Watershed Protection Plan. The site, at which the samples were collected, that resulted in the 303(b) listings, is currently being monitored four times a year to assess the continuing need for these listings.

Assessment Area F Other Identified Threats and/or Known Water Quality Problems

- Identified Base Flow Impacts
- Potential Water Quality Impacts from Petroleum E&P Activities
- Potential Water Quality Impacts from Abandoned/ Unused Water Wells
- Potential Water Quality Impacts from Intensive Development of Rural Areas

These other identified threats and/or known problems included in the investigative scope of the watershed planning process for this assessment area are discussed below or in Section 5.0.

Base Flow Impacts

In 1985, Senate Bill 1083, Acts of the 69th Legislature, Regular Session created the Texas Brush Control Program, now entitled the Water Supply Enhancement Program. The goal of this legislation, which was authored by Senator Bill Sims of San Angelo, is to enhance the State's water resources through selective control of brush species. This statute was codified in Chapter 203 of the Texas Agriculture Code. The TSSWCB is designated as the agency responsible for administering the program and is given authority to delegate responsibility for administering certain portions of the program to local soil and water conservation districts.

The *North Concho River Watershed Brush Control Planning, Assessment and Feasibility Study* was prepared by the UCRA, Texas A&M Research and Extension Center (now Texas AgriLife Research), TSSWCB, USDA Natural Resources Conservation Service and others and published in 1998. In that study, modelers, using the Soil and Water Assessment Tool (SWAT) model, determined that water yields could be increased by over 33,000 AFY assuming treatment of all moderate and heavy brush in the contributing subwatersheds of the North Concho River Watershed. This represents lost water that would supplement existing base flows and support aquatic life, wildlife and other uses if it was not being consumed by deep-rooted mesquites and/or intercepted by dense canopies of juniper. This study was the impetus that resulted in state and federal funding of brush control projects in Texas. The feasibility study targeted approximately 430,000 acres of brush for treatment. To date almost 340,000 acres of brush has been treated in the North Concho River Watershed.

The North Concho River Watershed was chosen as the pilot project of the State of Texas Brush Control Program and the UCRA was chosen to monitor hydrologic responses. "Hydrological changes that occurred concomitant with the proliferation of noxious brush were documented in the North Concho feasibility study. As part of that study, a comprehensive analysis of existing hydrological data was performed. The results of that analysis included the identification of various pre-brush and post-brush hydrologically characteristic norms for the watershed. These watershed norms include the frequency, annual distribution, duration and yield of stormwater events, annual base flows and groundwater elevations," *North Concho River Watershed Brush Control Planning, Assessment and Feasibility Study* (UCRA, 1998).

It is recognized that the size of the watershed, the myriad of variables involved, and funding constraints preclude an all-inclusive accounting of water inputs and outputs from which to perform accurate water balance calculations. The goal of the monitoring program is to measure the aforementioned parameters for the purpose of detecting "indications of a return of the watershed characteristics from the post-brush condition existent at the inception of the project, to the pre-brush conditions existent prior to 1960," (*North Concho River Watershed Brush Control Planning, Assessment and Feasibility Study,* UCRA, 1998).

To that end, the UCRA is in the ninth year of a ten year hydrologic response monitoring program. Elements of that program include periodic surface water flow measuring at ten fixed stations located on the North Concho River and one fixed station on Sterling Creek, periodic measurement of hydrostatic groundwater levels in 20-30 privately owned wells spaced throughout the watershed, characterization of storm event generated runoff flows, a special study of stream flows from the paired watersheds of the East Fork of Grape Creek and the West Fork of Grape Creek, a paired watershed research study of evapotranspiration at mesquite sites, a paired watershed research study of brush removal induced runoff characteristics at juniper sites, and a water quality study based on the field parameters of pH, specific conductance, dissolved oxygen. Results from this monitoring are presented below.

Hydrologic Response Monitoring Program

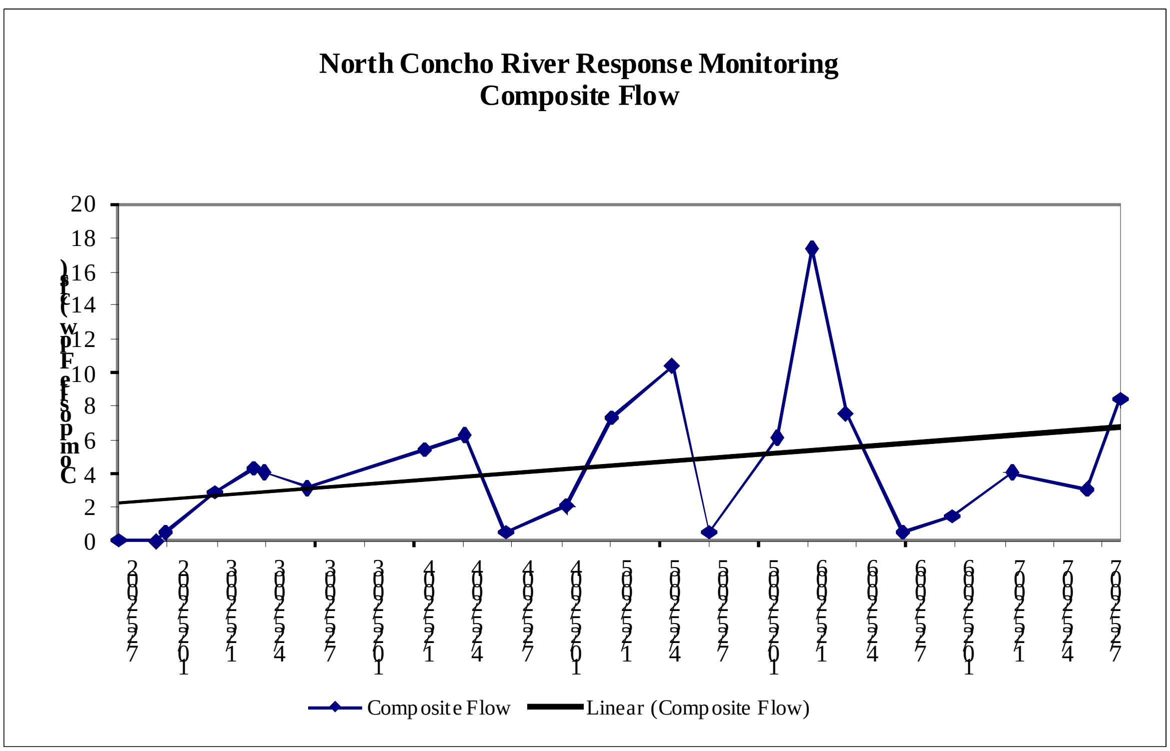
North Concho River Flow Monitoring

The UCRA measures stream flows on the North Concho River as one component of the hydrologic response monitoring that is being conducted in conjunction with the North Concho River Pilot Brush Control Project. The following is excerpted from an interim report published in 2006, "over the last several years of monitoring, the river has had dry segments scattered along its reach. Some of the most notable dry areas were above Sterling City and also between Carlsbad and Grape Creek where the river just disappeared underground. This phenomenon is attributed to depleted alluvial aquifers. Through time, these alluvial deposits have become saturated and now the river runs throughout its reach. Since the North Concho is again transporting water, rainfall events that generate runoff [typically] deliver water to O.C. Fisher Lake.

The UCRA currently monitors 10 surface water sites along the North Concho River and 1 site on Sterling Creek, just above the confluence of the North Concho. These stations are visited on at least a quarterly basis and flows are measured. The data accumulated since 2000 reflects a gradual gaining trend in base flows. Even more impressive are the perennial base flows that have continued non-stop over the last 18 months on both the North Concho River and Sterling Creek. During this same period, the region has experienced slightly below average precipitation, according to National Weather Service data recorded in San Angelo" (UCRA, 2006).

From July 2002 through August 2007, flow measurements were obtained at all ten fixed monitor stations a total of twenty-two times. These dates were used because there is no missing data and the time period is sufficient to determine a trend. The flow measured at each site was summed for each of the twenty-two dates to obtain the total cubic feet per second measured throughout the stream reach on each date. These values were then graphed to determine the trend of stream flow. Through the stated time period, the stream flow throughout the entire reach of the North Concho River is on an upward trend (Figure 38).

Figure 38. North Concho River Response Monitoring Composite Flow



Groundwater Monitoring

Analyses of groundwater monitoring data indicate that hydrostatic groundwater levels are rising. An excerpt from the interim report on the hydrologic response monitoring interim report provided to the TSSWCB is included below.

"Discrete monitoring event changes as well as cumulative changes in measured static groundwater elevations are tabulated and graphed for each well that is monitored. For each monitoring event, wells are sorted into three categories, i.e. wells in which a decline, a steady state, or a rise in measured hydrostatic elevation has occurred relative to the previous measurement. These data are tabulated and graphed.

On the graphs presented in Figures 39 and 40, cumulative quarterly average changes and cumulative annual average changes in static groundwater levels are plotted with trend-lines added. These graphs provide an illustration of hydrostatic groundwater changes through time and an indication of the direction of change in regional groundwater hydrostatic elevations.

Figure 39. Assessment Area F Groundwater Quarterly Average Change

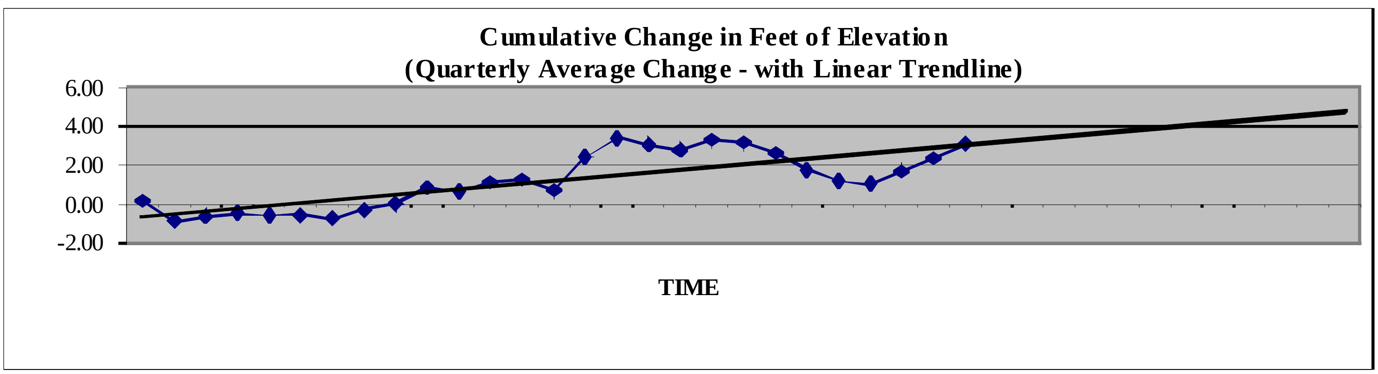
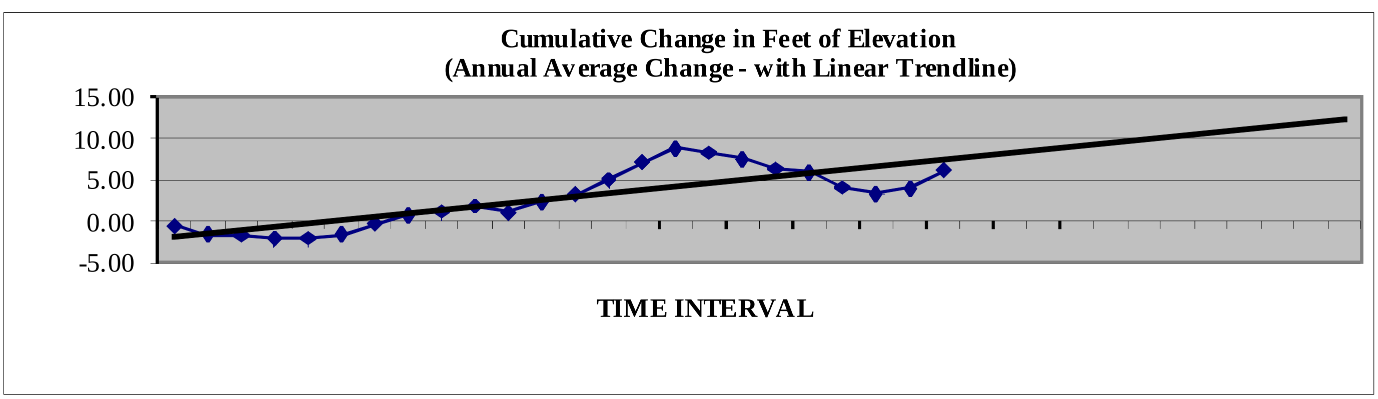


Figure 40. Assessment Area F Average Annual Groundwater Elevation Change



The cumulative changes that are displayed on the graphs illustrate that hydrostatic ground water elevations are trending upward. As previously mentioned, an all-inclusive accounting of water inputs and outputs on a watershed scale is impossible to achieve. As a result, the determination of unerring cause and effect relationships for the observed hydrologic phenomena is also impossible. However, given that the only identified significant change that has taken place on the watershed over the monitoring period is brush control, it is reasonable to conclude that brush control is the dominant cause for the observed positive hydrologic effects on ground water elevations. The data indicate that alluvial aquifers are being recharged and holding more of the recharge water in storage for longer periods of time; or put another way, the aquifers are not being constantly depleted by deep-rooted mesquites. Moreover, the groundwater that moves from the uplands to riparian areas is not being intercepted by deep-rooted upland mesquites and is able to supply more recharge water to the riparian alluvial aquifers. Therefore, the recharged alluvial aquifers are able to sustain base flows for longer periods of time and also curtail major channel transmission losses during storm events" (UCRA, 2006).

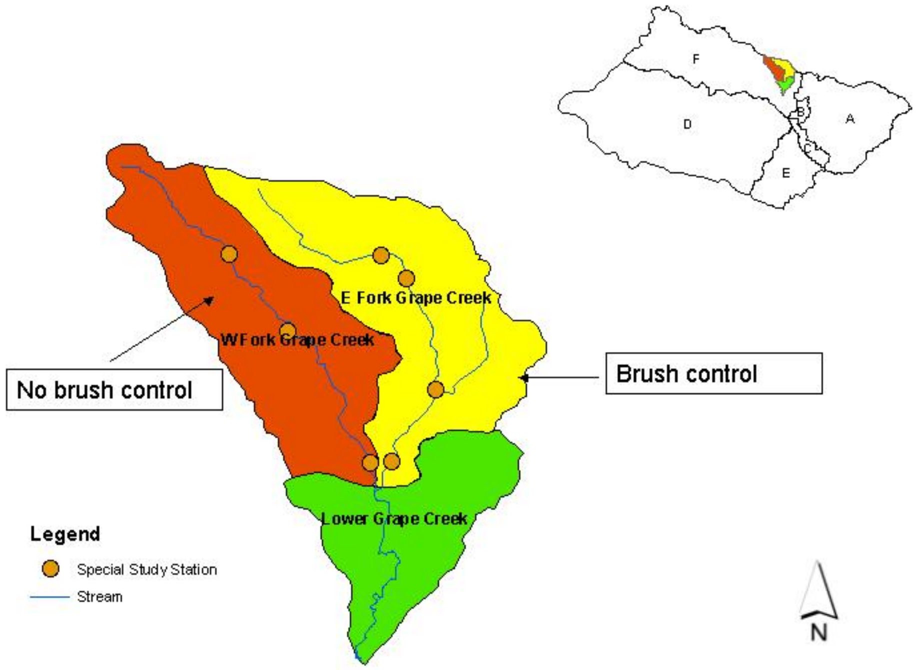
Paired Watershed Evapotranspiration Study

A research paper entitled, *Effects of Brush Control on Evaporation in the North Concho River Watershed Using Eddy Covariance Technique,* (TIAER, 2007) was submitted to the Soil and Water Conservation Society Journal. Additional instrumentation was deployed at the research sites and additional data was collected and included in the research paper. The paper was published in the September/October 2009 issue. The results of the paired watershed research project indicate water savings closely aligned with the predictions of SWAT Modeling conducted during development of the feasibility study for North Concho Brush Control Project. A copy of the published paper is included in Appendix G.

Grape Creek Paired Watershed Stream Flow Monitoring

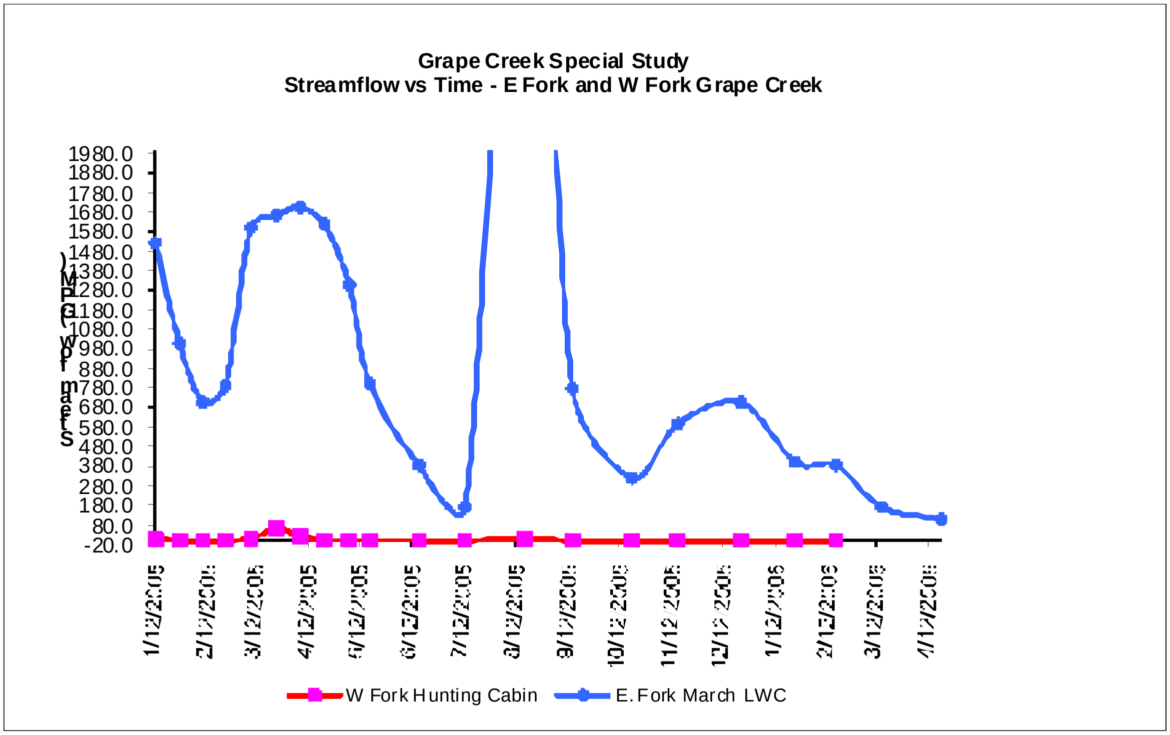
The Grape Creek Paired Watershed Sites are located in Assessment Area F north of the Grape Creek Community on the East And West Forks of Grape Creek (Figure 41).

Figure 41. Grape Creek Paired Watersheds Location Map



Comparative analysis of surface water flow monitoring data at the Grape Creek paired watershed sites (Figure 42), indicates the generation of significant stream flows at the treated site vs. the untreated site. The discussion following Figure 42 is excerpted from the 2006 hydrologic response monitoring interim report provided to the TSSWCB.

Figure 42. E Fork and W Fork Streamflow



"The watersheds of the East Fork and West Fork of Grape Creek are each approximately 25,000 acres in size. Approximately 75-80% of the acreage comprising the watershed of the East Fork of Grape Creek has been mechanically cleared of mesquite and Juniper. With the exception of only a few acres (<300), the watershed of the West Fork of Grape Creek has received no brush treatment.

Following significant rains that fell over the area of these adjacent watersheds in November 2004, the East Fork of Grape Creek began to exhibit base flows. Beginning in January 2005, the UCRA gained permission from the landowners of both watersheds and began periodically measuring flows at various fixed sites on the East Fork and West Fork of Grape Creek. Flow measurements are obtained at fixed sites that cover the entire stream-reach of the East and West Fork from the source springs to sites located just above their confluence.

Cumulative base flows for the East Fork of Grape Creek for all of 2005 plus the first quarter of 2006 equal 2,025 acre feet. The mean annual flow for 2005 calculates to 2.61cfs. These values are based on the measured flows at the measurement site located furthest downstream (just above the confluence with the West Fork of Grape Creek). Although some base flows were measured in the upper reaches of the West Fork of Grape Creek, channel transmission losses resulted in no net flow at the furthest downstream measurement site (located just above the confluence with the East Fork of Grape Creek).

On February 23, 2005, the UCRA installed pressure transducers in the streambeds of the East and West Forks of Grape Creek at the furthest downstream measurement sites of each. These were installed for the purposes of measuring storm event runoff. There have not been enough runoff events and thus, not enough data collected to generate rating curves for either site. Consequently, a quantitative assessment of how much storm water runoff has passed each of these transducers has not been possible. However, it should be noted that during most of the rainfall events that have occurred on the watersheds, the East Fork of Grape Creek experiences small runoff events while the West Fork does not. These small runoff events occur even during relatively minor rainfall events. This phenomenon illustrates the benefit of having perennial conditions existent within a watershed, i.e. even small rainfall events contribute to the total stream conveyance. Conversely, the West Fork of Grape Creek experienced no such benefits from these small rainfall events.

Another meaningful observation, resulting from the work performed by UCRA on Grape Creek, relates to the different characteristics exhibited by the East and West Forks of Grape Creek during a large runoff event that occurred on both watersheds in the middle of August 2005. While the West Fork experienced a large, flashy, one day event, the East Fork experienced not only a large, one day event, but also had significantly increased flows for several days afterward. Moreover, the pools of water that existed in the channel of the West Fork of Grape Creek after the runoff event were rapidly lost to groundwater recharge into depleted alluvial aquifers. This event was the only event for the entire year of 2005 and the first quarter of 2006 during which the West Fork of Grape Creek conveyed any water past its confluence with the East Fork of Grape Creek.

There exists no known plausible cause for the different hydrological behaviors displayed by these two watersheds other than brush control." (UCRA, 2006)

Hydrologic Response Monitoring Program Conclusions

The interim results from the various components of the hydrologic response monitoring indicated that the North Concho River Watershed is responding to brush control efforts and the river is returning to the hydrologic characteristics it exhibited prior to brush encroachment. It is notable that in the evapotranspiration study and the Paired Watershed Evapotranspiration study and the Grape Creek study, the amount of measured conserved water closely corresponds to the amounts predicted by the SWAT model in the feasibility study for the North Concho River Pilot Brush Control Project. The types of hydrologic responses being witnessed in the North Concho River Watershed can be expected to manifest in other watersheds possessing similar hydrogeological, land use, and land cover parameters where brush control is implemented. Hydrologic responses can be extrapolated to the Twin Buttes Reservoir Watershed where similar brush control efforts have been implemented.

Assessment Area F Water Quality Impacts from Petroleum E&P Activities

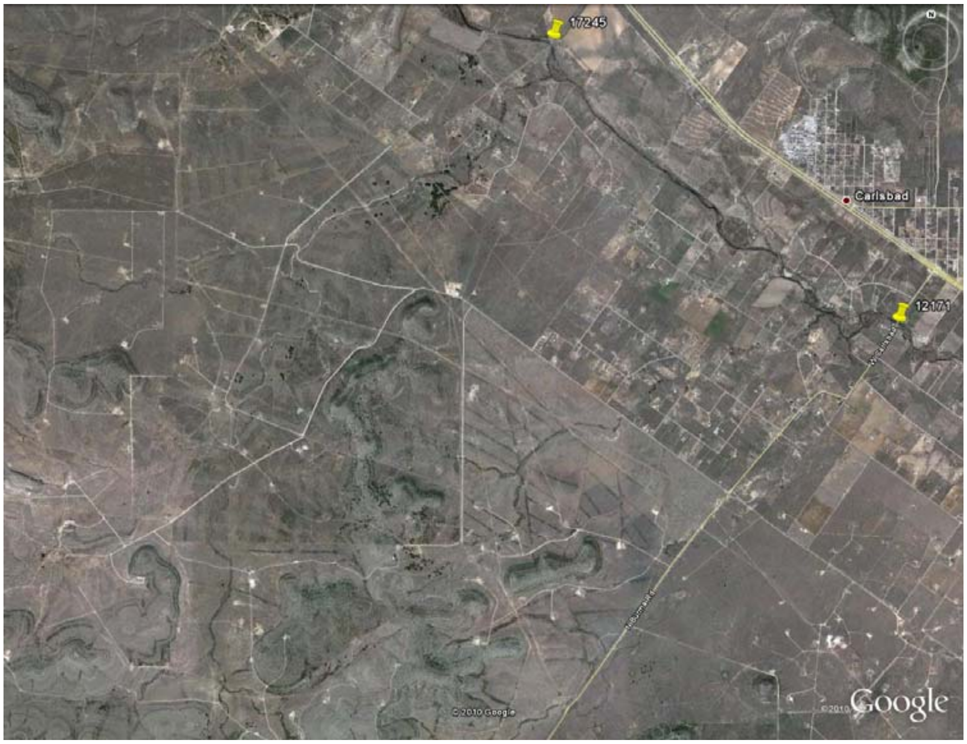
Assessment Area F consists of portions of five counties. These include Coke, Tom Green, Sterling, Glasscock, and Howard Counties. Active well counts are categorized by county and obviously, not all wells reported for a county are included in the assessment area's boundaries. The counts are from RRC active well counts reports and are provided to give the reader an idea of the scope of the potential threat that exists.

Table 32. Texas Railroad Commission Active Counts Reports

Texas Railroad Active Counts Reports			
County	**# Active oil wells**	**# Active gas wells**	**Total**
Coke	477	70	547
Tom Green	939	107	1046
Sterling	791	1672	2463
Glasscock	1608	148	1756
Howard	5653	50	5703
Totals	9468	2047	11515

An area of concern regarding water quality that is potentially affected by petroleum E&P activities is the elevated TDS levels periodically measured through the middle reaches of the North Concho River near the community of Carlsbad. Groundwater that dewaters to the river in this segment exhibits elevated chloride and sulfate levels. The concentrations fluctuate seasonally, with maximum measured levels of dissolved solids that approach 2000mg/L. Source tracking of the dissolved solids was beyond the scope of work performed for this study and the source is unknown with certainty. However, it is likely attributable either to the discharge of naturally occurring relatively highly mineralized water from shallow Permian aged rock formations and/or petroleum local E&P activities. An area of significant petroleum exploration and production activity exists southwest and updip of the vicinity of the elevated chlorides and sulfates (Figure 43). The yellow pointers are the sample station markers and the white points to the southwest are production pad sites; the road network between production sites is also visible.

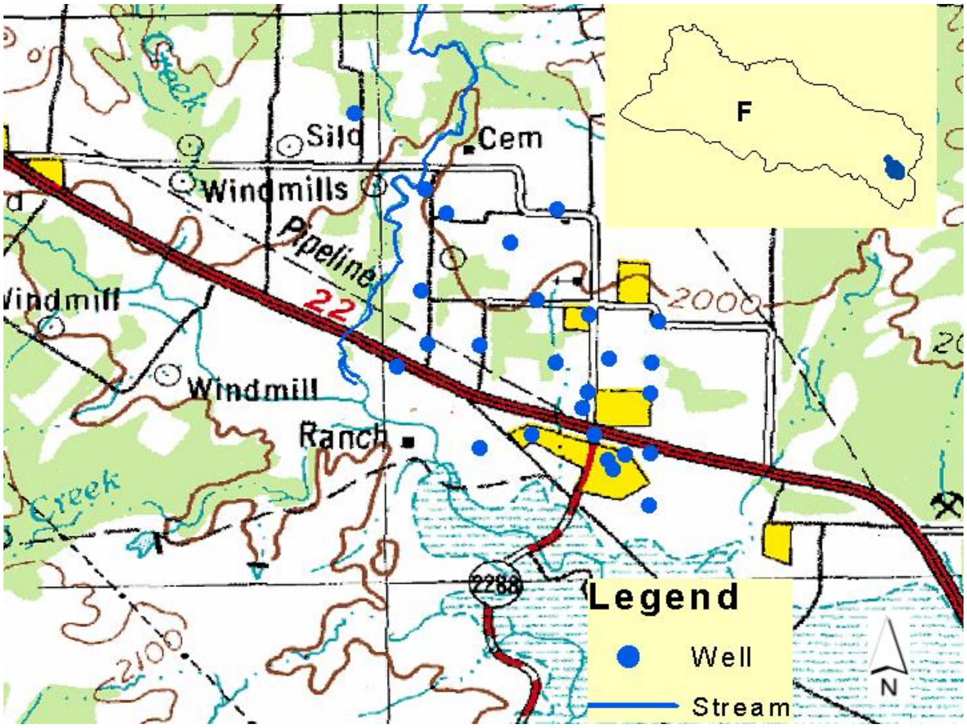
Figure 43. Petroleum E&P Activities Proximal to Stations 17245 and 12171



Water Quality Impacts from Intensive Development of Rural Areas (Grape Creek Special Study)

Grape Creek is an unincorporated community located northwest of San Angelo with a population of over 3,000 that was founded before 1900. There exists a public water supply system available to residents, but the community relies on OSSFs for wastewater treatment. Because of the concentrated density of OSSFs that were installed prior to regulatory constraints governing their installation and use, this area was considered a potential threat to shallow groundwater in the area.

Figure 44 Grape Creek Special Study Well Location Map



To determine if the groundwater was contaminated with bacteria derived from the OSSFs, samples from a total of 26 water wells spaced throughout the community were collected and analyzed for E. coli bacteria (Figure 44). One sampling event was conducted on 11/14/07 during a period of several months of very dry climatic condition. Such conditions may possibly have influenced the result by limiting the rate of percolation of water into the aquifer. Even though the results were negative for this groundwater monitoring event, large numbers of outdated, densely situated OSSFs are nevertheless considered a significant water quality threat, wherever they are located.

Other load duration curves, analytical charts, materials and maps developed for and used in the analysis and evaluation of Assessment Area F, are included in Appendix F.

6.0 BEST MANAGEMENT PRACTICES

The Watershed Protection Plan investigative and assessment process identified water quality impairments, impacts and potential impacts in six designated assessment areas. Based on the information developed through that process, BMPs were conceptually developed, screened, prioritized and selected for each assessment area. Alternative BMP concepts were developed to address the various nonpoint source pollutant issues, then screened by a selection process that included considerations of construction costs, maintenance costs, likelihood of implementation, environment effects, efficiency in dealing with the problem, public acceptability and the availability of willing project sponsors and/or managers.

A primary concern of the Stakeholder Group was to ensure that the best management practices developed in the Watershed Protection Plan would be implemented. Toward this end, the Stakeholder Group established the following goal *"The Concho River Watershed Protection Plan will not be prepared and published for the purpose of languishing on bookshelves, but will be a living document with all recommended BMPs implemented over time".*

As a result, a foundational managerial best management practice was conceptually defined that will serve as a framework for the implementation of the Watershed Protection Plan. It was designated BMP#1 of the Watershed Protection Plan.

Various managerial and structural best management practices have been selected to mitigate the water quality threats, impacts and impairments identified in the plan. Some of the BMPs target issues that pertain to a specific water quality concern or impairment, a specific assessment area, or conversely, may apply to similar water quality concerns in multiple assessment areas. Several of the recommended BMPs are politically appealing and involve community outreach efforts and networking with other agencies to effect implementation. Table 33 provides a summary of estimates of original design and construction costs, projected regular maintenance costs, projected corrective and/or infrequent maintenance costs, possible supplemental costs, potential funding sources, and a projected implementation schedule for each BMP.

Table 33 at the end of this section summarizes pertinent information about the proposed BMPs.

6.1 BMP#1 - PUBLIC OUTREACH AND EDUCATION

Project Title:
Concho River Basin Aquatic Research and Education Center

Objective:
To provide the organization, infrastructure and operational requirements that will be utilized to ensure the continued and full implementation of the Concho River Watershed Protection Plan.

Discussion:
Findings from investigations associated with development of the watershed plan indicate that the Concho River Watershed is or holds the potential to be impacted from a multitude of existing and emerging NPS sources.

Based on the experience with the San Angelo NPS program, it is recognized that public outreach and education is foundational to a successful implementation program. Without the development and maintenance of active partnerships, an engaged stakeholder group, highly visible BMPs, on-going contact with public officials, and the dissemination of public information, the success of the San Angelo NPS program would not have been possible.

BMP#1 provides a workable implementation strategy for the Concho River Watershed Protection Plan.

Project Elements:

Organization:

- Staffing and management personnel shall be furnished by the UCRA under the oversight and direction of its Board of Directors.
- An ongoing actively engaged Stakeholder Group, initially comprised of the existing watershed planning group, but open to membership, to provide liaison to various agencies, groups, and individuals and contribute to the adaptive management process that will inevitably be required. Stakeholder meetings will be held annually or as needed.
- An organizational partnership between UCRA, City of San Angelo and the San Angelo Museum of Fine Arts will be established. The Education Center will be available to the City of San Angelo for use in the development and implementation of the public education and outreach activities and the public participation/involvement requirements of its MS4 Phase II stormwater permitting requirements. SAMFA will cooperatively integrate Center programs and facilities into an overall environmental education effort and in conjunction with museum programming.

Infrastructure:

- All existing structural demonstration BMPs will be utilized. The innovative technological BMP located at the Paseo (Downtown Project) site will be used extensively in public outreach efforts.
- The Living Laboratory constructed at the Paseo (Downtown Project) site, consisting of four attractive treated stormwater ponds, will be operated as a demonstration of various aquatic habitats. This facility will be an integral part of the NPS interpretive outreach effort.
- A NPS Classroom/Interpretive Center/Meeting Room will be developed through the renovation of an existing building owned by SAMFA. This building is located in close proximity to the Downtown Project BMP and the Living Laboratory. The building will be utilized extensively by UCRA, COSA and SAMFA as a classroom for public outreach activities, as an interpretive center for on-site facilities, and as a meeting room for NPS public meetings and stakeholder group meetings.

Operational Requirements:

- Organizational networking is critical to the public outreach effort. There are numerous federal, state, county and city government agencies, soil and water conservation districts and groundwater conservation districts located within the watershed. The Center will serve as the hub of an active network of cooperating individuals, entities, groups and agencies.
- A Continual Display/NPS Public Interpretive Center, located in one of the most frequently utilized locations in the watershed, will be a major project effort.
- Development of interpretive facilities is planned to create the best advantage for multi-users and to enhance planned Center activities.
- Utilization of all existing structural NPS BMPs will be a major part of Center activities.
- Programs, displays and habitats for the Living Laboratory will be developed on a continual on-going basis.
- Media and other public information outlets will be utilized to inform the community of NPS issues, Center events, project milestones, water quality successes and proposed projects.
- A Public Water Issue Forum will be scheduled periodically and held at the Center. A panel of elected and appointed officials from throughout the watershed will be invited to attend and address any pertinent water quality issues.
- The Annual River Event for area students is a valuable tool in public outreach. Center staff will continue to plan, schedule and implement these events.
- NPS Teacher Workshops: the UCRA has conducted successful teacher workshops for the past several years. Teacher workshops will continue to be held annually.
- Volunteer Water Quality Monitoring Program currently in operation as West Texas Watch will continue under the direction of the Center.
- Pesticide-Herbicide/Chemical Use Workshops will be periodically scheduled. These workshops would primarily target public agency staff who routinely utilize these materials, and focusing on the proper use of chemicals in the prevention of NPS water pollution.

Implementation Schedule:
It is anticipated that this WPP would be implemented over a ten (10) year period. A three-phased schedule for implementation is proposed:

- Phase 1: Sept 1, 2007 - August 31, 2010 (includes completion of building renovation)
- Phase 2: Sept 1, 2010 - August 31, 2013
- Phase 3: Sept 1, 2013 - August 31, 2016.

Cost of Implementation:

- Phase 1: $524,676: Funded: TCEQ 319, UCRA, San Angelo Museum of Fine Arts, City of San Angelo, and San Angelo Health Foundation
- Phase 2: $300,000: Unfunded: TCEQ/TSSWCB 319, UCRA
- Phase 3: $300,000: Unfunded: TCEQ/TSSWCB 319, UCRA

6.2 BMP#2 - Brush Control Programs

Project Title:
Concho River Watershed Initiative for Watershed Restoration and Maintenance

Objective:
Ensure the continued state, federal and private funding of existing brush removal programs in the Concho River Watershed and expand those programs where possible. Maximize the public and official perceptions regarding the program's benefits to the watershed's water resources. Provide response monitoring and hydrologic research findings to state and federal planners for use in similarly impacted areas. The ultimate objective is the restoration of sub-watersheds to the pre-brush hydrologic condition.

Discussion:
Initial feasibility studies conducted within the Upper Colorado River Watershed (1998 and 2000) indicated that treatment of brush on targeted areas would result in significant restoration of the aquatic habitats. Historical hydrologic data reported a loss of perennial stream base flows and watershed yields to surface supplies over the last 35 years, primarily due to brush infestation in the watersheds. The encroachment of woody brush resulted largely from a lack of proper range management attributable to a myriad of factors, including the inability of most landowners to finance required practices. The result was destruction of the native aquatic habitat of a great portion of the Concho River Watershed. The State of Texas allocated significant funds through the Texas State Soil and Water Conservation Board to provide financial incentives to landowners in the upper portions of the watershed for brush control. USDA has also provided considerable financial resources for brush removal through their Environmental Quality Incentives Program (EQIP). Hydrologic response monitoring, primarily performed in the North Concho River Watershed, but also in the Twin Buttes Reservoir watershed, has indicated trends toward restoration of the hydrological conditions of the pre-brush era. Following these studies, the United States Army Corp of Engineers (USACE) developed a Section 1135 ecosystem restoration project for O.C. Fisher Lake. The initial stages of implementation include the removal of saltcedar, mesquite and other noxious brush from the reservoir basin and surrounding properties to conserve impounded water, increase stream flows and improve water quality.

Project Elements:
- Encourage and coordinate federal, state and private entities in efforts to remove phraetophytic brush from the Concho River Watershed.
- Establish priority zones and areas to focus resources to maximize hydrologic benefits.
- Implement a comprehensive hydrologic response monitoring program on affected watersheds and scientifically document the hydrologic benefits.
- Continue scientific hydrologic research projects, such as the paired watershed studies.
- Prepare and disseminate information to planners, legislative bodies, landowners and the public regarding benefits of programs.
- Report and publicize watershed responses to brush removal efforts.

- Report and publicize hydrological research results to promote program funding and continuation.
- Encourage and coordinate state and federal planners in efforts to discover and utilize new and innovative technologies or methods in brush control.
- Ensure continued local sponsorship of the O.C. Fisher Reservoir Ecosystem Restoration Project.

Implementation Schedule:
Some of the elements contained within this BMP will be implemented under BMP#1 as related to public education and involvement, networking and agency coordination. The remaining elements related to on-going monitoring and research (M/R) activities should be completed by August 31, 2010 on the North Concho River Watershed and then refocused on the Twin Buttes Reservoir Watershed from 9-1-10 thru 8-31-15. Actual brush removal has been projected over the next five (5) state bienniums with follow-up treatments extended over the next 15 years. Initial construction activities on the O.C. Fisher 1135 project should be completed by 2015.

Cost of Implementation:

- O.C. Fisher 1135 Project - $2,897,940 provided by USACE, $100,000 from TSSWCB WSEP funds and $865,980 from local sources. Total project cost is estimated at $3,863,920.
- Texas WSEP and USDA EQIP – The following table has been prepared to illustrate anticipated funding levels, funding sources and implementation schedules to monitor and implement the brush program and provide follow-up funding for rangeland maintenance.

Period	M/R Activities	Brush Removal	Follow-up
*FY 08-	$240,000 (TSSWCB)	$800,000 (TSSWCB)	$50,000 (EQIP)
FY 10-11	$170,000 (TSSWCB	$1.5 Million	$0.5 Million (TSSWCB-EQIP)
FY 12-13	$100,000 (TSSWCB	$1.5 Million	$0.5 Million (TSSWCB-EQIP)
FY 14-15	$100,000 (TSSWCB	$1.5 Million	$0.5 Million (TSSWCB-EQIP)
FY 16-17		$1.5 Million	$0.5 Million (TSSWCB-EQIP)
FY 18-19		$1.5 Million	$0.5 Million (TSSWCB-EQIP)
FY 20-21			$0.5 Million (TSSWCB–EQIP)
FY 22-23			$0.5 Million (TSSWCB-EQIP)
FY24			$0.25 Million (TSSWCB-EQIP)
Totals	**$ 610,000**	**$8,300,000**	**$3,800,000**

* (funded)

6.3 BMP#3 - Kickapoo Creek Watershed Restoration Project

Project Title:
United States Army Corp of Engineers Section 206 Watershed Restoration Project – Kickapoo Creek.

Objective:
Restore the aquatic ecosystem of the Kickapoo Creek Watershed to its pre-brush condition and re-establish the perennial base flow characteristics of the stream and the native aquatic ecosystem. This will be accomplished through the use of several range management methods and techniques.

Discussion:
The initial planning phase of this project was funded and implemented by USACE in 2004 – 2005. Funding to continue the project was not available. UCRA was and is the local project sponsor. Project participants in the initial phase were, U.S. Fish and Wildlife Service, the USDA Natural Resources Conservation Service, UCRA, USACE and a local stakeholder advisory group, through which a comprehensive project plan was prepared. Other completed or partially completed project tasks included a soil and topographic survey, vegetation survey, wildlife evaluation, research of the geologic setting, collection the GPS coordinates, preparation of a water well inventory, watershed mapping, conceptual model development, hydrologic modeling/monitoring, identification of impact designations and zones, cost/benefit analysis, landowner inventory preparation, and the generation of a water rights inventory.

Project Elements:

- Ensure continued existence of a local project sponsor.
- Maintain landowner interest and encourage continuation of the stakeholder group.
- Encourage USACE and U.S. Congress to fund the continuation of the project.
- Provide local project coordination and support, including liaison with landowners.
- Coordinate participation and support of local entities to include municipal and county governments, the Lipan Kickapoo Water Conservation District, the soil and water conservation districts and local offices of the NRCS, TSSWCB and USGS.

Implementation Schedule:
The implementation schedule is dependent on the date of federal appropriations availability. The implementation time frame, proposed in the project management plan, is an eight (8) year construction period followed by five years of project monitoring.

Cost of Implementation:
A total projected budget of $6.4 million is included in the project management plan. Approximately $300,000 of that total was funded and expended developing the project management plan. This project will be funded by USACE and associated landowner cost share.

6.4 BMP#4 - Agricultural Water Conservation and Groundwater Management

Project Title:
Concho River Base Flow Maintenance Initiative (including Agricultural Water Conservation and Groundwater Management)

Project Objective:
The prevention of a reoccurrence of the recent loss of a large portion of the entire aquatic habitat from the Concho River below San Angelo and associated affects on domestic water supplies in the riparian corridor.

Project Discussion:
During the late 1990's the Concho River below San Angelo (a reach of approximately 40 downstream river-miles) experienced a complete loss of base flows, due in part to the severe regional drought coupled with other factors. Fish kills were reported throughout the stream reach and water quality complaints were made as pools began to separate and dry. Loss of the native aquatic ecosystem occurred with major effects along the riparian corridor. Thousands of native pecan trees perished. This phenomenon was a first-time occurrence, though the region has suffered many droughts over time.

The Concho River is a gaining stream. Under normal conditions, water within the shallow alluvial aquifer moves down slope and slightly downstream to the riverbed where it discharges and contributes to the base flow. The aerial extent of the aquifer is large, recharge is rapid and considerable storage capacity exists in the underground system. In its native state, a relatively drought proof hydrologic system existed that provided minimal base flows to the stream on a virtually continuous basis. The area surrounding this stream is flat, fertile and tillable. According to *TWDB Report 360, Aquifers of the Edwards Plateau*, well yields in the aquifer are highly variable and range from less than 10 gpm to over 500 gpm.

In combination, these characteristics stimulated the development of a large area used extensively for irrigation farming. In recent years, cost share programs resulted in the drilling of hundreds of new water wells and the installation of center pivot irrigation systems. It is suspected that over pumping of the aquifer for crop irrigation has impacted the diminishment and loss of base stream flows. Some observers surmise that the loss of base flows was a result of changes in disposal protocols by the San Angelo wastewater disposal facility, continued residential development along the stream and illegal pumping from the river. It is difficult to formulate and implement methods to meet project objectives that would require considerable voluntary cooperation from many agencies and individuals.

Project Elements:
- Organize a work group comprised of the Lipan-Kickapoo Water Conservation District, effected Soil and Water Conservation Districts, the City of San Angelo, the Tom Green County Water Control and Improvement District No.1, the Texas State Soil and Water

Conservation Board, the Texas Commission on Environmental Quality, the Concho River Watermaster Program and the Upper Colorado River Authority.

- Hold work group meetings to prepare a drought contingency plan for the Concho River utilizing an alternative best management plan development and screening process. Potential alternatives could include agricultural water conservation and groundwater management, management of in-stream diversions, controlled upstream releases, management of upstream stormwater and others to be determined.
- Adoption of contingency plan by the work group and all participating entities.

Implementation Schedule:
All elements identified can be implemented under the Concho River Basin Aquatic Research and Education Center (BMP#1). It is anticipated that BMP#4 could be fully implemented from September 1, 2007 - August 31, 2010.

Cost Implementation:
All costs associated with this BMP have been included with costs to complete BMP#1 funded by TCEQ 319 grant funds and local sources.

6.5 BMP#5 - Reduce Agricultural Waste Impact within Assessment Area A

Project Title:
Develop strategy and approach to reduce water quality impacts associated with agricultural operations within the main Concho River Sub-watershed below San Angelo.

Objectives:
Eliminate water quality impact of regulated/unregulated agricultural operations within the sub-watershed. Control and reduce excessive nitrate content of groundwater within the Lipan Aquifer in eastern Tom Green, Concho and South Runnels Counties (Assessment Area A).

Project Discussion:
The water quality assessment for Area A documents the impact of agricultural sources within the sub-watershed, on which regulated CAFOs are located. It is clear that the substantial organic and nutrient loadings resulting from collective periodic releases by several regulated operations are in violation of permit requirements. Unregulated agricultural operations may also be impacting water quality. Fixed station routine water quality monitoring and special monitoring conducted as a part of this project have confirmed this assessment. The TCEQ regional offices responsible for permit enforcement in the sub-watershed (Abilene and San Angelo) have cooperated with the UCRA in the preparation of this BMP.

Other issues involve excessive nitrate concentration in surface water found on several tributaries and in the lower portions of the Concho River (stream segment 1421). Nitrate concentration measured at the Concho River at Paint Rock monitoring site often exceeds drinking water limits (10 mg/l as N), particularly during winter months. This stream segment provides the surface water supply for the city of Paint Rock. Tributaries such as Dry Hollow Creek, Lipan Creek, Kickapoo Creek and Little Concho Creek also display excessive nitrate concentrations. The source of the nitrates in these tributaries and the Concho River was recognized in previous studies (*Clean Rivers Special Study*, *High Levels of Nitrate in Groundwater Within the Lipan Aquifer, Tom Green and Concho Counties,* June 2000). The source of nitrates was attributed to the dewatering of the shallow alluvial aquifer to the Concho River and some of its tributaries. Previous UCRA special studies have documented that the intensive farming practices prevalent in the area may also be a substantial contributor to this problem, through the leaching of nitrate from nitrogen fertilizers into the shallow groundwater.

In recent years, the number of CAFOs has increased within the stream segment 1421 watershed and manure is routinely disposed by agreement with area farmers for soil amendment to agricultural fields. This could be a growing influence on the nitrate problem. It is anticipated that national regulatory and economic factors may result in the growth of the number CAFOs operating in Assessment Area A through relocation. It is apparent that there is an existing and growing threat to water quality through increased potential transport of nitrogen to shallow groundwater and the intensification of an on-going problem.

Project Elements:

- Organize stakeholder sub-group to specifically address agricultural issues. Group to include agricultural representatives, landowners within Assessment Area A, groundwater conservation district representatives, soil and water district directors, regulatory staff and other appropriate members. The sub-group will collect, develop and make applicable resources/information available as related to agricultural waste and waste management. Include sources of design and operational assistance for operators from governmental entities and trade organizations. Regulatory conditions for existing operations could also be made available. Sub-group would evaluate agricultural waste problems on an area-wide basis to make recommendations to the stakeholder group regarding actions or policy in mitigating water quality threats.
- Inform existing CAFO owners and operators of the presence of the stakeholder sub-group and the potential assistance and/or resources that may be available from that group.
- Review and comment on CAFO permit applications and renewals based on existing and projected conditions (including ground and surface water quality). Comment could include recommending expanded permit requirements i.e., intensive nutrient management protocols and groundwater monitoring.
- Continue complaint response and monitoring of discharges and cooperation with TCEQ Regional investigation offices.
- Continue and expand water quality and hydrologic monitoring in Assessment Area A and provide stakeholder sub-group with analysis of water quality and hydrologic data collected.
- Cooperate and assist Lipan Kickapoo Water Conservation District and local SWCDs in securing funding (each through sub-contract) to develop education and outreach programs designed to provide information regarding improved farming techniques regarding existing soil fertility and fertilization based on agronomic rates.
- In cooperation with the Lipan Kickapoo Water Conservation District, add groundwater quality (nitrate) and hydrologic data collected since publication of the UCRA Clean Rivers Special Study to the Concho River WPP GIS data base and develop and implement a comprehensive monitoring program to track changes in groundwater levels and nitrate concentrations within Assessment Area A.

Implementation Schedule:

Some elements identified can be implemented under the Concho River Basin Aquatic Research and Education Center (BMP#1). It is anticipated that organizational elements of this BMP could be fully implemented from September 1, 2007 - August 31, 2010. Following this, work could continue as required for the duration of BMP#1 (August 31, 2016). Element 6 will require future funding sources and should be scheduled to coordinate with BMP#1 completion (8-31-16). Element 7 should also be scheduled to mesh with BMP#1 completion and should be implemented at the earliest possible date.

Implementation Costs:
All costs associated with Elements 1-5 are included with costs to complete BMP#1. Cost estimates for Elements 6 - 7 are assumed to be eligible through TSSWCB 319 funding under single application and award:

		Element 6	Element 7	Total Cost
Phase I	9.1.08 – 8.31.10	$15,000	$75,000	$90,000
Phase II	9.1.10 – 8.31.13	$22,500	$90,000	$112,500
Phase III	9.1.13 – 8.31.08	$22,500	$90,000	$112,500
Totals		**$60,000**	**$255,000**	**$315,000**

6.6 BMP#6 - Structural Controls on Pulliam Draw

Project Title:
Planning and construction of stormwater control facility(s) in East San Angelo (Pulliam Draw).

Objectives:
Reduce or eliminate the threat of the export of stormwater pollutants to Assessment Area A from an area extensively developed for residential, commercial, agricultural and light/heavy industrial uses.

Project Discussion:
The Pulliam Draw watershed, located in East San Angelo, is extensively developed for residential, commercial, agricultural and light/heavy industrial uses. The 7,500 acre watershed, a large portion of which is located outside the city limits, discharges to the Concho River below Bell Street Reservoir. While some private facility stormwater controls exist within the area, no other control or treatment facilities exist. Several TCEQ point source industrial permit holders and industrial solid waste generators are located in the watershed. Some solid waste and wastewater enforcement actions have occurred in recent years that have involved dairy waste, lead and cadmium violations and PCB contamination. Dumping of industrial waste has occurred in this area in the past. Assessment of Area A has determined a significant threat to downstream water quality and the aquatic environment, which exists within this watershed.

Project Elements:
It has been determined that the elimination of the water quality threat could best be served through the development of stormwater treatment controls. This BMP could be implemented by the City of San Angelo Stormwater Program with assistance from the Concho River Watershed Protection Plan Stakeholder Group.

- Propose to seek funding for contracts with professionals to perform an engineering feasibility study to find potential or available sites, propose alternative treatment facilities, explore potential recreational uses and values for the project, and provide screening of alternatives with project selection and cost estimates.
- Propose to seek funding to implement findings of feasibility study.

Implementation Schedule:
While implementation for some of the work may be provided under BMP#1, project completion will depend upon funding and contracting by the City of San Angelo. It is anticipated that this BMP could be fully implemented by August 31, 2013.

Implementation Costs:
Portions of the work will be funded under BMP#1. The total cost estimate for the remaining portion (City of San Angelo) is $300,000 ($180,000 - TCEQ 319 grant and $120,000 local sources).

6.7 BMP#7 - City of San Angelo Comprehensive Stormwater Ordinance

Project Title:
The preparation, adoption and enforcement of a comprehensive stormwater ordinance and development design manual for the City of San Angelo.

Project Objectives:
Control and prevention of continued unregulated commercial and residential development within the City of San Angelo and the extraterritorial jurisdiction in regard to stormwater control.

Project Discussion:
To date, COSA has not had a comprehensive stormwater ordinance or development design manual to effectively manage new development and the manner in which stormwater is handled by developers. The city has experienced considerable difficulty with prior urban development resulting in extensive flooding and multiple water quality issues. Streets are the main conduits for stormwater handling within the city. It is imperative that new development does not continue to adversely affect existing problems. The San Angelo urban area consists of a small fraction of the total watershed of stream segment 1421 (Concho River below Lake Nasworthy and O.C. Fisher Reservoir), but is a large contributor of flood flows passing USGS flow gage at Paint Rock. This is verified by comparing USGS flow data at the Paint Rock gage and the gage located immediately below Bell Street Reservoir. It follows that the main flow contributor (urban runoff) may have the greatest effect on water quality within the segment. COSA recently began to develop and enact an ordinance and design manual and the process has resulted in considerable criticism and resistance from developers and local design professionals.

Project Elements:
The following actions are required to assist and encourage COSA in the development of stormwater ordinances, design standards and the enforcement of those standards following adoption. This BMP should be implemented by the Concho River Watershed Protection Plan Stakeholder Group.

- Continue to participate in the development of standards and provide technical assistance in regard to NPS issues.
- Monitor and comment on draft documents as they are prepared.
- Participate and advise in the process of adoption review and approval by City Council.
- Assist City staff as required for design review of proposed controls in critical areas.
- Provide input to City in regard to necessary amendments or changes that would be desirable following initial adoption.

Implementation Schedule and Costs:
Implementation of this BMP will be accomplished within the schedule and estimated costs of BMP#1 (see Section 6.1).

6.8 BMP#8 - Structural Control on Red Arroyo

Project Title:
Planning and construction of structural stormwater control facility(s) on Red Arroyo, in San Angelo urban area.

Project Objectives:
Reduce or eliminate the continued discharge of stormwater pollutants, primarily TSS, to Assessment Area B and prevent export of pollutants to Assessment Area A from Bell Street Reservoir.

Project Discussion:
The Red Arroyo drainage area consists of approximately 8,500 acres of residential and intense commercial development. Considerable portions of the watershed are undeveloped and much of the area consists of an outcrop exposure of the San Angelo Formation. One of the components of this structure is a red clay soil type that is easily subject to erosion. Flood flows from significant storms down this drainage take on the appearance of the dominant soil type, or a distinctive red color. The drainage discharges to the South Concho River immediately below the Metcalfe Dam, near the city water treatment plant. Originally, the confluence was above the dam, but a ditch was constructed many years ago to divert the flow and heavy solids loading from the creek away from the inlet to the city's water treatment plant above the dam. The stream below Metcalfe dam and extending to the confluence with the North Concho in Bell Street Reservoir contains excessive accumulations of sediment. With the exception of several decorative impoundments located on tributaries to Red Arroyo and a wide grassy floodway, no stormwater controls are located within the drainage system.

Project Elements:
This project could be implemented through the COSA program. Propose to seek funding to contract with professionals to perform engineering feasibility study to consider potential or available sites, propose alternative treatment facilities, explore potential recreational uses and values for the project, and provide screening of alternatives with project selection and project cost estimates.

- Propose to seek funding to implement findings of feasibility study.

Implementation Schedule:
Some of the work within this BMP will be provided under BMP#1, but completion of the work elements will depend upon funding and contracting by COSA. It is anticipated that this BMP could be fully implemented by August 31, 2013.

Implementation Costs:
Portions of the work will be funded under BMP#1. The total cost estimate for the remaining portion (City of San Angelo) is $300,000 ($180,000 - TCEQ 319 grant and $120,000 local sources).

6.9 BMP#9 - Update and Implement North Concho River NPS Master Plan

Project Title:
North Concho River Urban Runoff Nonpoint Source Abatement Revised and Updated Master Plan

Project Objectives:
Revise and update existing Master Plan to continue the systematic development and construction of BMPs within the North Concho River urban watershed.

Project Discussion:
The urban portion of the North Concho River watershed consists of approximately 7,750 acres and is almost completely developed for residential, commercial and light industrial use. Although some new growth is occurring, little undeveloped property remains in the watershed with much of the area urbanized over a long period of time. Changes in land use have been common in recent years with major occurrences, such as the construction of the Houston-Harte Freeway. Urban portions of the North Concho have been the focus of a significant NPS study, and BMP construction beginning with the initial 1996 NPS/UR project funded by the EPA CWA 319(h) program administered by TCEQ. The NPS abatement program has been quite successful and water quality has improved with significant fish kills eliminated. Unfortunately, poor water quality conditions still exist and it is critical that the program continue. The Master Plan (now 10 years old) needs updating, as the initial five design development projects have been constructed and some land use changes have occurred. Reported project design, technology and cost information is also outdated.

Project Elements:
It is recommended that the North Concho River Urban Runoff Nonpoint Source Abatement Master Plan (1996) be revised to contain the following.

- Update mapping and hydrologic modeling for all seven major sub-watersheds identified in the plan.
- Update list of potential BMPs to be constructed in the watershed.
- Prepare new list of priority BMPs with design development and detailed cost estimates for five projects to be constructed over the next ten years.
- Begin construction of the five recommended high priority construction projects as approved by San Angelo City Council.

Implementation Schedule:
While some of the elements within this BMP will be provided through BMP#1, completion of the work elements will be contingent upon contracts with COSA. It is anticipated that this BMP could be fully implemented by August 31, 2018 thru multiple TCEQ 319 grant applications.

Implementation Costs:

Portions of the work will be funded under BMP#1. The remaining portion (COSA) is estimated to cost $ 1,500,000 ($900,000 - TCEQ 319 grant funds and $600,000 - local sources).

6.10 BMP#10 - North Concho River Bank Stabilization and Sludge Dredging

Project Title:
City of San Angelo One Half Cent Sales Tax River Improvement Project

Project Objectives:
Improve the aesthetic quality and public use of the environment surrounding the in-town section of the North Concho River, which includes water quality improvements.

Project Discussion:
Voters in San Angelo approved $11 million of an approximate $25 million project (approximately $15 million in water quality improvements) funded with sales tax revenues to enhance the in-town sections of the North Concho River-Phase 1. Phases 2 and 3 of the project address the remaining sections of the river, but funding has not yet been appropriated. The design phase of the project is scheduled to begin in early 2008. The UCRA has been designated by COSA to coordinate design activities related to water quality, bank and tree stabilization and sludge dredging. The in-town section of the river consists primarily of a series of in-channel dams and reservoirs dominated by urban runoff. The impoundments and river become progressively larger as the stream proceeds through the city. Through numerous studies, including stormwater monitoring conducted for this WPP, it is clear that accumulations of sludge in upstream impoundments are currently hydraulically exported downstream, exerting an oxygen depressive effect and re-introducing nutrients to the aquatic environment. The effects of these conditions are being experienced in Assessment Areas A and B.

Project Elements:
The following elements may be implemented by the City of San Angelo and the Upper Colorado River Authority.

- Preliminary planning, public input and permitting
- Project design phase
- Review/approval of project plans, specifications and contract documents
- Solicitation of bid proposals
- Award of construction contract
- Project construction and construction supervision
- Construction completion and final inspections

Implementation Schedule:
Phases 1 and 2 projects complete by August 31, 2013.
Phase 3 completed by 2016.

Implementation Costs:
Water Quality Portions of Total Project

	City of San Angelo	TCEQ 319	Misc. Sources	Totals
Phase I	$3.6 million	$0.5 million	$0.9 million	$5.0 million
Phase II	$3.6 million	$0.5 million	$0.9 million	$5.0 million
Phase III	$3.6 million	$0.5 million	$0.9 million	$5.0 million
Totals	**$10.8 million**	**$1.5 million**	**$2.7 million**	**$15.0 million**

6.11 BMP#11 - Develop Comprehensive Monitoring and Response System

Project Title:
Concho River Watershed Coordinated Monitoring and Response System

Project Objectives:
Provide a clearinghouse and system to record and monitor all salinity complaints, reported spills, investigations and remediation efforts that occur within the Concho River Watershed. Provide funding for use by groundwater conservation districts in the capping/plugging of unused or abandoned water wells located in the watershed.

Project Discussion:
One of the greatest perceived threats to water quality in the region is the intrusion of saline water into fresh groundwater sources, which ultimately reaches surface water. The Texas Clean Rivers Program Upper Basin Steering Committee has named this issue as a top water quality priority. Potential sources of saline water include unused or abandoned water wells, petroleum E&P activities, and industrial solid waste or wastewater disposal. Several entities in the watershed routinely investigate salinity complaints and include: six groundwater conservation districts, three state agencies, one river authority and one municipal water district. A central clearinghouse to record/monitor all salinity related complaints and investigative activities would be a valuable management tool that would lead to a unified effort regarding watershed salinity issues and concerns. While there are existing resources to plug leaking or improperly plugged oil wells, there are no existing resources to cap or plug unused water wells. Groundwater conservation districts consider this a major water quality threat. Some GCDs are currently addressing this issue by providing landowners the materials to cap unused wells, but these efforts are limited by funding constraints.

Project Elements:
Project elements could be implemented by the Concho River Watershed Stakeholder Group.

- Contact all watershed entities involved in salinity response, create a networking mechanism, and hold periodic meetings to encourage participation by all entities.
- Establish a central point of contact for collection and logging of complaint and investigation data and information.
- Develop a salinity complaint data layer in the watershed GIS geo-database
- Monitor salinity clearinghouse input in relation to salinity impairments or trends identified through CRP surface water quality monitoring.
- Ensure follow-up and/or complaint closures on watershed salinity complaints.
- Design, organize and implement in-depth investigations and/or long-term studies related to salinity issues.
- Establish water well plugging/capping fund for use by GCDs in high priority situations. Applications from GCDs for funding could be reviewed, ranked and awarded by the WPP Stakeholder group. Funding could be provided on a 60/40 cost share basis with GCDs and/or landowners providing 40% of the cost.

Implementation Schedule:
Implementation of this BMP could be accomplished in alignment of BMP#1 schedules.

Implementation Costs:
Elements 1-6 could be funded through BMP#1. Element 7 could be funded through 319 applications to the TSSWCB.

		TSSWCB 319	Local Funds	Totals
Phase I	9.1.08 - 8.31.10	$18,000	$12,000	$30,000
Phase II	9.1.10 - 8.31.13	27,000	18,000	45,000
Phase III	9.1.13 - 8.31.16	27,000	18,000	45,000
Totals		**$72,000**	**$48,000**	**$120,000**

6.12 BMP#12 - Adoption of Unified Subdivision Policy

Project Title:
Concho River Watershed Unified Subdivision Policy and Draft an Ordinance

Project Objectives:
Provide a comprehensive coordinated subdivision policy and draft an ordinance allowing reasonable maximum protection of water resources for municipal and county governments within the watershed and monitor existing areas of heavy development.

Project Discussion:
For aesthetic and monetary reasons, sub-division development in the Concho River Watershed (particularly in rural areas), favors expansion near or immediately adjacent to rivers and streams. As this type of development increases, a significant risk to water resources occurs. Subdivision development requires the provision of both potable water and wastewater disposal. In the absence of organized systems, these services must be provided onsite, with either or both creating a potentially serious threat to the aquatic environment if not managed correctly. The emplacement of impervious cover within sub-divisions intensifies stormwater and has the potential to seriously affect water quality. It is imperative that a unified sub-division policy be adopted by entities located in the watershed. The adoption of a comprehensive policy by one county, for example, may provide incentives for development in counties with no policy in place.

The policy should encourage the concept of low impact development. The goal of low impact development principles is to mimic a site's predevelopment hydrology through design. Instead of treating stormwater as a disposal issue, i.e. convey stormwater away from the generation source in as efficient a method as possible, low impact development design principles focus on the detention, filtration, storage, evaporation, and infiltration of stormwater close to the generation source. This is primarily accomplished through designing and constructing cost effective landscape features such as open spaces, street medians, etc.

It is proposed to periodically monitor groundwater bacteriological quality in a heavily developed area in Assessment Area F (and other areas as identified). This monitoring would approximate the data collection conducted as a part of the WPP development and be conducted on a biennial basis beginning in 2009.

Project Elements:
- Schedule presentation to all county commissioner courts of counties located within the watershed to present the WPP and this BMP.
- Enlist county government representatives and other qualified individuals to assist the stakeholder group in the drafting of a proposed unified sub-division policy.
- Following completion of the draft policy, present to all county commissioners' courts for approval.
- Coordinate changes or amendments to sub-division policy as required.

- Conduct biannual bacteriological monitoring in Assessment Area F (and other areas as identified.

Implementation Schedule & Costs:
Implementation will be accomplished within the schedule and estimated costs of BMP#1.

Table 33. Recommended BMP Information Summary

Concho River Basin Watershed Protection Plan . BMP Implementation Schedule & Costs.									
	Existing & Potential Funding Sources								
Project	TCEQ NPS	TSSWCB NPS	Local Source	USACOE	TSSWCB (WSEP)	NRCS (EQIP)	Misc	Total Cost	Completion Date
BMP#1 Phase I	$ 314,806		$ 209,870					$ 524,676	08/31/10
BMP#2 Phase 2/3	$ 360,000		$ 240,000					$ 600,000	08/31/16
BMP#2 (funded)			$ 865,980	$ 2,897,940	$ 1,140,000	$ 50,000		$ 4,953,920	08/31/15
BMP#2 (un-funded)					$ 7,870,000	$ 3,750,000		$ 11,620,000	08/31/24
BMP#3 (funded)				$ 300,000				$ 300,000	
BMP#3 (un-funded)			$ 1,525,000	$ 4,575,000				$ 6,100,000	12/31/21
BMP#4 (funded)	BMP#1							$ -	08/31/16
BMP#4 (un-funded)								$ -	
BMP#5 (funded)	BMP#1							$ -	08/31/16
BMP#5 un-funded)		$ 190,000	$ 125,000					$ 315,000	08/31/16
BMP#6 (funded)	BMP#1							$ -	08/31/10
BMP#6 (un-funded)	$ 180,000			$ 120,000				$ 300,000	08/31/13
BMP #7	BMP#1							$ -	08/31/10
BMP#8 (funded)	BMP#1							$ -	08/31/10
BMP#8 (un-funded)	$ 180,000			$ 120,000				$ 300,000	08/31/13
BMP#9	$ 900,000			$ 600,000				$ 1,500,000	08/31/18
BMP#10 Phase I	$ 500,000			$ 3,600,000			$ 900,000	$ 5,000,000	12/31/10
BMP#10 Phase II	$ 500,000			$ 3,600,000			$ 900,000	$ 5,000,000	12/31/13
BMP#10 Phase III	$ 500,000			$ 3,600,000			$ 900,000	$ 5,000,000	12/31/16
BMP#11 Phase I		$ 18,000		$ 12,000				$ 30,000	08/31/10
BMP#11 Phase II		$ 27,000		$ 18,000				$ 45,000	08/31/13
BMP#11 Phase III		$ 27,000		$ 18,000				$ 45,000	08/31/16
BMP#12	BMP#1							$ -	08/31/10

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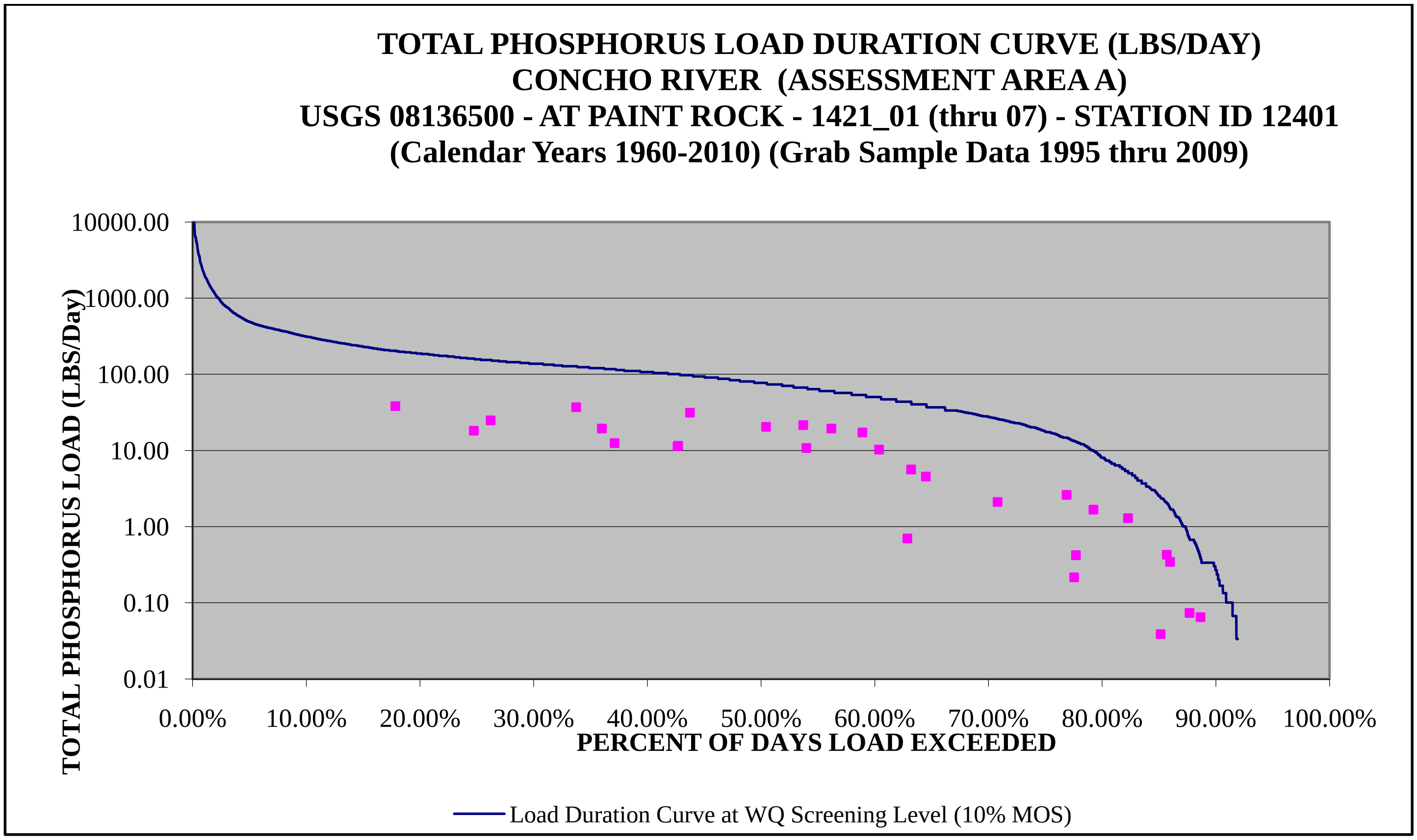
APPENDIX A

Assessment Area A Supporting Data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CONCHO RIVER (ASSESSMENT AREA A)
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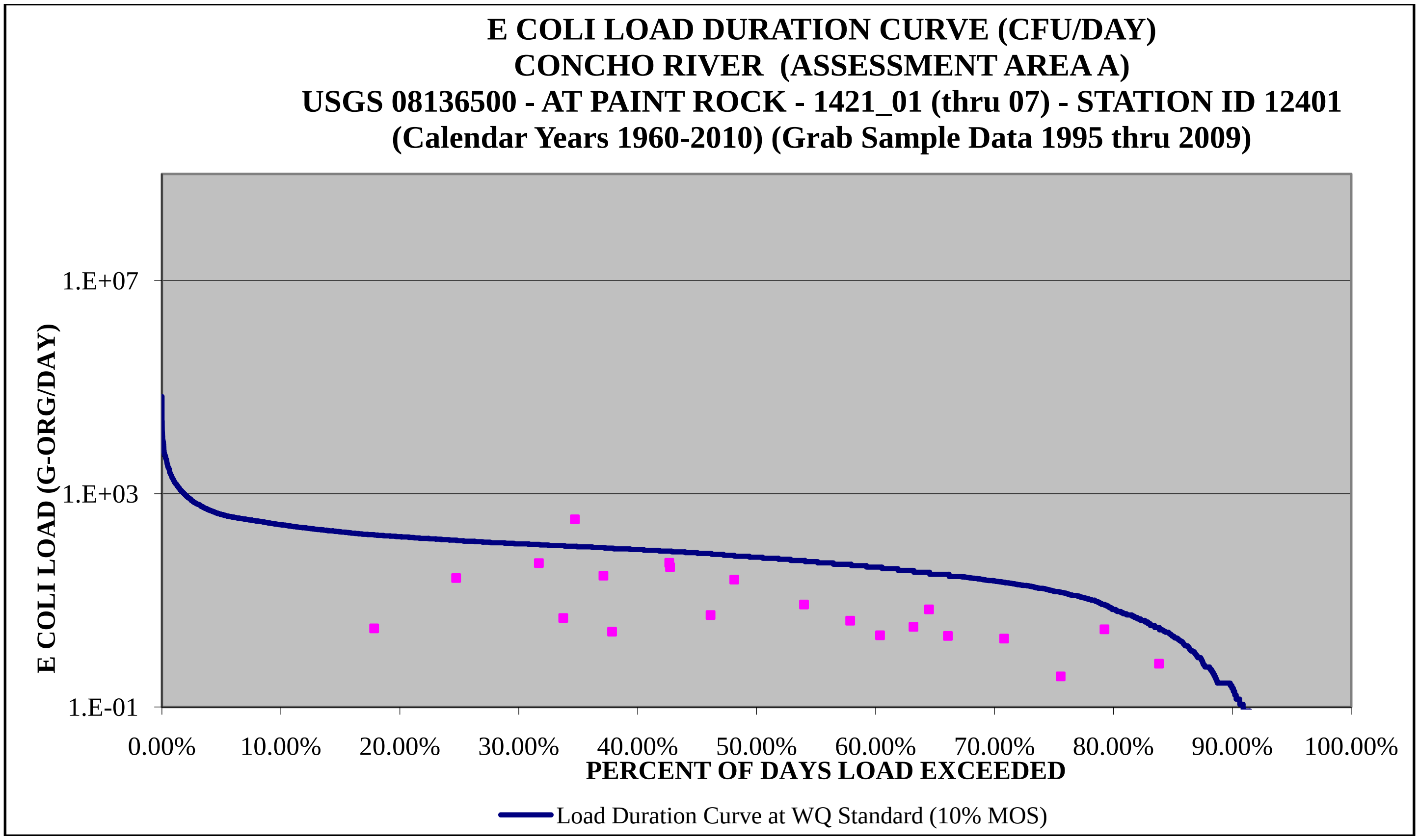
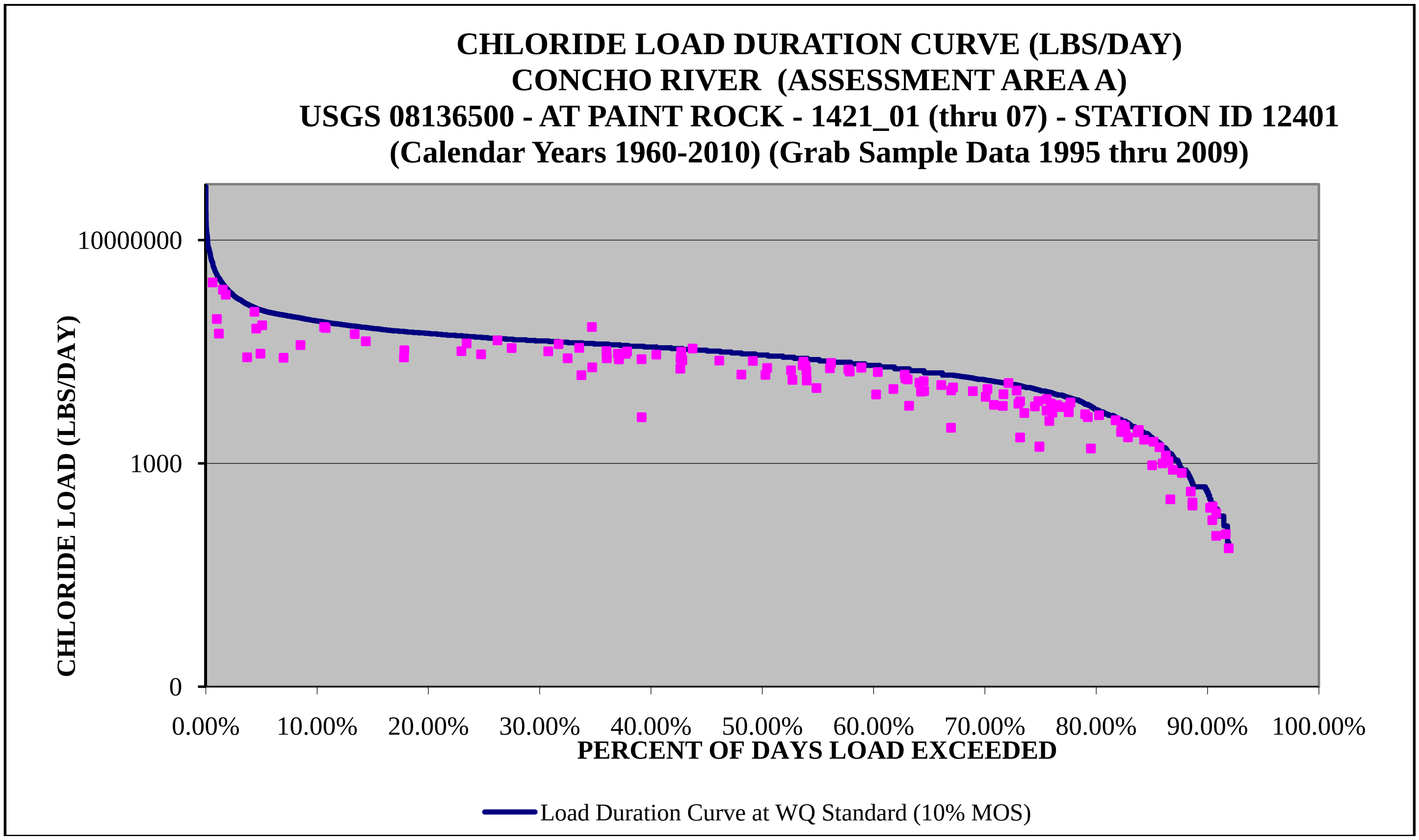
(Calendar Years 1960-2010) (Grab Sample Data 1995 thru 2009)
TOTAL PHOSPHORUS LOAD (LBS/Day)
10000.00
1000.00
100.00
10.00
1.00
0.10
0.01
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
PERCENT OF DAYS LOAD EXCEEDED
Load Duration Curve at WQ Screening Level (10% MOS)


E COLI LOAD DURATION CURVE (CFU/DAY)
CONCHO RIVER (ASSESSMENT AREA A)
USGS 08136500 - AT PAINT ROCK - 1421_01 (thru 07) - STATION ID 12401
(Calendar Years 1960-2010) (Grab Sample Data 1995 thru 2009)
E COLI LOAD (G-ORG/DAY)
1.E+07
1.E+03
1.E-01
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
PERCENT OF DAYS LOAD EXCEEDED
Load Duration Curve at WQ Standard (10% MOS)


CHLORIDE LOAD DURATION CURVE (LBS/DAY)
CONCHO RIVER (ASSESSMENT AREA A)
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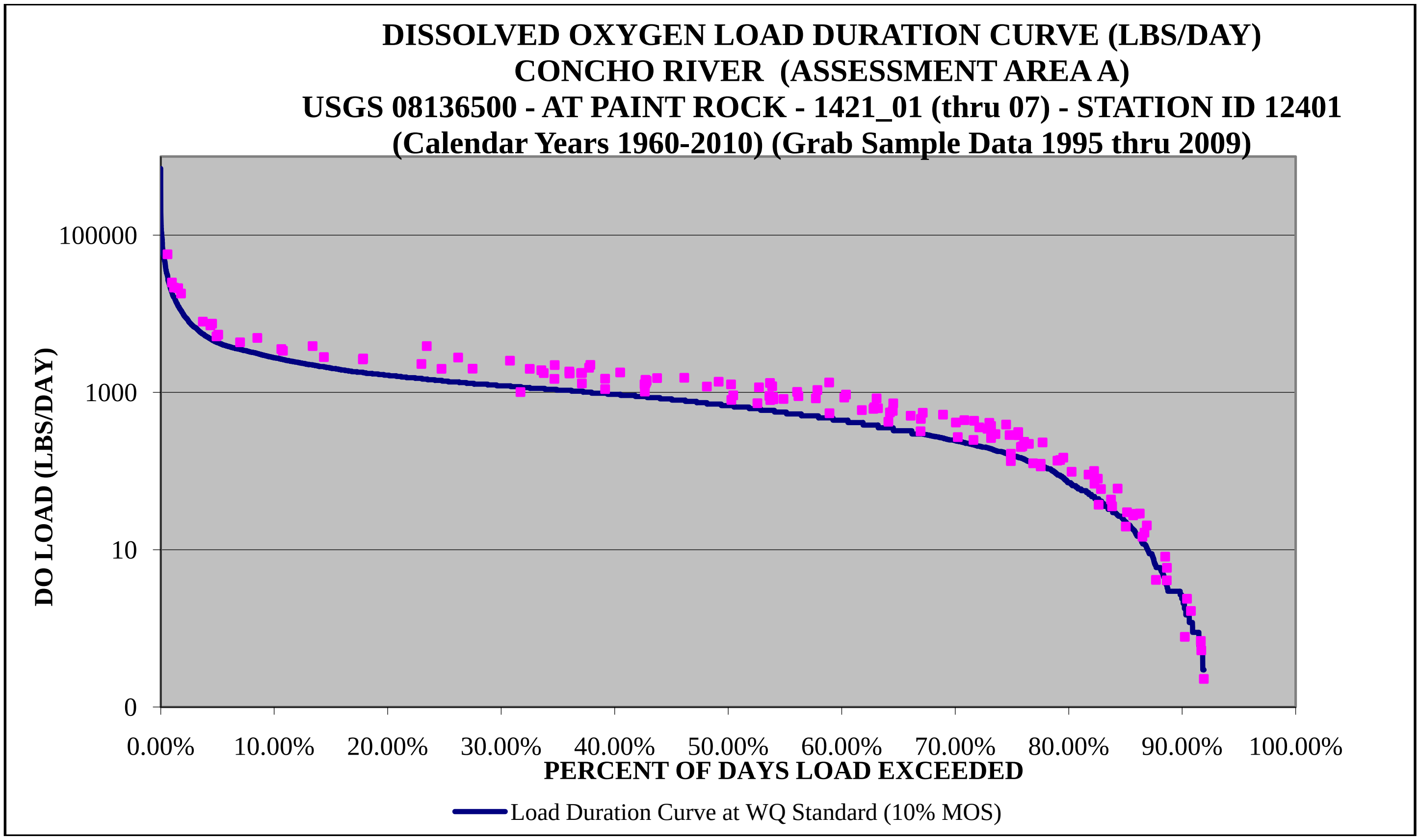
(Calendar Years 1960-2010) (Grab Sample Data 1995 thru 2009)
CHLORIDE LOAD (LBS/DAY)
10000000
1000
0
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
PERCENT OF DAYS LOAD EXCEEDED
Load Duration Curve at WQ Standard (10% MOS)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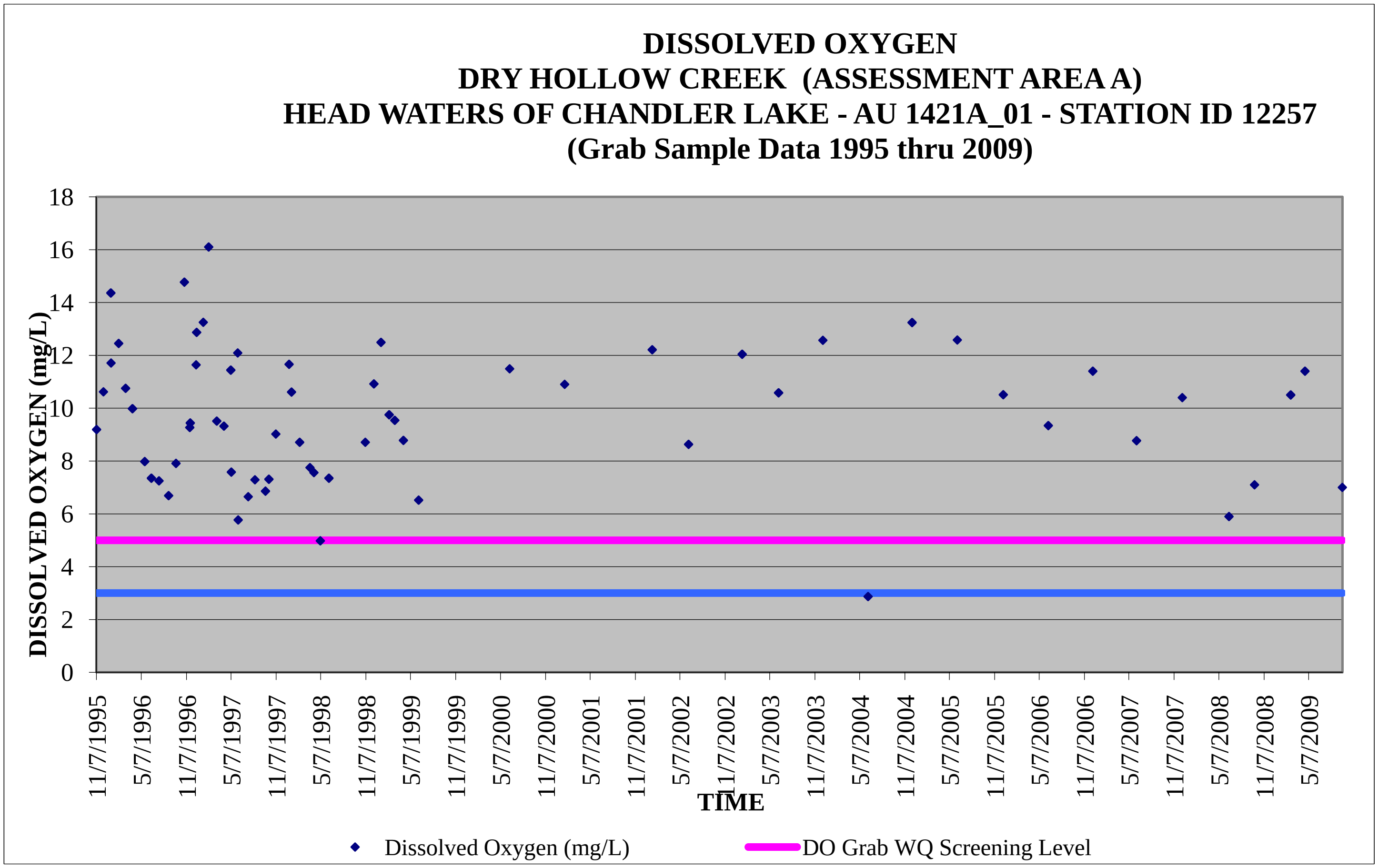
(Calendar Years 1960-2010) (Grab Sample Data 1995 thru 2009)
DO LOAD (LBS/DAY)
100000
1000
10
0
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
PERCENT OF DAYS LOAD EXCEEDED
Load Duration Curve at WQ Standard (10% MOS)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DRY HOLLOW CREEK (ASSESSMENT AREA A)
HEAD WATERS OF CHANDLER LAKE - AU 1421A_01 - STATION ID 12257
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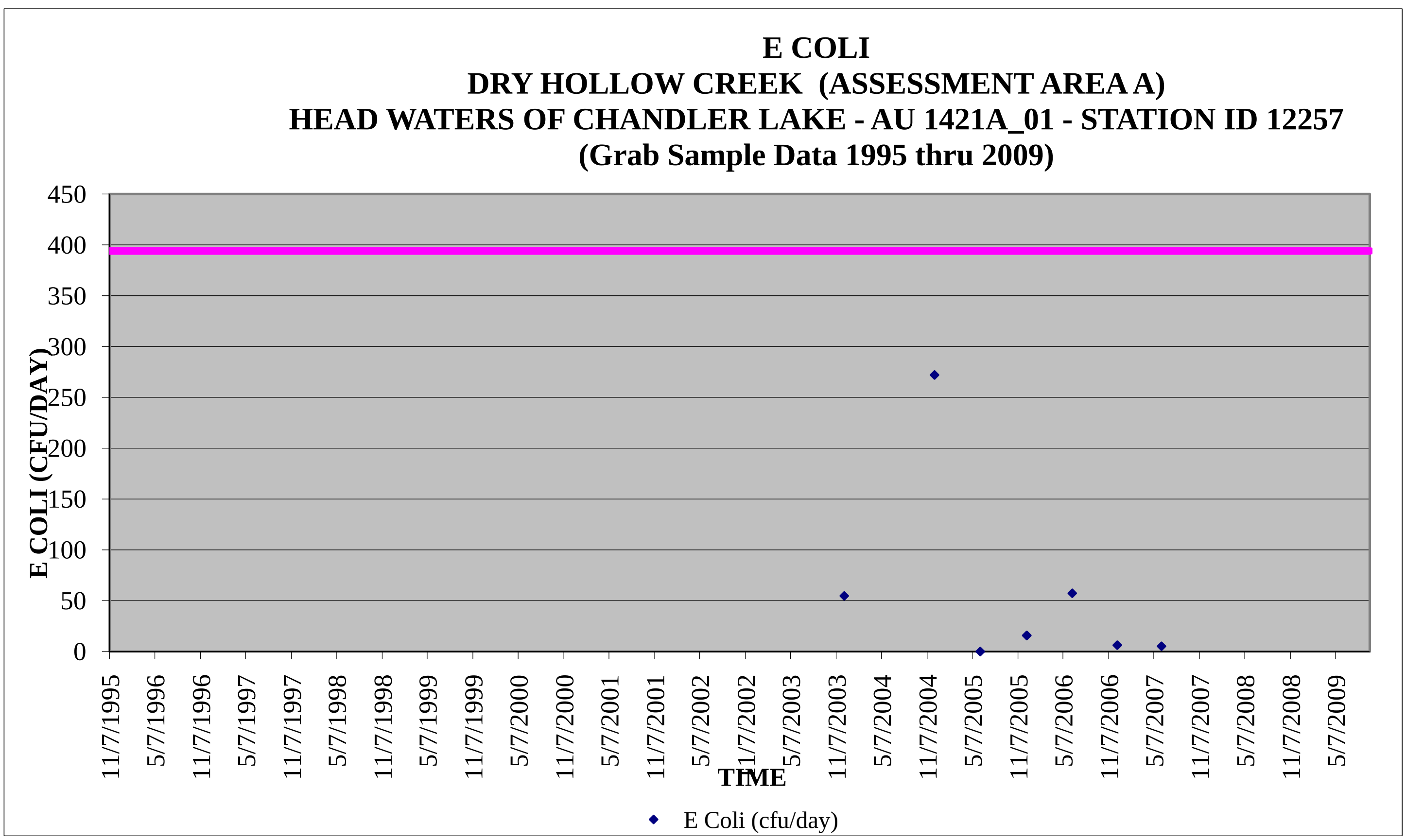
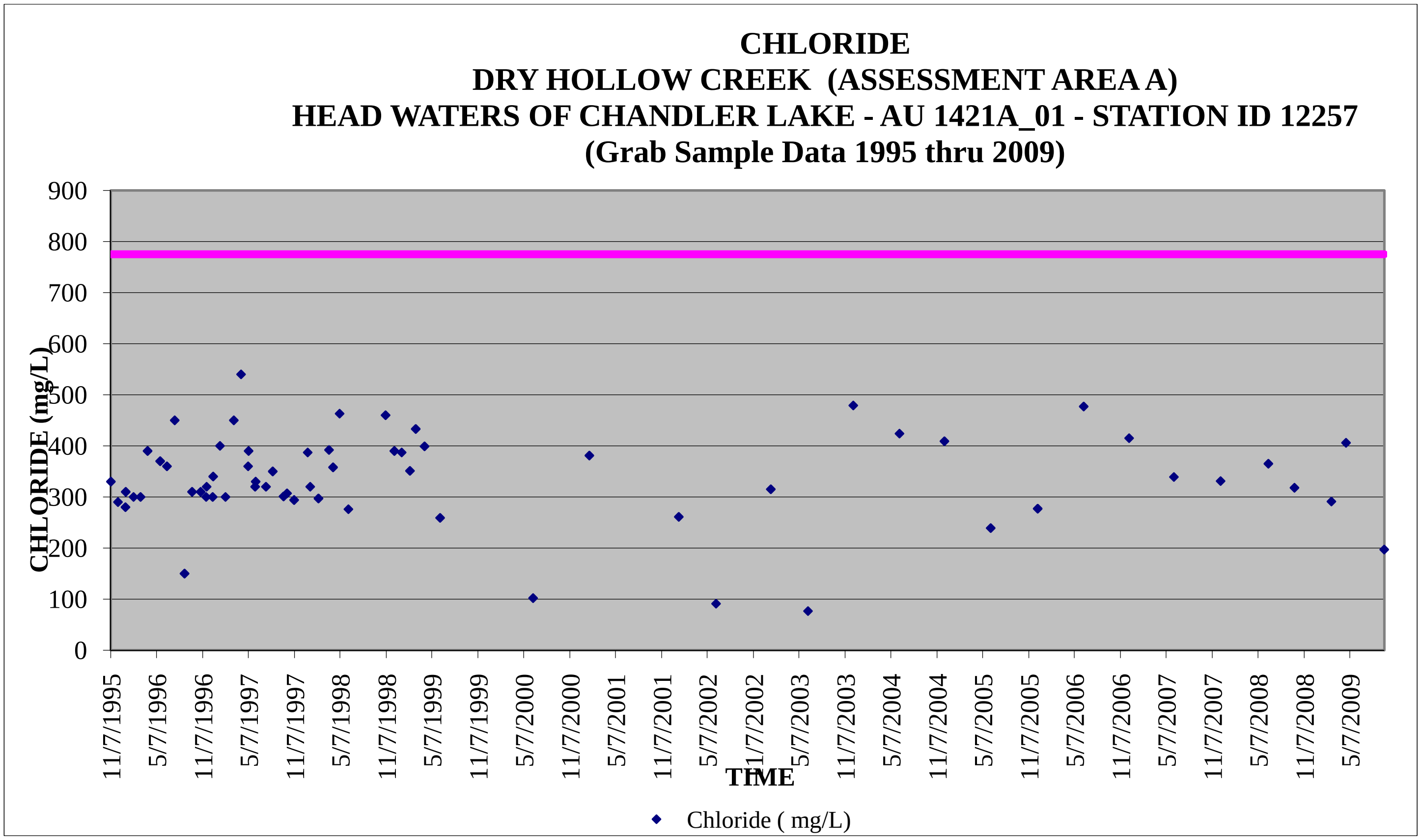
DISSOLVED OXYGEN (mg/L)
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level


E COLI
DRY HOLLOW CREEK (ASSESSMENT AREA A)
HEAD WATERS OF CHANDLER LAKE - AU 1421A_01 - STATION ID 12257
(Grab Sample Data 1995 thru 2009)
E COLI (CFU/DAY)
TIME
E Coli (cfu/day)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HEAD WATERS OF CHANDLER LAKE - AU 1421A_01 - STATION ID 12257
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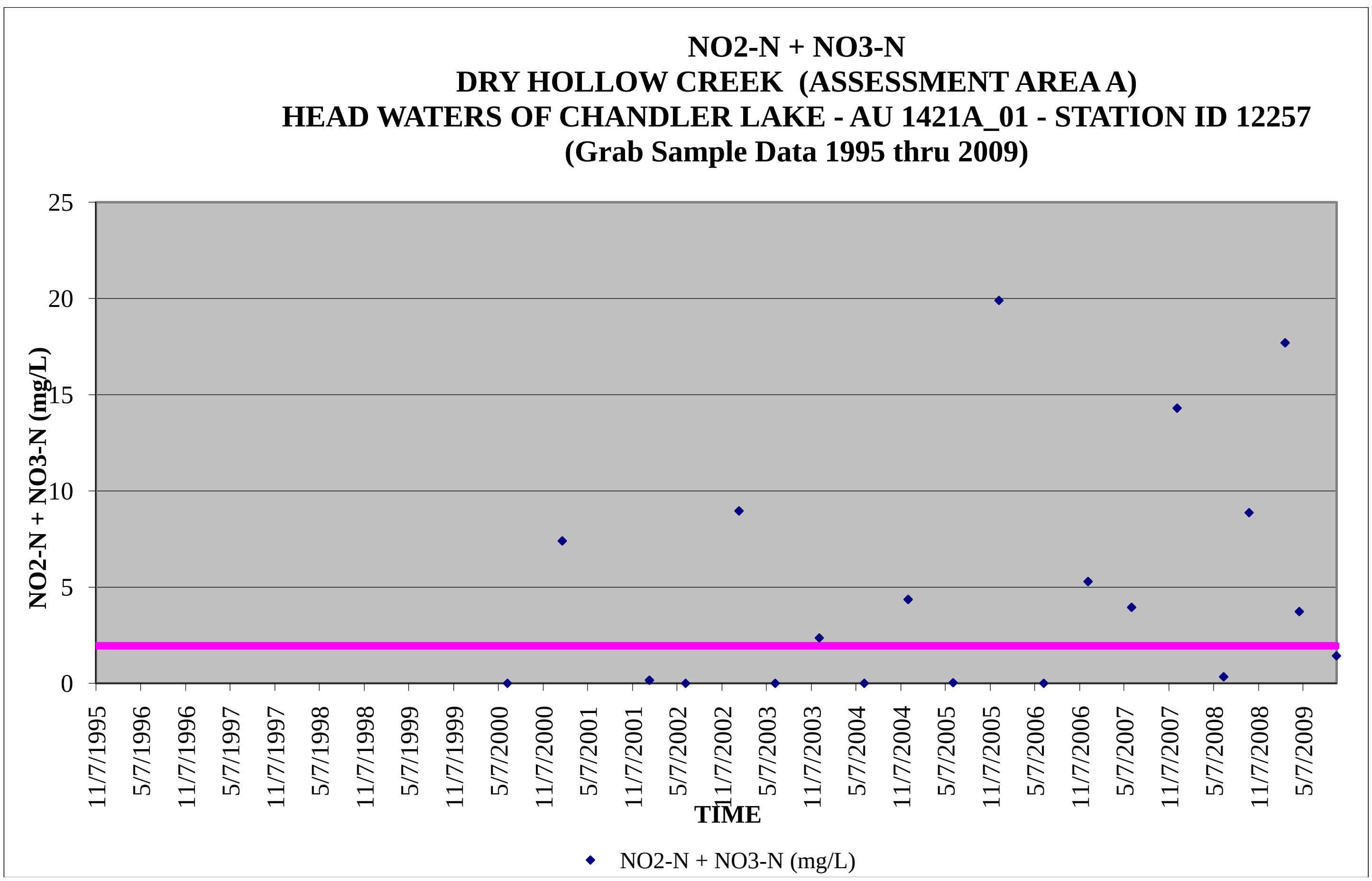
CHLORIDE (mg/L)
TIME
Chloride (mg/L)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HEAD WATERS OF CHANDLER LAKE - AU 1421A_01 - STATION ID 12257
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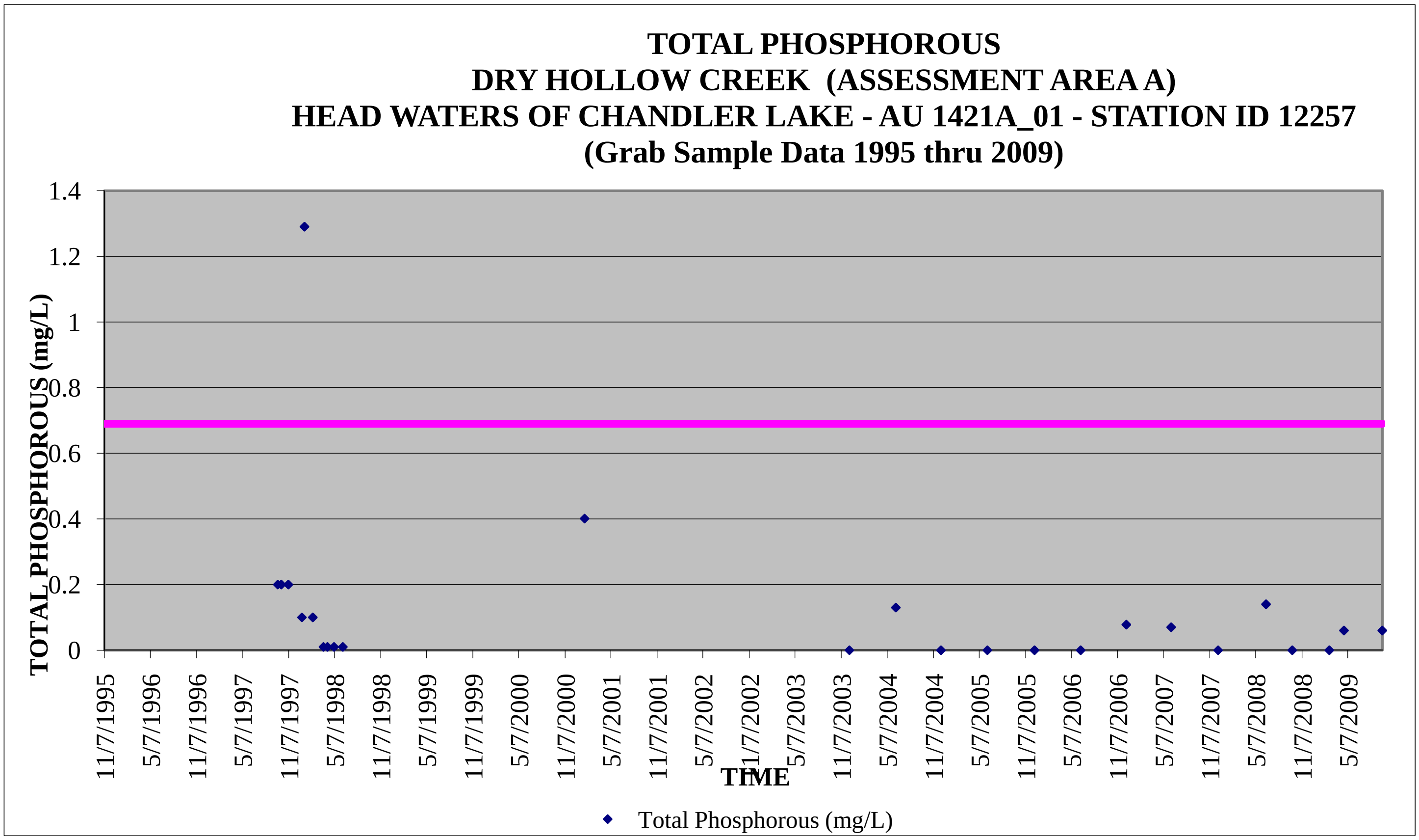
NO2-N + NO3-N (mg/L)
TIME
NO2-N + NO3-N (mg/L)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HEAD WATERS OF CHANDLER LAKE - AU 1421A_01 - STATION ID 12257
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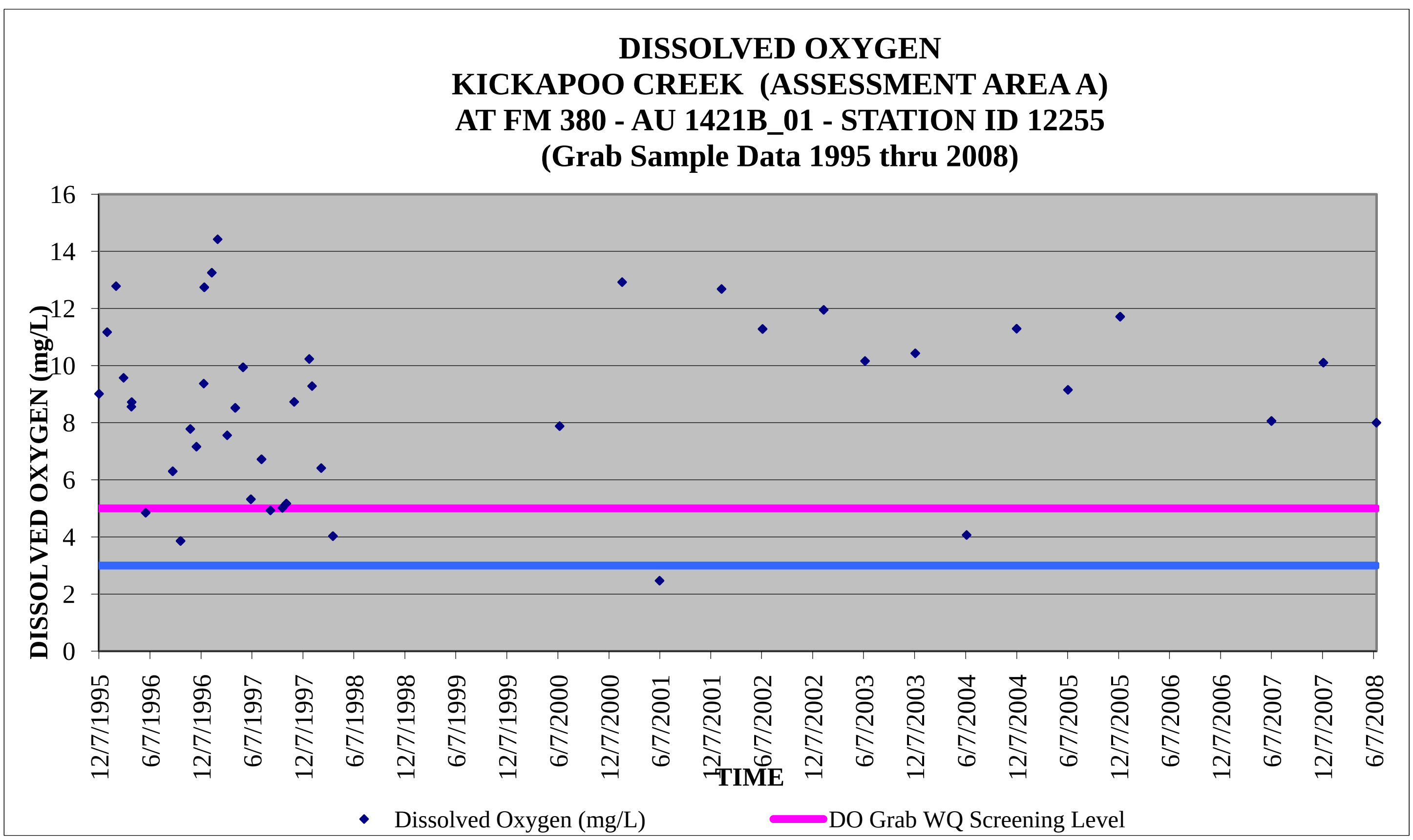
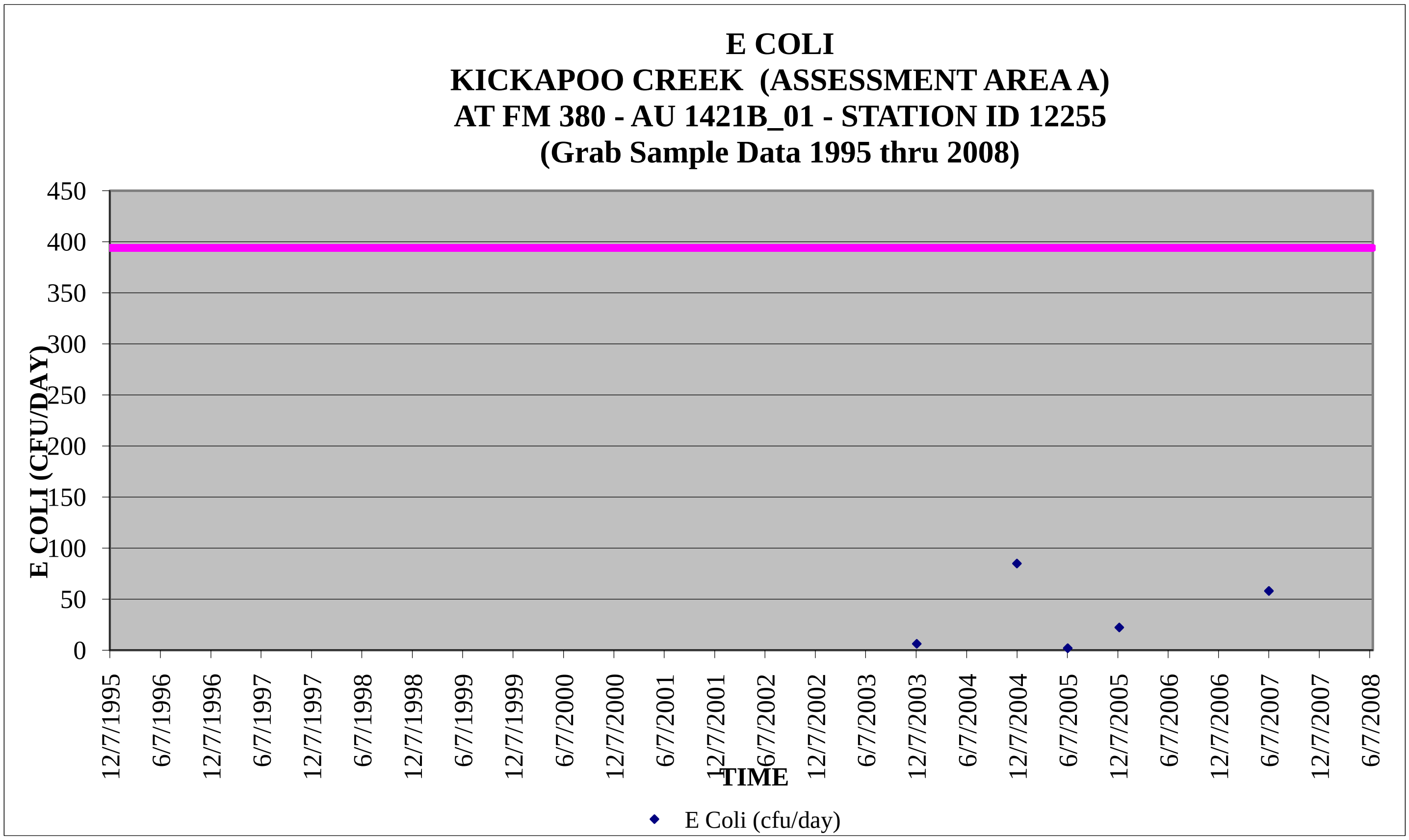
TOTAL PHOSPHOROUS (mg/L)
TIME
Total Phosphorous (mg/L)


DISSOLVED OXYGEN
KICKAPOO CREEK (ASSESSMENT AREA A)
AT FM 380 - AU 1421B_01 - STATION ID 12255
(Grab Sample Data 1995 thru 2008)
DISSOLVED OXYGEN (mg/L)
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level


E COLI
KICKAPOO CREEK (ASSESSMENT AREA A)
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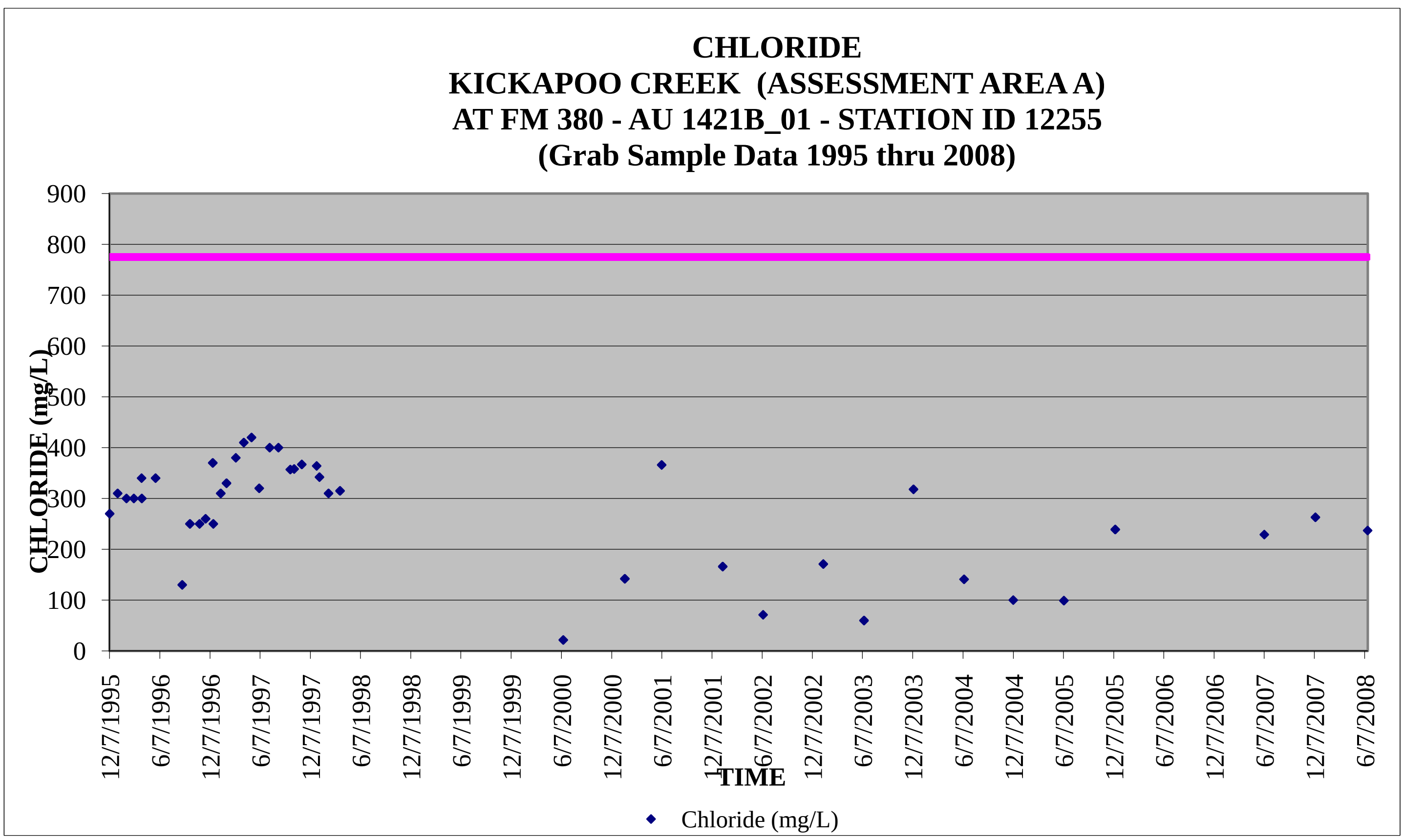
E COLI (CFU/DAY)
TIME
E Coli (cfu/day)


CHLORIDE
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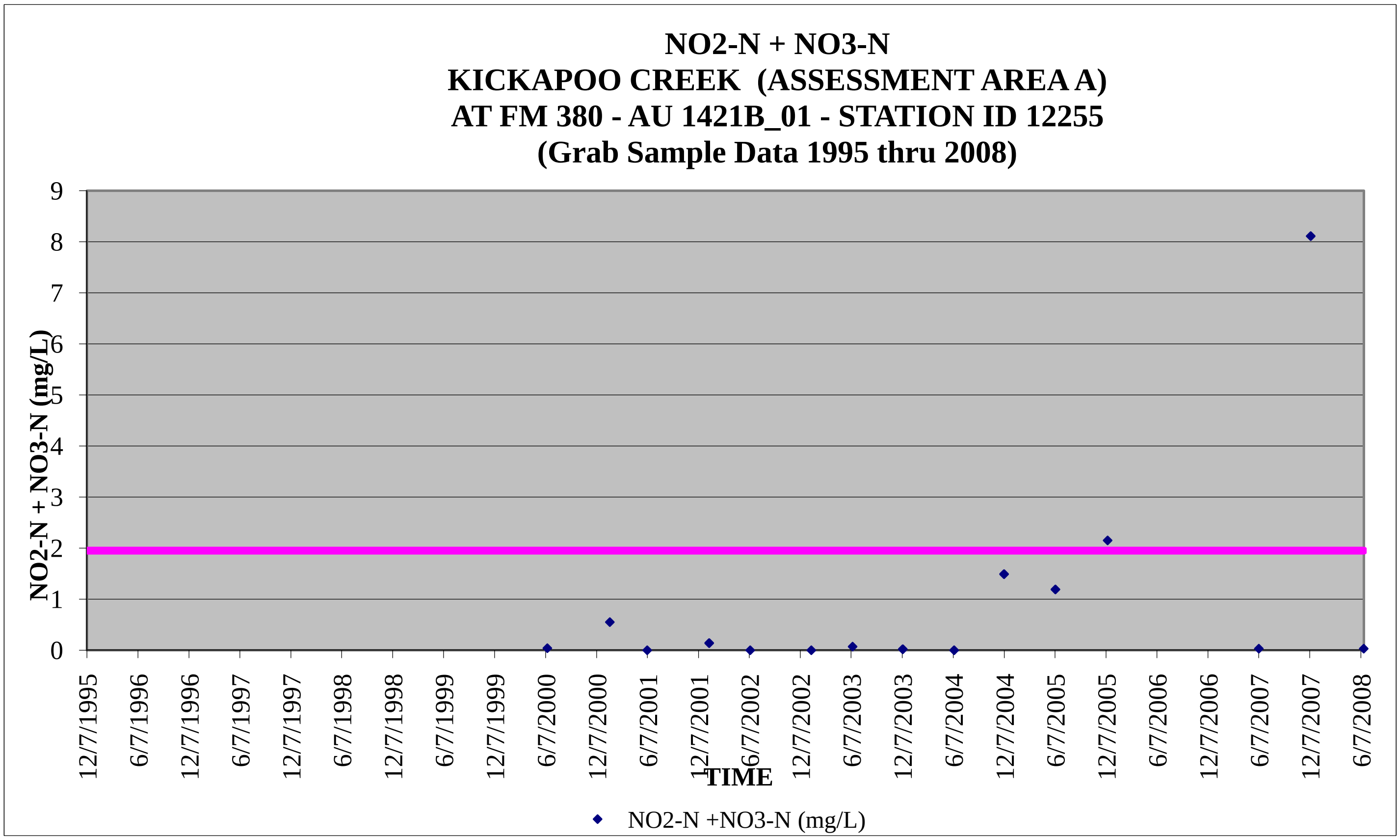
TIME
Chloride (mg/L)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KICKAPOO CREEK (ASSESSMENT AREA A)
AT FM 380 - AU 1421B_01 - STATION ID 12255
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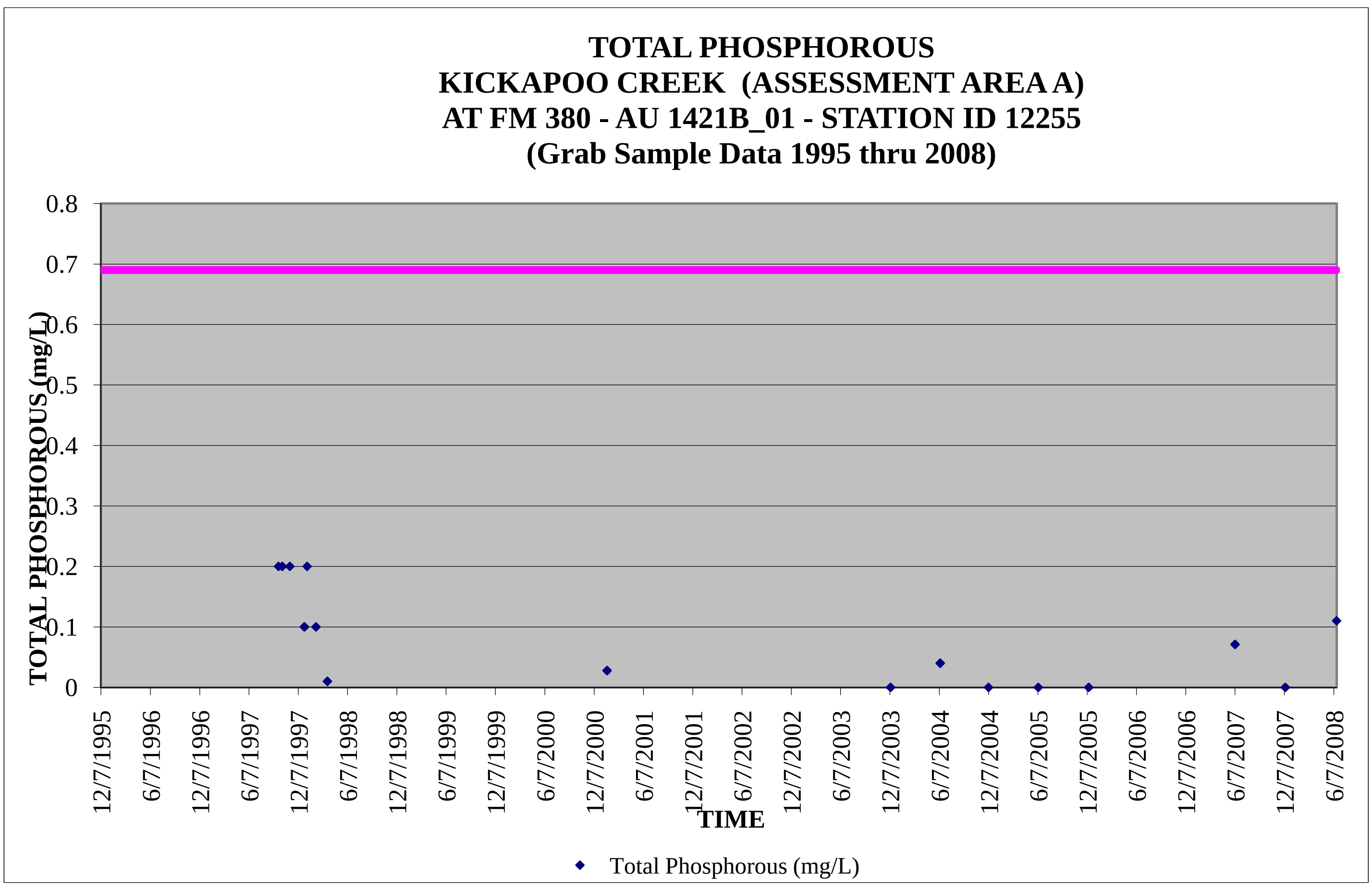
TIME
NO2-N +NO3-N (mg/L)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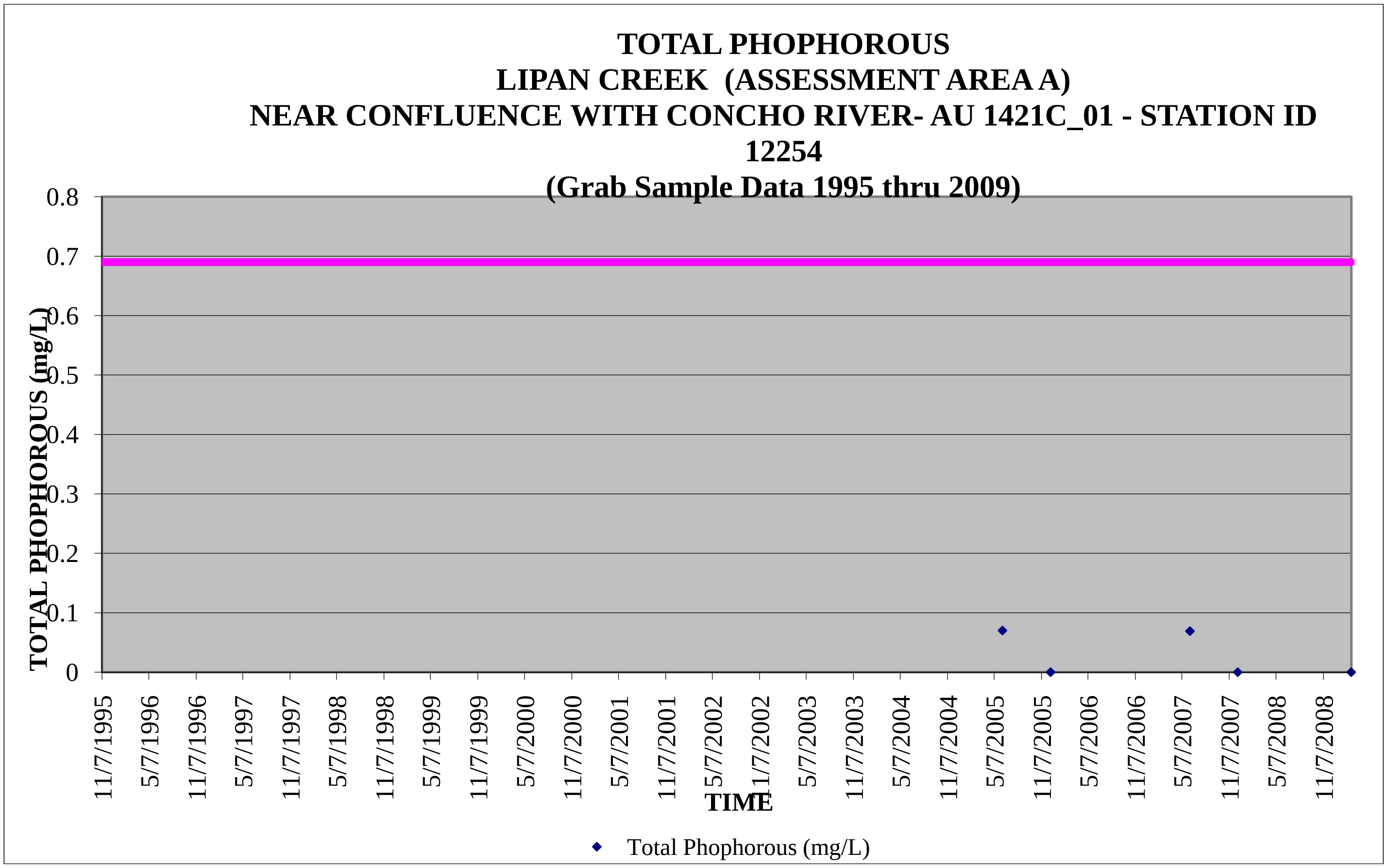
TOTAL PHOSPHOROUS (mg/L)
TIME
Total Phosphorous (mg/L)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NEAR CONFLUENCE WITH CONCHO RIVER- AU 1421C_01 - STATION ID 12254
(Grab Sample Data 1995 thru 2009)
TOTAL PHOPHOROUS (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11/7/1995
5/7/1996
11/7/1996
5/7/1997
11/7/1997
5/7/1998
11/7/1998
5/7/1999
11/7/1999
5/7/2000
11/7/2000
5/7/2001
11/7/2001
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11/7/2004
5/7/2005
11/7/2005
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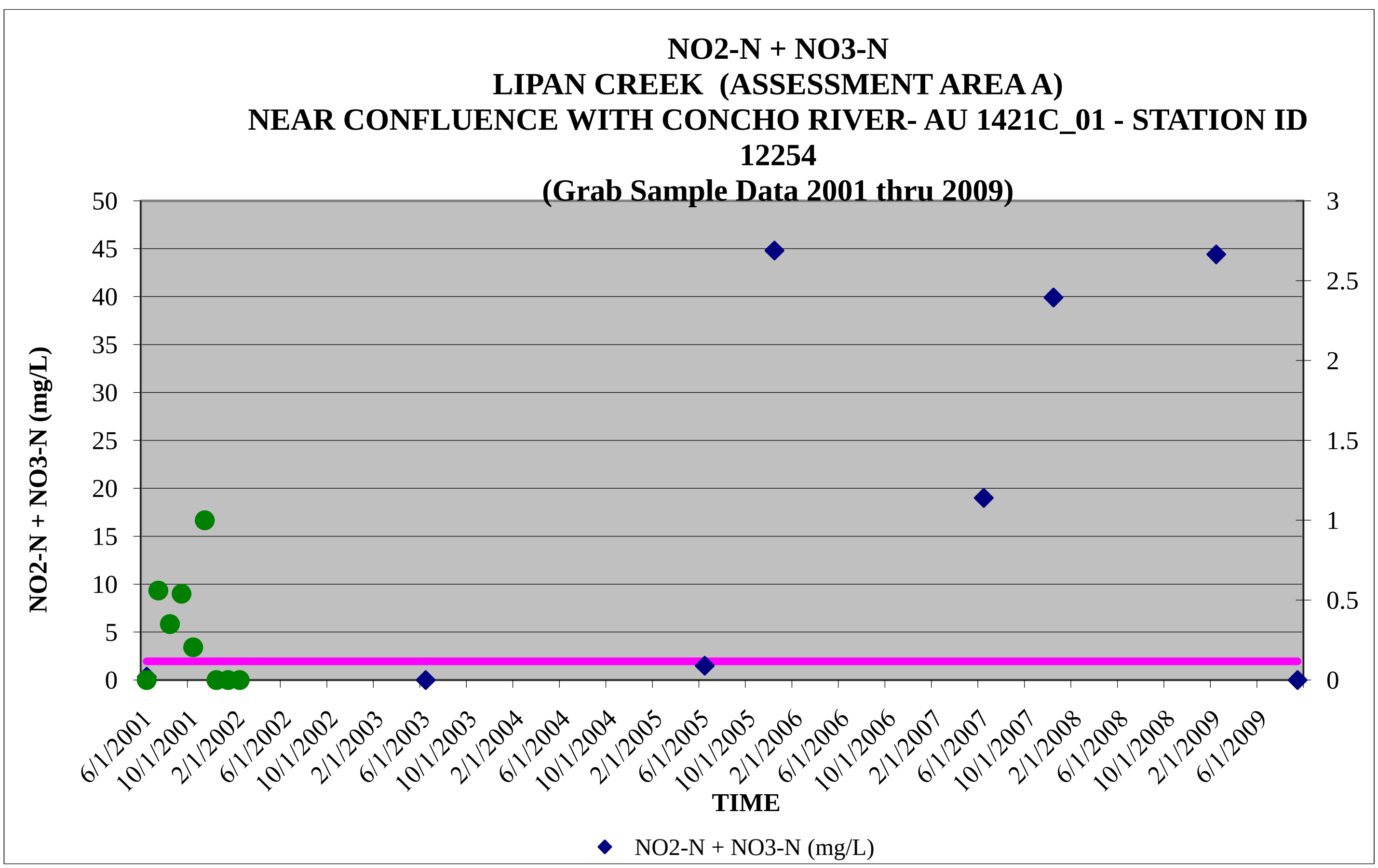
5/7/2007
11/7/2007
5/7/2008
11/7/2008
TIME
Total Phophorous (mg/L)


NO2-N + NO3-N
LIPAN CREEK (ASSESSMENT AREA A)
NEAR CONFLUENCE WITH CONCHO RIVER- AU 1421C_01 - STATION ID 12254
(Grab Sample Data 2001 thru 2009)
NO2-N + NO3-N (mg/L)
50
45
40
35
30
25
20
15
10
5
0
3
2.5
2
1.5
1
0.5
0
6/1/2001
10/1/2001
2/1/2002
6/1/2002
10/1/2002
2/1/2003
6/1/2003
10/1/2003
2/1/2004
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2/1/2007
6/1/2007
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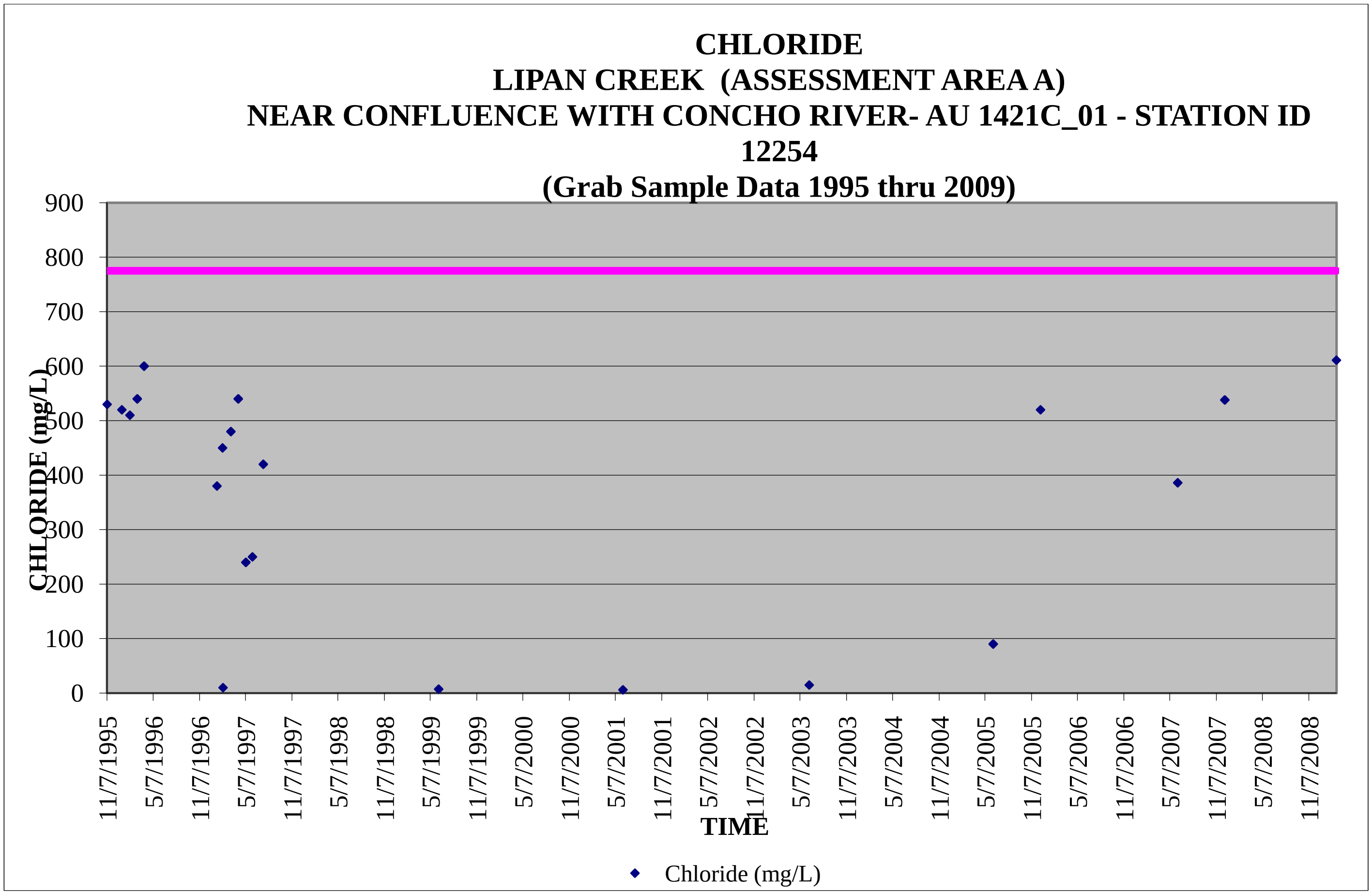
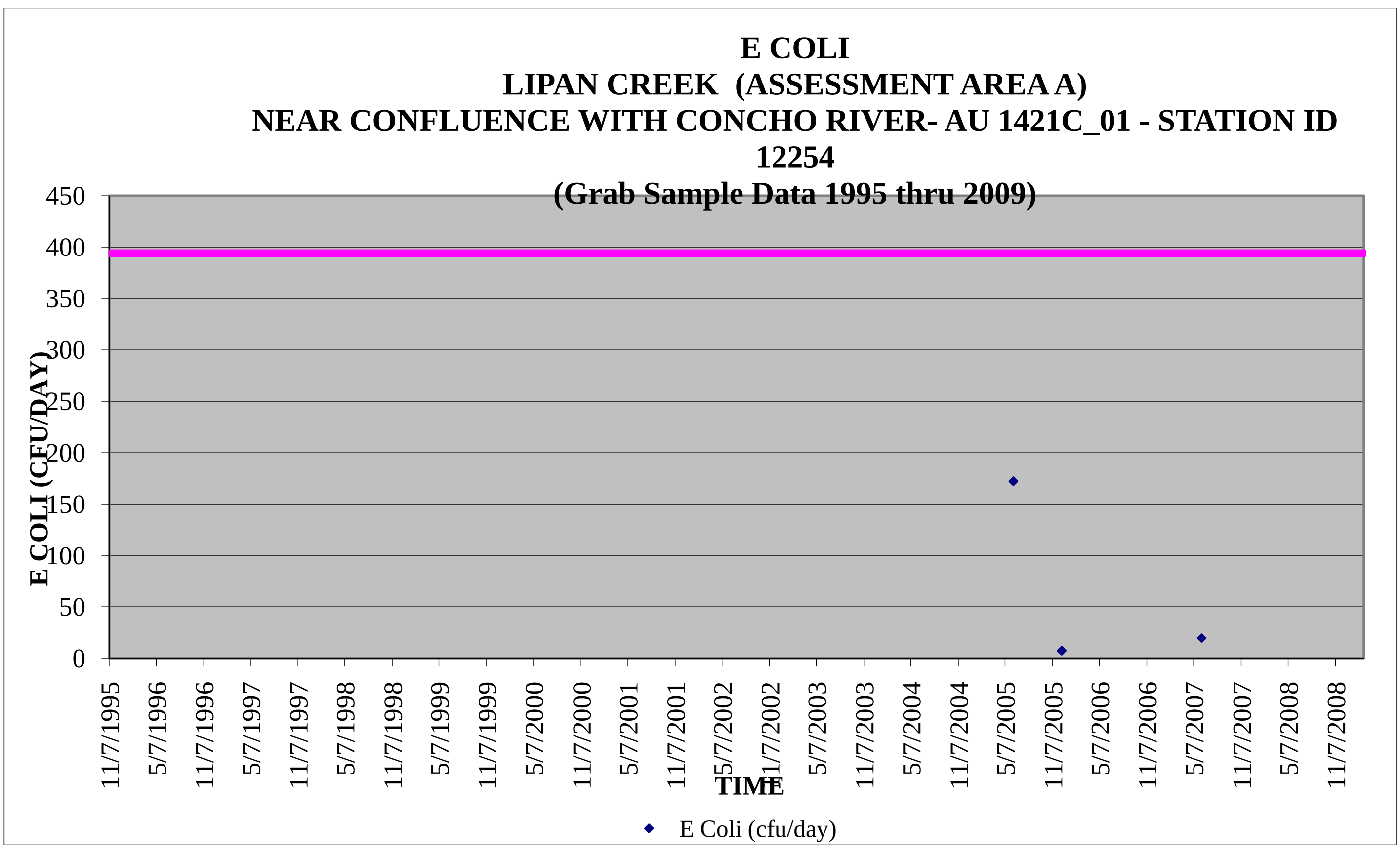
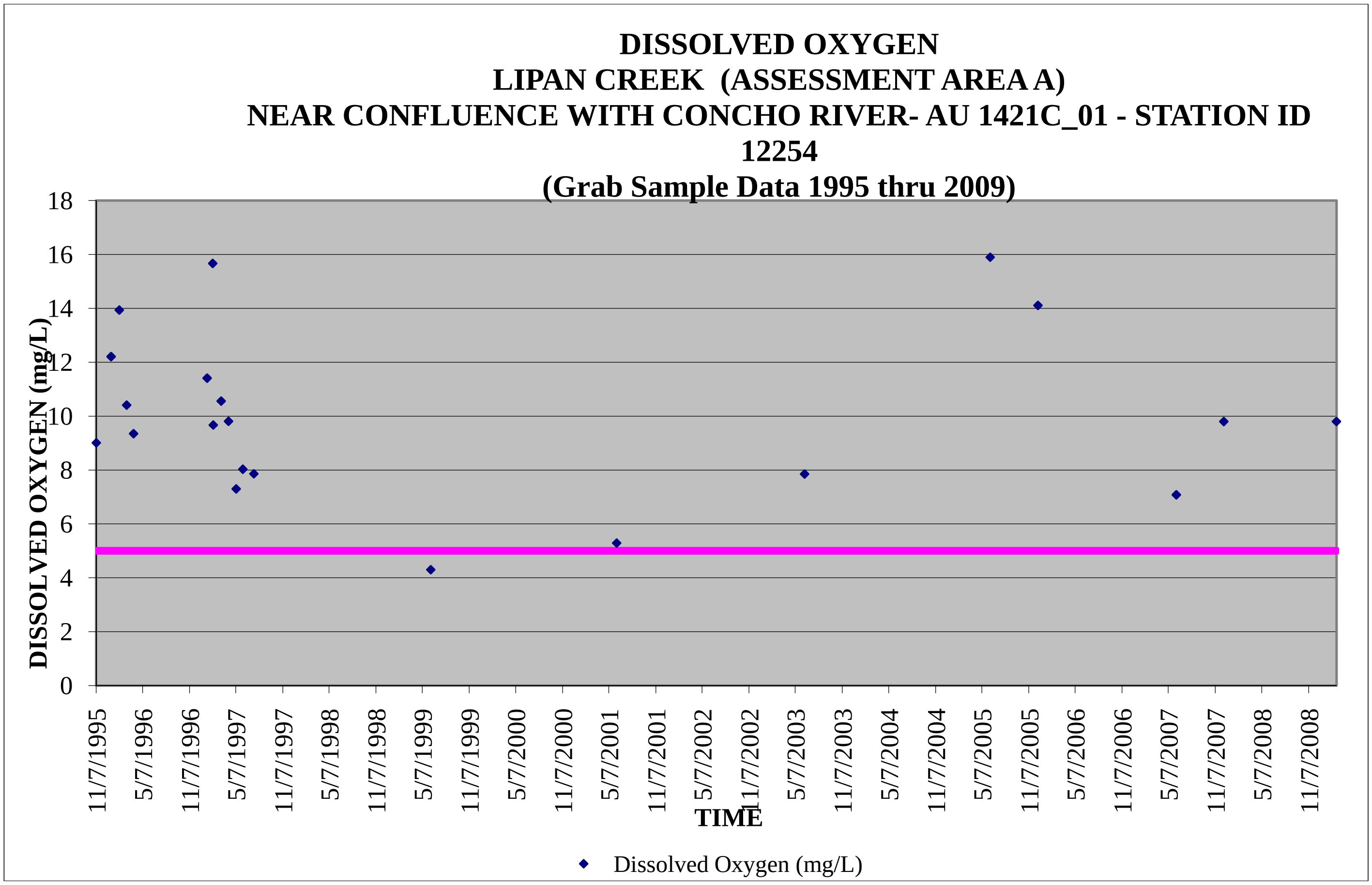
TIME
NO2-N + NO3-N (mg/L)

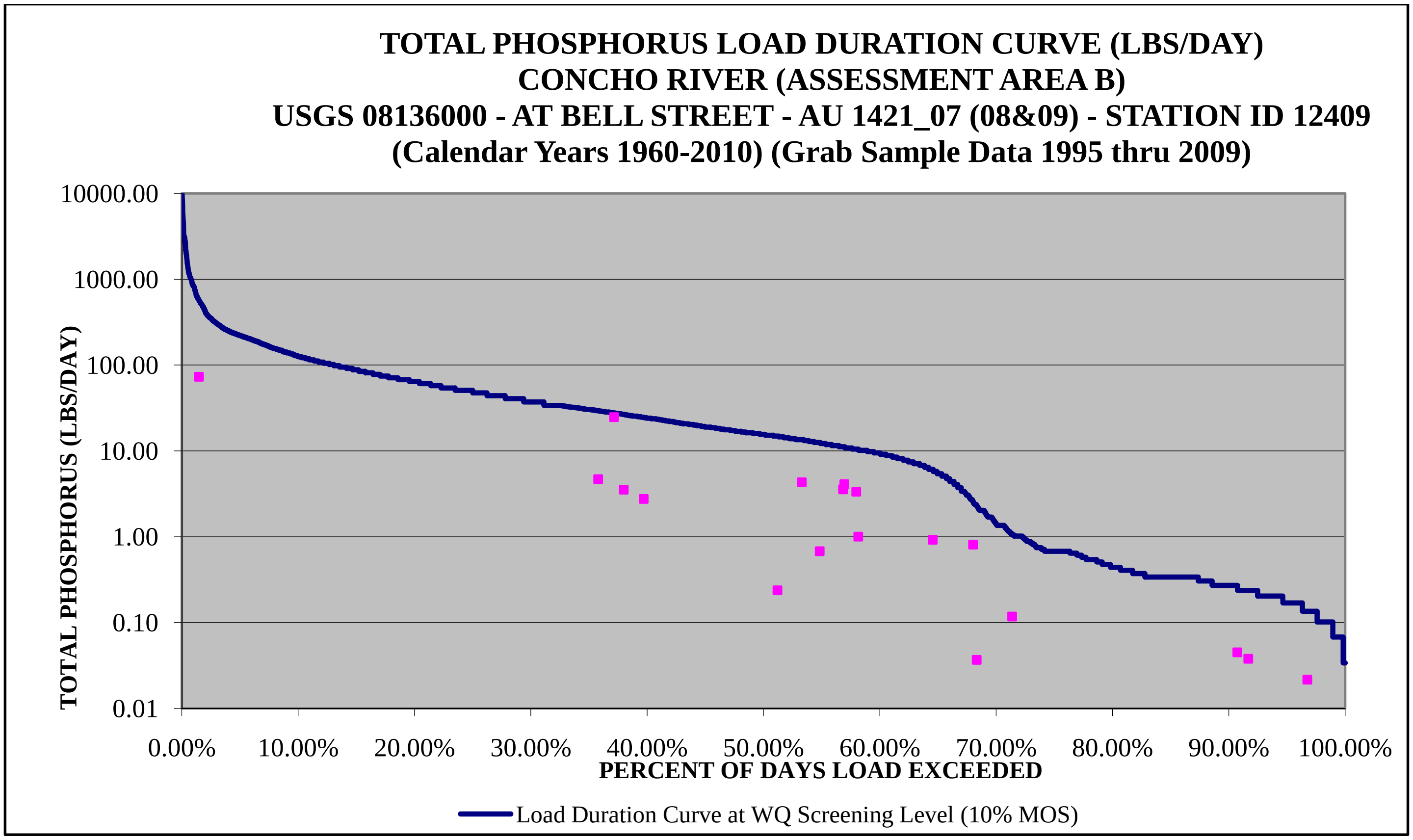

CHLORIDE
LIPAN CREEK (ASSESSMENT AREA A)
NEAR CONFLUENCE WITH CONCHO RIVER- AU 1421C_01 - STATION ID 12254
(Grab Sample Data 1995 thru 2009)
CHLORIDE (mg/L)
900
800
700
600
500
400
300
200
100
0
11/7/1995
5/7/1996
11/7/1996
5/7/1997
11/7/1997
5/7/1998
11/7/1998
5/7/1999
11/7/1999
5/7/2000
11/7/2000
5/7/2001
11/7/2001
5/7/2002
11/7/2002
5/7/2003
11/7/2003
5/7/2004
11/7/2004
5/7/2005
11/7/2005
5/7/2006
11/7/2006
5/7/2007
11/7/2007
5/7/2008
11/7/2008
TIME
Chloride (mg/L)

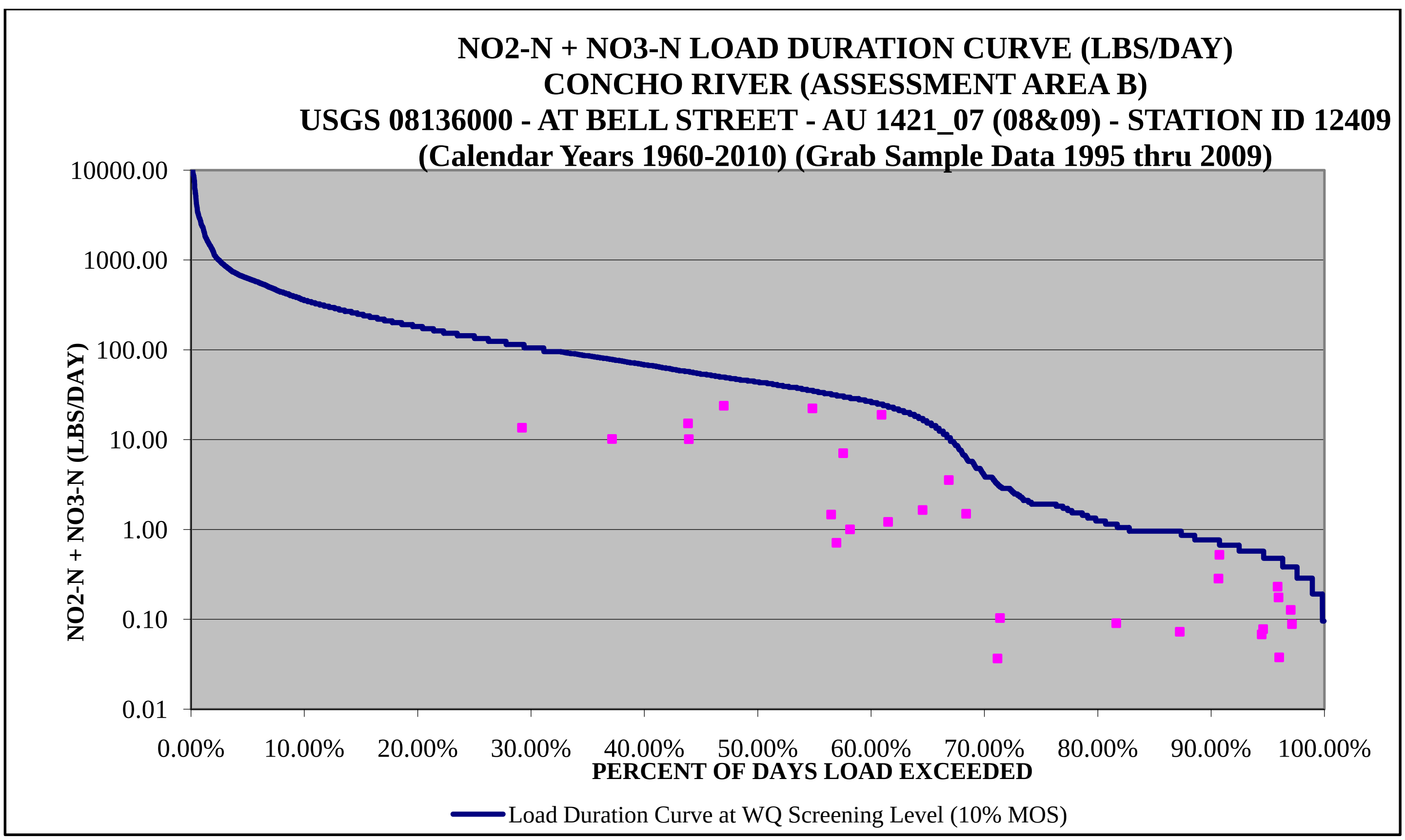

E COLI
LIPAN CREEK (ASSESSMENT AREA A)
NEAR CONFLUENCE WITH CONCHO RIVER- AU 1421C_01 - STATION ID 12254
(Grab Sample Data 1995 thru 2009)
E COLI (CFU/DAY)
450
400
350
300
250
200
150
100
50
0
11/7/1995
5/7/1996
11/7/1996
5/7/1997
11/7/1997
5/7/1998
11/7/1998
5/7/1999
11/7/1999
5/7/2000
11/7/2000
5/7/2001
11/7/2001
5/7/2002
11/7/2002
5/7/2003
11/7/2003
5/7/2004
11/7/2004
5/7/2005
11/7/2005
5/7/2006
11/7/2006
5/7/2007
11/7/2007
5/7/2008
11/7/2008
TIME
E Coli (cfu/day)

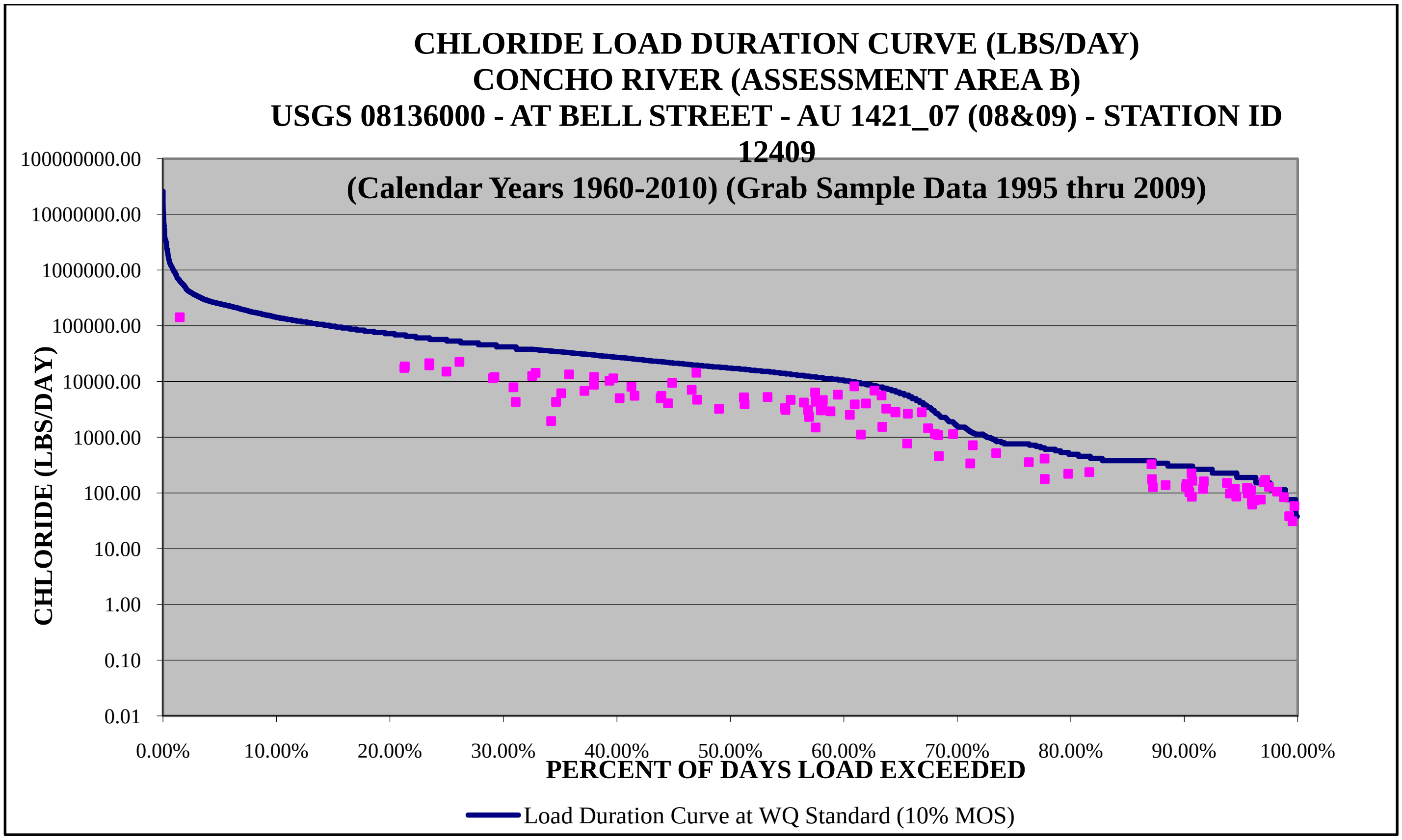

DISSOLVED OXYGEN
LIPAN CREEK (ASSESSMENT AREA A)
NEAR CONFLUENCE WITH CONCHO RIVER- AU 1421C_01 - STATION ID 12254
(Grab Sample Data 1995 thru 2009)
DISSOLVED OXYGEN (mg/L)
0
2
4
6
8
10
12
14
16
18
11/7/1995
5/7/1996
11/7/1996
5/7/1997
11/7/1997
5/7/1998
11/7/1998
5/7/1999
11/7/1999
5/7/2000
11/7/2000
5/7/2001
11/7/2001
5/7/2002
11/7/2002
5/7/2003
11/7/2003
5/7/2004
11/7/2004
5/7/2005
11/7/2005
5/7/2006
11/7/2006
5/7/2007
11/7/2007
5/7/2008
11/7/2008
TIME
Dissolved Oxygen (mg/L)

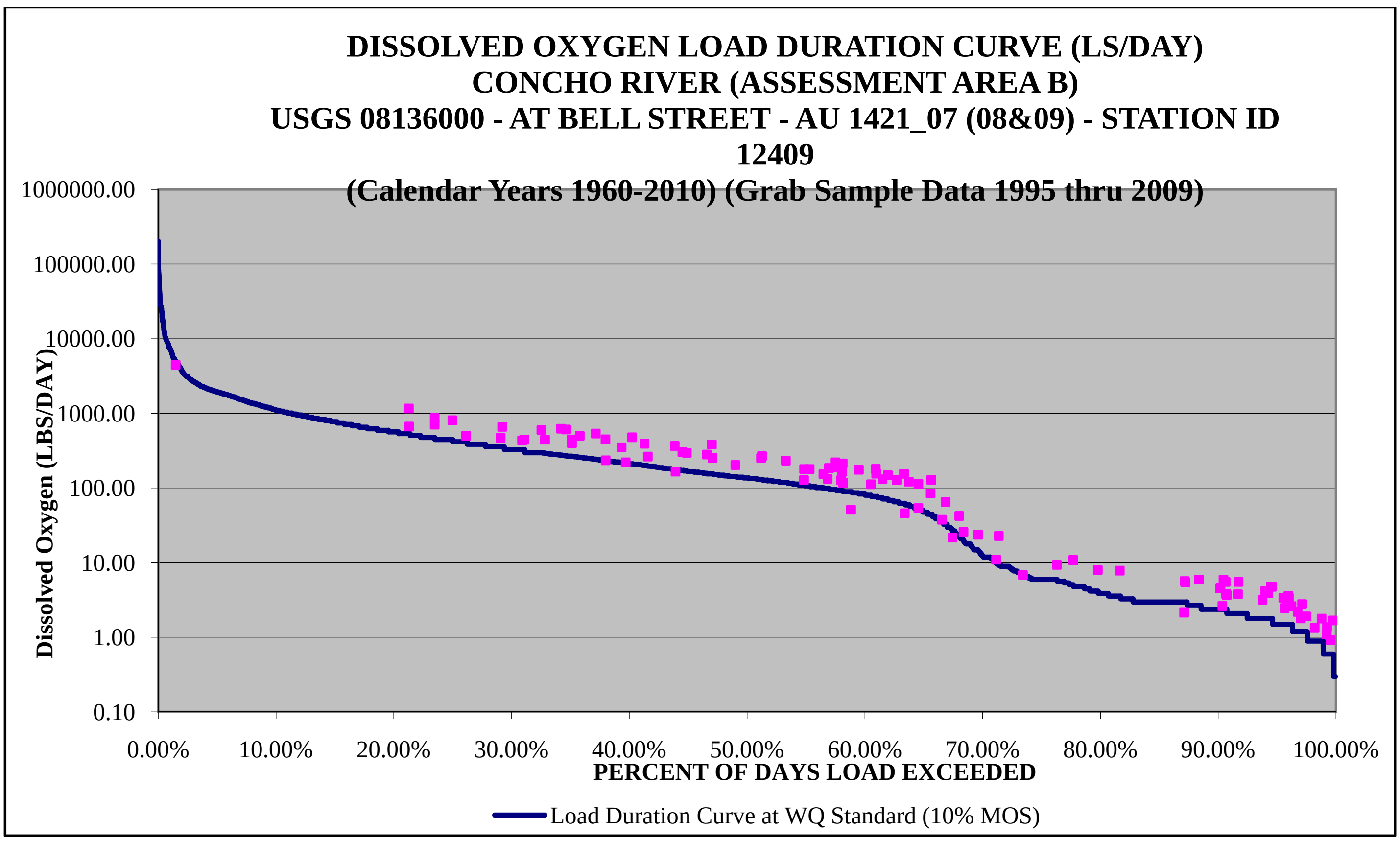
APPENDIX B

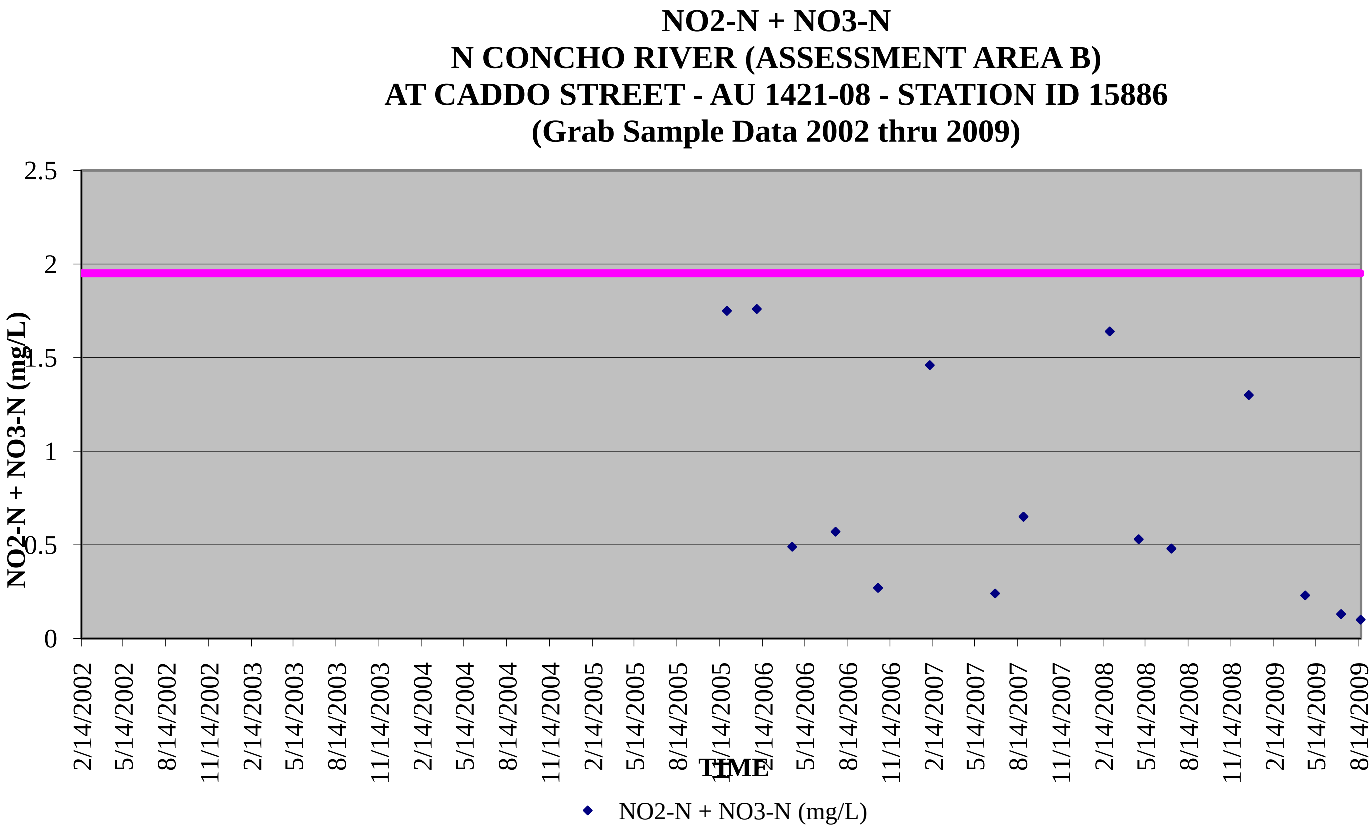
Assessment Area B Supporting Data

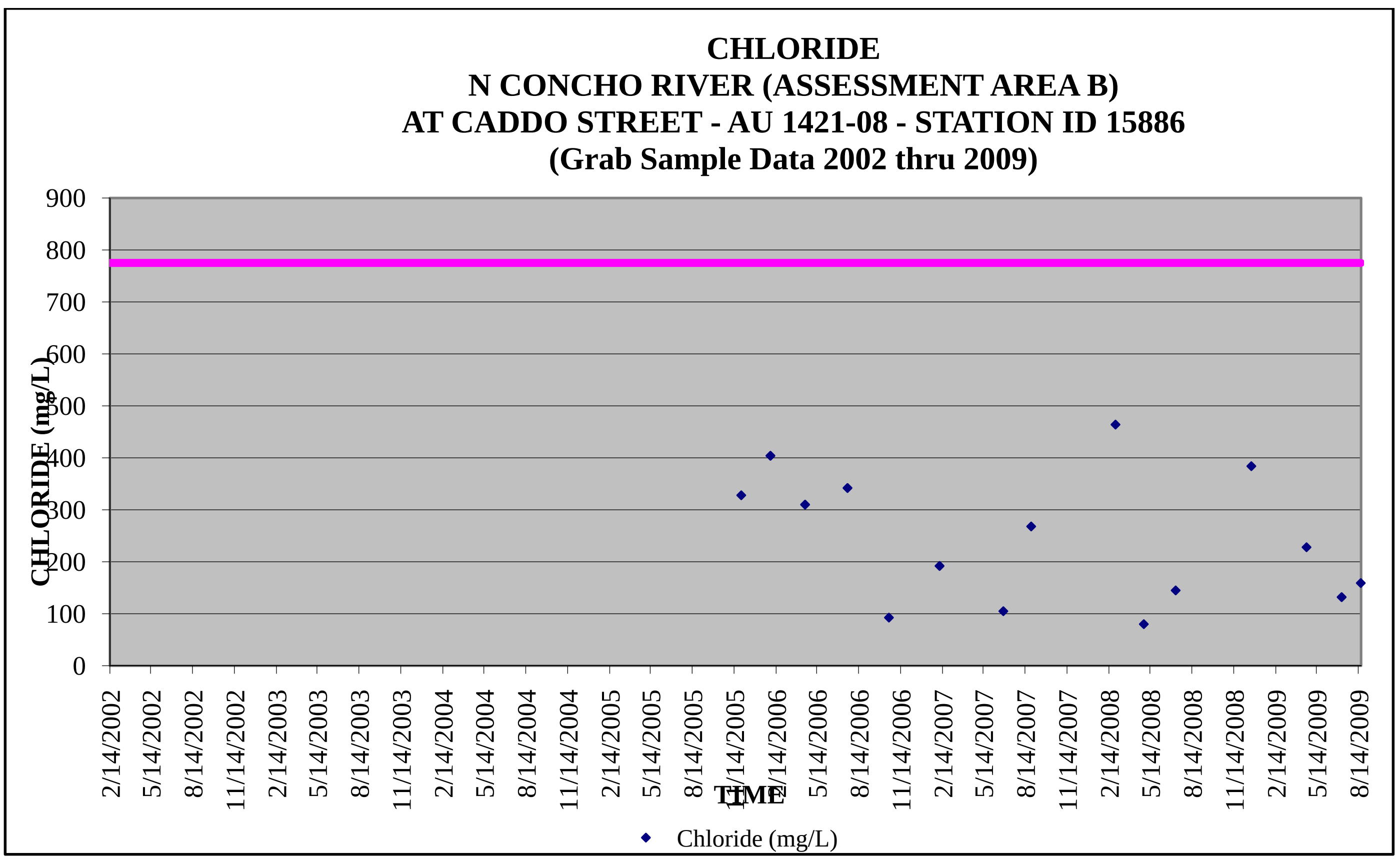

TOTAL PHOSPHORUS LOAD DURATION CURVE (LBS/DAY)
CONCHO RIVER (ASSESSMENT AREA B)
USGS 08136000 - AT BELL STREET - AU 1421_07 (08&09) - STATION ID 12409
(Calendar Years 1960-2010) (Grab Sample Data 1995 thru 2009)
TOTAL PHOSPHORUS (LBS/DAY)
10000.00
1000.00
100.00
10.00
1.00
0.10
0.01
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
PERCENT OF DAYS LOAD EXCEEDED
Load Duration Curve at WQ Screening Level (10% MOS)

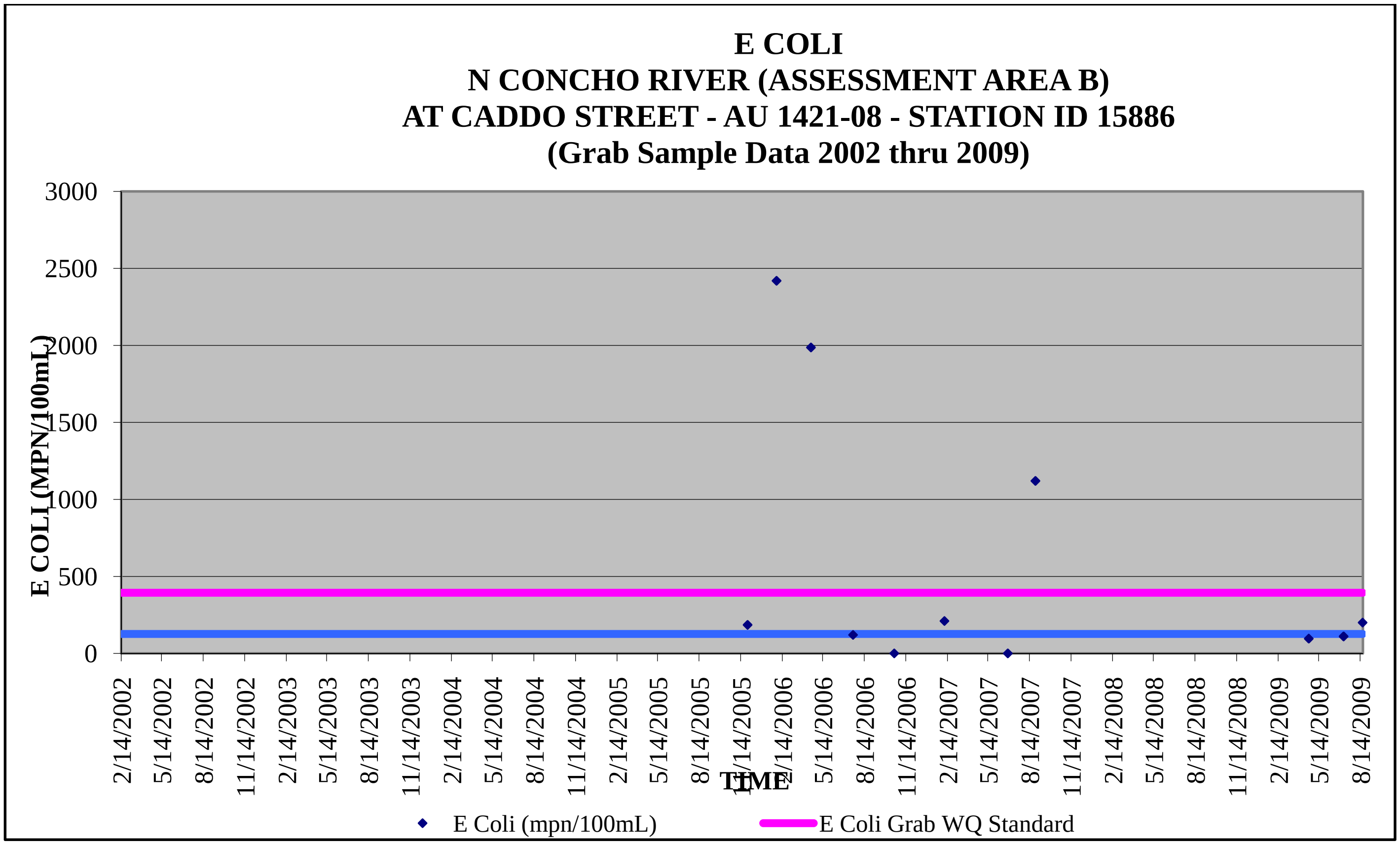

NO2-N + NO3-N LOAD DURATION CURVE (LBS/DAY)
CONCHO RIVER (ASSESSMENT AREA B)
USGS 08136000 - AT BELL STREET - AU 1421_07 (08&09) - STATION ID 12409
(Calendar Years 1960-2010) (Grab Sample Data 1995 thru 2009)
NO2-N + NO3-N (LBS/DAY)
10000.00
1000.00
100.00
10.00
1.00
0.10
0.01
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
PERCENT OF DAYS LOAD EXCEEDED
Load Duration Curve at WQ Screening Level (10% MOS)

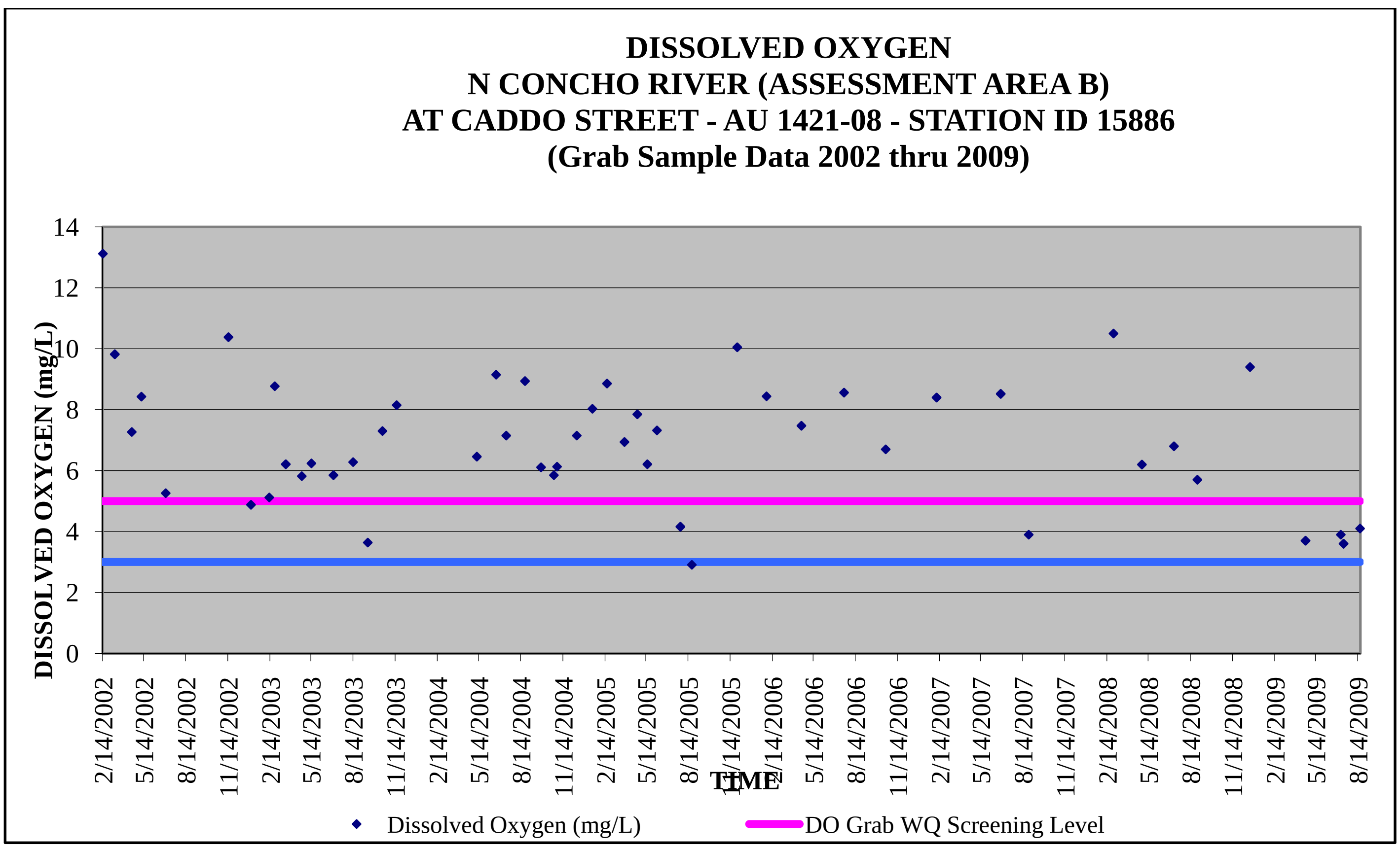

CHLORIDE LOAD DURATION CURVE (LBS/DAY)
CONCHO RIVER (ASSESSMENT AREA B)
USGS 08136000 - AT BELL STREET - AU 1421_07 (08&09) - STATION ID 12409
(Calendar Years 1960-2010) (Grab Sample Data 1995 thru 2009)
CHLORIDE (LBS/DAY)
100000000.00
10000000.00
1000000.00
100000.00
10000.00
1000.00
100.00
10.00
1.00
0.10
0.01
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
PERCENT OF DAYS LOAD EXCEEDED
Load Duration Curve at WQ Standard (10% MOS)

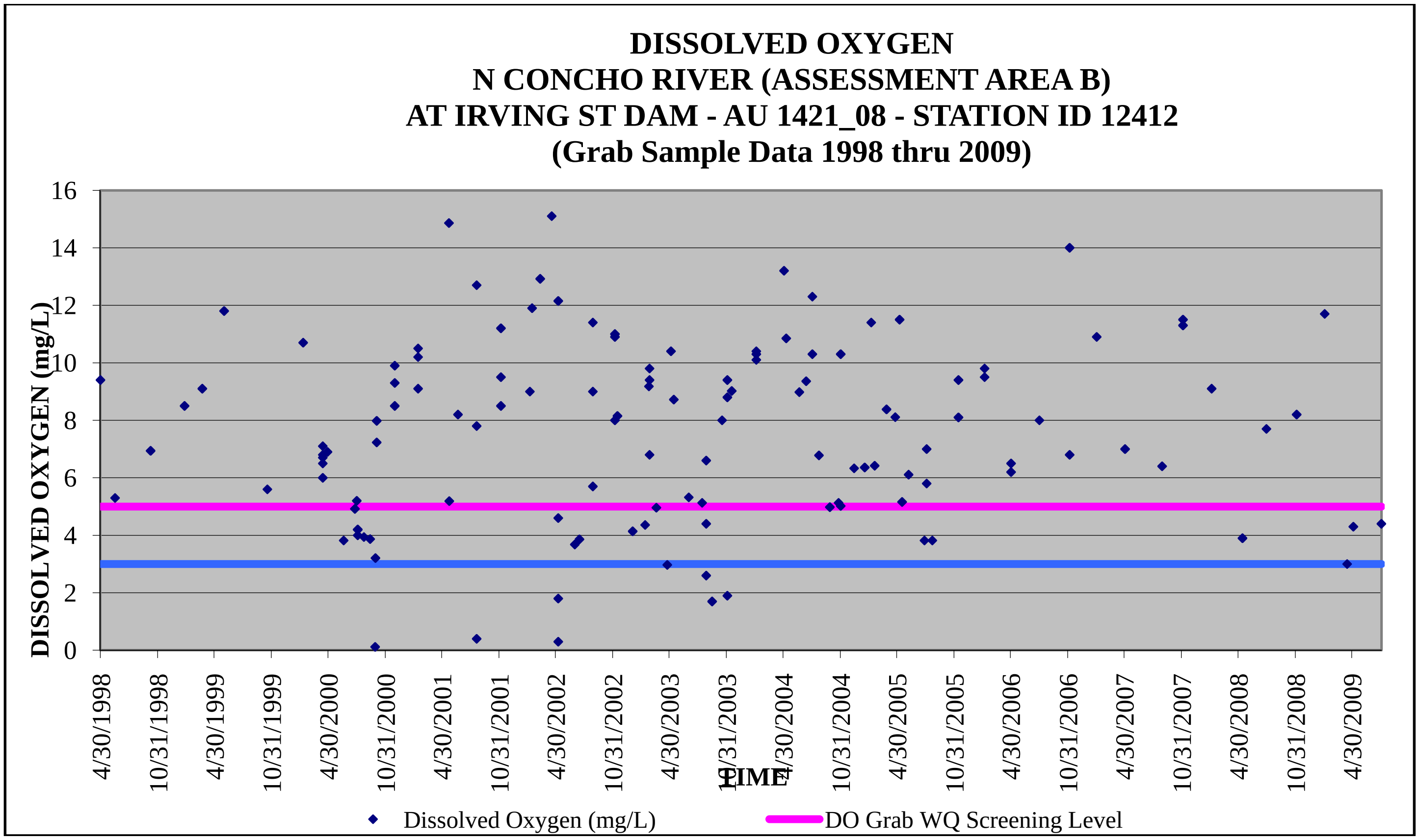

DISSOLVED OXYGEN LOAD DURATION CURVE (LS/DAY)
CONCHO RIVER (ASSESSMENT AREA B)
USGS 08136000 - AT BELL STREET - AU 1421_07 (08&09) - STATION ID 12409
(Calendar Years 1960-2010) (Grab Sample Data 1995 thru 2009)
Dissolved Oxygen (LBS/DAY)
1000000.00
100000.00
10000.00
1000.00
100.00
10.00
1.00
0.10
0.00%
10.00%
20.00%
30.00%
40.00%
50.00%
60.00%
70.00%
80.00%
90.00%
100.00%
PERCENT OF DAYS LOAD EXCEEDED
Load Duration Curve at WQ Standard (10% MOS)

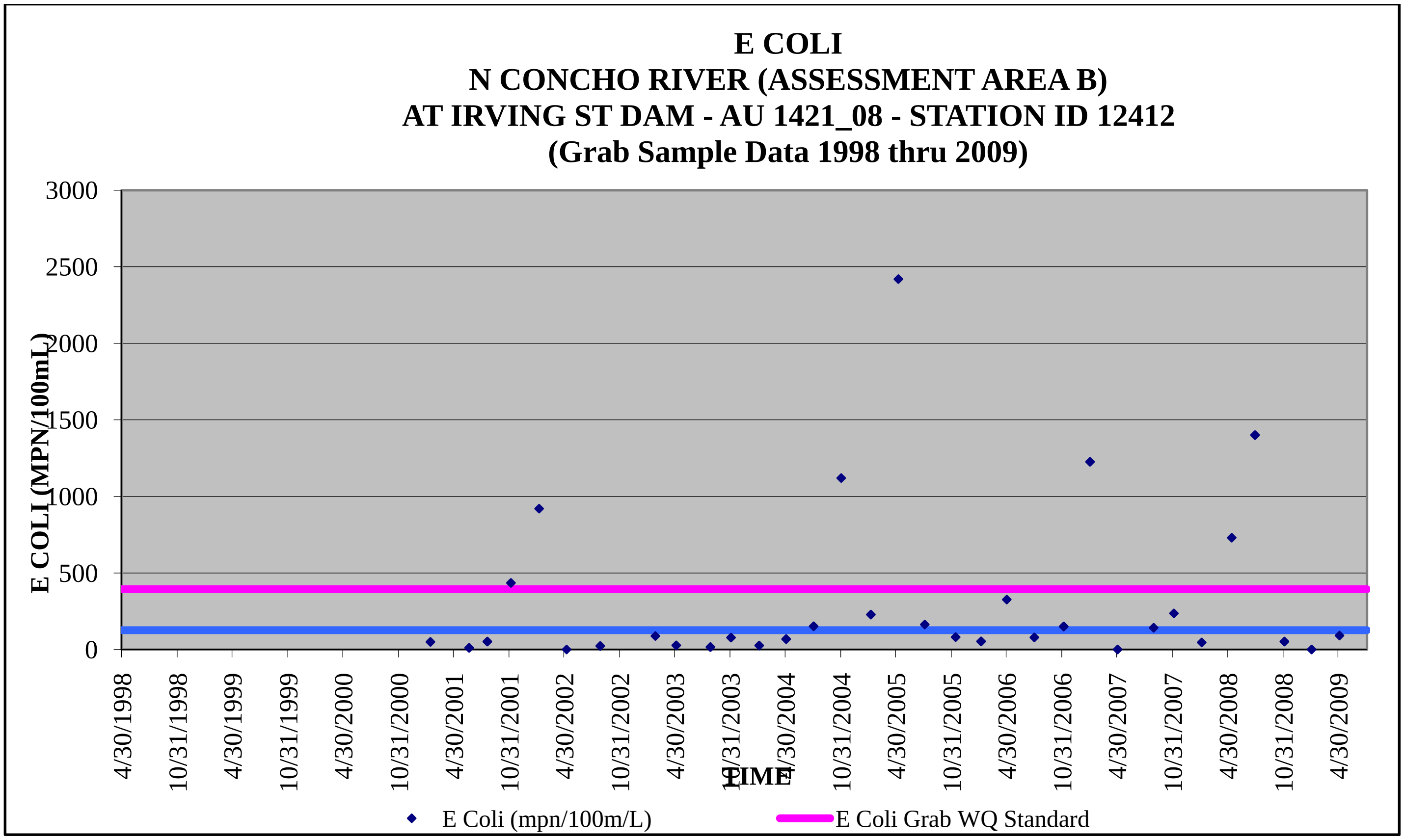

NO2-N + NO3-N
N CONCHO RIVER (ASSESSMENT AREA B)
AT CADDO STREET - AU 1421-08 - STATION ID 15886
(Grab Sample Data 2002 thru 2009)
NO2-N + NO3-N (mg/L)
2.5
2
1.5
1
0.5
0
2/14/2002
5/14/2002
8/14/2002
11/14/2002
2/14/2003
5/14/2003
8/14/2003
11/14/2003
2/14/2004
5/14/2004
8/14/2004
11/14/2004
2/14/2005
5/14/2005
8/14/2005
11/14/2005
2/14/2006
5/14/2006
8/14/2006
11/14/2006
2/14/2007
5/14/2007
8/14/2007
11/14/2007
2/14/2008
5/14/2008
8/14/2008
11/14/2008
2/14/2009
5/14/2009
8/14/2009
TIME
NO2-N + NO3-N (mg/L)

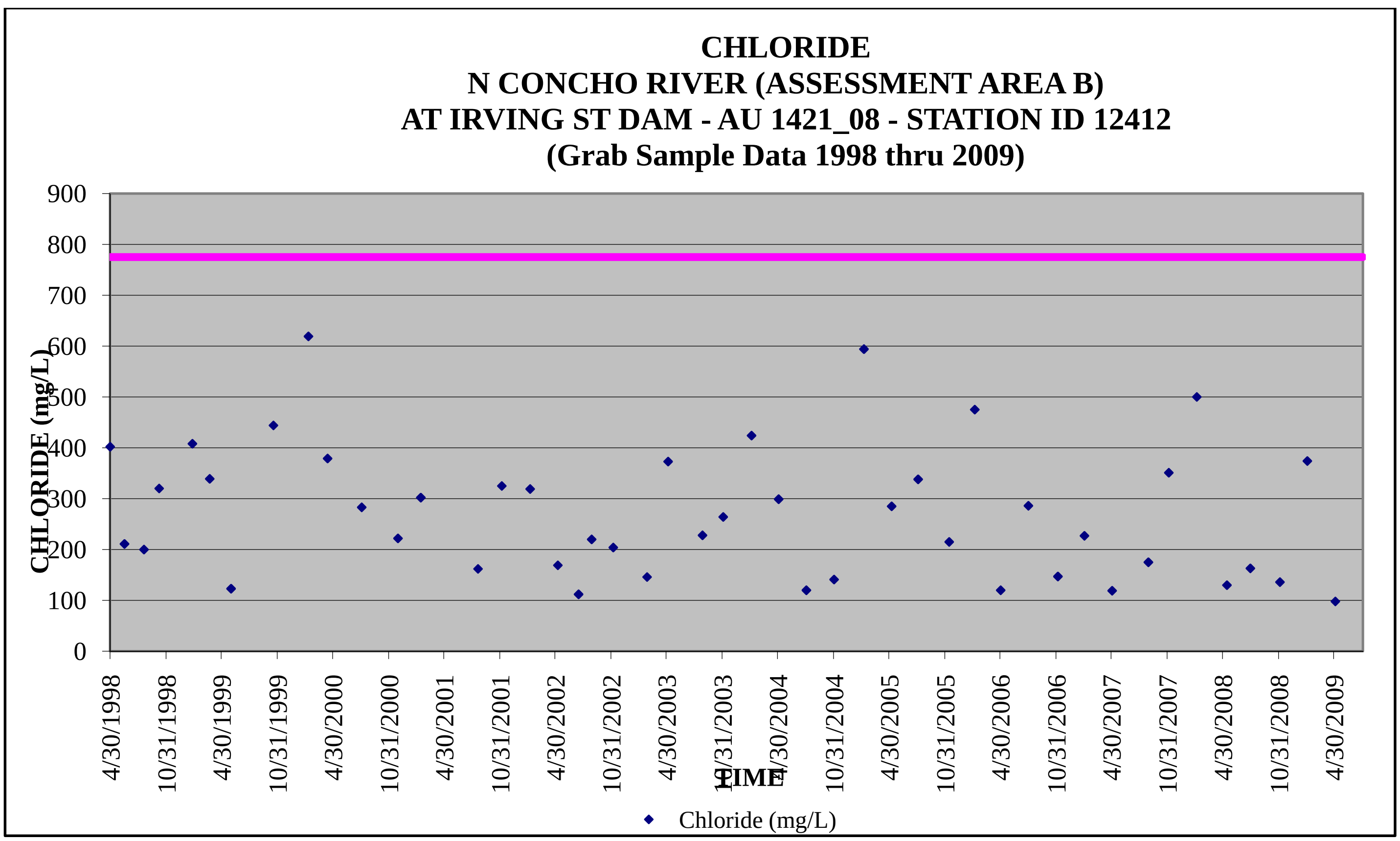

CHLORIDE
N CONCHO RIVER (ASSESSMENT AREA B)
AT CADDO STREET - AU 1421-08 - STATION ID 15886
(Grab Sample Data 2002 thru 2009)
CHLORIDE (mg/L)
900
800
700
600
500
400
300
200
100
0
2/14/2002
5/14/2002
8/14/2002
11/14/2002
2/14/2003
5/14/2003
8/14/2003
11/14/2003
2/14/2004
5/14/2004
8/14/2004
11/14/2004
2/14/2005
5/14/2005
8/14/2005
11/14/2005
2/14/2006
5/14/2006
8/14/2006
11/14/2006
2/14/2007
5/14/2007
8/14/2007
11/14/2007
2/14/2008
5/14/2008
8/14/2008
11/14/2008
2/14/2009
5/14/2009
8/14/2009
TIME
Chloride (mg/L)

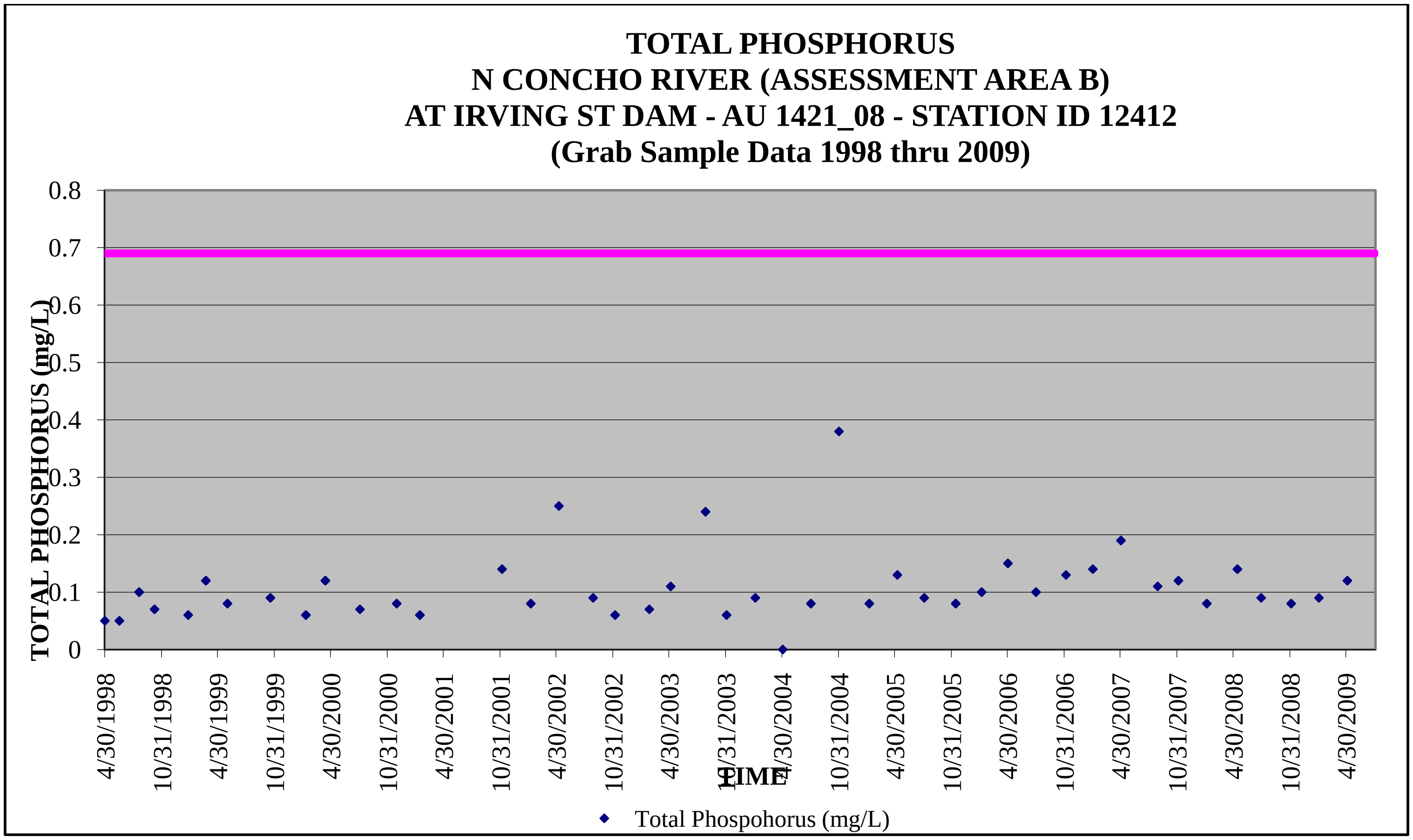

E COLI
N CONCHO RIVER (ASSESSMENT AREA B)
AT CADDO STREET - AU 1421-08 - STATION ID 15886
(Grab Sample Data 2002 thru 2009)
E COLI (MPN/100mL)
3000
2500
2000
1500
1000
500
0
2/14/2002
5/14/2002
8/14/2002
11/14/2002
2/14/2003
5/14/2003
8/14/2003
11/14/2003
2/14/2004
5/14/2004
8/14/2004
11/14/2004
2/14/2005
5/14/2005
8/14/2005
11/14/2005
2/14/2006
5/14/2006
8/14/2006
11/14/2006
2/14/2007
5/14/2007
8/14/2007
11/14/2007
2/14/2008
5/14/2008
8/14/2008
11/14/2008
2/14/2009
5/14/2009
8/14/2009
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

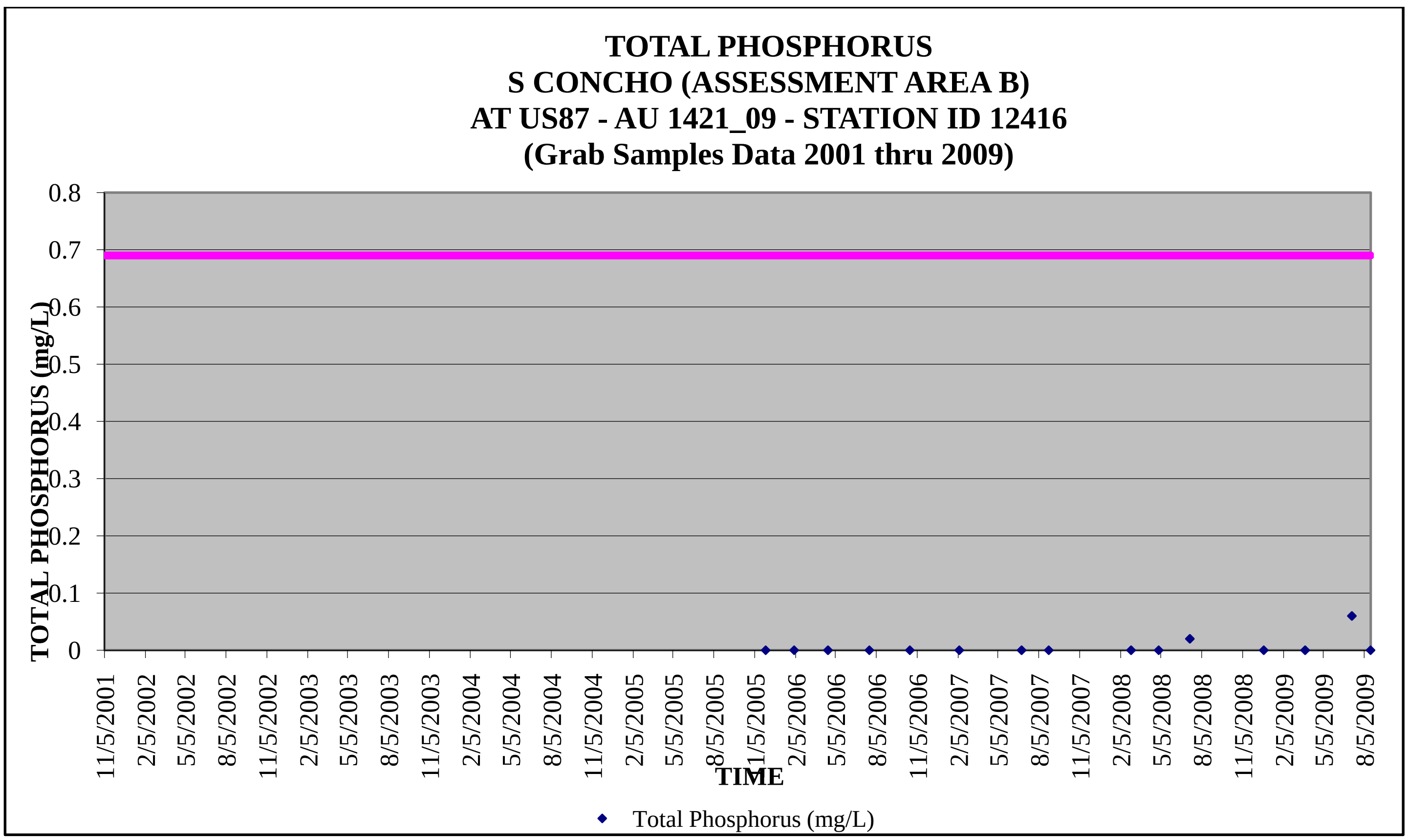

DISSOLVED OXYGEN
N CONCHO RIVER (ASSESSMENT AREA B)
AT CADDO STREET - AU 1421-08 - STATION ID 15886
(Grab Sample Data 2002 thru 2009)
DISSOLVED OXYGEN (mg/L)
14
12
10
8
6
4
2
0
2/14/2002
5/14/2002
8/14/2002
11/14/2002
2/14/2003
5/14/2003
8/14/2003
11/14/2003
2/14/2004
5/14/2004
8/14/2004
11/14/2004
2/14/2005
5/14/2005
8/14/2005
11/14/2005
2/14/2006
5/14/2006
8/14/2006
11/14/2006
2/14/2007
5/14/2007
8/14/2007
11/14/2007
2/14/2008
5/14/2008
8/14/2008
11/14/2008
2/14/2009
5/14/2009
8/14/2009
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level

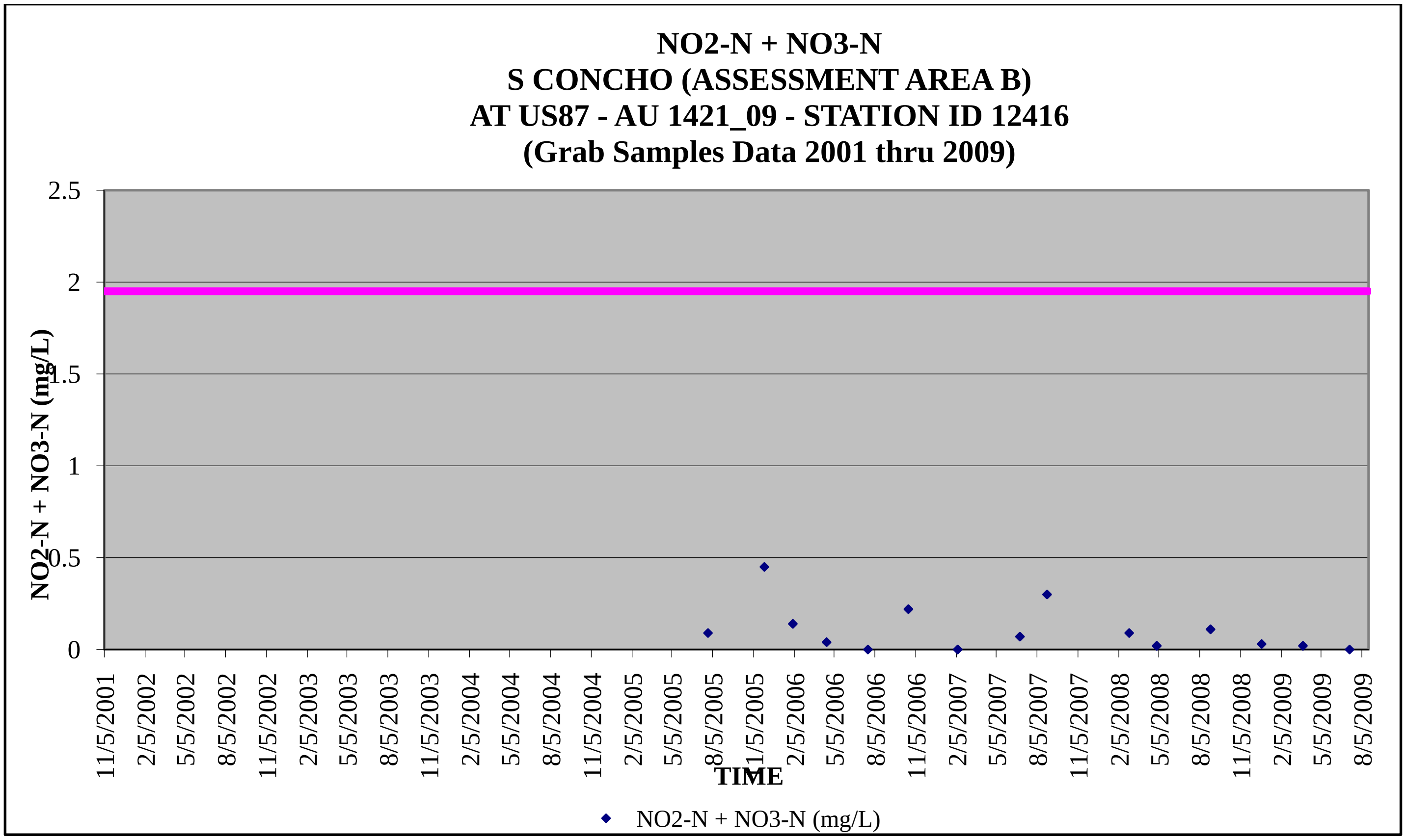

DISSOLVED OXYGEN
N CONCHO RIVER (ASSESSMENT AREA B)
AT IRVING ST DAM - AU 1421_08 - STATION ID 12412
(Grab Sample Data 1998 thru 2009)
DISSOLVED OXYGEN (mg/L)
16
14
12
10
8
6
4
2
0
4/30/1998
10/31/1998
4/30/1999
10/31/1999
4/30/2000
10/31/2000
4/30/2001
10/31/2001
4/30/2002
10/31/2002
4/30/2003
10/31/2003
4/30/2004
10/31/2004
4/30/2005
10/31/2005
4/30/2006
10/31/2006
4/30/2007
10/31/2007
4/30/2008
10/31/2008
4/30/2009
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level

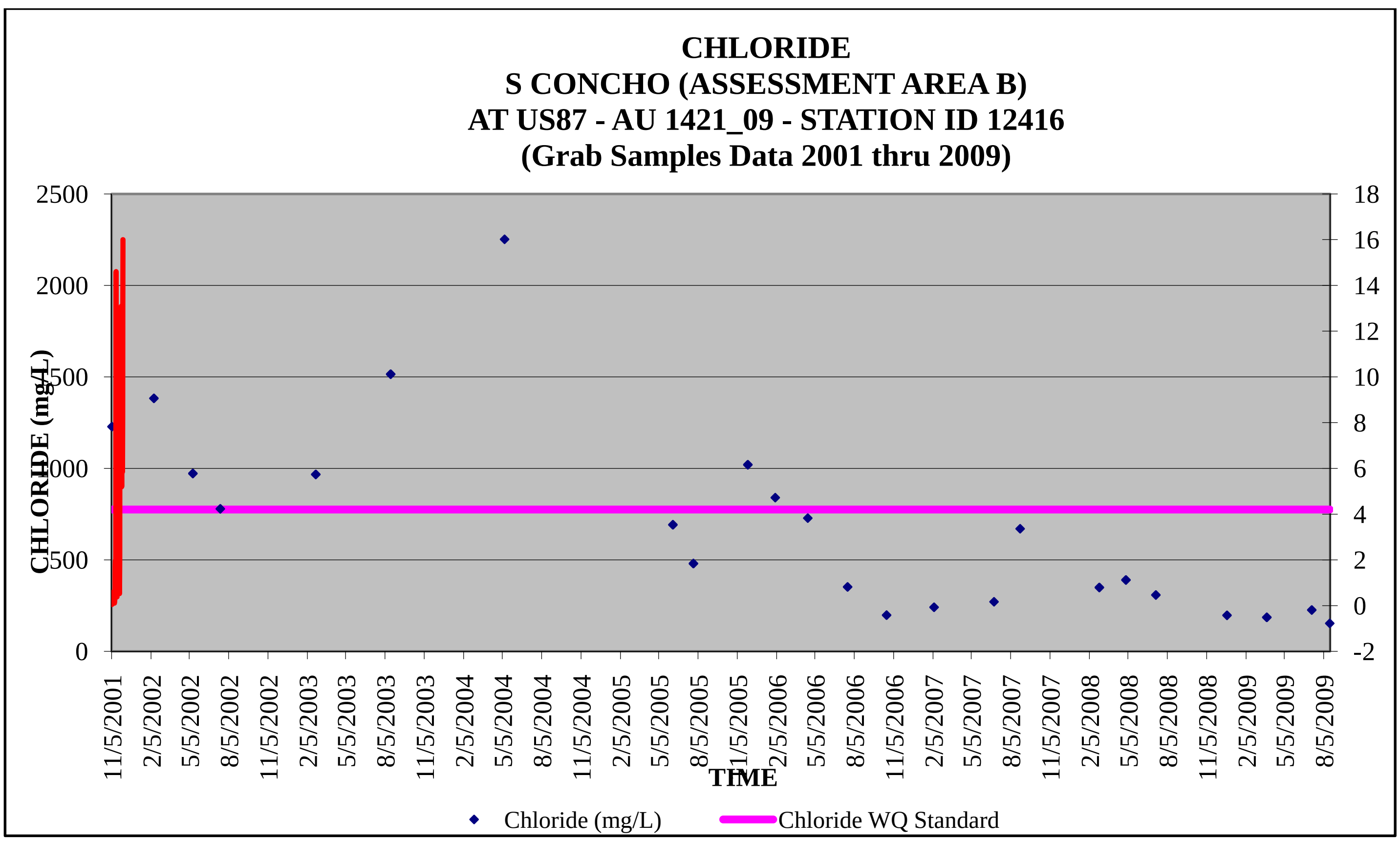

E COLI
N CONCHO RIVER (ASSESSMENT AREA B)
AT IRVING ST DAM - AU 1421_08 - STATION ID 12412
(Grab Sample Data 1998 thru 2009)
E COLI (MPN/100mL)
3000
2500
2000
1500
1000
500
0
4/30/1998
10/31/1998
4/30/1999
10/31/1999
4/30/2000
10/31/2000
4/30/2001
10/31/2001
4/30/2002
10/31/2002
4/30/2003
10/31/2003
4/30/2004
10/31/2004
4/30/2005
10/31/2005
4/30/2006
10/31/2006
4/30/2007
10/31/2007
4/30/2008
10/31/2008
4/30/2009
TIME
E Coli (mpn/100m/L)
E Coli Grab WQ Standard

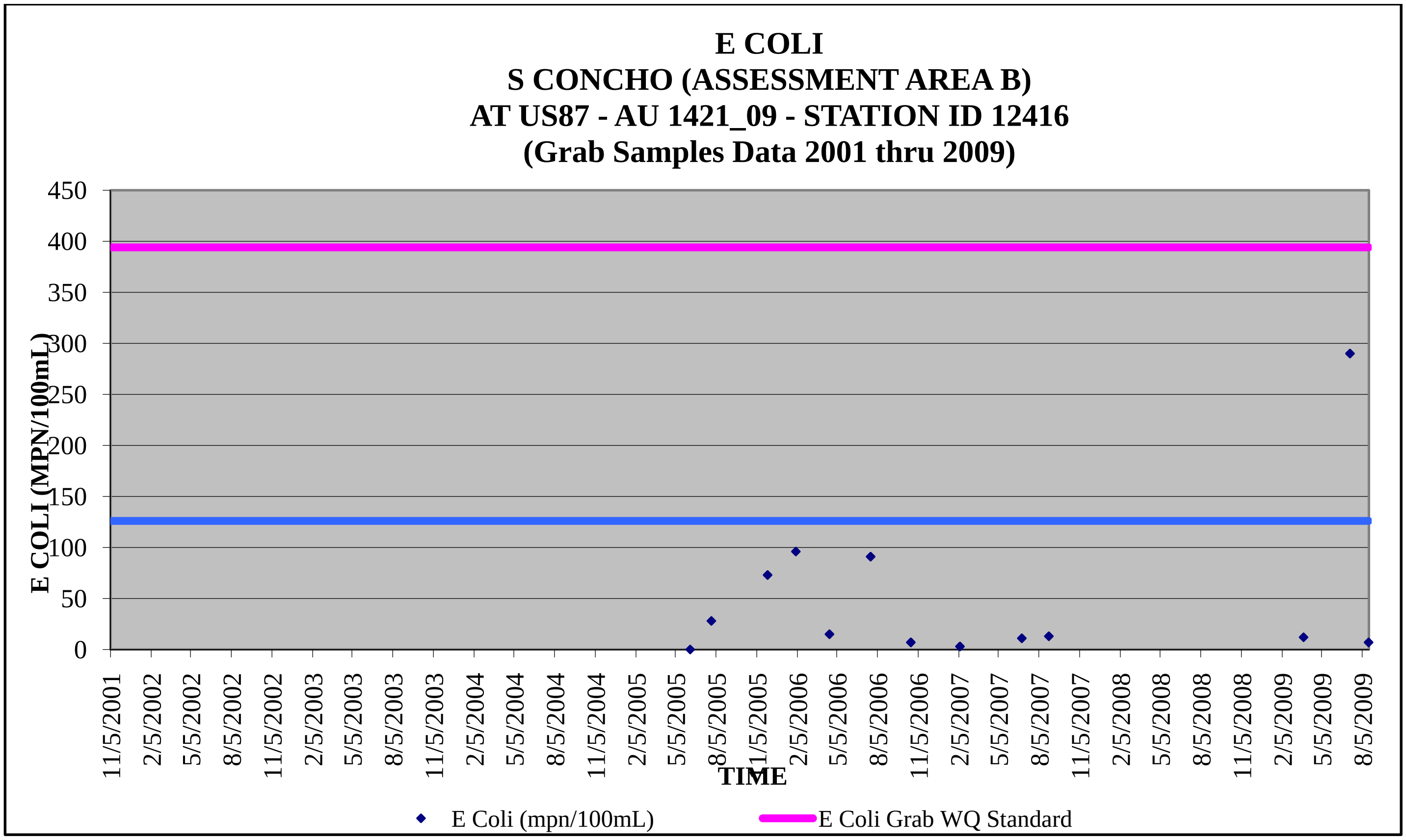

CHLORIDE
N CONCHO RIVER (ASSESSMENT AREA B)
AT IRVING ST DAM - AU 1421_08 - STATION ID 12412
(Grab Sample Data 1998 thru 2009)
CHLORIDE (mg/L)
900
800
700
600
500
400
300
200
100
0
4/30/1998
10/31/1998
4/30/1999
10/31/1999
4/30/2000
10/31/2000
4/30/2001
10/31/2001
4/30/2002
10/31/2002
4/30/2003
10/31/2003
4/30/2004
10/31/2004
4/30/2005
10/31/2005
4/30/2006
10/31/2006
4/30/2007
10/31/2007
4/30/2008
10/31/2008
4/30/2009
TIME
Chloride (mg/L)

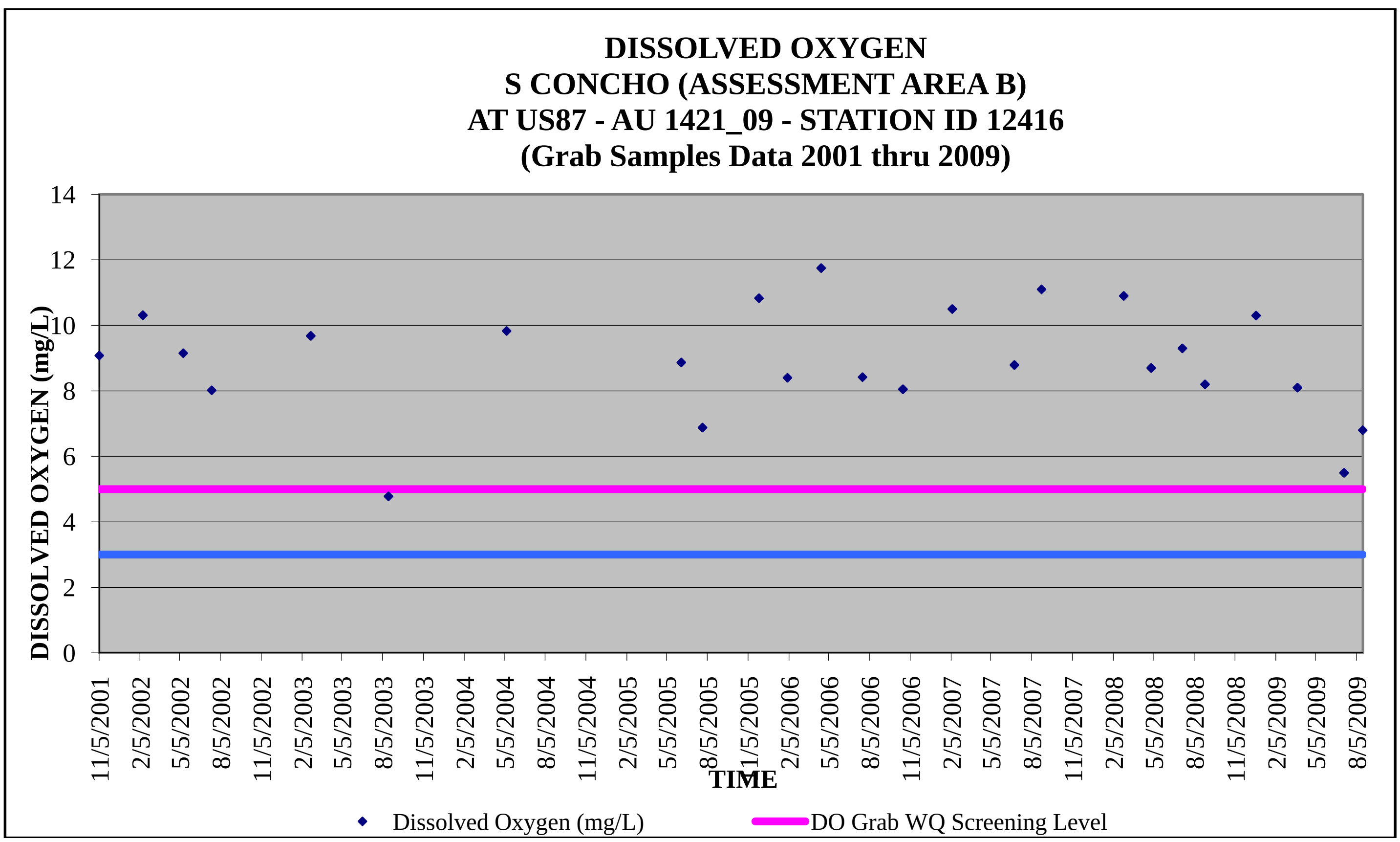

TOTAL PHOSPHORUS
N CONCHO RIVER (ASSESSMENT AREA B)
AT IRVING ST DAM - AU 1421_08 - STATION ID 12412
(Grab Sample Data 1998 thru 2009)
TOTAL PHOSPHORUS (mg/L)
TIME
Total Phospohorus (mg/L)


TOTAL PHOSPHORUS
S CONCHO (ASSESSMENT AREA B)
AT US87 - AU 1421_09 - STATION ID 12416
(Grab Samples Data 2001 thru 2009)
TOTAL PHOSPHORUS (mg/L)
TIME
Total Phosphorus (mg/L)


NO2-N + NO3-N
S CONCHO (ASSESSMENT AREA B)
AT US87 - AU 1421_09 - STATION ID 12416
(Grab Samples Data 2001 thru 2009)
NO2-N + NO3-N (mg/L)
TIME
NO2-N + NO3-N (mg/L)

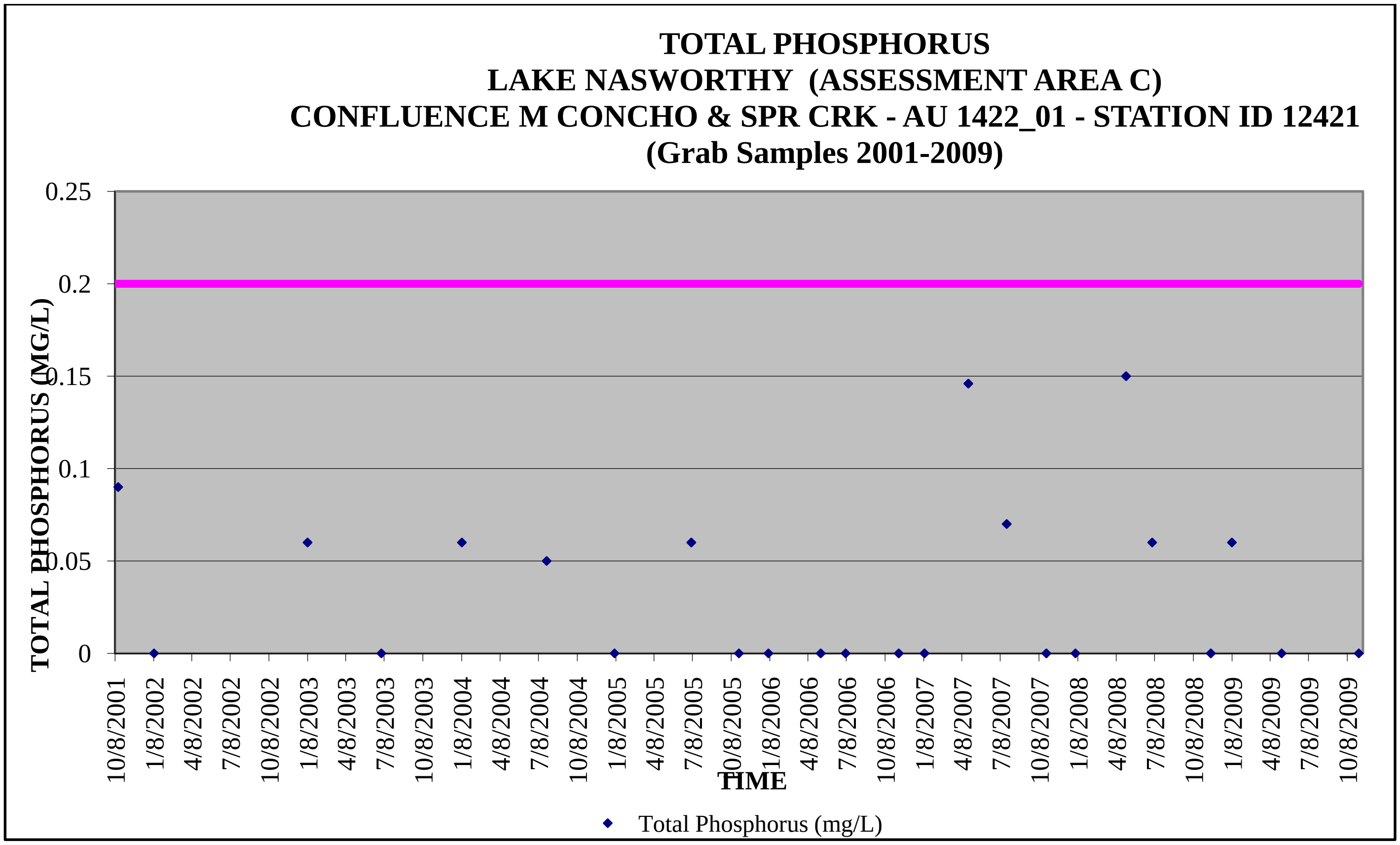

CHLORIDE
S CONCHO (ASSESSMENT AREA B)
AT US87 - AU 1421_09 - STATION ID 12416
(Grab Samples Data 2001 thru 2009)
CHLORIDE (mg/L)
TIME
Chloride (mg/L)
Chloride WQ Standard

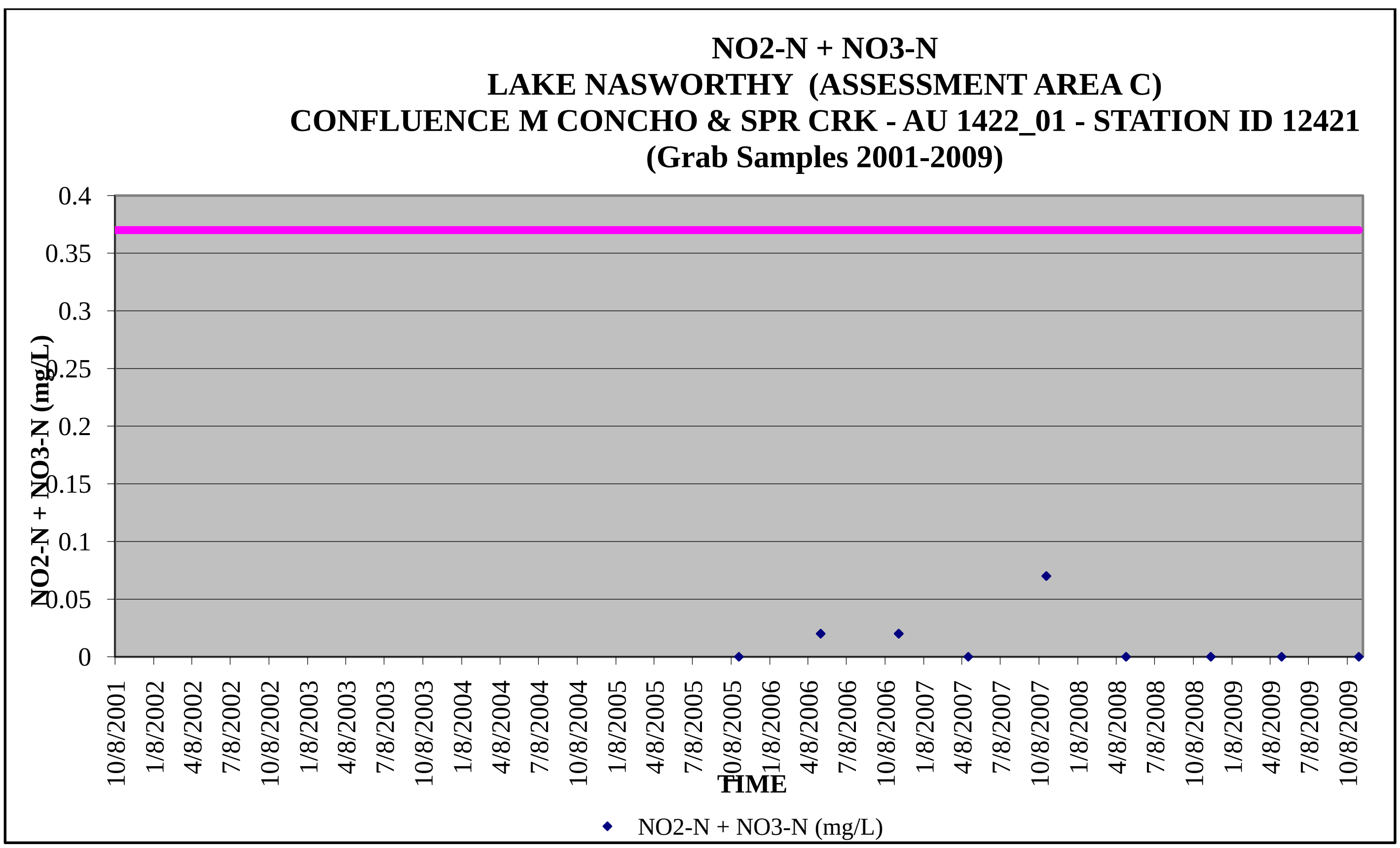

E COLI
S CONCHO (ASSESSMENT AREA B)
AT US87 - AU 1421_09 - STATION ID 12416
(Grab Samples Data 2001 thru 2009)
E COLI (MPN/100mL)
0
50
100
150
200
250
300
350
400
450
11/5/2001
2/5/2002
5/5/2002
8/5/2002
11/5/2002
2/5/2003
5/5/2003
8/5/2003
11/5/2003
2/5/2004
5/5/2004
8/5/2004
11/5/2004
2/5/2005
5/5/2005
8/5/2005
11/5/2005
2/5/2006
5/5/2006
8/5/2006
11/5/2006
2/5/2007
5/5/2007
8/5/2007
11/5/2007
2/5/2008
5/5/2008
8/5/2008
11/5/2008
2/5/2009
5/5/2009
8/5/2009
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

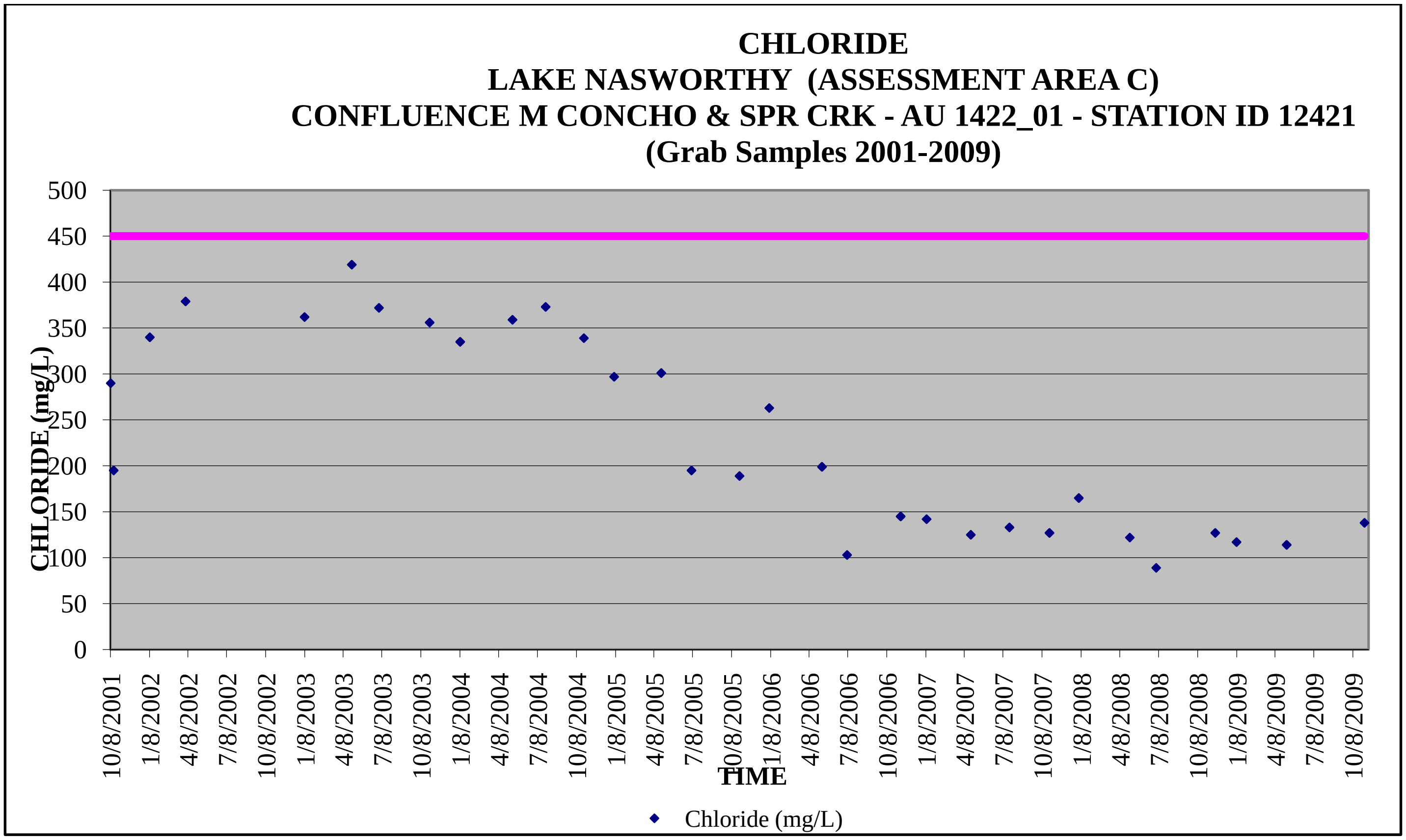

DISSOLVED OXYGEN
S CONCHO (ASSESSMENT AREA B)
AT US87 - AU 1421_09 - STATION ID 12416
(Grab Samples Data 2001 thru 2009)
DISSOLVED OXYGEN (mg/L)
0
2
4
6
8
10
12
14
11/5/2001
2/5/2002
5/5/2002
8/5/2002
11/5/2002
2/5/2003
5/5/2003
8/5/2003
11/5/2003
2/5/2004
5/5/2004
8/5/2004
11/5/2004
2/5/2005
5/5/2005
8/5/2005
11/5/2005
2/5/2006
5/5/2006
8/5/2006
11/5/2006
2/5/2007
5/5/2007
8/5/2007
11/5/2007
2/5/2008
5/5/2008
8/5/2008
11/5/2008
2/5/2009
5/5/2009
8/5/2009
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level

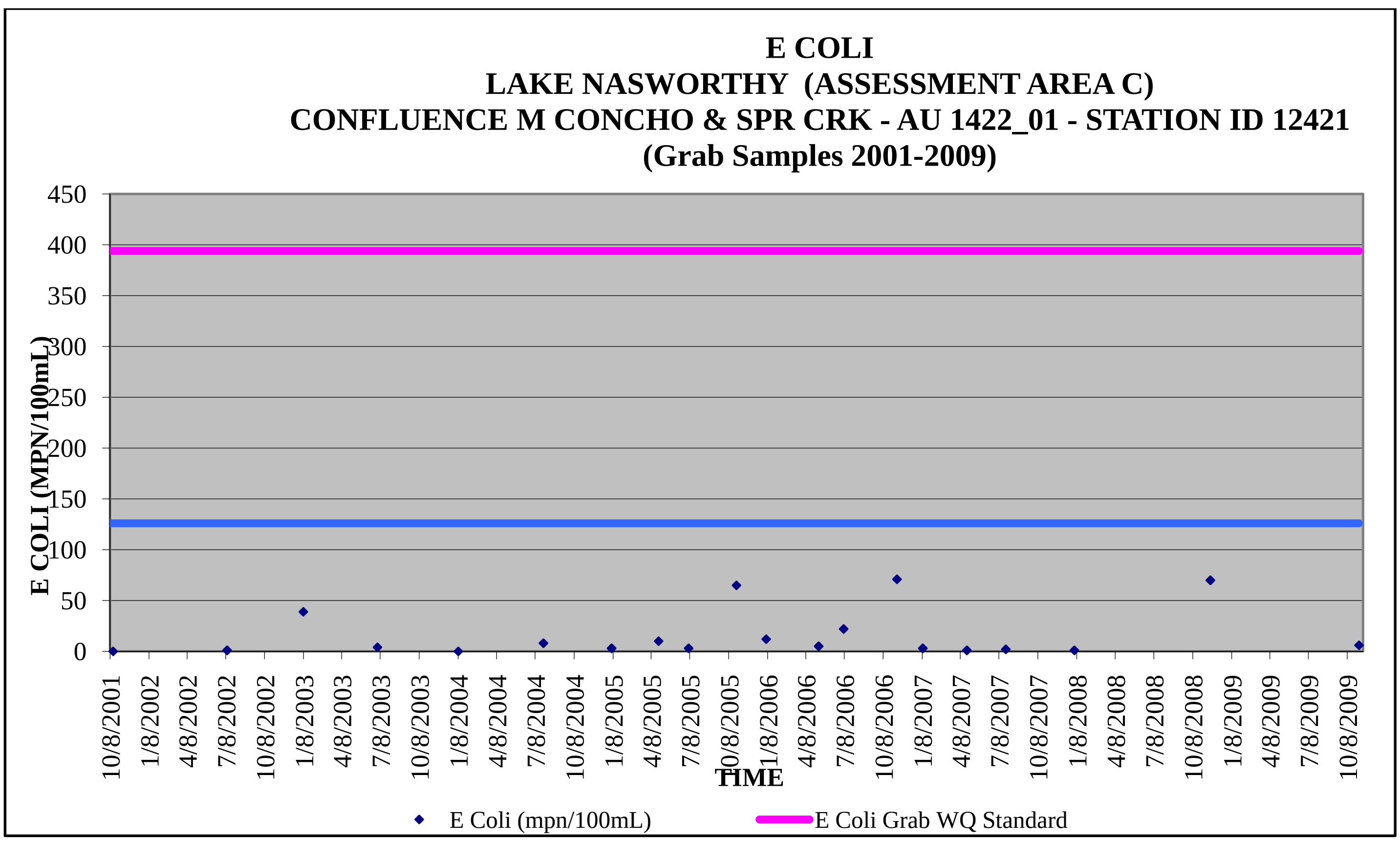
APPENDIX C

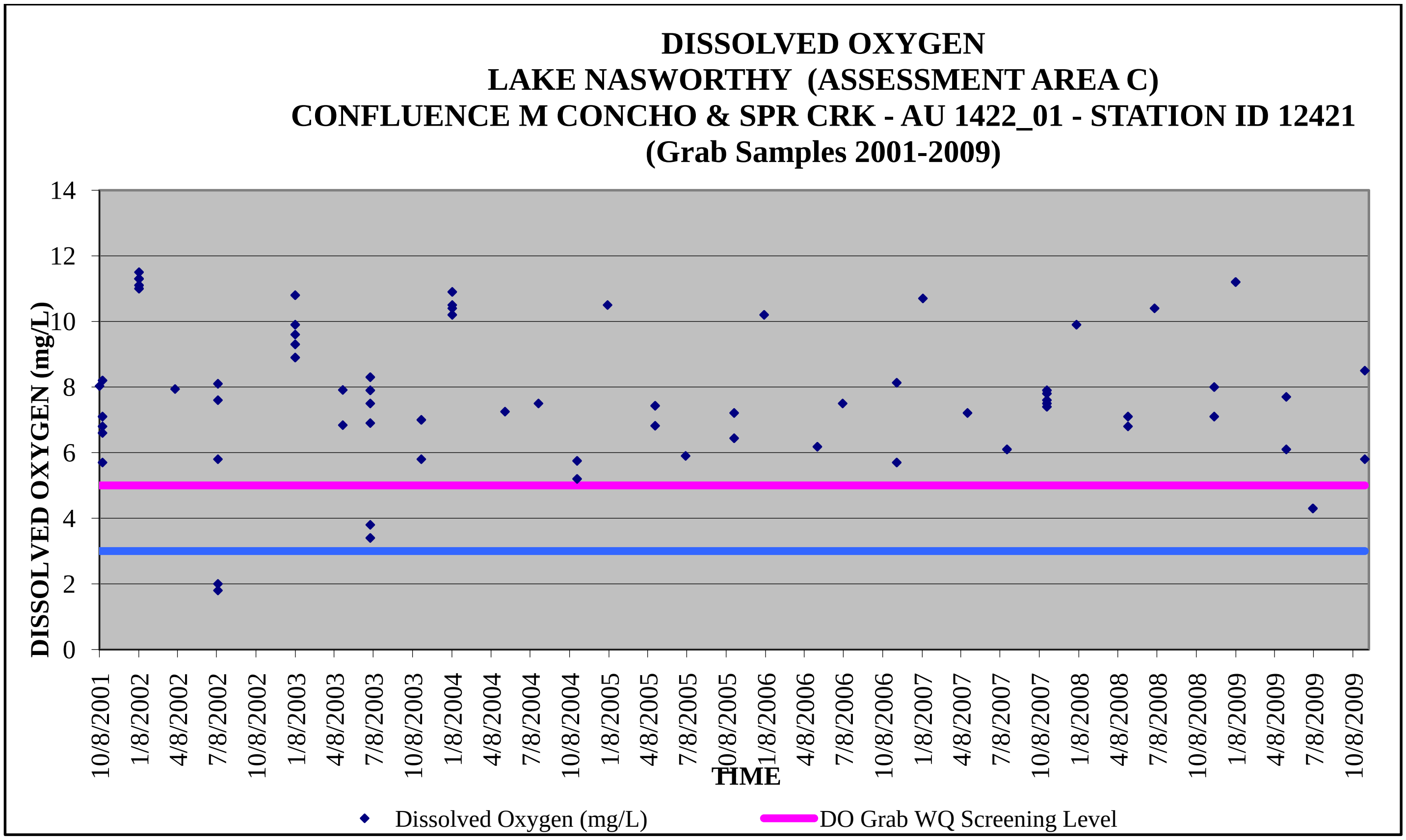
Assessment Area C Supporting Data

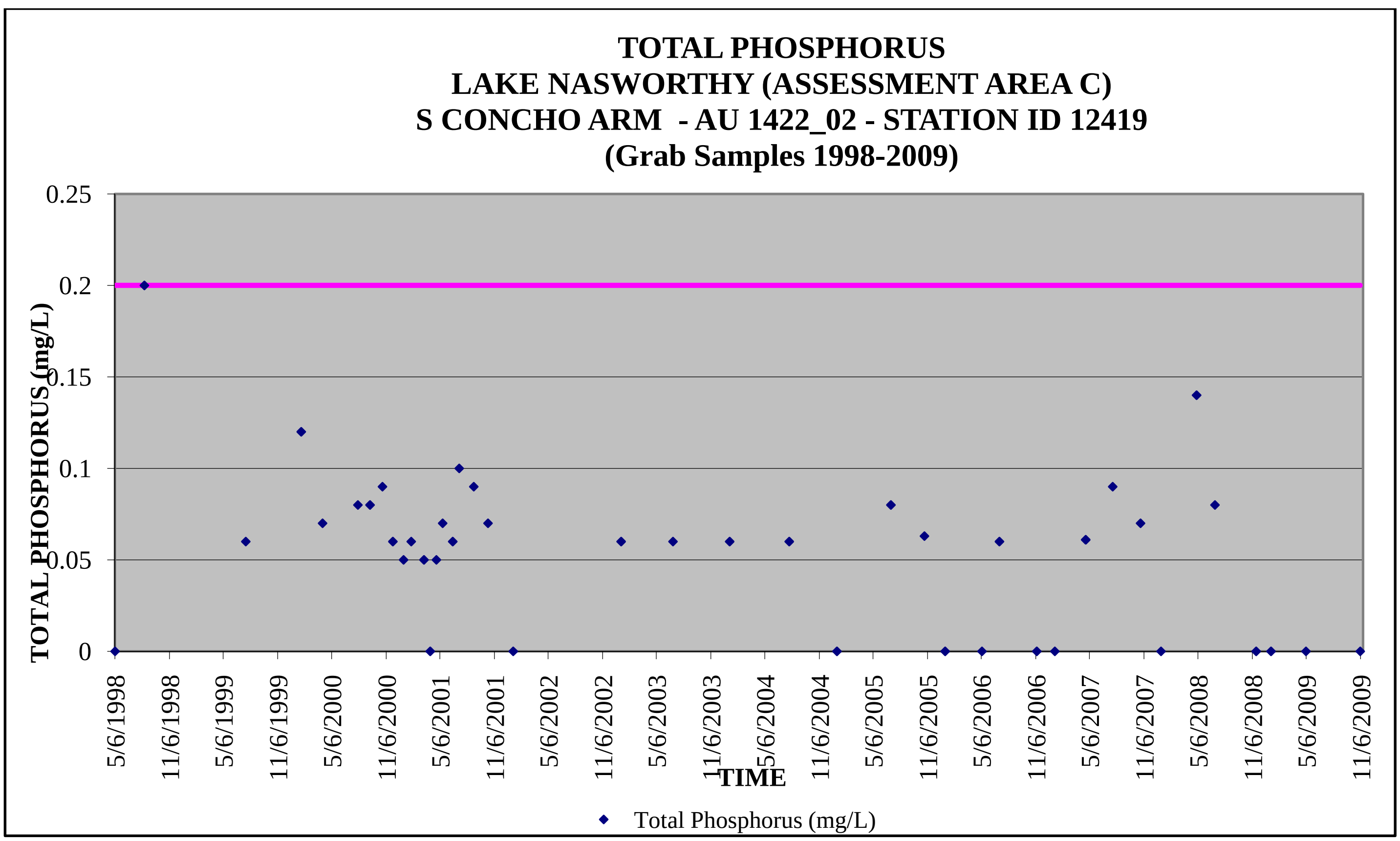

TOTAL PHOSPHORUS
LAKE NASWORTHY (ASSESSMENT AREA C)
CONFLUENCE M CONCHO & SPR CRK - AU 1422_01 - STATION ID 12421
(Grab Samples 2001-2009)
TOTAL PHOSPHORUS (MG/L)
0.25
0.2
0.15
0.1
0.05
0
TIME
Total Phosphorus (mg/L)

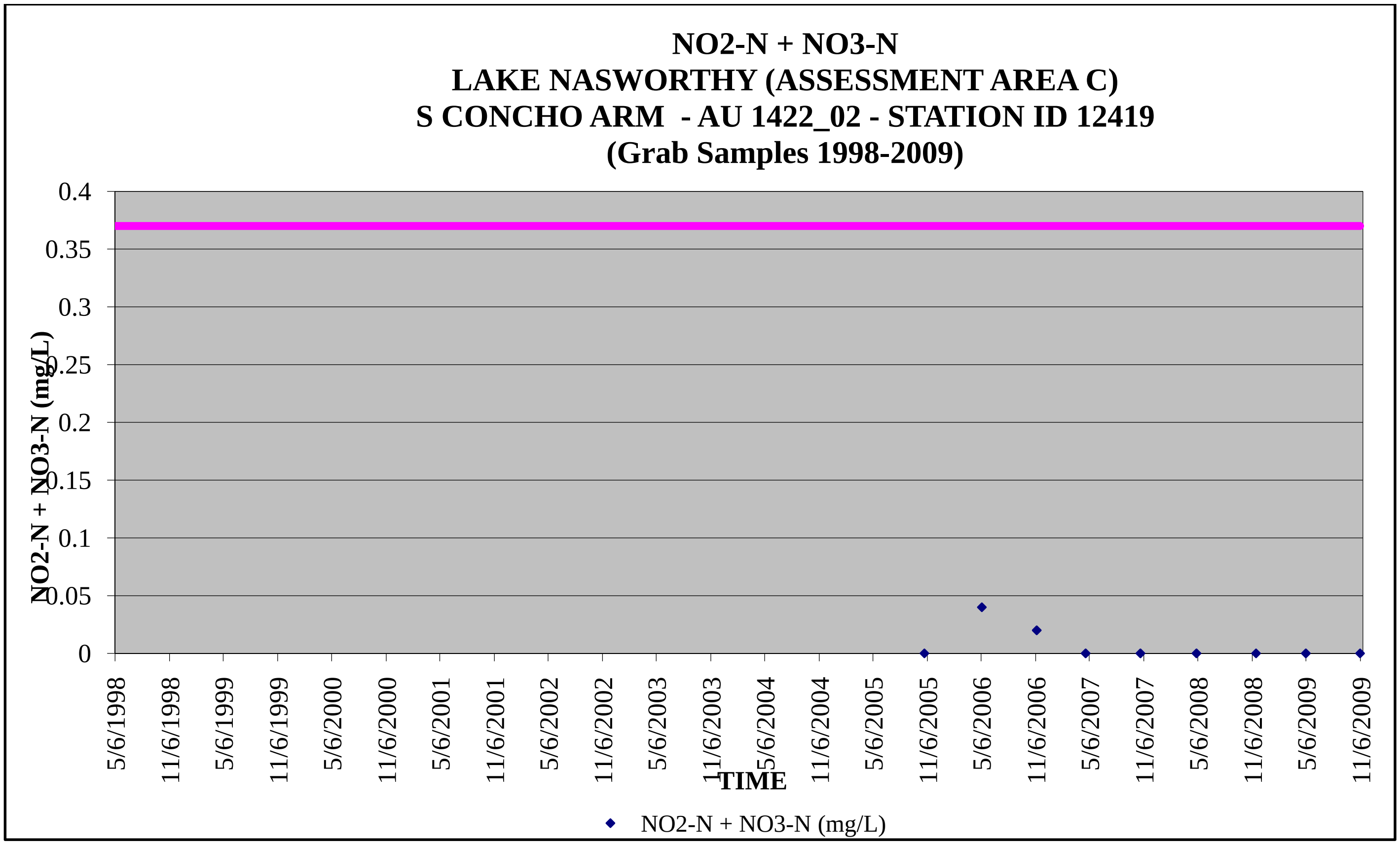

NO2-N + NO3-N
LAKE NASWORTHY (ASSESSMENT AREA C)
CONFLUENCE M CONCHO & SPR CRK - AU 1422_01 - STATION ID 12421
(Grab Samples 2001-2009)
NO2-N + NO3-N (mg/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
TIME
NO2-N + NO3-N (mg/L)

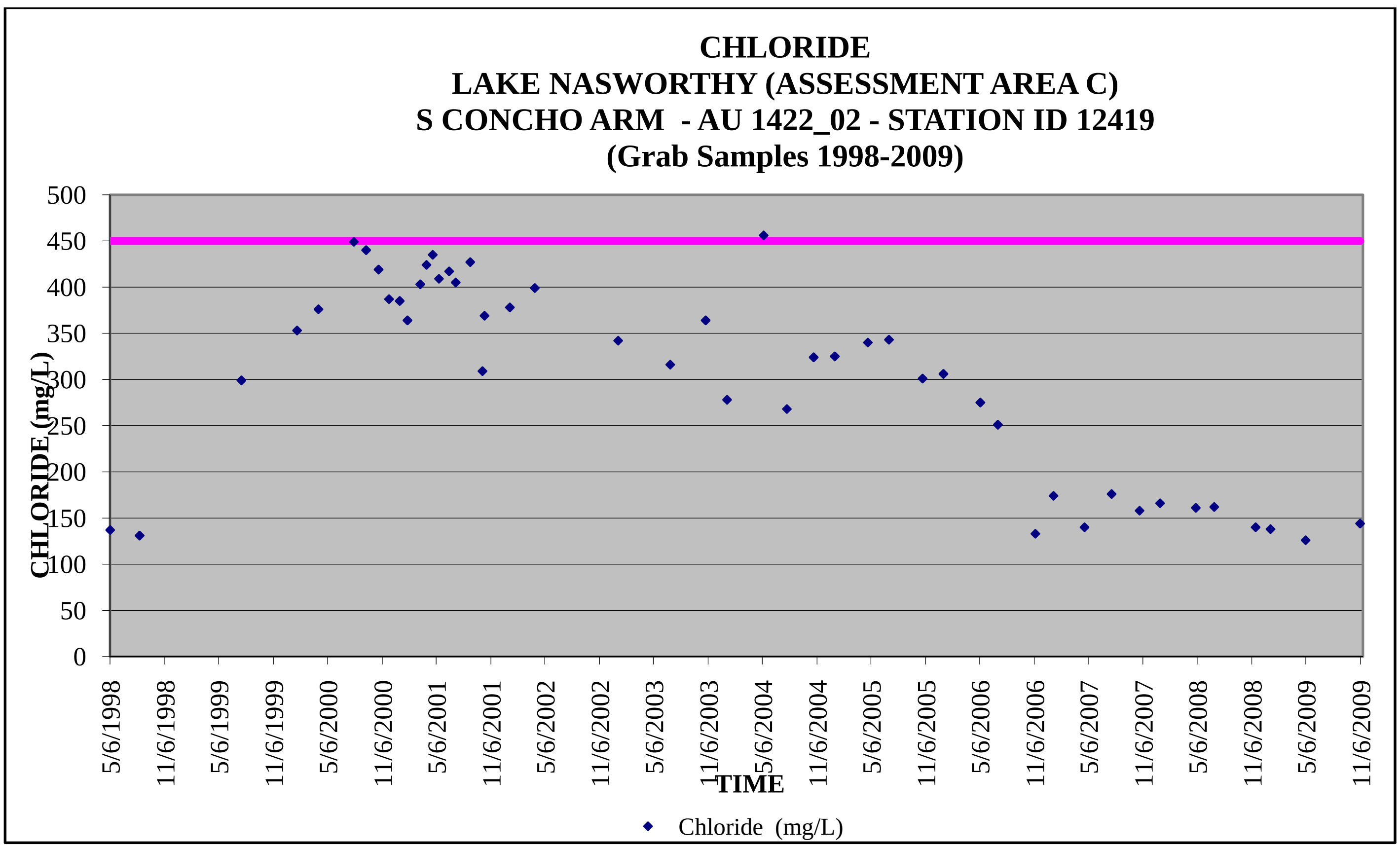

CHLORIDE
LAKE NASWORTHY (ASSESSMENT AREA C)
CONFLUENCE M CONCHO & SPR CRK - AU 1422_01 - STATION ID 12421
(Grab Samples 2001-2009)
CHLORIDE (mg/L)
TIME
Chloride (mg/L)

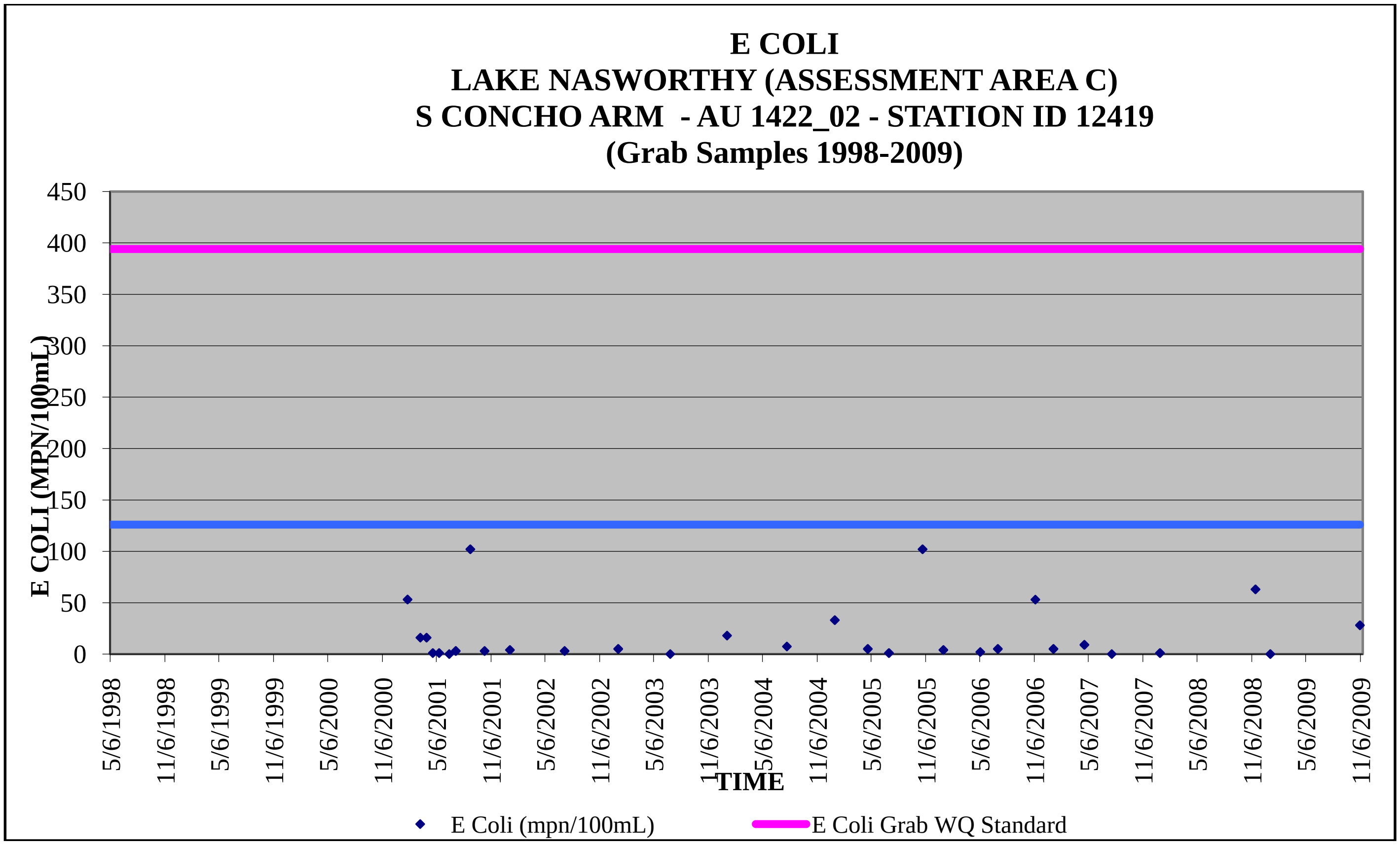

E COLI
LAKE NASWORTHY (ASSESSMENT AREA C)
CONFLUENCE M CONCHO & SPR CRK - AU 1422_01 - STATION ID 12421
(Grab Samples 2001-2009)
E COLI (MPN/100mL)
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

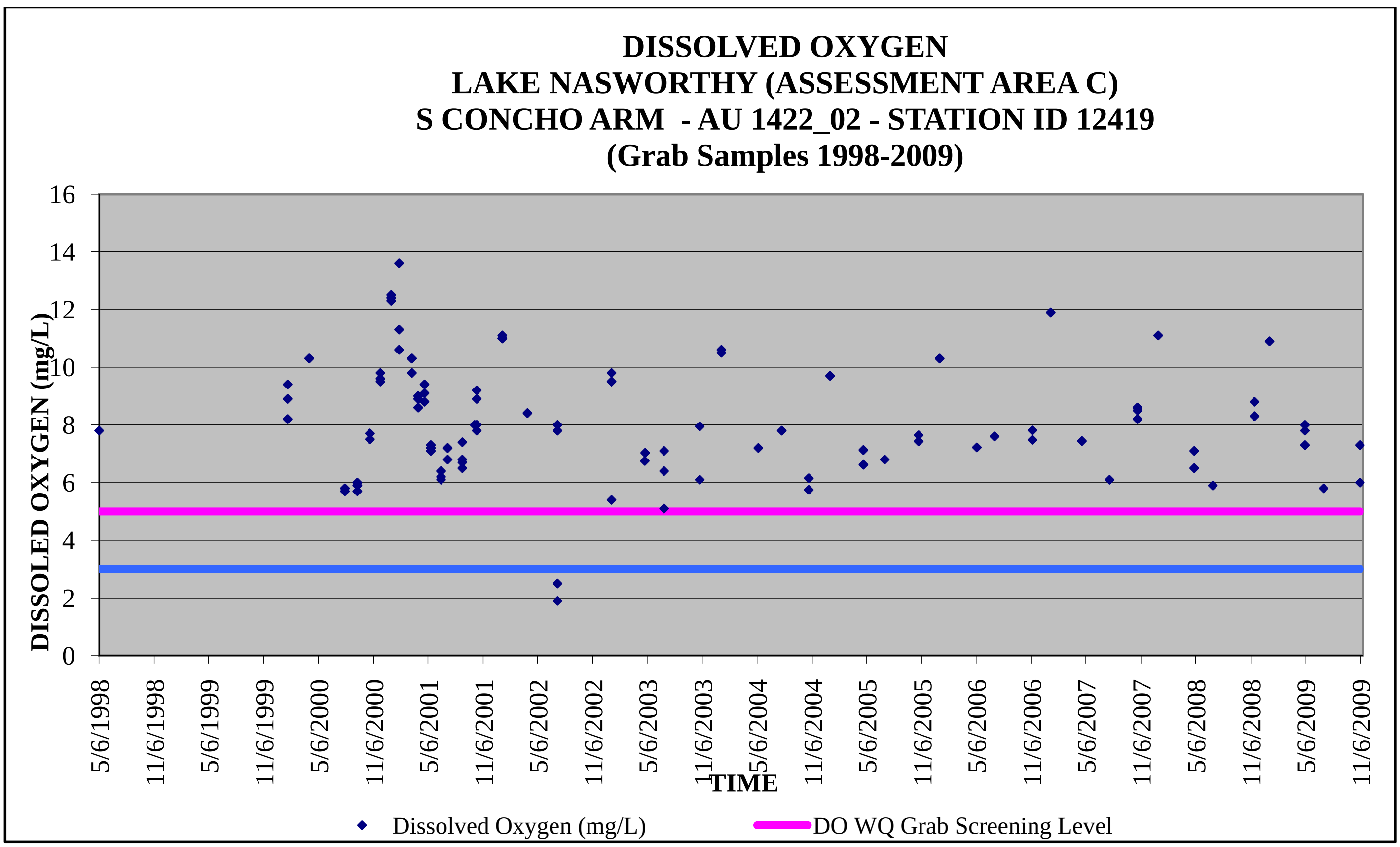

DISSOLVED OXYGEN
LAKE NASWORTHY (ASSESSMENT AREA C)
CONFLUENCE M CONCHO & SPR CRK - AU 1422_01 - STATION ID 12421
(Grab Samples 2001-2009)
DISSOLVED OXYGEN (mg/L)
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level

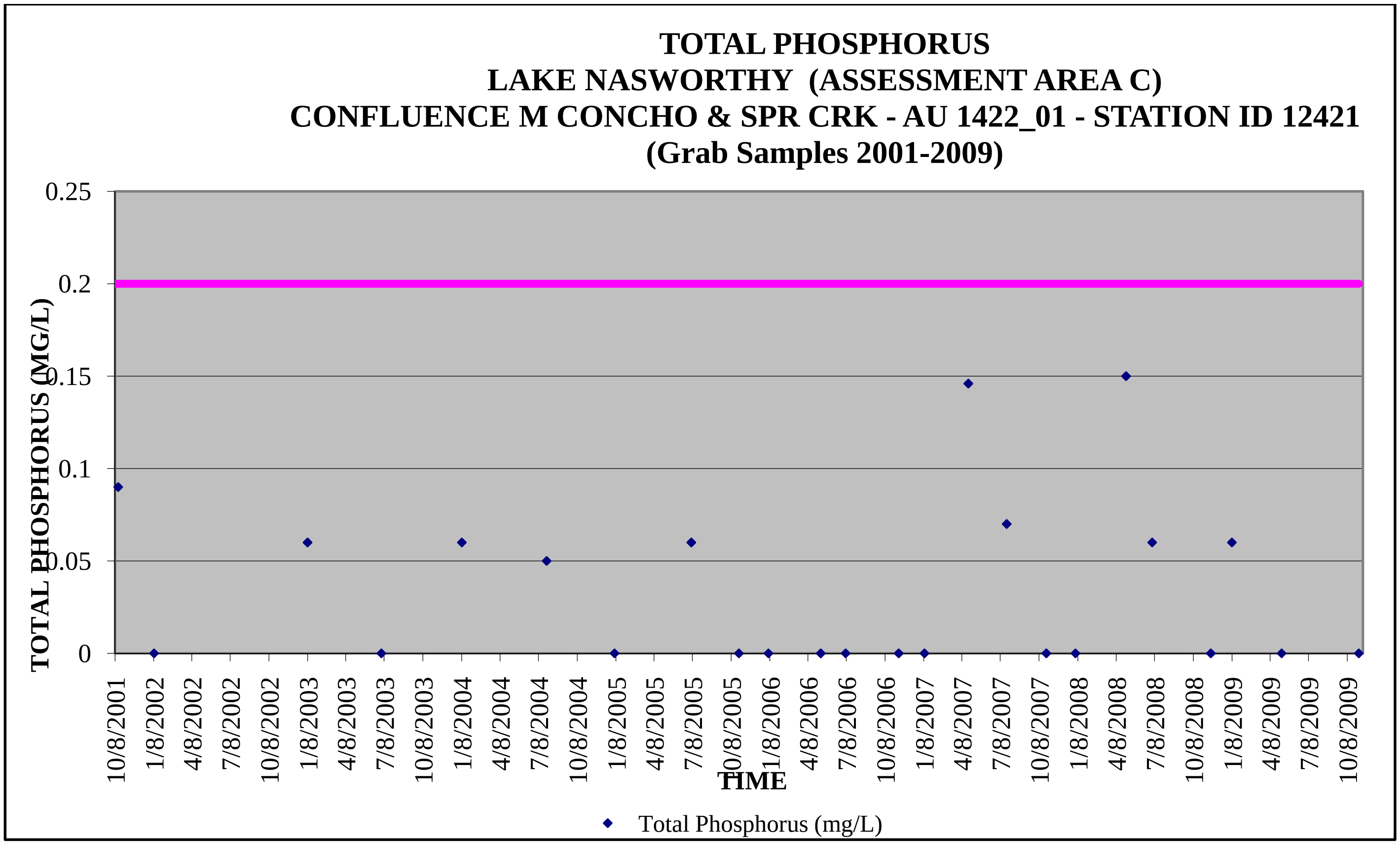

TOTAL PHOSPHORUS
LAKE NASWORTHY (ASSESSMENT AREA C)
S CONCHO ARM - AU 1422_02 - STATION ID 12419
(Grab Samples 1998-2009)
TOTAL PHOSPHORUS (mg/L)
TIME
Total Phosphorus (mg/L)

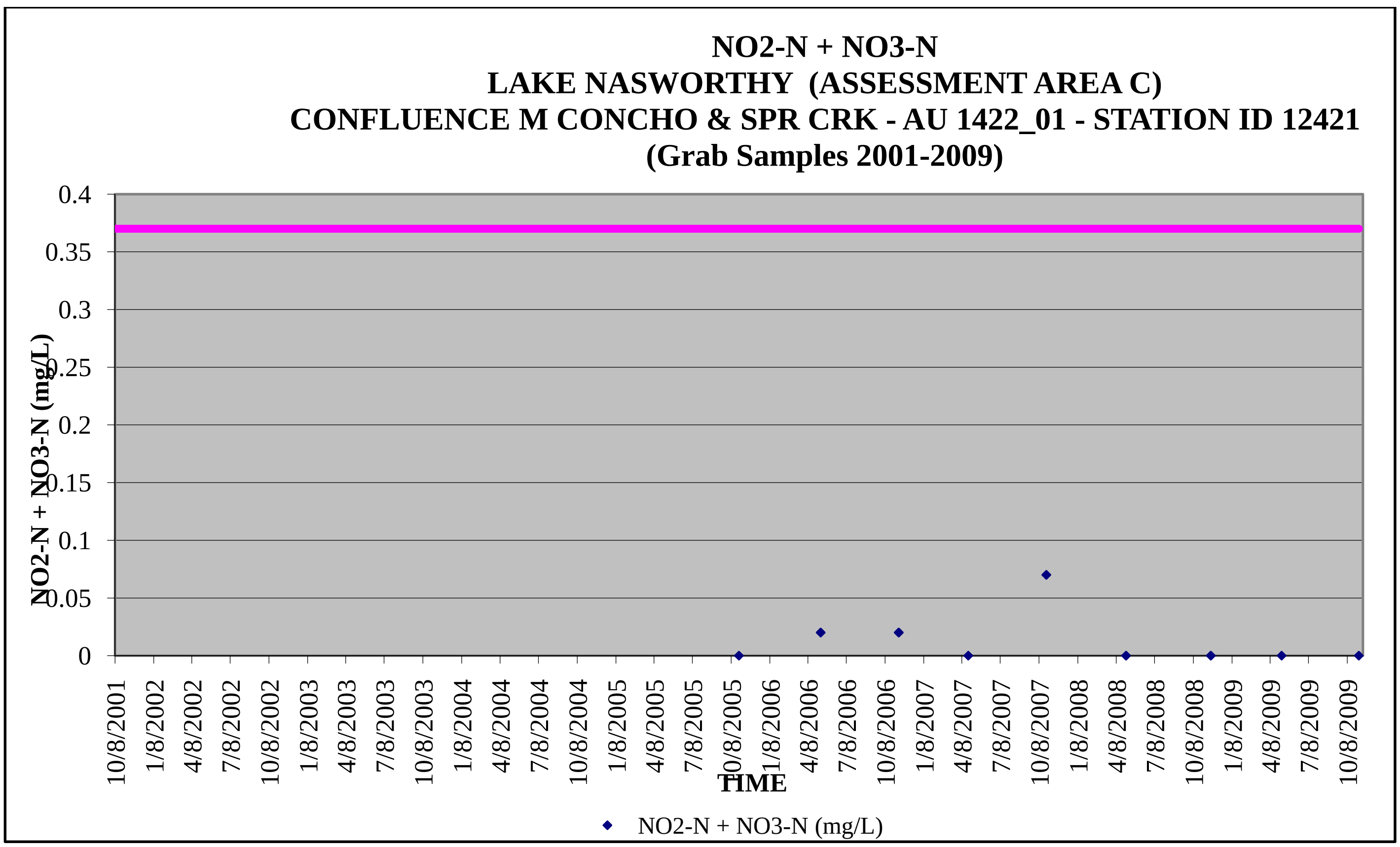

NO2-N + NO3-N
LAKE NASWORTHY (ASSESSMENT AREA C)
S CONCHO ARM - AU 1422_02 - STATION ID 12419
(Grab Samples 1998-2009)
NO2-N + NO3-N (mg/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
11/6/2009
TIME
NO2-N + NO3-N (mg/L)

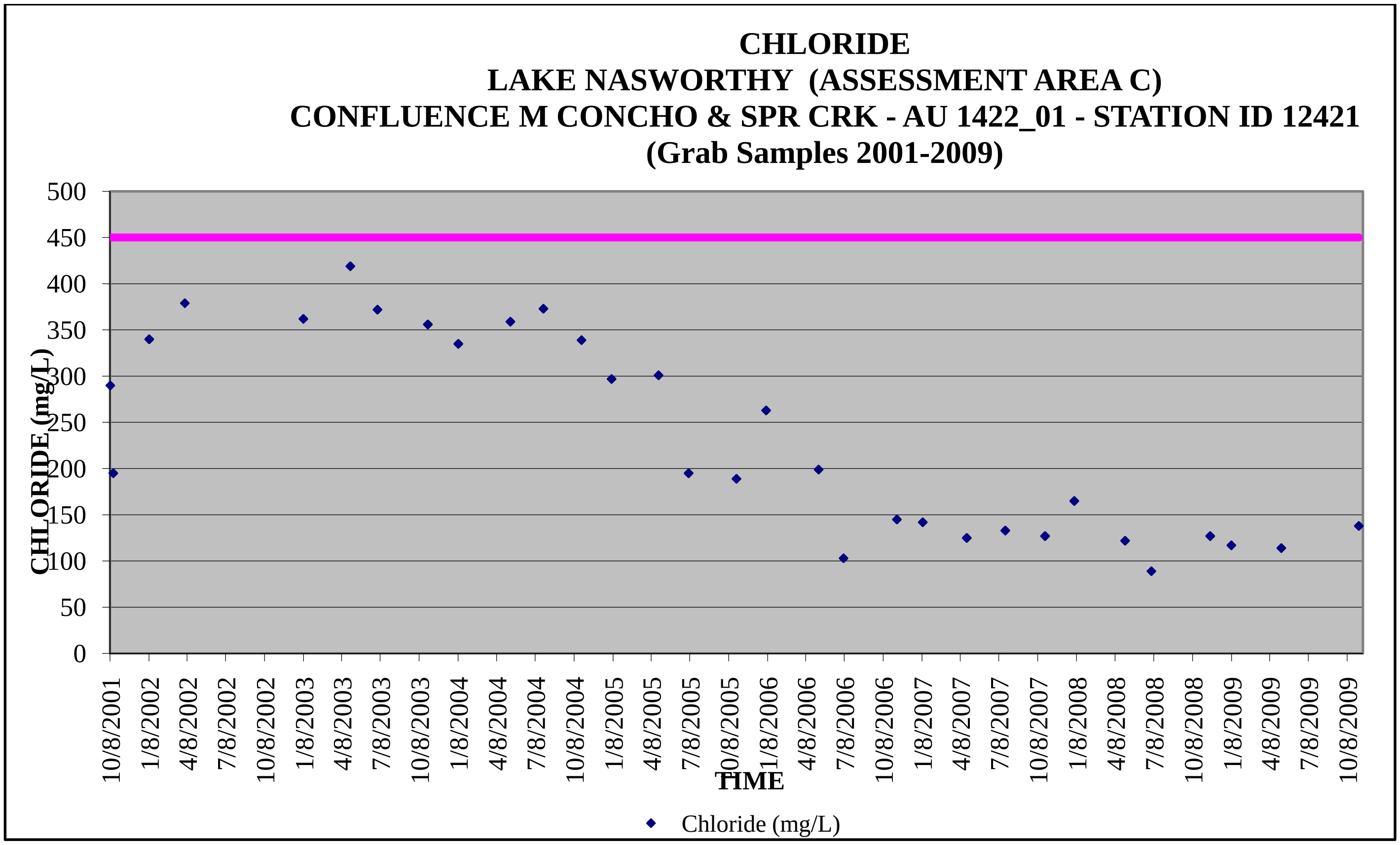

CHLORIDE
LAKE NASWORTHY (ASSESSMENT AREA C)
S CONCHO ARM - AU 1422_02 - STATION ID 12419
(Grab Samples 1998-2009)
CHLORIDE (mg/L)
500
450
400
350
300
250
200
150
100
50
0
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
11/6/2009
TIME
Chloride (mg/L)

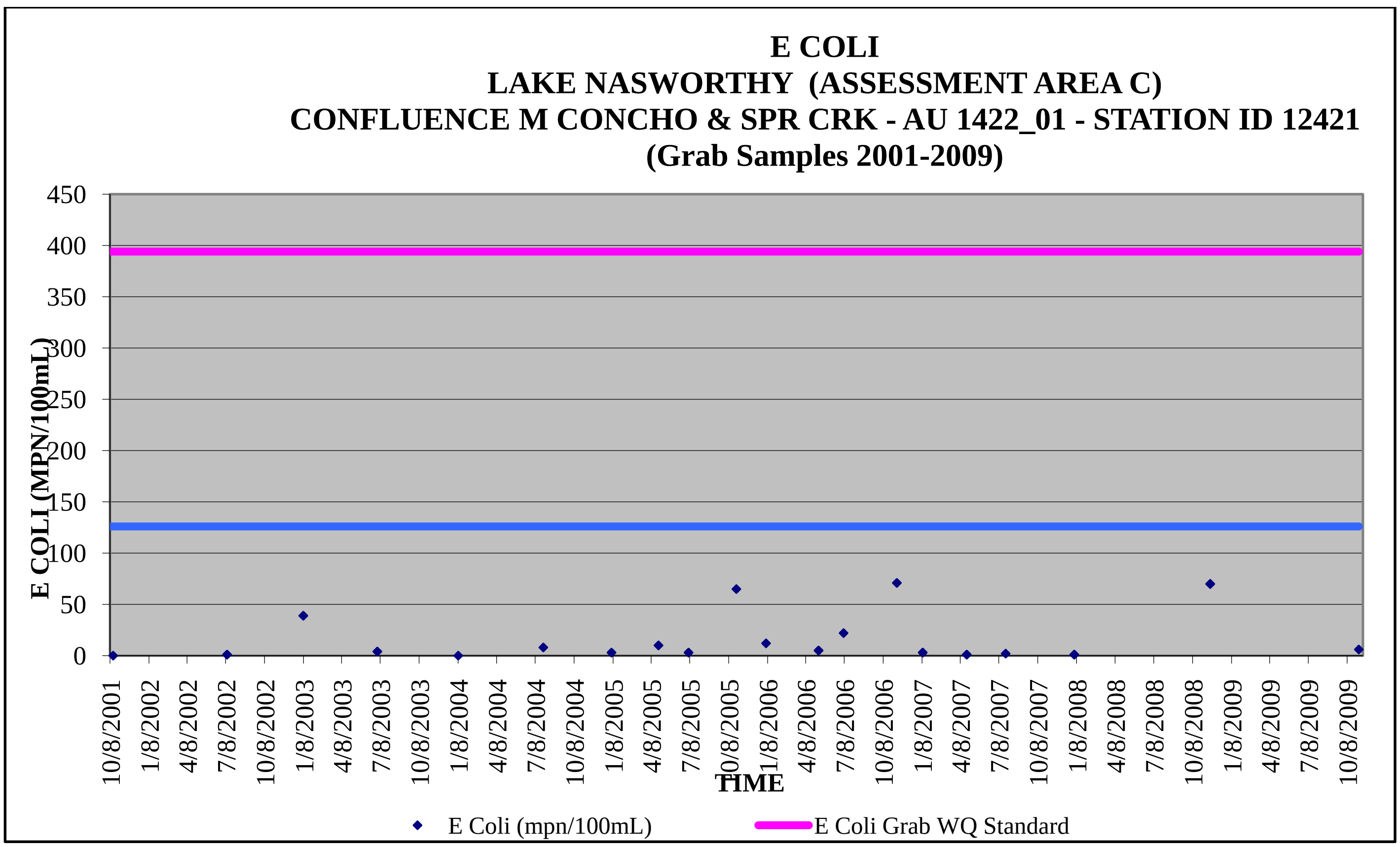

E COLI
LAKE NASWORTHY (ASSESSMENT AREA C)
S CONCHO ARM - AU 1422_02 - STATION ID 12419
(Grab Samples 1998-2009)
E COLI (MPN/100mL)
450
400
350
300
250
200
150
100
50
0
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
11/6/2009
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

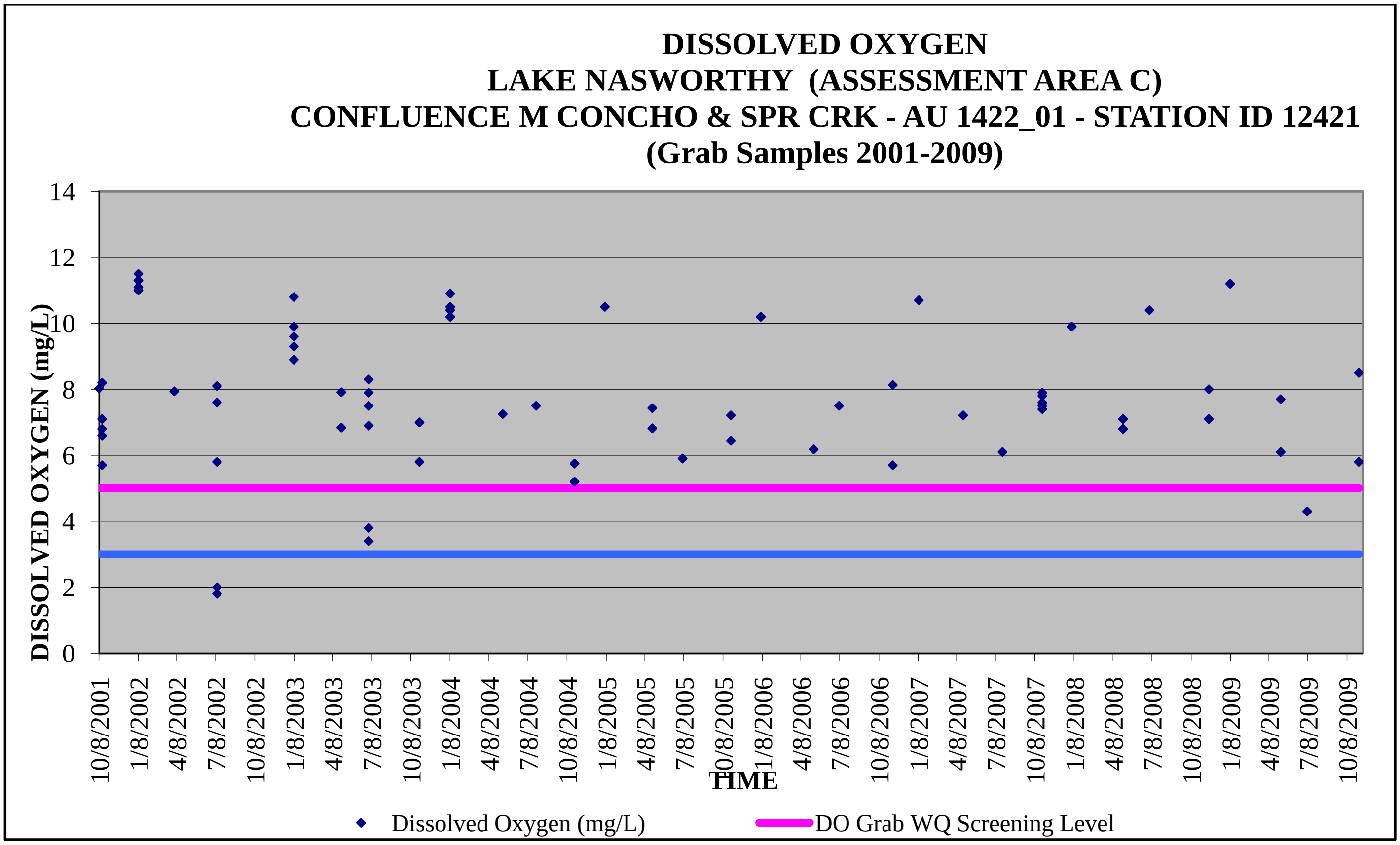

DISSOLVED OXYGEN
LAKE NASWORTHY (ASSESSMENT AREA C)
S CONCHO ARM - AU 1422_02 - STATION ID 12419
(Grab Samples 1998-2009)
DISSOLED OXYGEN (mg/L)
16
14
12
10
8
6
4
2
0
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
11/6/2009
TIME
Dissolved Oxygen (mg/L)
DO WQ Grab Screening Level


TOTAL PHOSPHORUS
LAKE NASWORTHY (ASSESSMENT AREA C)
CONFLUENCE M CONCHO & SPR CRK - AU 1422_01 - STATION ID 12421
(Grab Samples 2001-2009)
TOTAL PHOSPHORUS (MG/L)
0.25
0.2
0.15
0.1
0.05
0
10/8/2001
1/8/2002
4/8/2002
7/8/2002
10/8/2002
1/8/2003
4/8/2003
7/8/2003
10/8/2003
1/8/2004
4/8/2004
7/8/2004
10/8/2004
1/8/2005
4/8/2005
7/8/2005
10/8/2005
1/8/2006
4/8/2006
7/8/2006
10/8/2006
1/8/2007
4/8/2007
7/8/2007
10/8/2007
1/8/2008
4/8/2008
7/8/2008
10/8/2008
1/8/2009
4/8/2009
7/8/2009
10/8/2009
TIME
Total Phosphorus (mg/L)


NO2-N + NO3-N
LAKE NASWORTHY (ASSESSMENT AREA C)
CONFLUENCE M CONCHO & SPR CRK - AU 1422_01 - STATION ID 12421
(Grab Samples 2001-2009)
NO2-N + NO3-N (mg/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10/8/2001
1/8/2002
4/8/2002
7/8/2002
10/8/2002
1/8/2003
4/8/2003
7/8/2003
10/8/2003
1/8/2004
4/8/2004
7/8/2004
10/8/2004
1/8/2005
4/8/2005
7/8/2005
10/8/2005
1/8/2006
4/8/2006
7/8/2006
10/8/2006
1/8/2007
4/8/2007
7/8/2007
10/8/2007
1/8/2008
4/8/2008
7/8/2008
10/8/2008
1/8/2009
4/8/2009
7/8/2009
10/8/2009
TIME
NO2-N + NO3-N (mg/L)

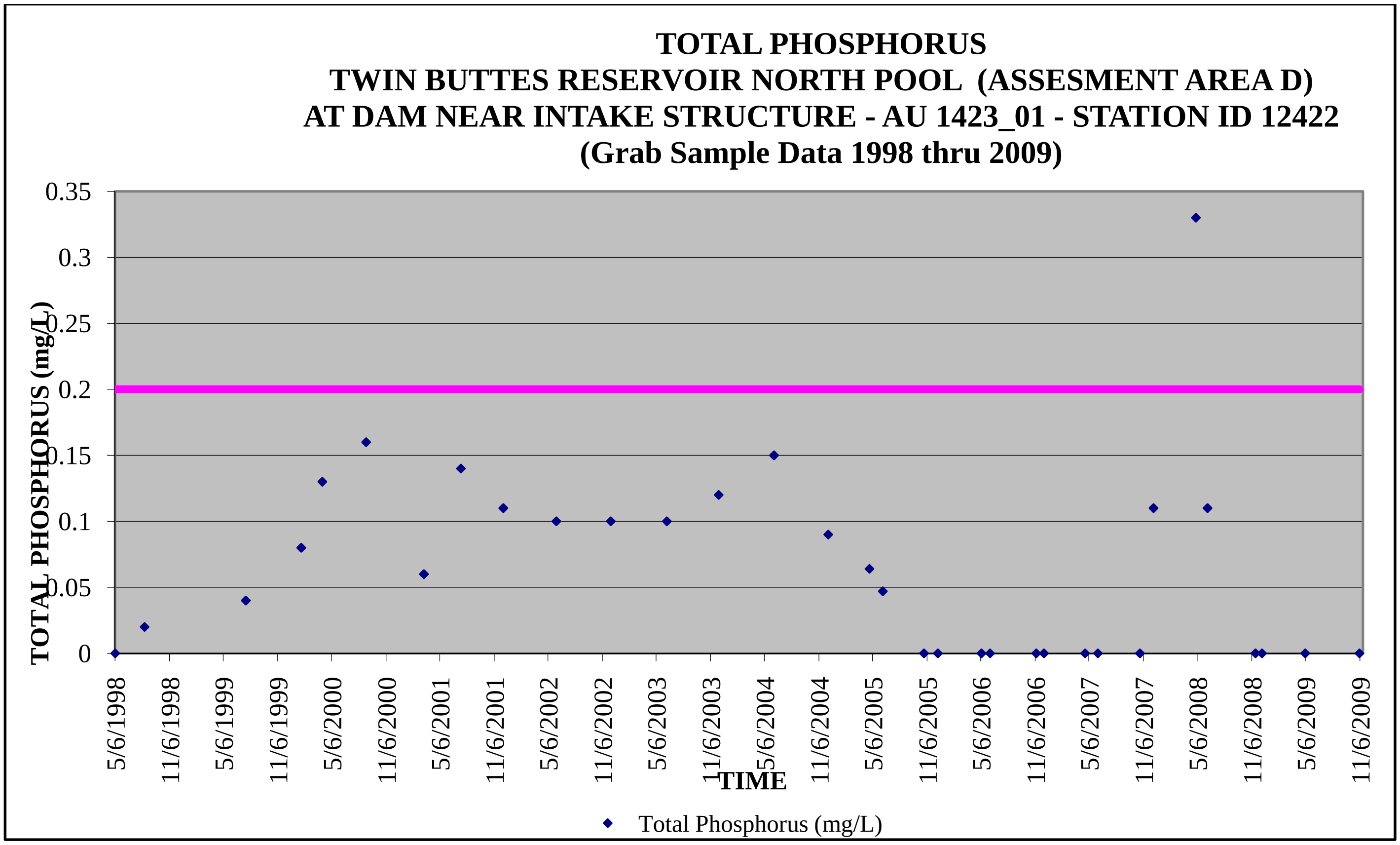

CHLORIDE
LAKE NASWORTHY (ASSESSMENT AREA C)
CONFLUENCE M CONCHO & SPR CRK - AU 1422_01 - STATION ID 12421
(Grab Samples 2001-2009)
CHLORIDE (mg/L)
TIME
Chloride (mg/L)

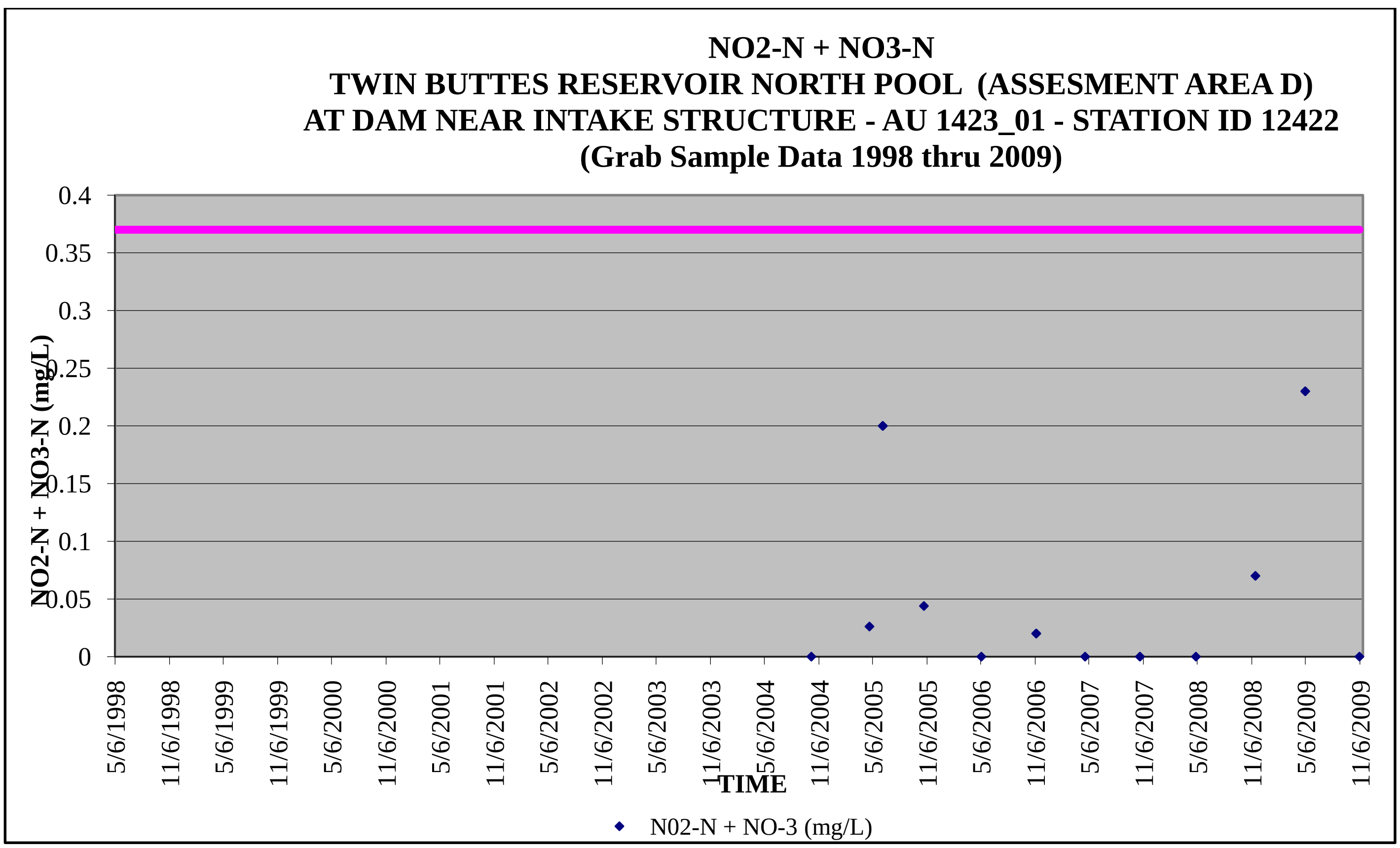

E COLI
LAKE NASWORTHY (ASSESSMENT AREA C)
CONFLUENCE M CONCHO & SPR CRK - AU 1422_01 - STATION ID 12421
(Grab Samples 2001-2009)
E COLI (MPN/100mL)
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

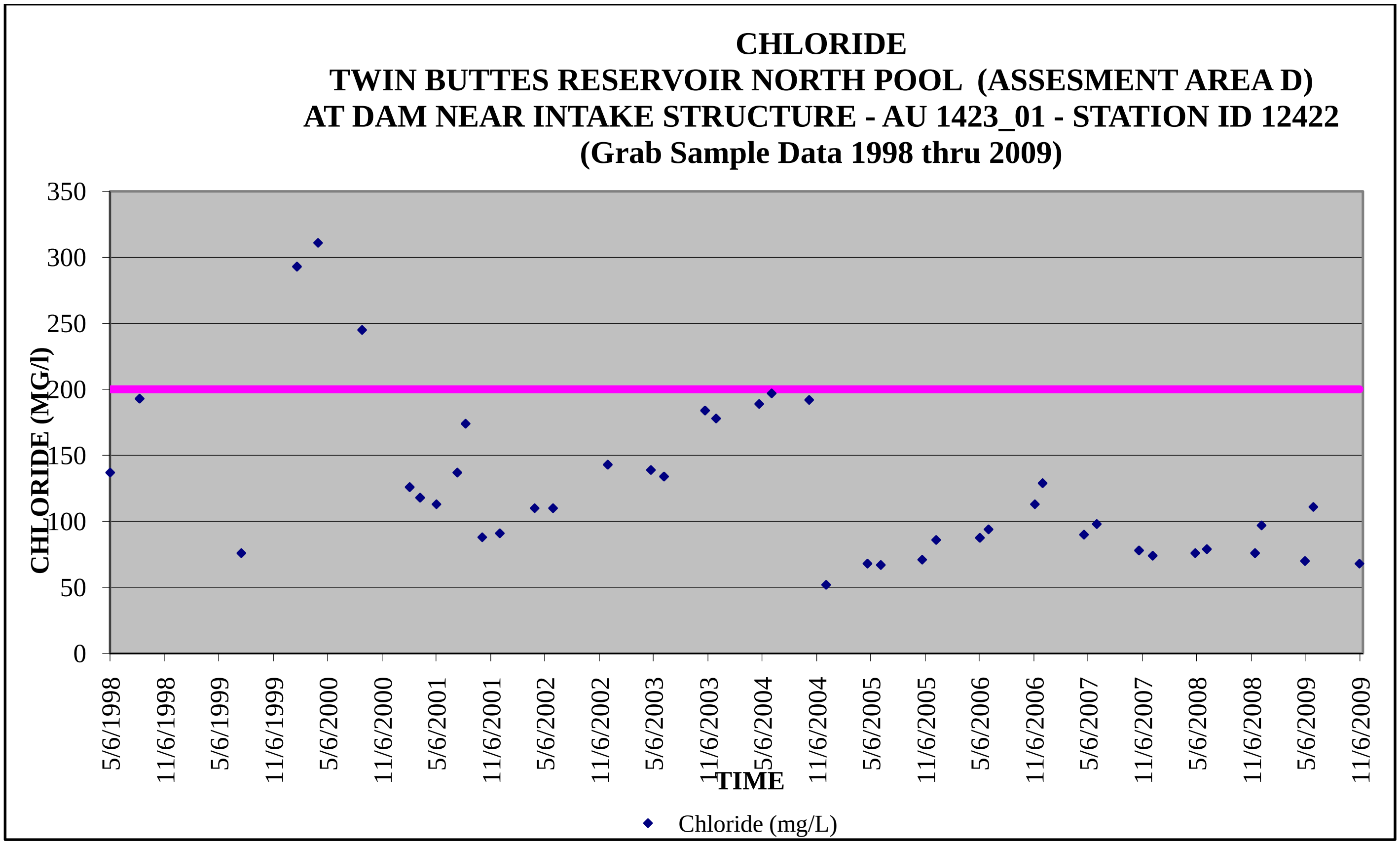

DISSOLVED OXYGEN
LAKE NASWORTHY (ASSESSMENT AREA C)
CONFLUENCE M CONCHO & SPR CRK - AU 1422_01 - STATION ID 12421
(Grab Samples 2001-2009)
DISSOLVED OXYGEN (mg/L)
14
12
10
8
6
4
2
0
10/8/2001
1/8/2002
4/8/2002
7/8/2002
10/8/2002
1/8/2003
4/8/2003
7/8/2003
10/8/2003
1/8/2004
4/8/2004
7/8/2004
10/8/2004
1/8/2005
4/8/2005
7/8/2005
10/8/2005
1/8/2006
4/8/2006
7/8/2006
10/8/2006
1/8/2007
4/8/2007
7/8/2007
10/8/2007
1/8/2008
4/8/2008
7/8/2008
10/8/2008
1/8/2009
4/8/2009
7/8/2009
10/8/2009
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level

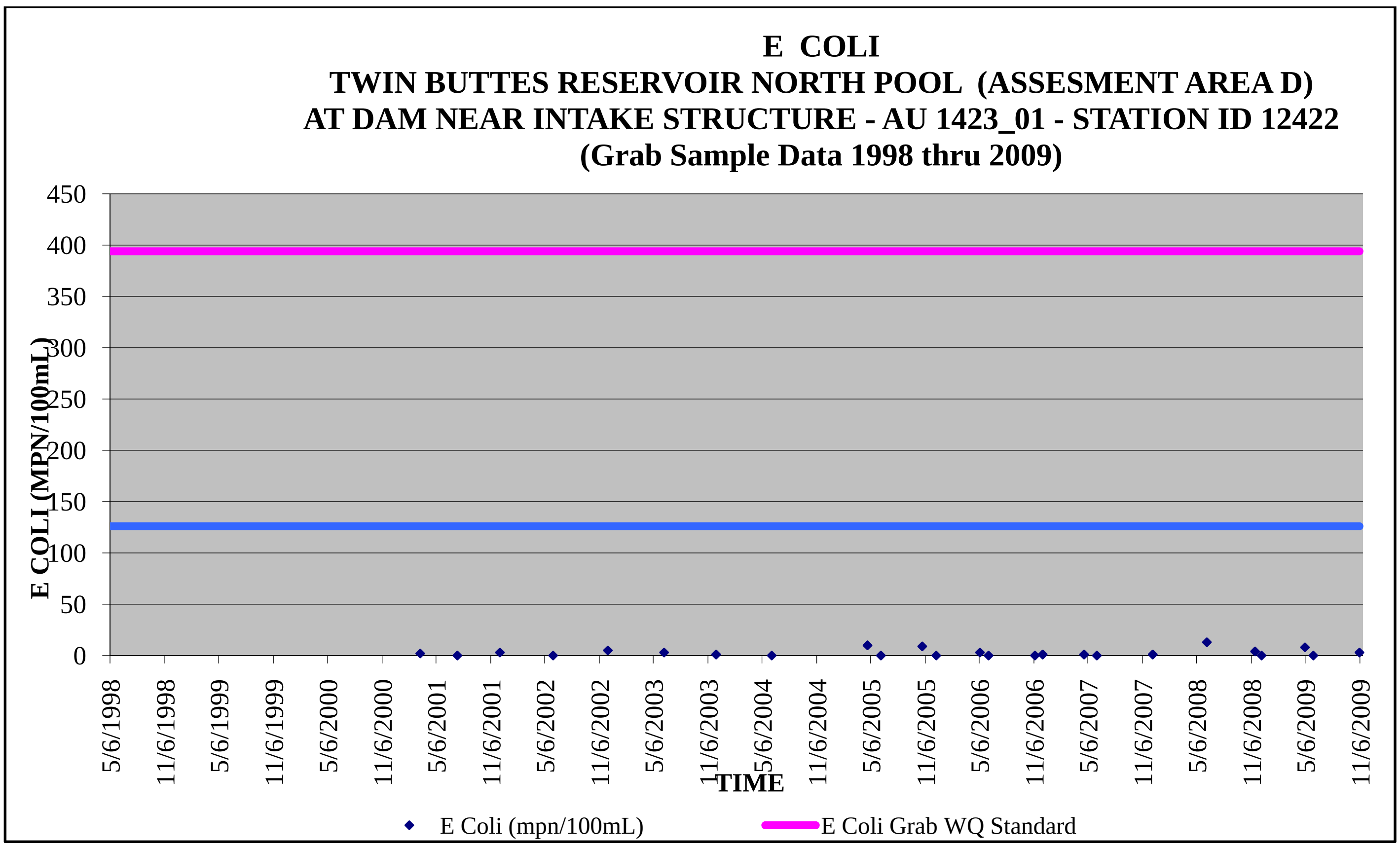
APPENDIX D

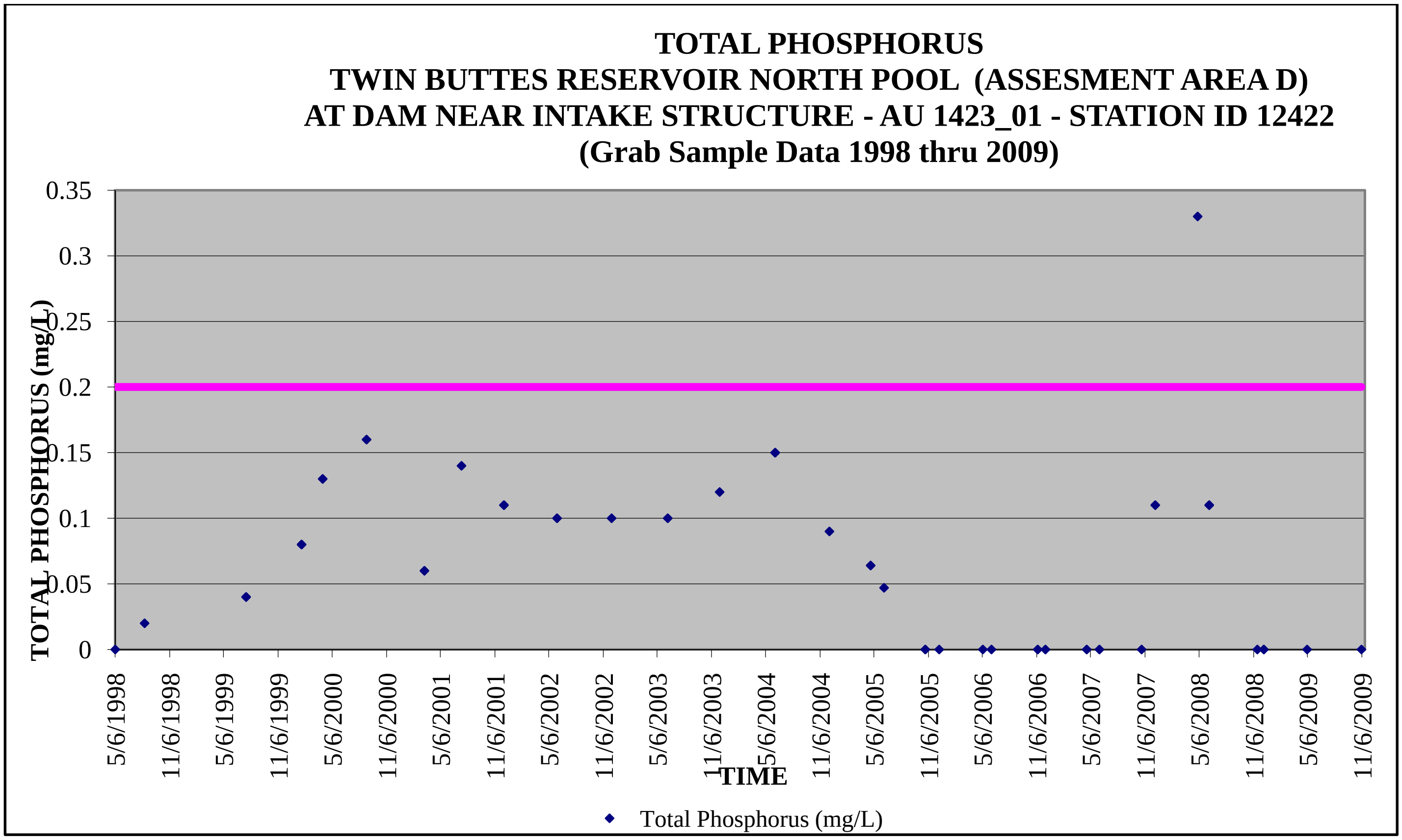
Assessment Area D Supporting Data

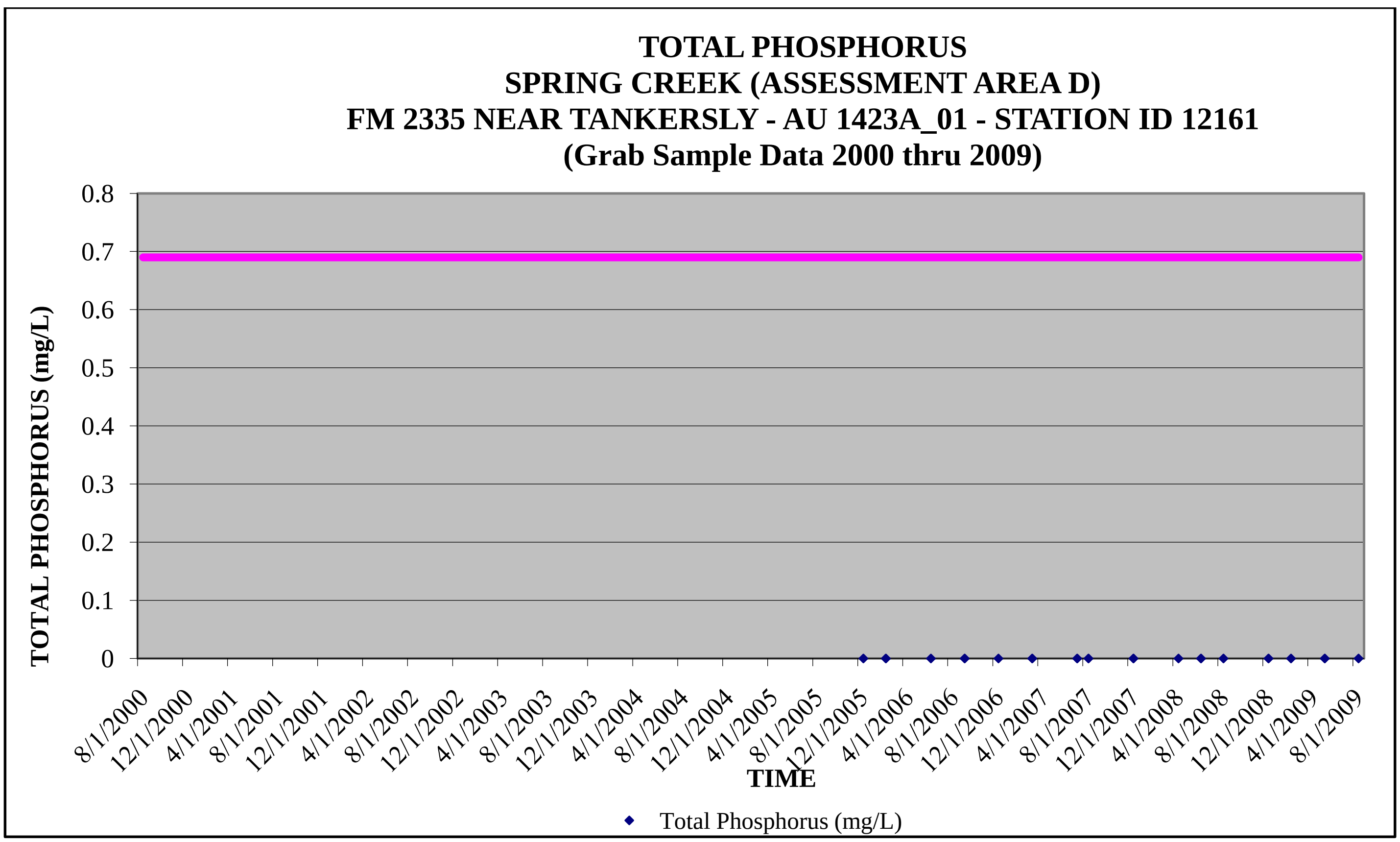

TOTAL PHOSPHORUS
TWIN BUTTES RESERVOIR NORTH POOL (ASSESMENT AREA D)
AT DAM NEAR INTAKE STRUCTURE - AU 1423_01 - STATION ID 12422
(Grab Sample Data 1998 thru 2009)
TOTAL PHOSPHORUS (mg/L)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
11/6/2009
TIME
Total Phosphorus (mg/L)

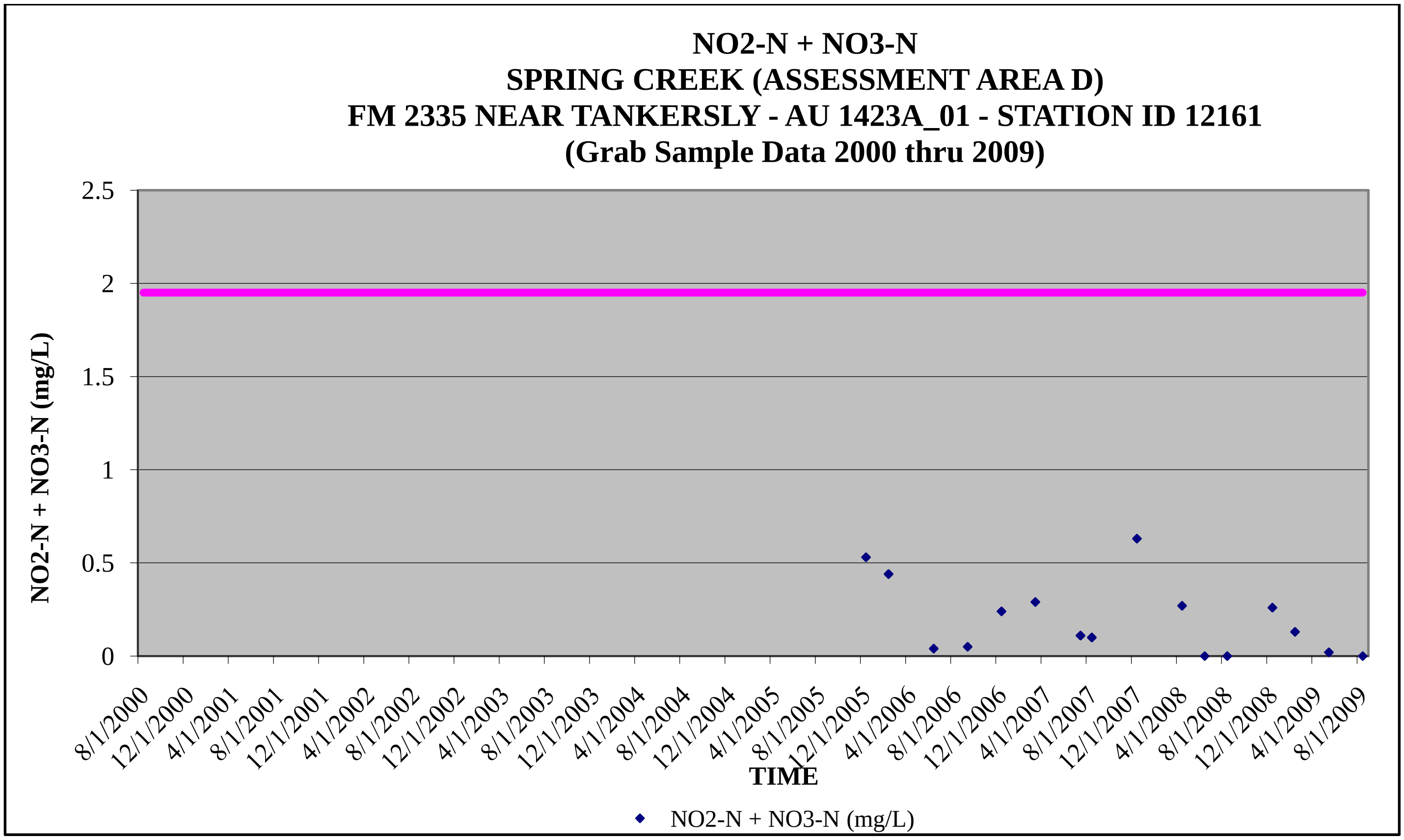

NO2-N + NO3-N
TWIN BUTTES RESERVOIR NORTH POOL (ASSESMENT AREA D)
AT DAM NEAR INTAKE STRUCTURE - AU 1423_01 - STATION ID 12422
(Grab Sample Data 1998 thru 2009)
NO2-N + NO3-N (mg/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
11/6/2009
TIME
N02-N + NO-3 (mg/L)

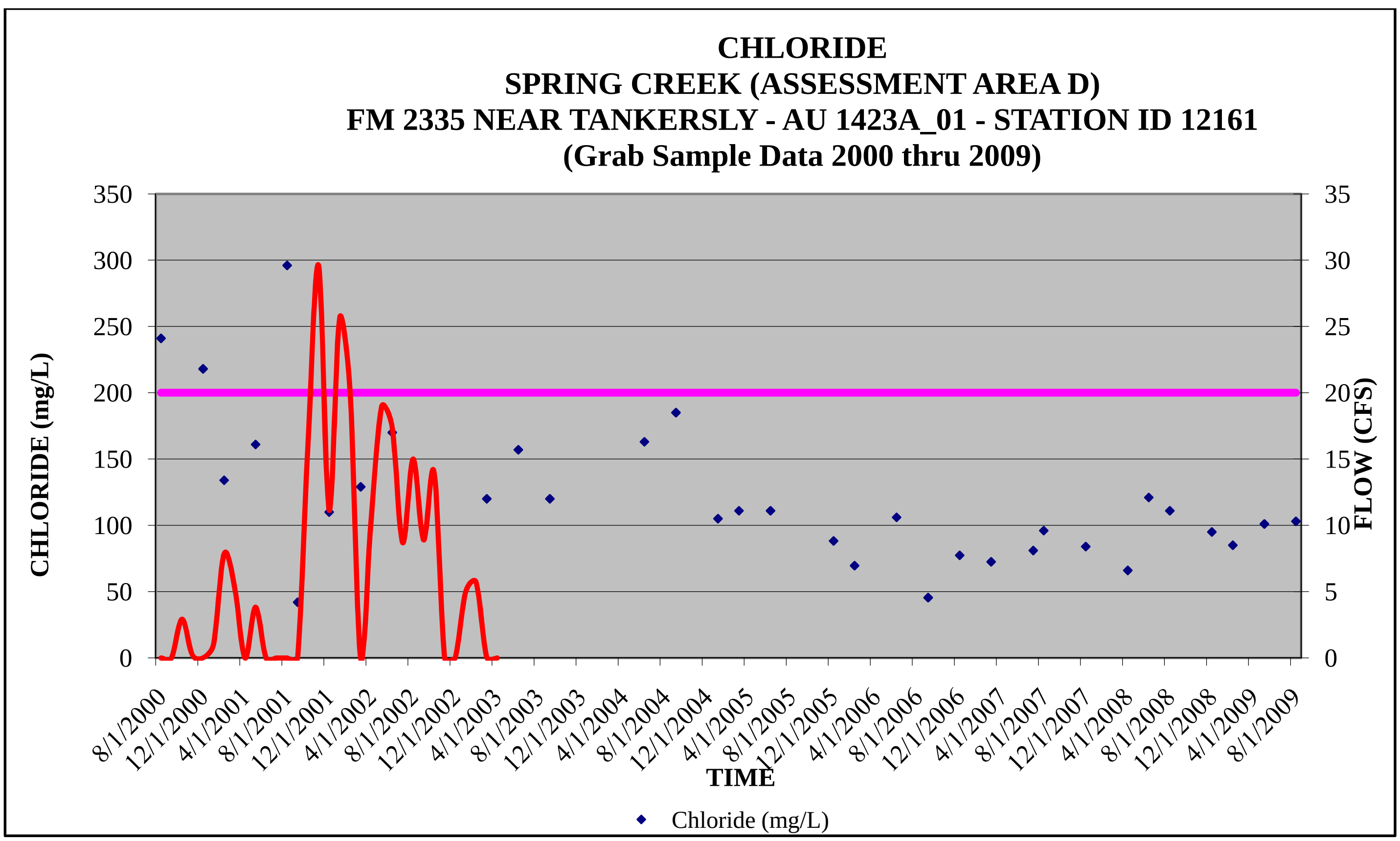

CHLORIDE
TWIN BUTTES RESERVOIR NORTH POOL (ASSESMENT AREA D)
AT DAM NEAR INTAKE STRUCTURE - AU 1423_01 - STATION ID 12422
(Grab Sample Data 1998 thru 2009)
CHLORIDE (MG/l)
0
50
100
150
200
250
300
350
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
11/6/2009
TIME
Chloride (mg/L)

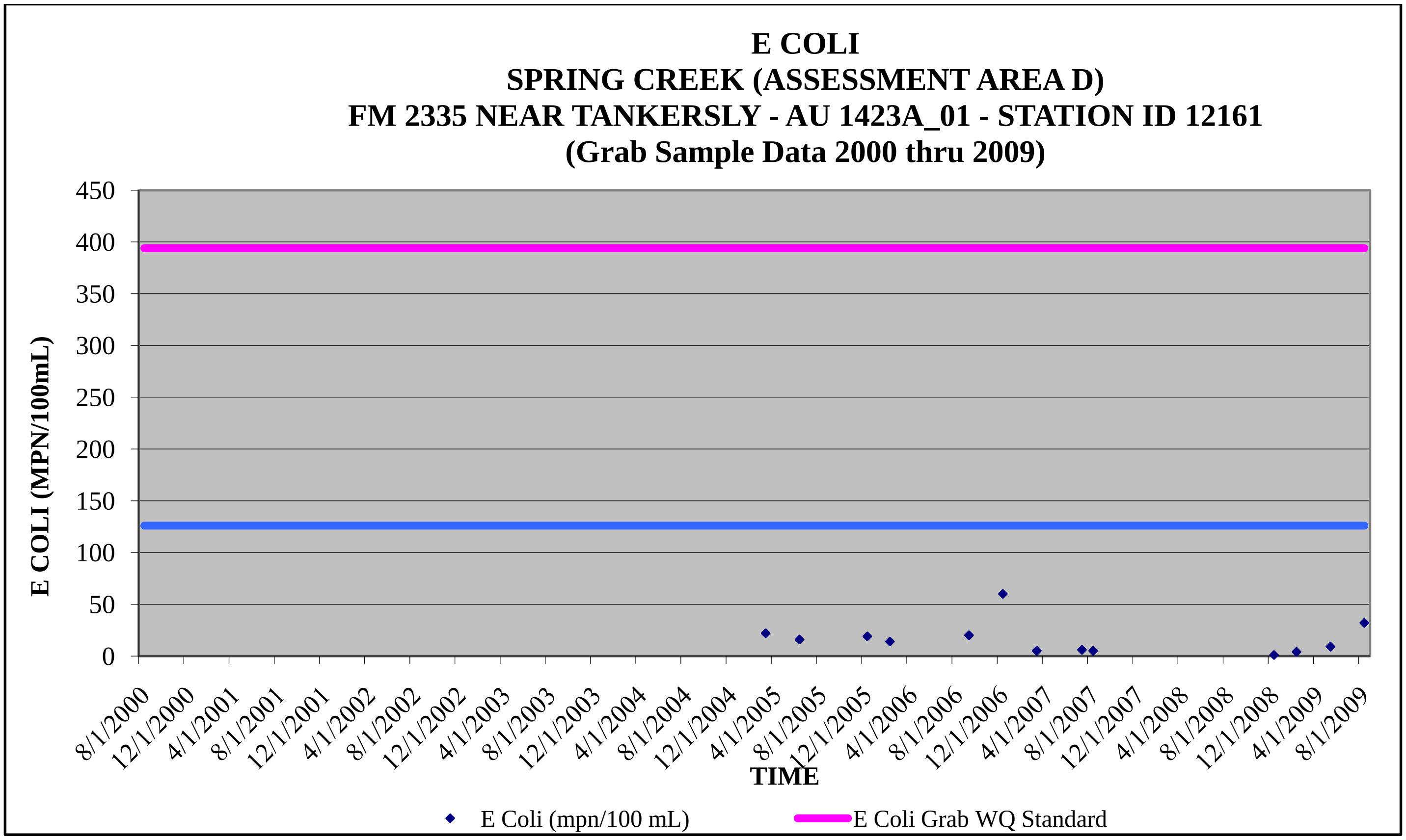

E COLI
TWIN BUTTES RESERVOIR NORTH POOL (ASSESMENT AREA D)
AT DAM NEAR INTAKE STRUCTURE - AU 1423_01 - STATION ID 12422
(Grab Sample Data 1998 thru 2009)
E COLI (MPN/100mL)
0
50
100
150
200
250
300
350
400
450
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
11/6/2009
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

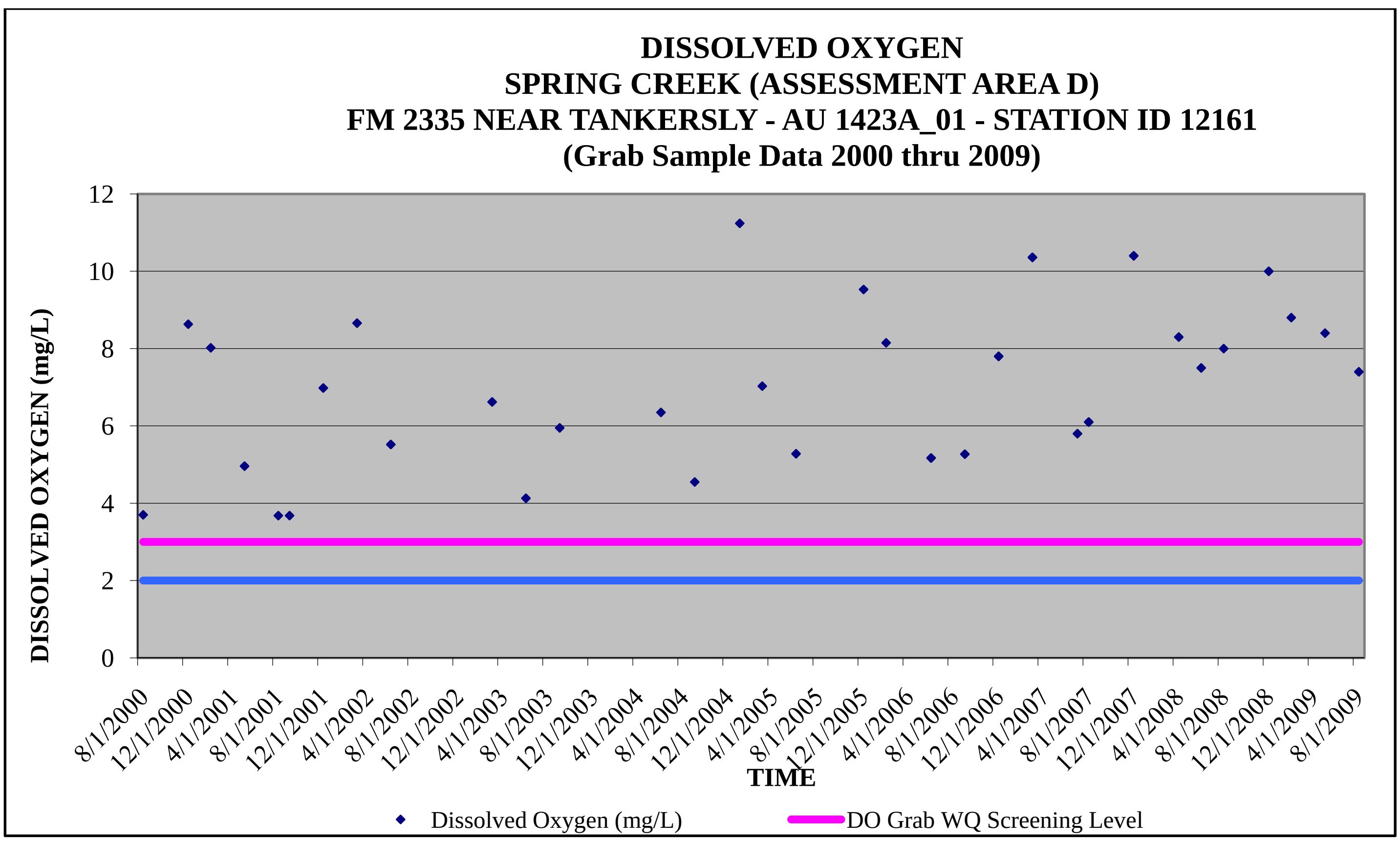

TOTAL PHOSPHORUS
TWIN BUTTES RESERVOIR NORTH POOL (ASSESMENT AREA D)
AT DAM NEAR INTAKE STRUCTURE - AU 1423_01 - STATION ID 12422
(Grab Sample Data 1998 thru 2009)
TOTAL PHOSPHORUS (mg/L)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
11/6/2009
TIME
Total Phosphorus (mg/L)

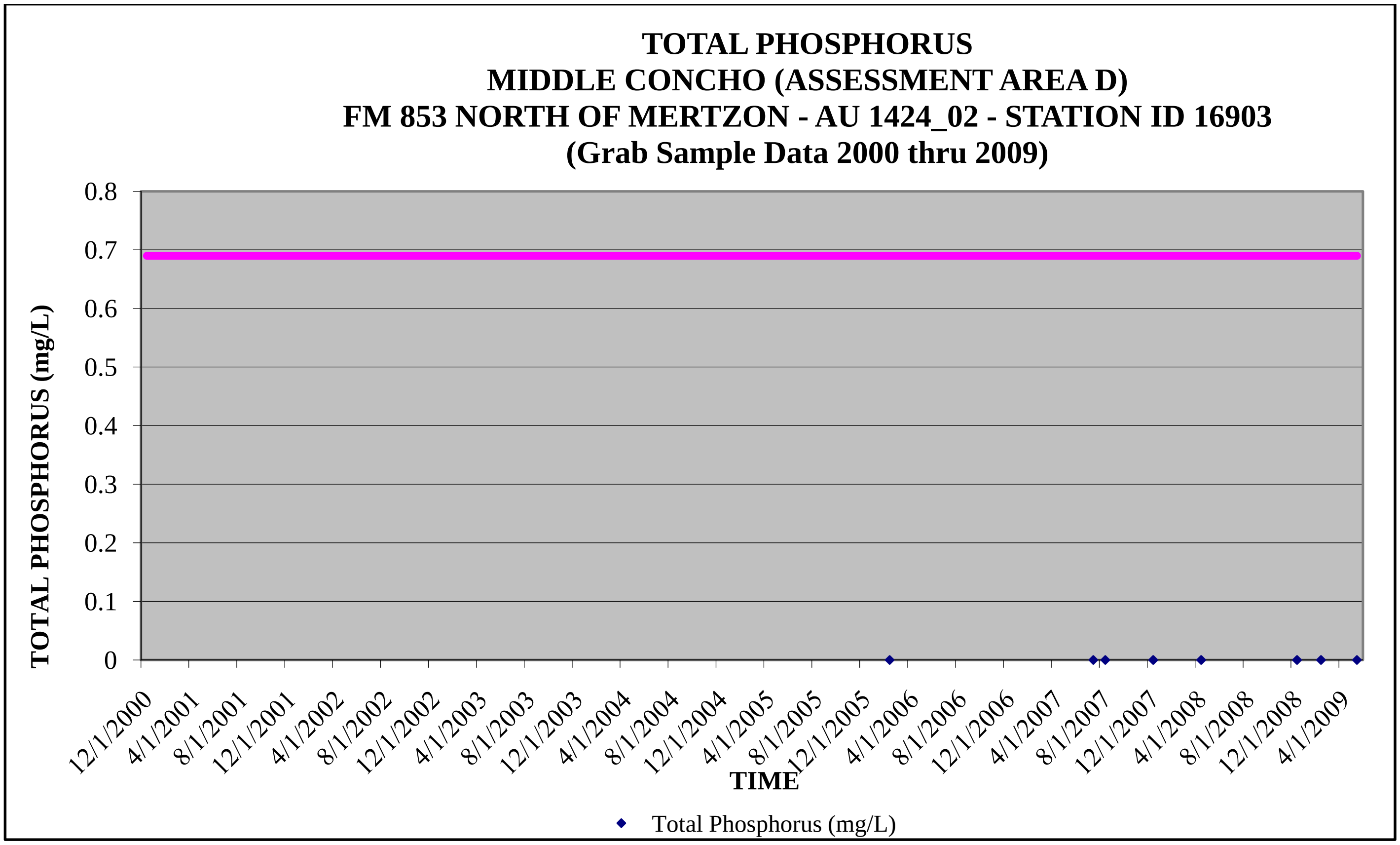

TOTAL PHOSPHORUS
SPRING CREEK (ASSESSMENT AREA D)
FM 2335 NEAR TANKERSLY - AU 1423A_01 - STATION ID 12161
(Grab Sample Data 2000 thru 2009)
TOTAL PHOSPHORUS (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
TIME
Total Phosphorus (mg/L)

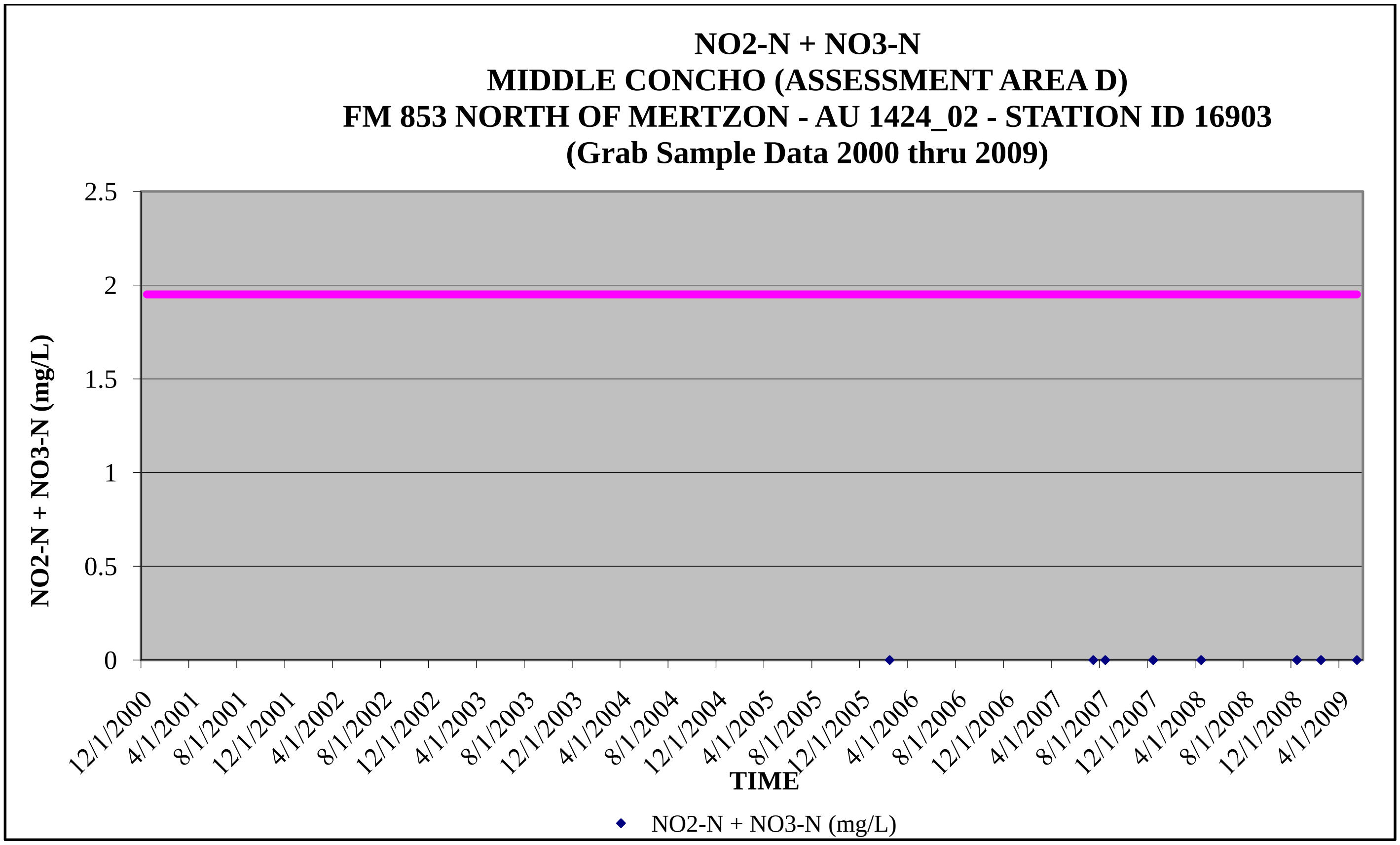

NO2-N + NO3-N
SPRING CREEK (ASSESSMENT AREA D)
FM 2335 NEAR TANKERSLY - AU 1423A_01 - STATION ID 12161
(Grab Sample Data 2000 thru 2009)
NO2-N + NO3-N (mg/L)
2.5
2
1.5
1
0.5
0
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
TIME
NO2-N + NO3-N (mg/L)

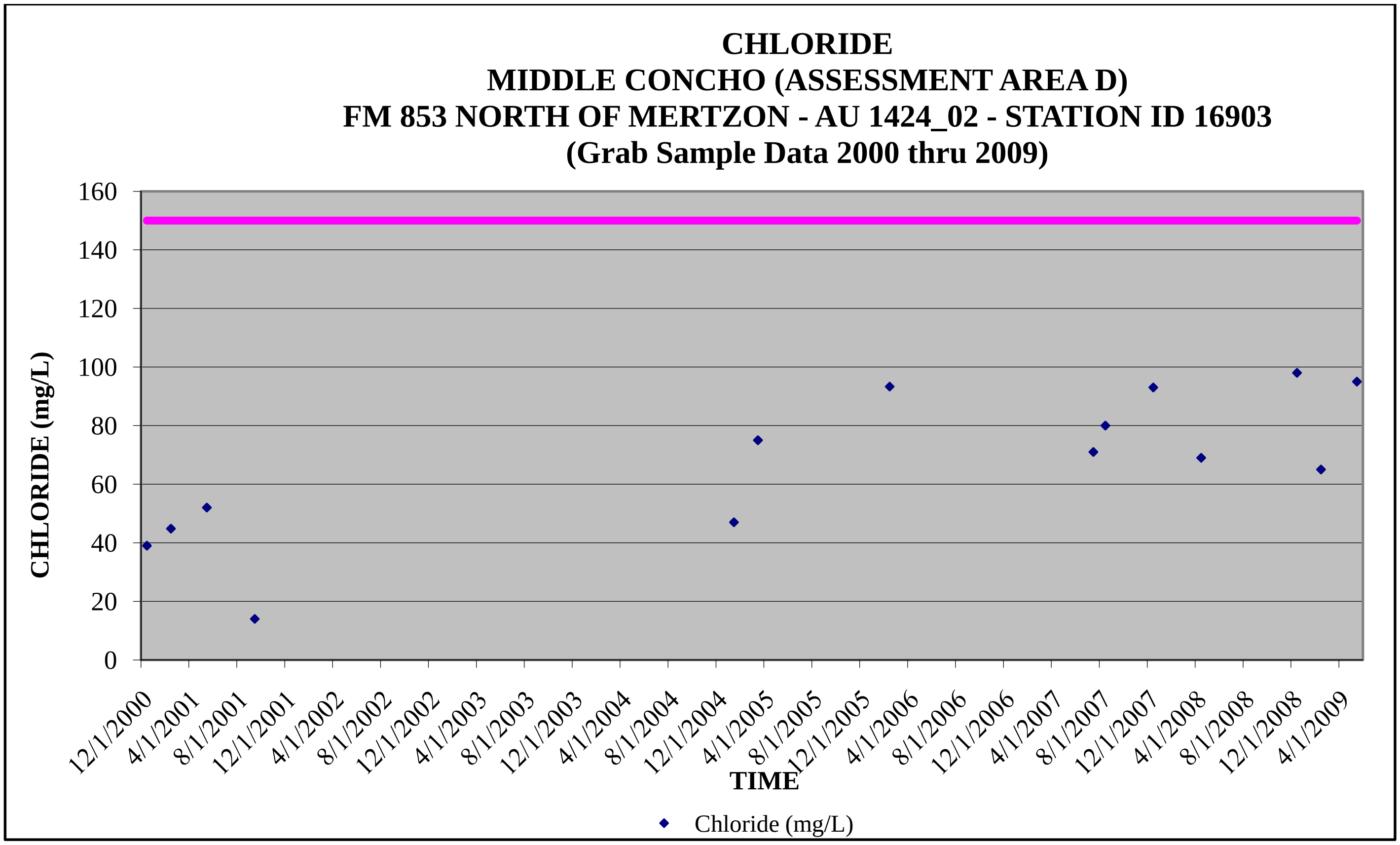

CHLORIDE
SPRING CREEK (ASSESSMENT AREA D)
FM 2335 NEAR TANKERSLY - AU 1423A_01 - STATION ID 12161
(Grab Sample Data 2000 thru 2009)
CHLORIDE (mg/L)
FLOW (CFS)
350
300
250
200
150
100
50
0
35
30
25
20
15
10
5
0
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
TIME
Chloride (mg/L)

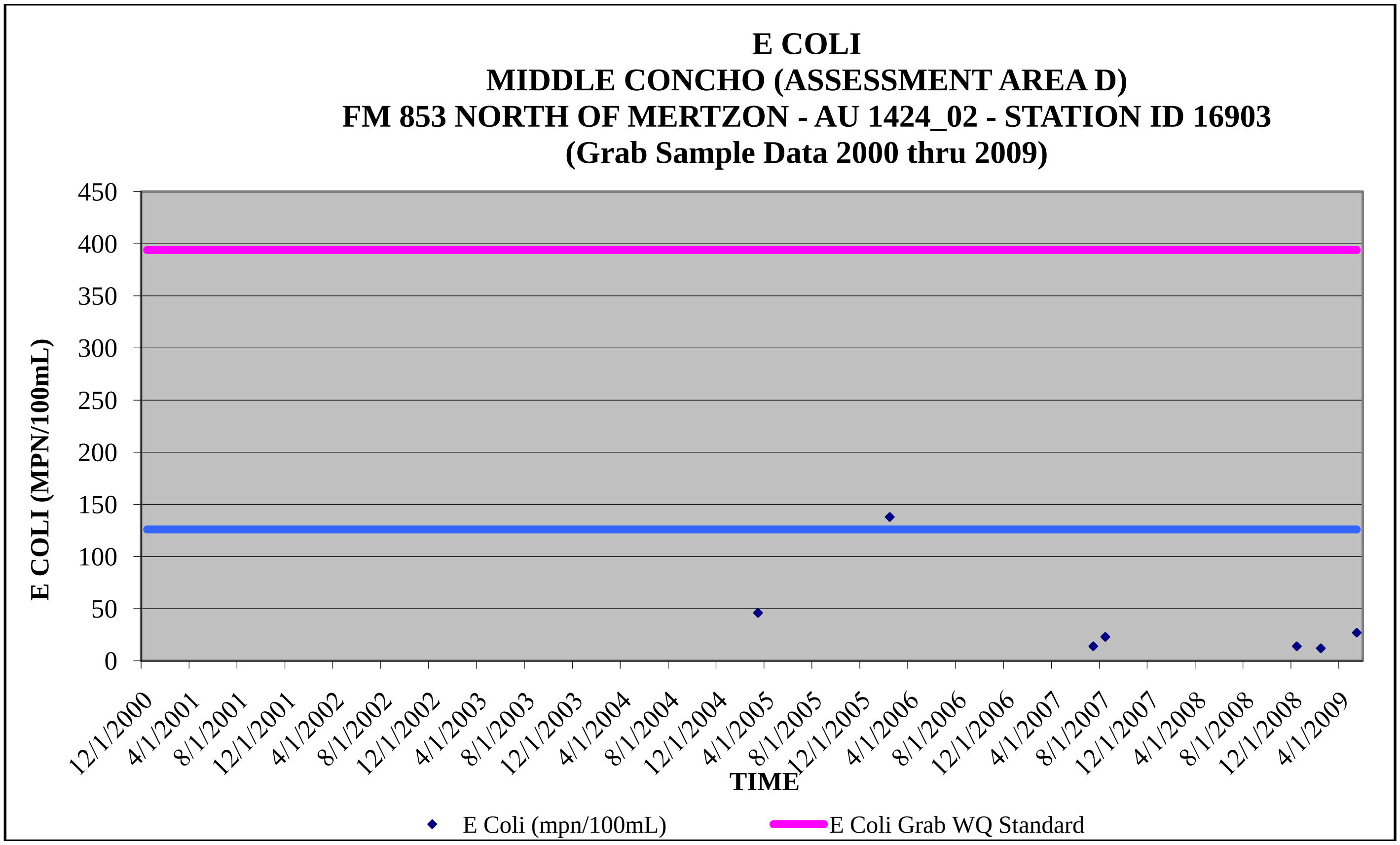

E COLI
SPRING CREEK (ASSESSMENT AREA D)
FM 2335 NEAR TANKERSLY - AU 1423A_01 - STATION ID 12161
(Grab Sample Data 2000 thru 2009)
E COLI (MPN/100mL)
0
50
100
150
200
250
300
350
400
450
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
TIME
E Coli (mpn/100 mL)
E Coli Grab WQ Standard

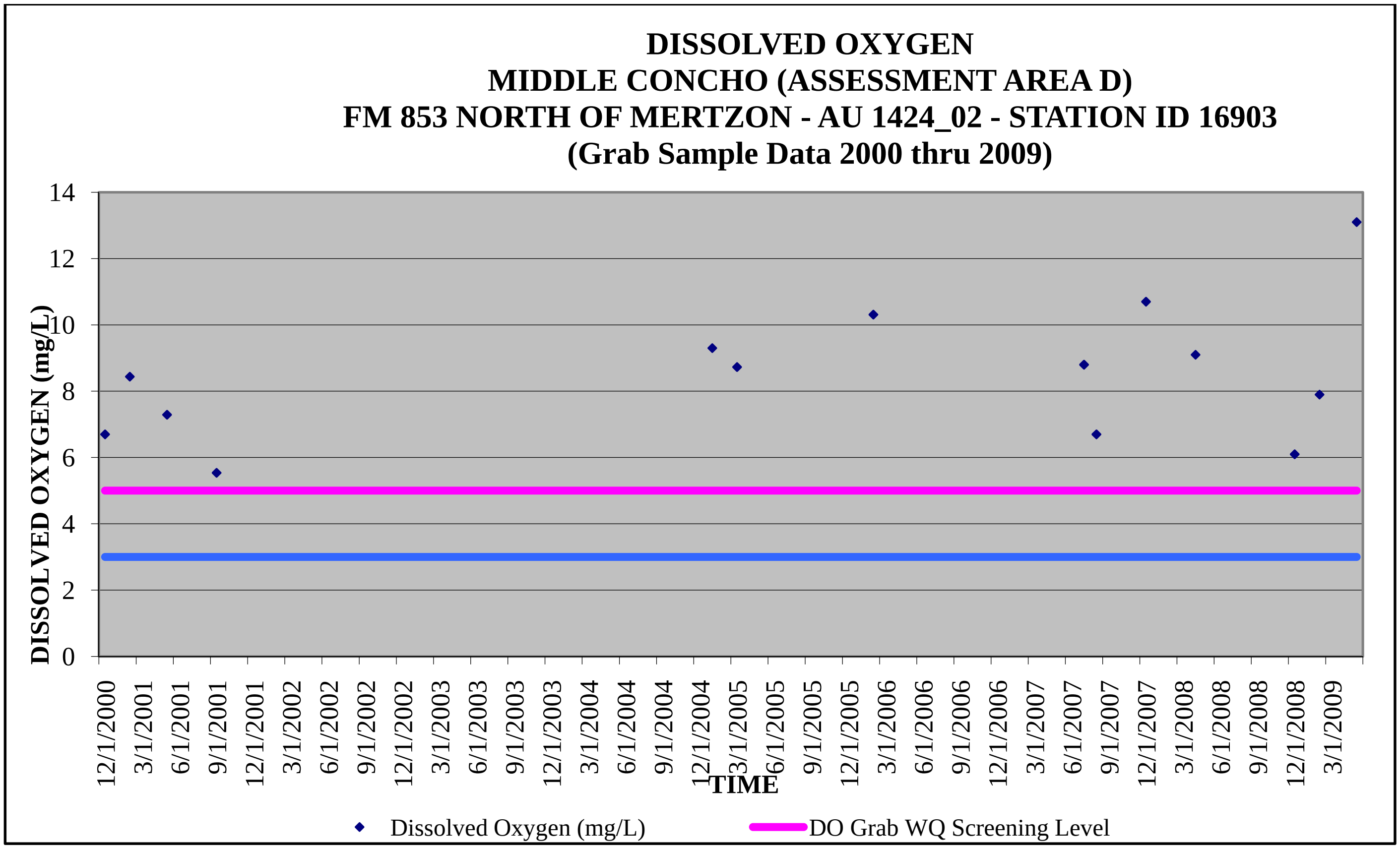

DISSOLVED OXYGEN
SPRING CREEK (ASSESSMENT AREA D)
FM 2335 NEAR TANKERSLY - AU 1423A_01 - STATION ID 12161
(Grab Sample Data 2000 thru 2009)
DISSOLVED OXYGEN (mg/L)
0
2
4
6
8
10
12
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level

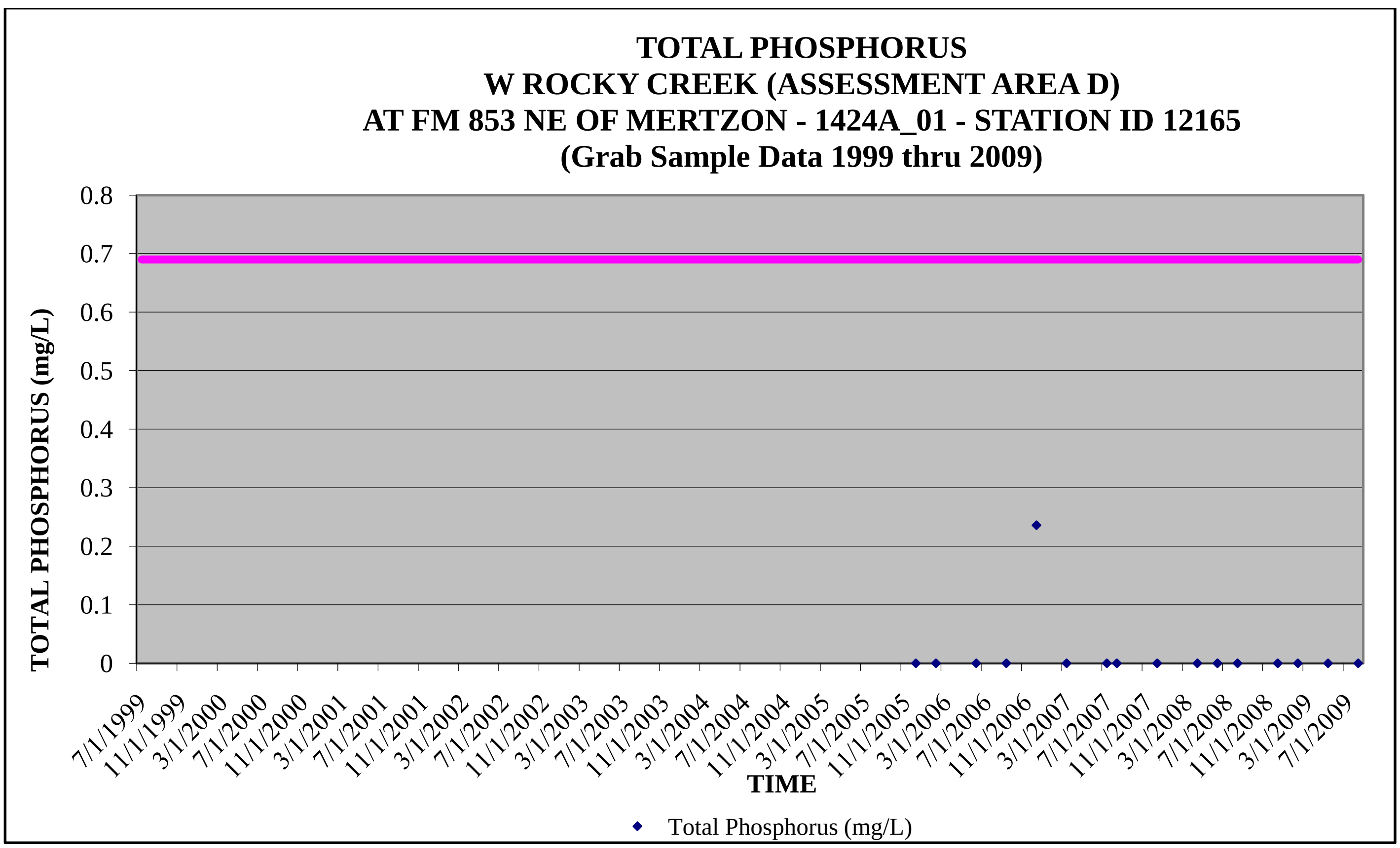

TOTAL PHOSPHORUS
MIDDLE CONCHO (ASSESSMENT AREA D)
FM 853 NORTH OF MERTZON - AU 1424_02 - STATION ID 16903
(Grab Sample Data 2000 thru 2009)
TOTAL PHOSPHORUS (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
TIME
Total Phosphorus (mg/L)

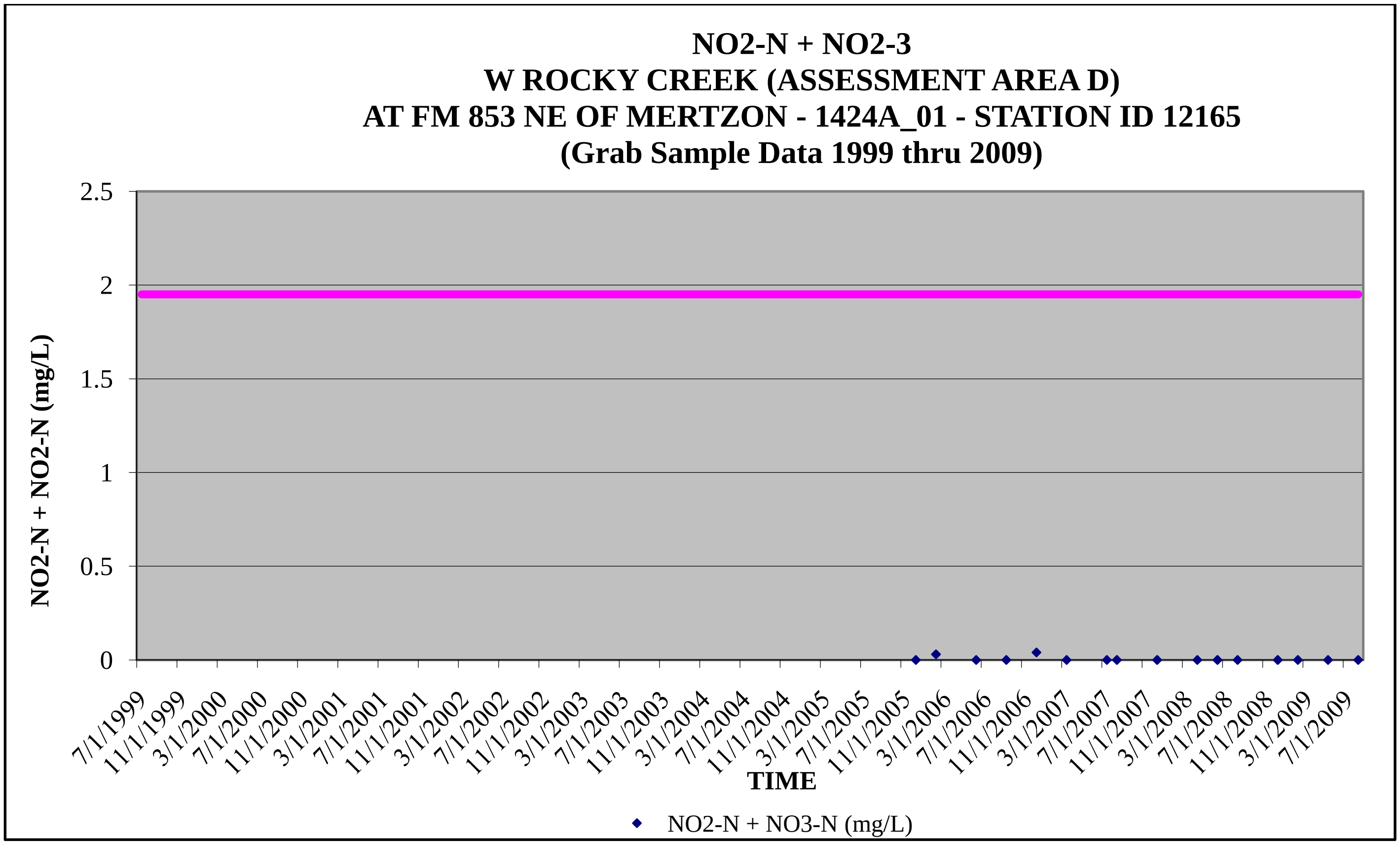

NO2-N + NO3-N
MIDDLE CONCHO (ASSESSMENT AREA D)
FM 853 NORTH OF MERTZON - AU 1424_02 - STATION ID 16903
(Grab Sample Data 2000 thru 2009)
NO2-N + NO3-N (mg/L)
2.5
2
1.5
1
0.5
0
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
TIME
NO2-N + NO3-N (mg/L)

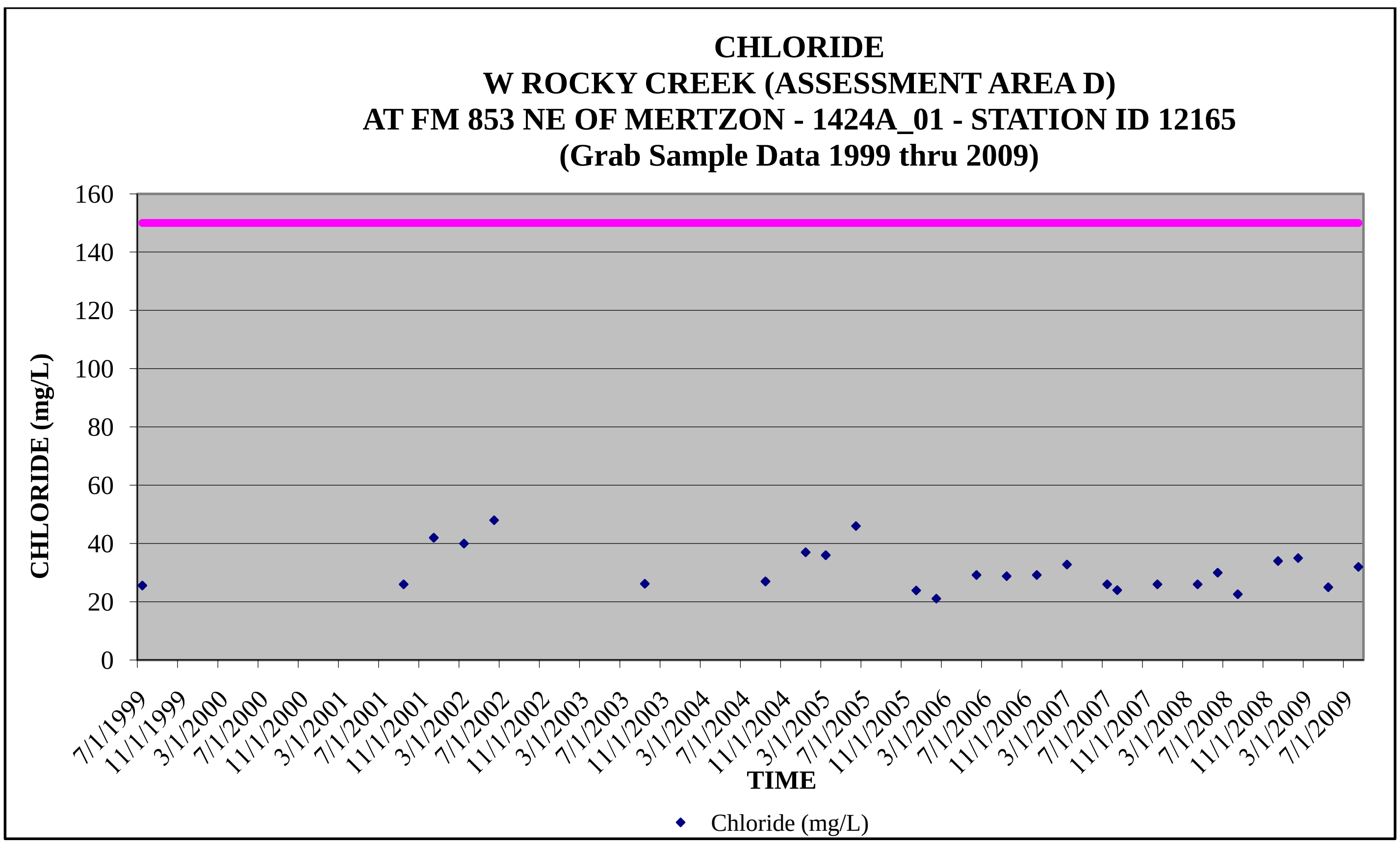

CHLORIDE
MIDDLE CONCHO (ASSESSMENT AREA D)
FM 853 NORTH OF MERTZON - AU 1424_02 - STATION ID 16903
(Grab Sample Data 2000 thru 2009)
CHLORIDE (mg/L)
TIME
Chloride (mg/L)

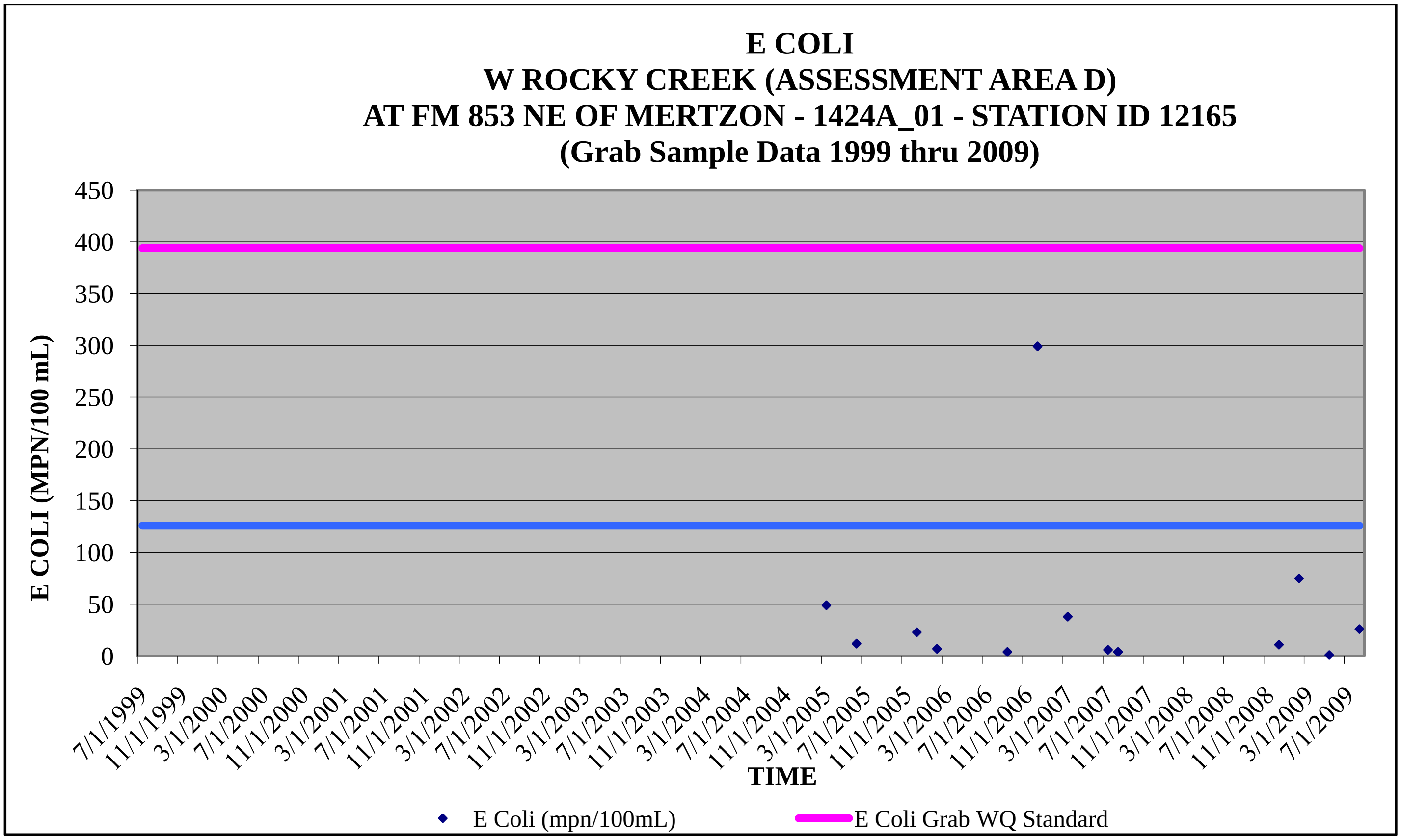

E COLI
MIDDLE CONCHO (ASSESSMENT AREA D)
FM 853 NORTH OF MERTZON - AU 1424_02 - STATION ID 16903
(Grab Sample Data 2000 thru 2009)
E COLI (MPN/100mL)
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

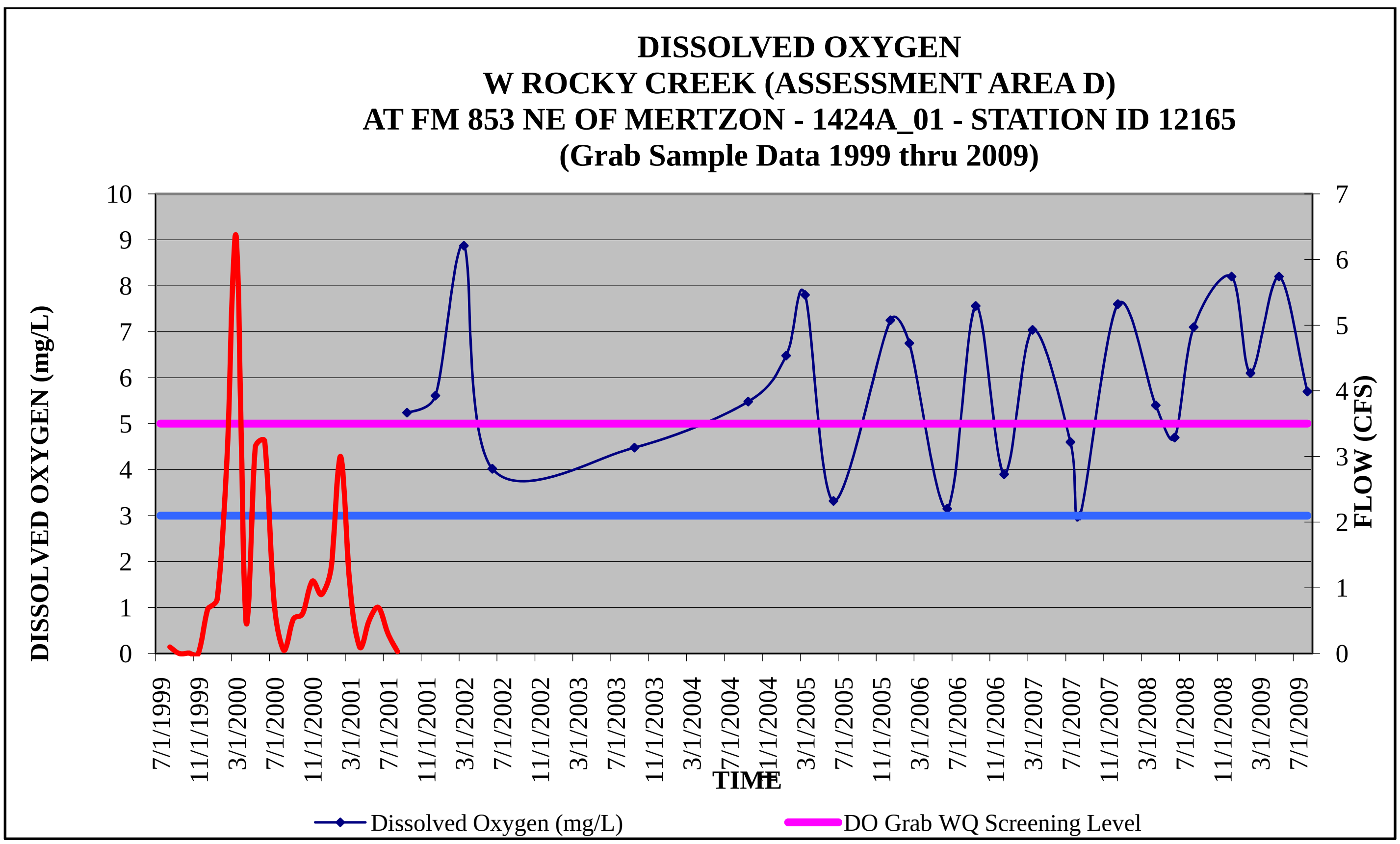

DISSOLVED OXYGEN
MIDDLE CONCHO (ASSESSMENT AREA D)
FM 853 NORTH OF MERTZON - AU 1424_02 - STATION ID 16903
(Grab Sample Data 2000 thru 2009)
DISSOLVED OXYGEN (mg/L)
14
12
10
8
6
4
2
0
12/1/2000
3/1/2001
6/1/2001
9/1/2001
12/1/2001
3/1/2002
6/1/2002
9/1/2002
12/1/2002
3/1/2003
6/1/2003
9/1/2003
12/1/2003
3/1/2004
6/1/2004
9/1/2004
12/1/2004
3/1/2005
6/1/2005
9/1/2005
12/1/2005
3/1/2006
6/1/2006
9/1/2006
12/1/2006
3/1/2007
6/1/2007
9/1/2007
12/1/2007
3/1/2008
6/1/2008
9/1/2008
12/1/2008
3/1/2009
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level

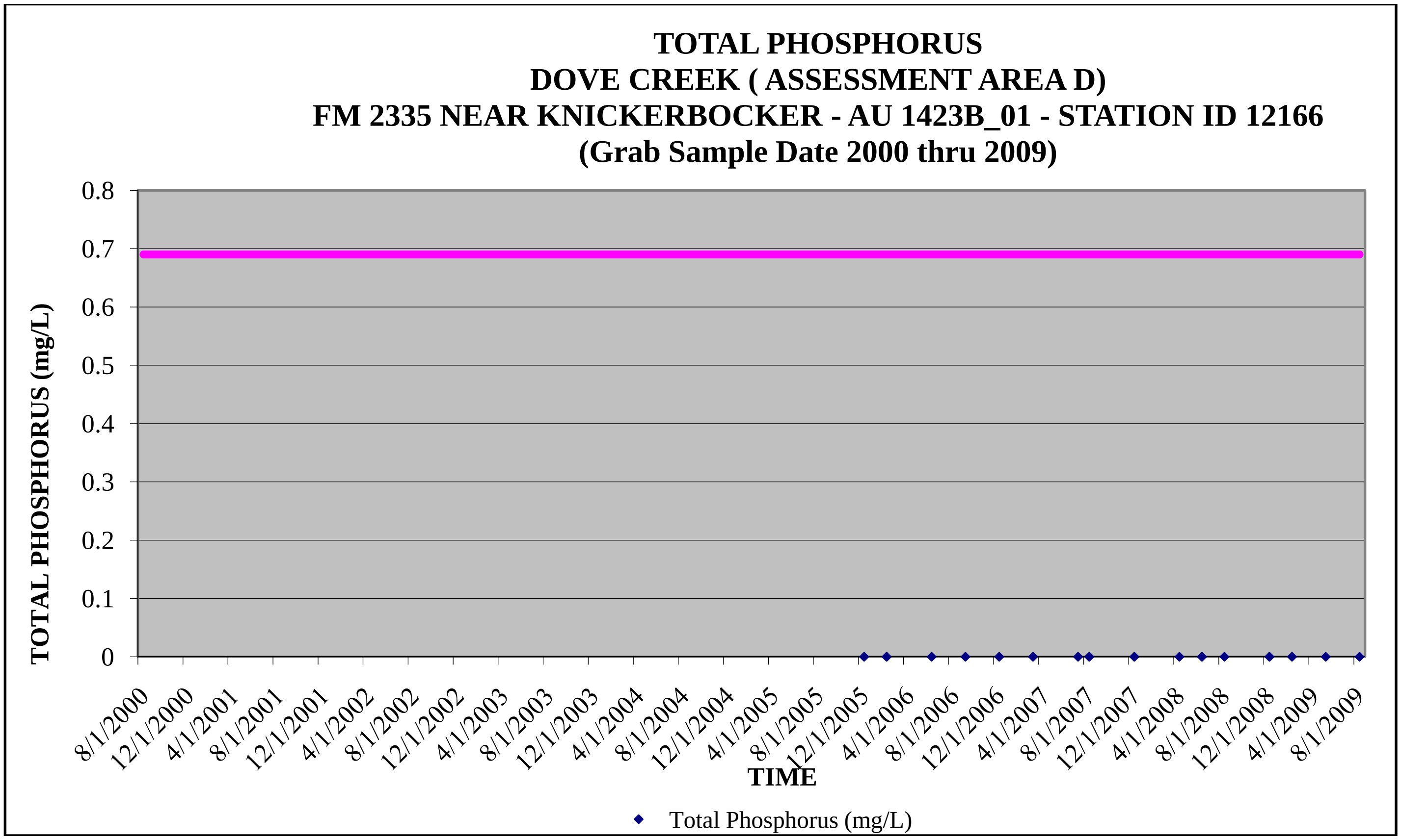

TOTAL PHOSPHORUS
W ROCKY CREEK (ASSESSMENT AREA D)
AT FM 853 NE OF MERTZON - 1424A_01 - STATION ID 12165
(Grab Sample Data 1999 thru 2009)
TOTAL PHOSPHORUS (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
7/1/1999
11/1/1999
3/1/2000
7/1/2000
11/1/2000
3/1/2001
7/1/2001
11/1/2001
3/1/2002
7/1/2002
11/1/2002
3/1/2003
7/1/2003
11/1/2003
3/1/2004
7/1/2004
11/1/2004
3/1/2005
7/1/2005
11/1/2005
3/1/2006
7/1/2006
11/1/2006
3/1/2007
7/1/2007
11/1/2007
3/1/2008
7/1/2008
11/1/2008
3/1/2009
7/1/2009
TIME
Total Phosphorus (mg/L)

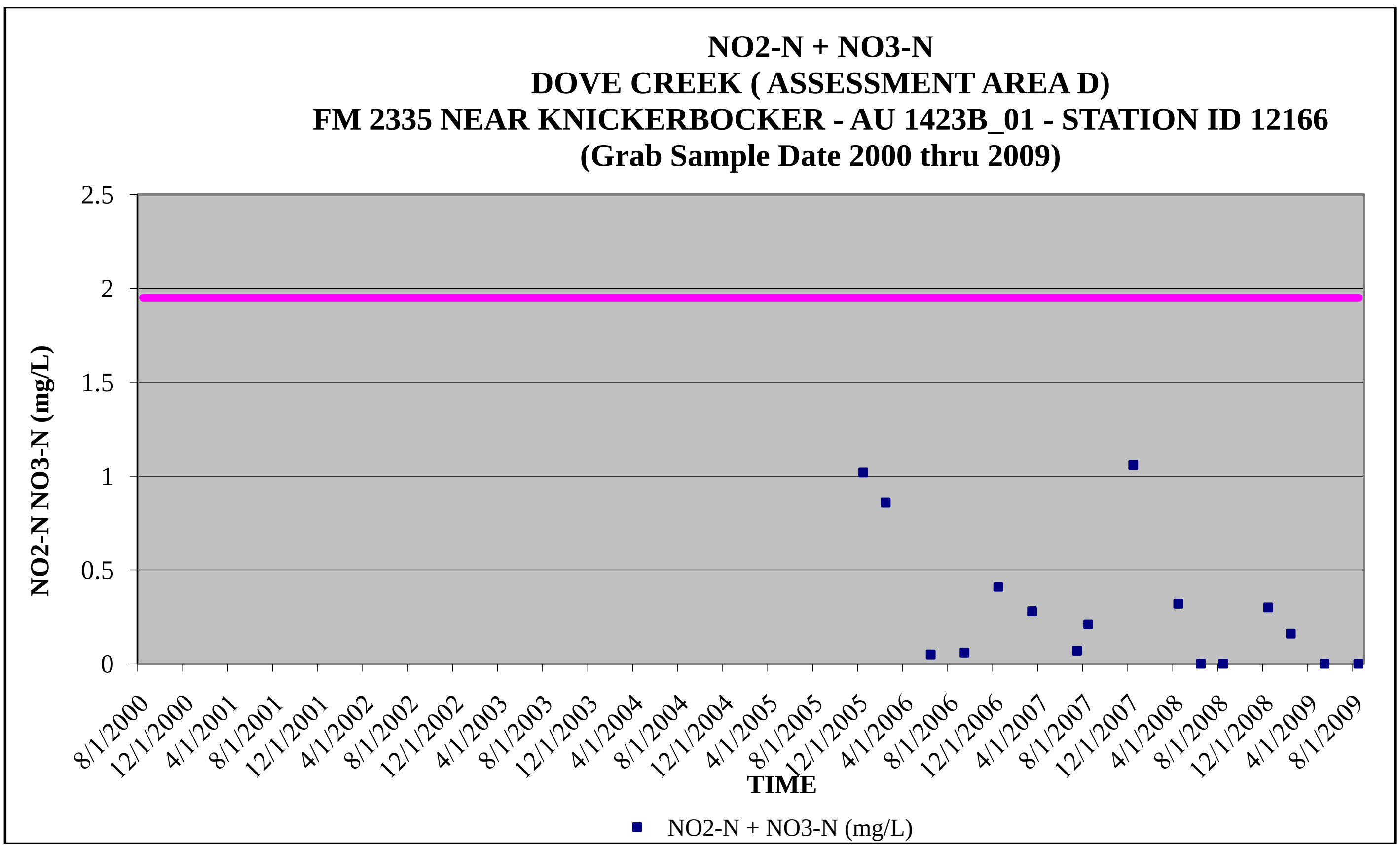

NO2-N + NO2-3
W ROCKY CREEK (ASSESSMENT AREA D)
AT FM 853 NE OF MERTZON - 1424A_01 - STATION ID 12165
(Grab Sample Data 1999 thru 2009)
NO2-N + NO2-N (mg/L)
2.5
2
1.5
1
0.5
0
7/1/1999
11/1/1999
3/1/2000
7/1/2000
11/1/2000
3/1/2001
7/1/2001
11/1/2001
3/1/2002
7/1/2002
11/1/2002
3/1/2003
7/1/2003
11/1/2003
3/1/2004
7/1/2004
11/1/2004
3/1/2005
7/1/2005
11/1/2005
3/1/2006
7/1/2006
11/1/2006
3/1/2007
7/1/2007
11/1/2007
3/1/2008
7/1/2008
11/1/2008
3/1/2009
7/1/2009
TIME
NO2-N + NO3-N (mg/L)

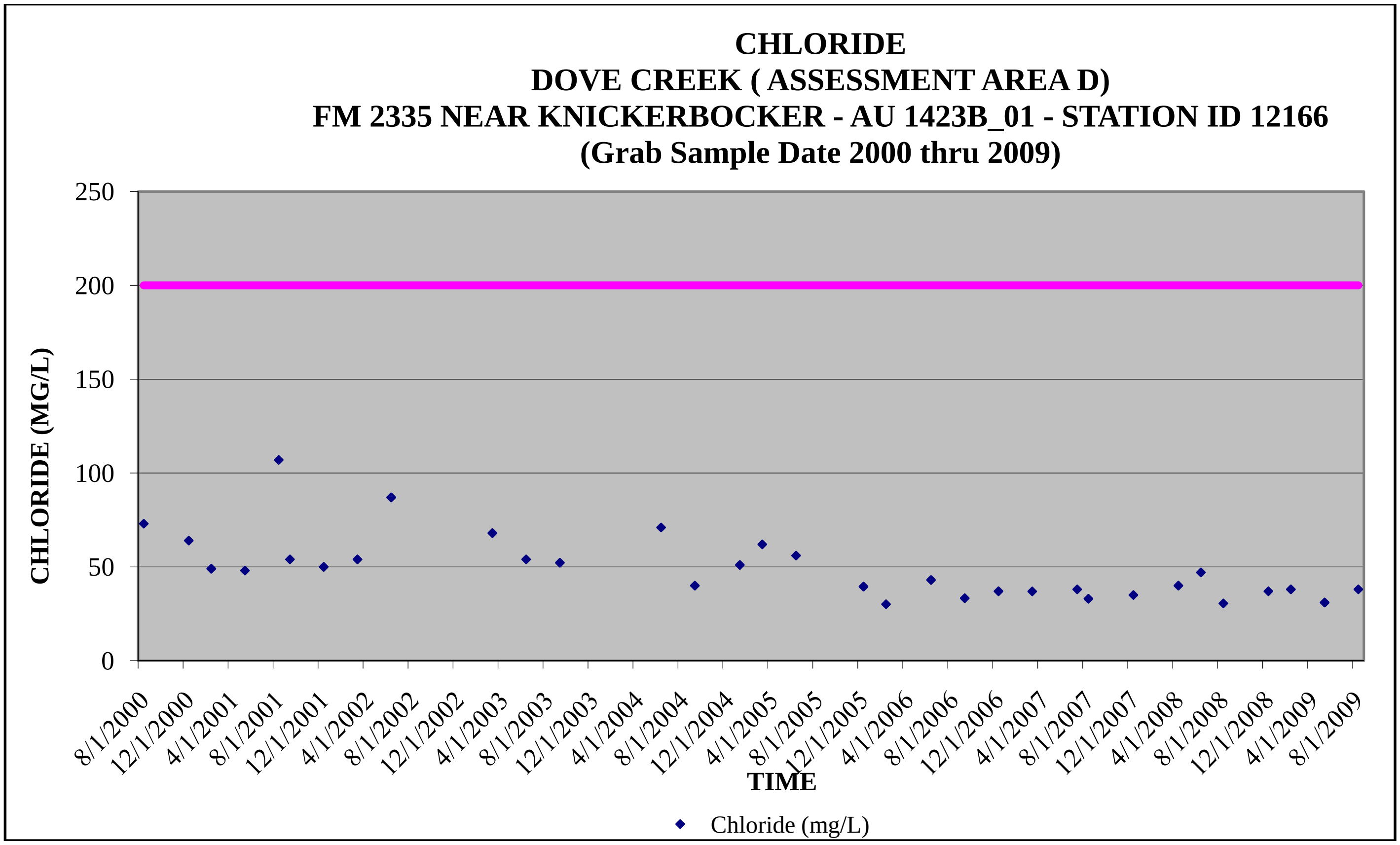

CHLORIDE
W ROCKY CREEK (ASSESSMENT AREA D)
AT FM 853 NE OF MERTZON - 1424A_01 - STATION ID 12165
(Grab Sample Data 1999 thru 2009)
CHLORIDE (mg/L)
160
140
120
100
80
60
40
20
0
7/1/1999
11/1/1999
3/1/2000
7/1/2000
11/1/2000
3/1/2001
7/1/2001
11/1/2001
3/1/2002
7/1/2002
11/1/2002
3/1/2003
7/1/2003
11/1/2003
3/1/2004
7/1/2004
11/1/2004
3/1/2005
7/1/2005
11/1/2005
3/1/2006
7/1/2006
11/1/2006
3/1/2007
7/1/2007
11/1/2007
3/1/2008
7/1/2008
11/1/2008
3/1/2009
7/1/2009
TIME
Chloride (mg/L)

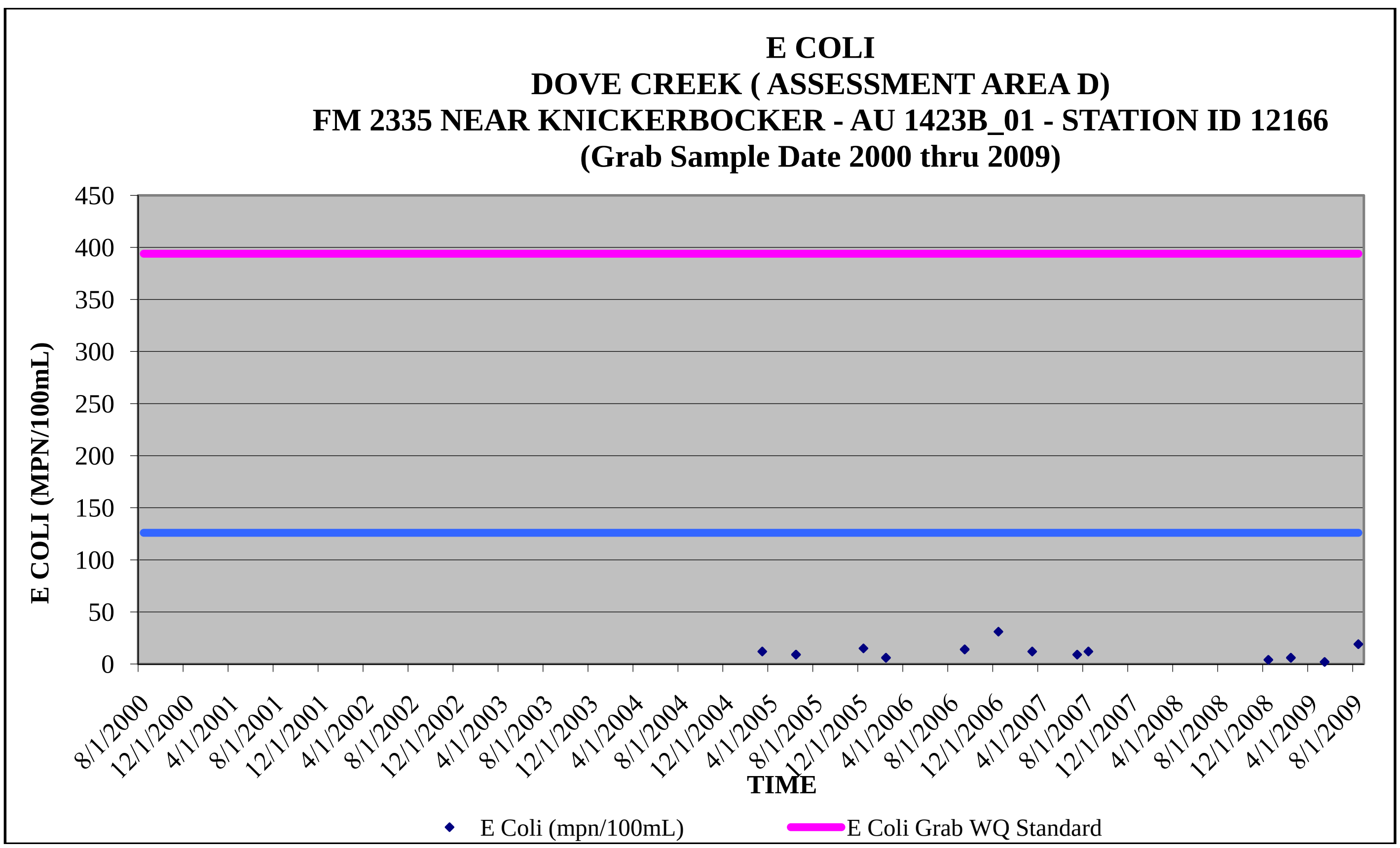

E COLI
W ROCKY CREEK (ASSESSMENT AREA D)
AT FM 853 NE OF MERTZON - 1424A_01 - STATION ID 12165
(Grab Sample Data 1999 thru 2009)
E COLI (MPN/100 mL)
450
400
350
300
250
200
150
100
50
0
7/1/1999
11/1/1999
3/1/2000
7/1/2000
11/1/2000
3/1/2001
7/1/2001
11/1/2001
3/1/2002
7/1/2002
11/1/2002
3/1/2003
7/1/2003
11/1/2003
3/1/2004
7/1/2004
11/1/2004
3/1/2005
7/1/2005
11/1/2005
3/1/2006
7/1/2006
11/1/2006
3/1/2007
7/1/2007
11/1/2007
3/1/2008
7/1/2008
11/1/2008
3/1/2009
7/1/2009
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

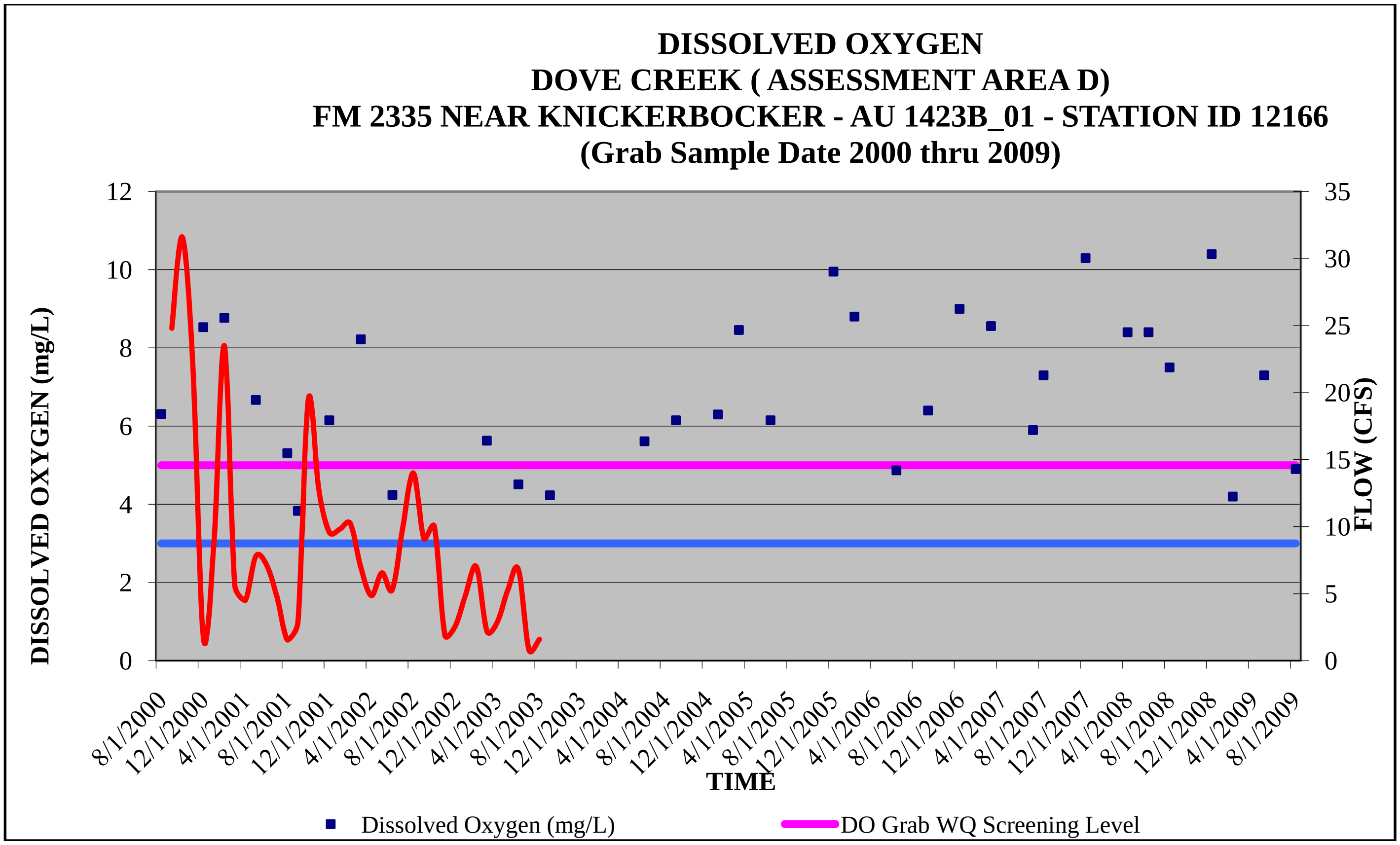

DISSOLVED OXYGEN
W ROCKY CREEK (ASSESSMENT AREA D)
AT FM 853 NE OF MERTZON - 1424A_01 - STATION ID 12165
(Grab Sample Data 1999 thru 2009)
DISSOLVED OXYGEN (mg/L)
10
9
8
7
6
5
4
3
2
1
0
FLOW (CFS)
7
6
5
4
3
2
1
0
7/1/1999
11/1/1999
3/1/2000
7/1/2000
11/1/2000
3/1/2001
7/1/2001
11/1/2001
3/1/2002
7/1/2002
11/1/2002
3/1/2003
7/1/2003
11/1/2003
3/1/2004
7/1/2004
11/1/2004
3/1/2005
7/1/2005
11/1/2005
3/1/2006
7/1/2006
11/1/2006
3/1/2007
7/1/2007
11/1/2007
3/1/2008
7/1/2008
11/1/2008
3/1/2009
7/1/2009
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level

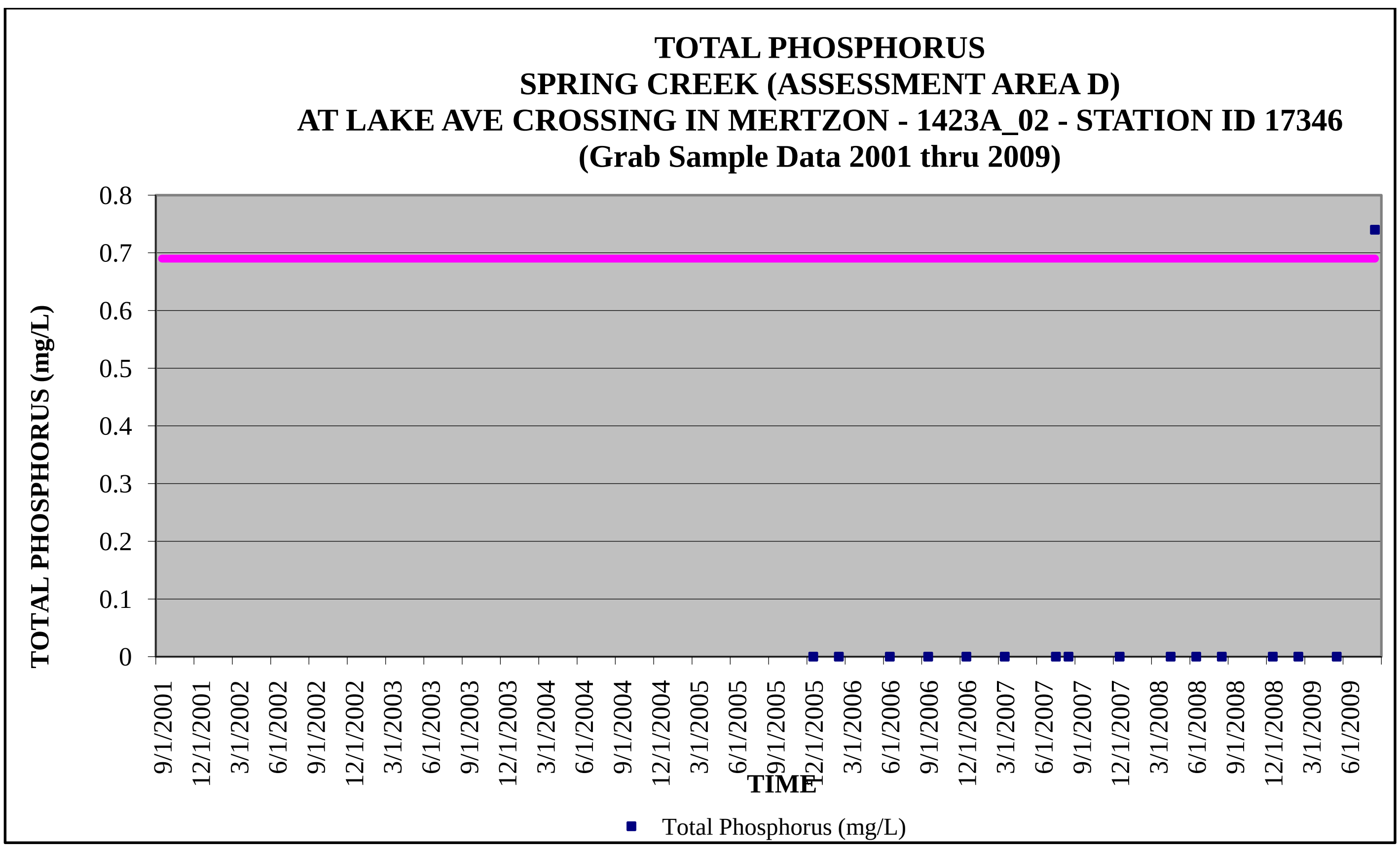

TOTAL PHOSPHORUS
DOVE CREEK (ASSESSMENT AREA D)
FM 2335 NEAR KNICKERBOCKER - AU 1423B_01 - STATION ID 12166
(Grab Sample Date 2000 thru 2009)
TOTAL PHOSPHORUS (mg/L)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
TIME
Total Phosphorus (mg/L)

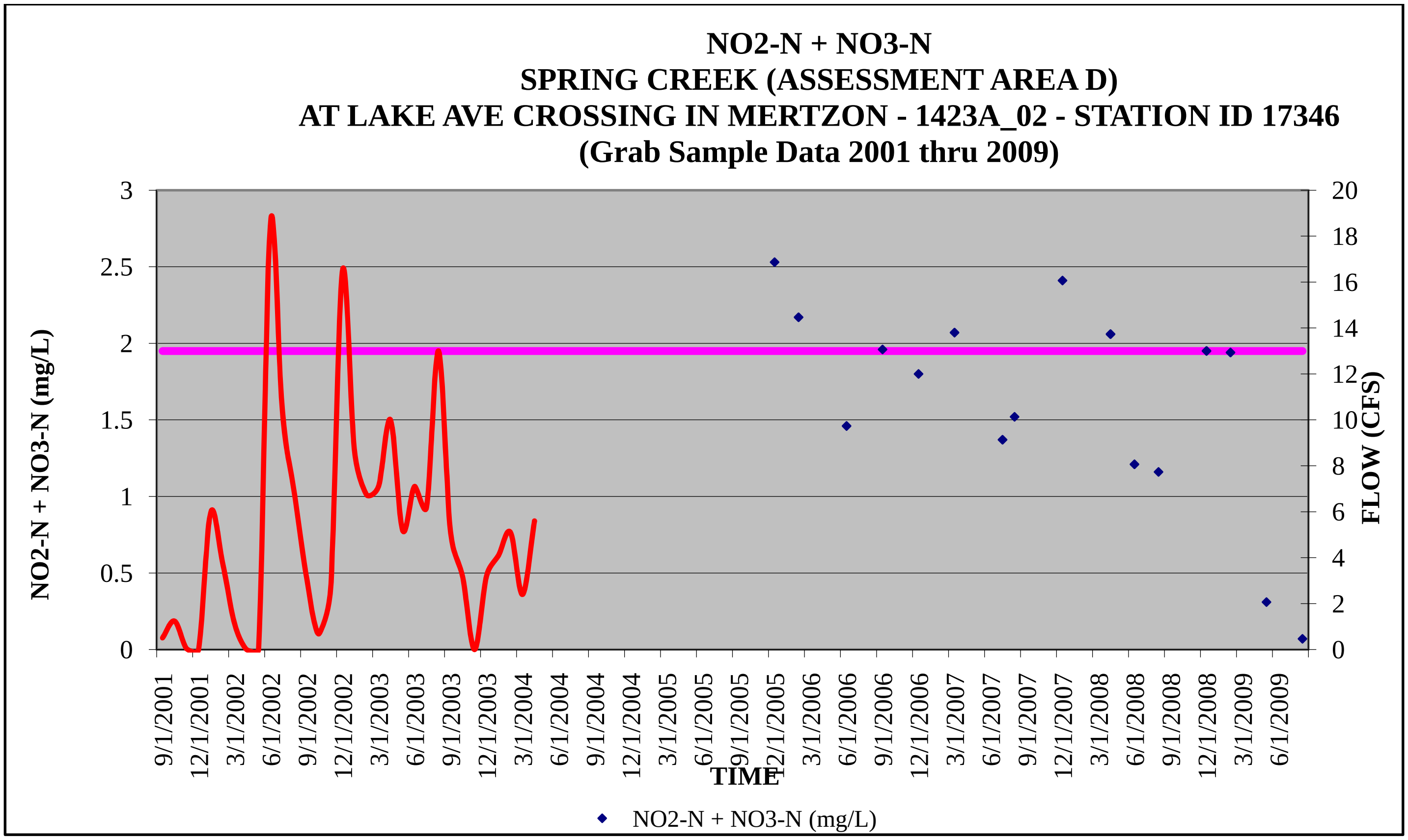

NO2-N + NO3-N
DOVE CREEK (ASSESSMENT AREA D)
FM 2335 NEAR KNICKERBOCKER - AU 1423B_01 - STATION ID 12166
(Grab Sample Date 2000 thru 2009)
NO2-N NO3-N (mg/L)
2.5
2
1.5
1
0.5
0
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
TIME
NO2-N + NO3-N (mg/L)

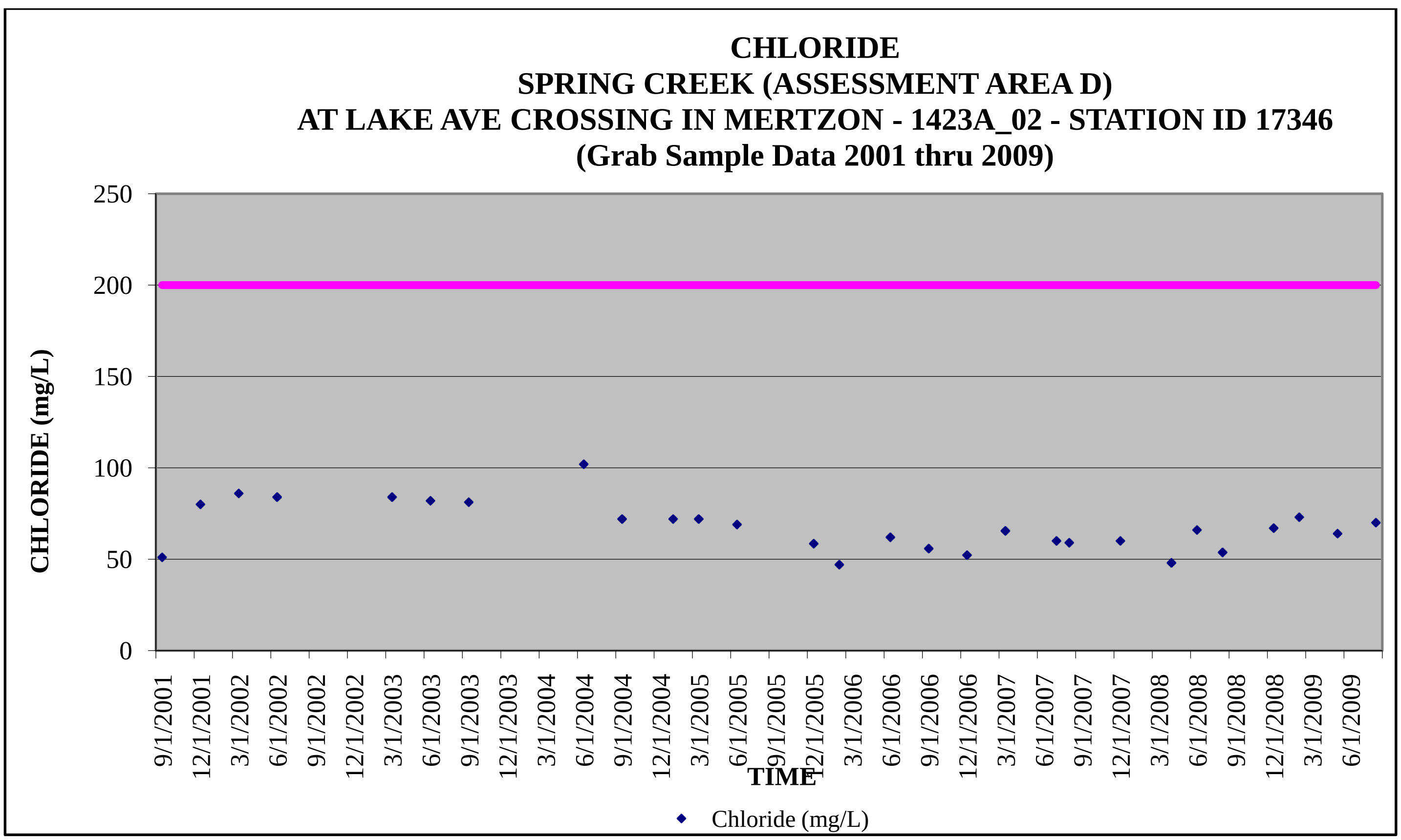

CHLORIDE
DOVE CREEK (ASSESSMENT AREA D)
FM 2335 NEAR KNICKERBOCKER - AU 1423B_01 - STATION ID 12166
(Grab Sample Date 2000 thru 2009)
CHLORIDE (MG/L)
250
200
150
100
50
0
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
TIME
Chloride (mg/L)

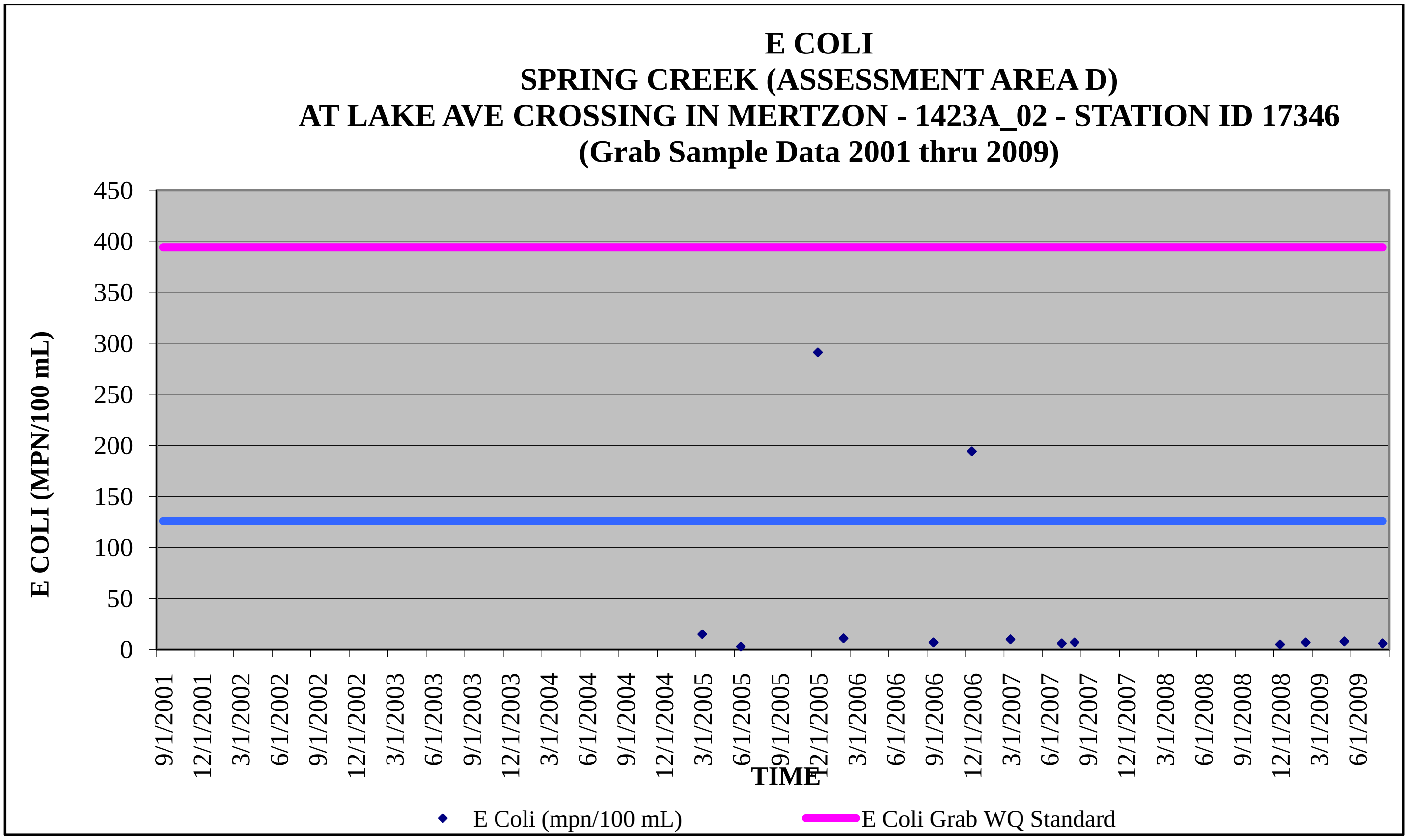

E COLI
DOVE CREEK (ASSESSMENT AREA D)
FM 2335 NEAR KNICKERBOCKER - AU 1423B_01 - STATION ID 12166
(Grab Sample Date 2000 thru 2009)
E COLI (MPN/100mL)
450
400
350
300
250
200
150
100
50
0
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

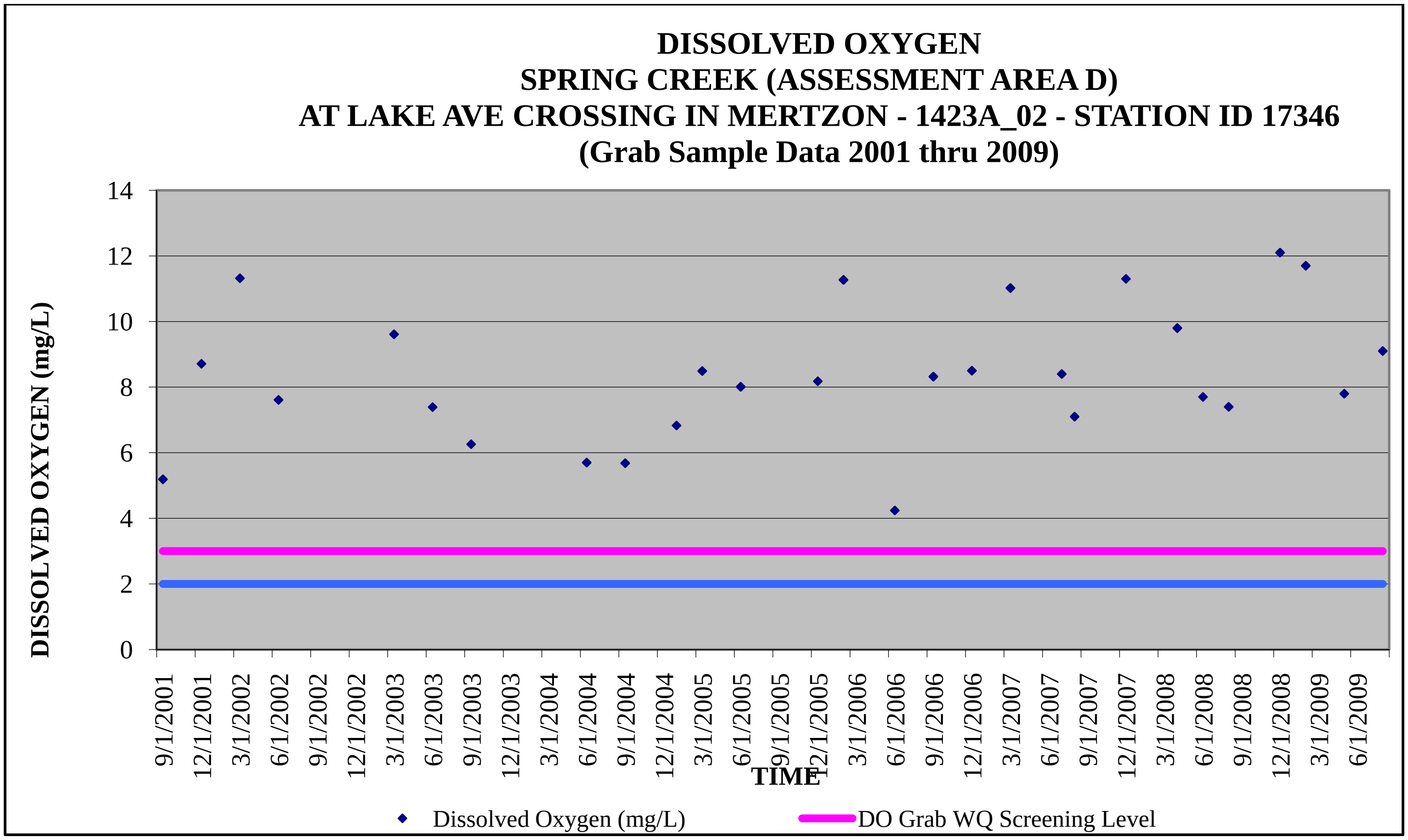

DISSOLVED OXYGEN
DOVE CREEK (ASSESSMENT AREA D)
FM 2335 NEAR KNICKERBOCKER - AU 1423B_01 - STATION ID 12166
(Grab Sample Date 2000 thru 2009)
DISSOLVED OXYGEN (mg/L)
FLOW (CFS)
TIME
8/1/2000
12/1/2000
4/1/2001
8/1/2001
12/1/2001
4/1/2002
8/1/2002
12/1/2002
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level


TOTAL PHOSPHORUS
SPRING CREEK (ASSESSMENT AREA D)
AT LAKE AVE CROSSING IN MERTZON - 1423A_02 - STATION ID 17346
(Grab Sample Data 2001 thru 2009)
TOTAL PHOSPHORUS (mg/L)
TIME
9/1/2001
12/1/2001
3/1/2002
6/1/2002
9/1/2002
12/1/2002
3/1/2003
6/1/2003
9/1/2003
12/1/2003
3/1/2004
6/1/2004
9/1/2004
12/1/2004
3/1/2005
6/1/2005
9/1/2005
12/1/2005
3/1/2006
6/1/2006
9/1/2006
12/1/2006
3/1/2007
6/1/2007
9/1/2007
12/1/2007
3/1/2008
6/1/2008
9/1/2008
12/1/2008
3/1/2009
6/1/2009
Total Phosphorus (mg/L)


NO2-N + NO3-N
SPRING CREEK (ASSESSMENT AREA D)
AT LAKE AVE CROSSING IN MERTZON - 1423A_02 - STATION ID 17346
(Grab Sample Data 2001 thru 2009)
NO2-N + NO3-N (mg/L)
FLOW (CFS)
TIME
NO2-N + NO3-N (mg/L)

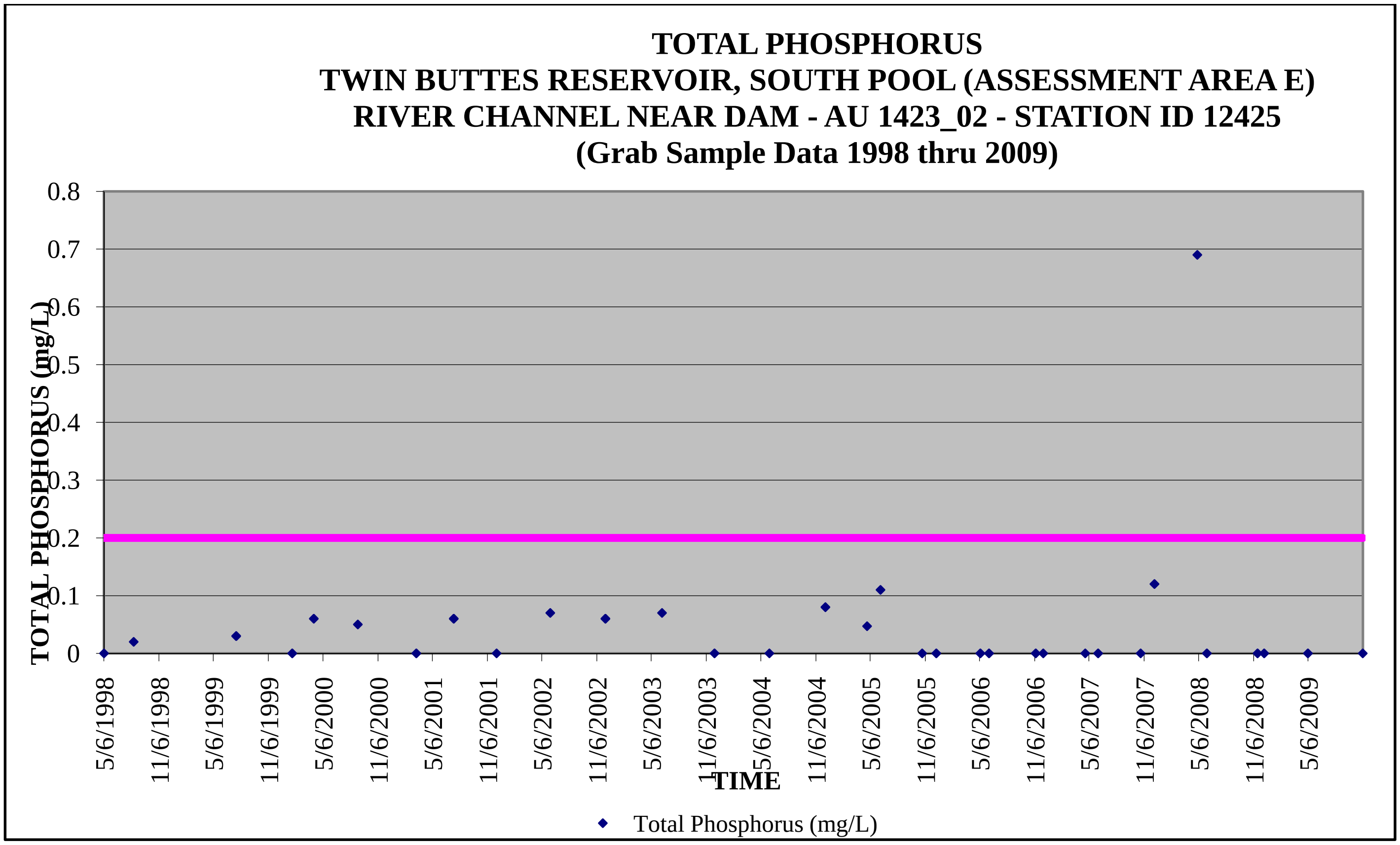

CHLORIDE
SPRING CREEK (ASSESSMENT AREA D)
AT LAKE AVE CROSSING IN MERTZON - 1423A_02 - STATION ID 17346
(Grab Sample Data 2001 thru 2009)
CHLORIDE (mg/L)
TIME
Chloride (mg/L)

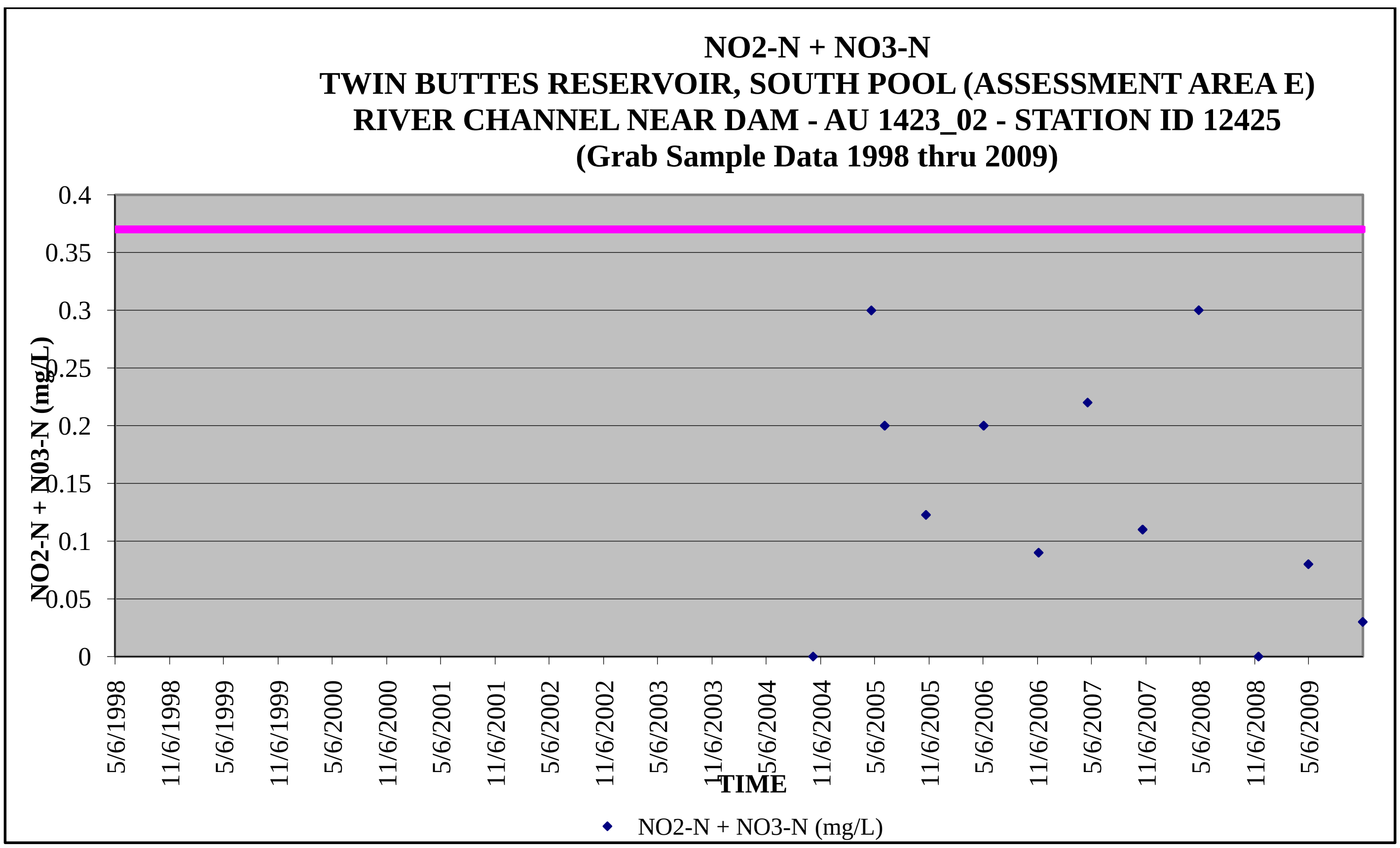

E COLI
SPRING CREEK (ASSESSMENT AREA D)
AT LAKE AVE CROSSING IN MERTZON - 1423A_02 - STATION ID 17346
(Grab Sample Data 2001 thru 2009)
E COLI (MPN/100 mL)
TIME
E Coli (mpn/100 mL)
E Coli Grab WQ Standard

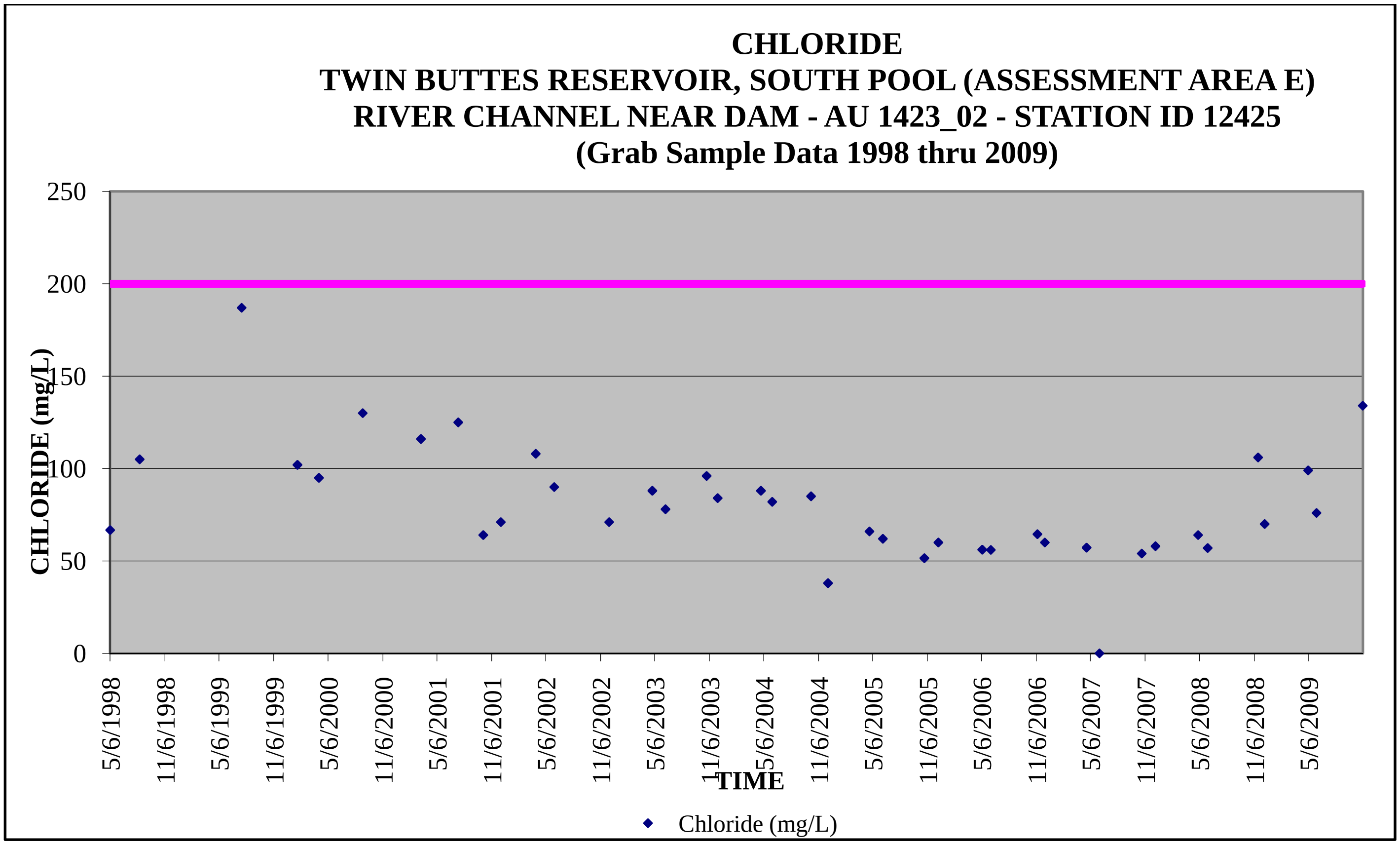

DISSOLVED OXYGEN
SPRING CREEK (ASSESSMENT AREA D)
AT LAKE AVE CROSSING IN MERTZON - 1423A_02 - STATION ID 17346
(Grab Sample Data 2001 thru 2009)
DISSOLVED OXYGEN (mg/L)
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level

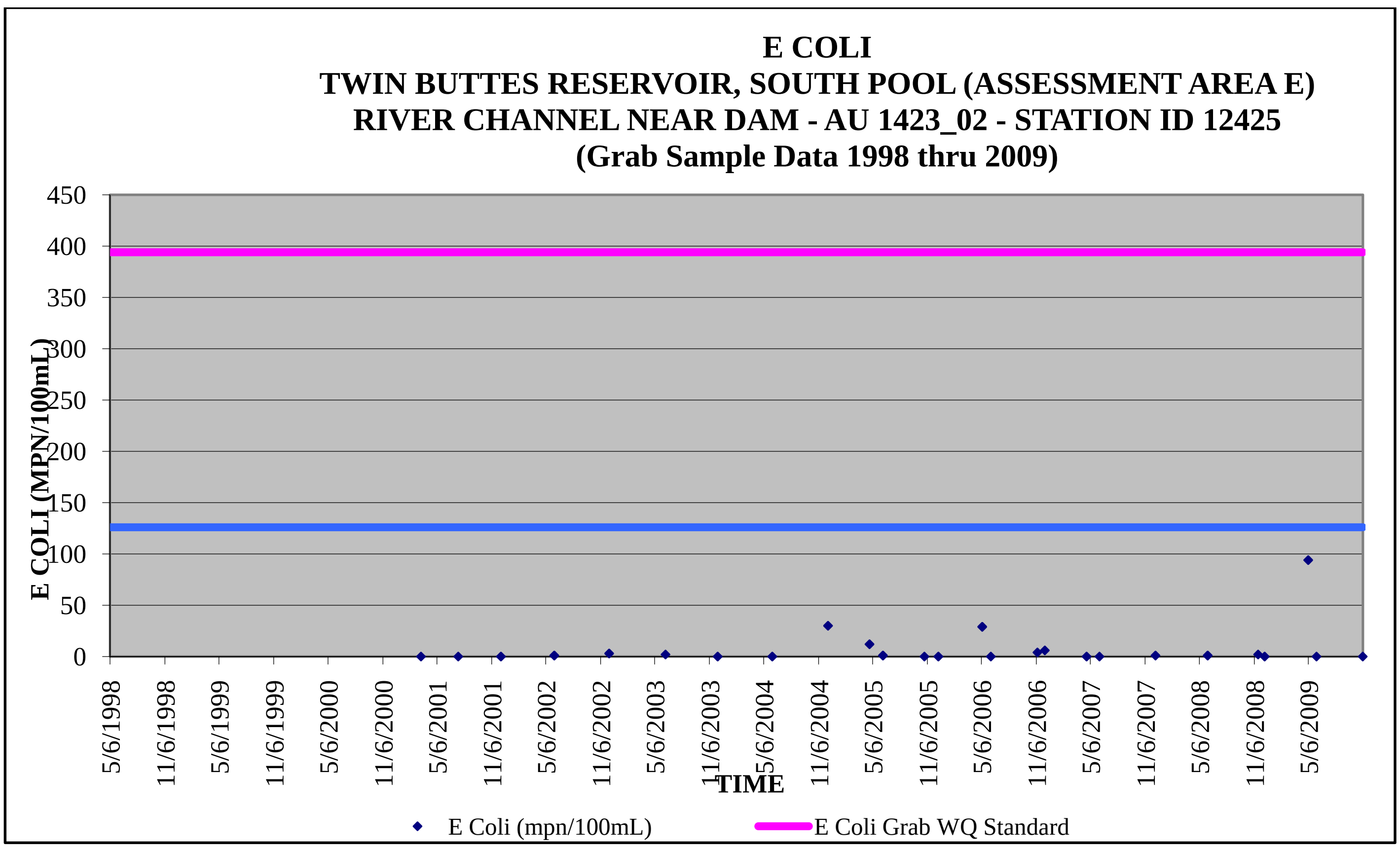
APPENDIX E

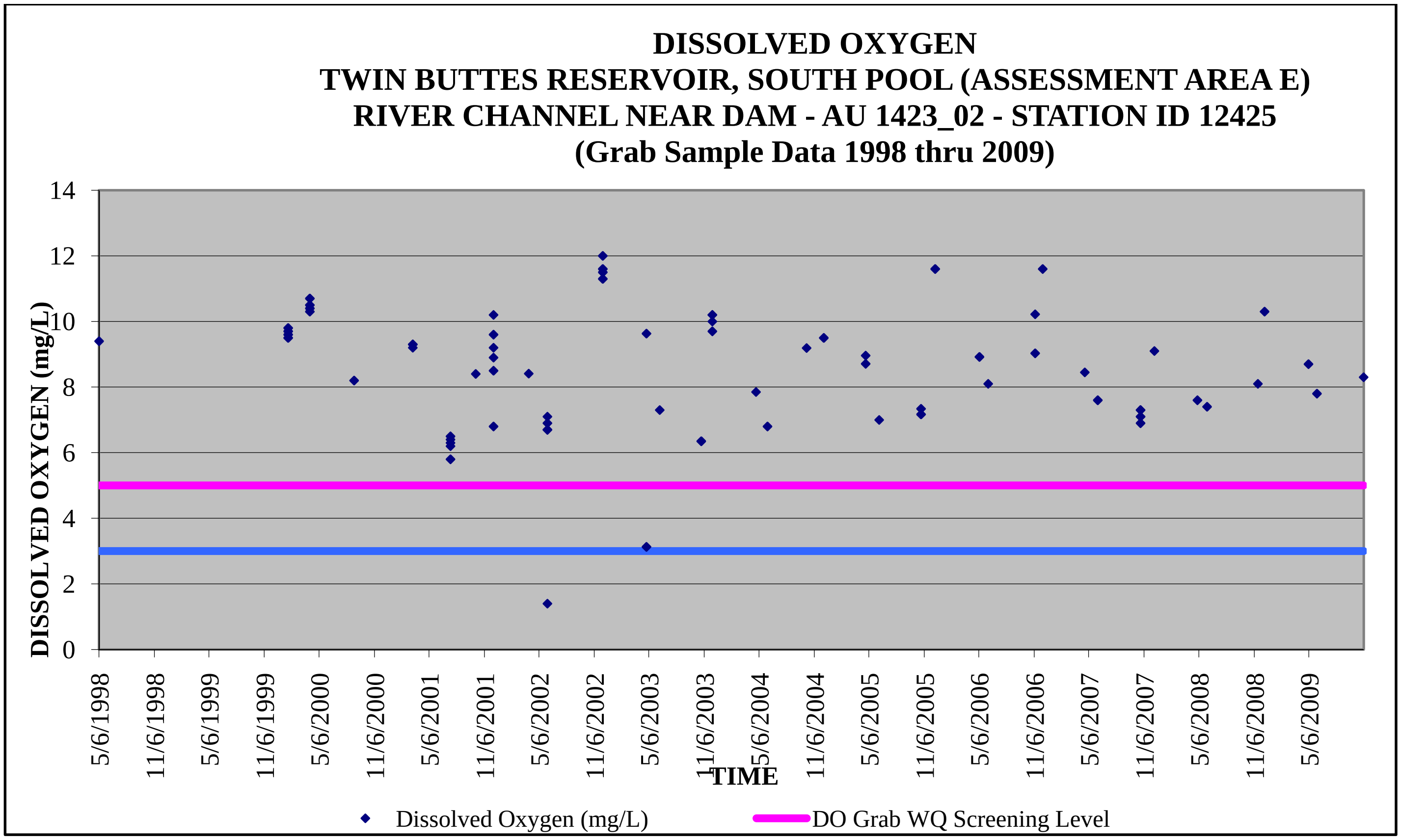
Assessment Area E Supporting Data

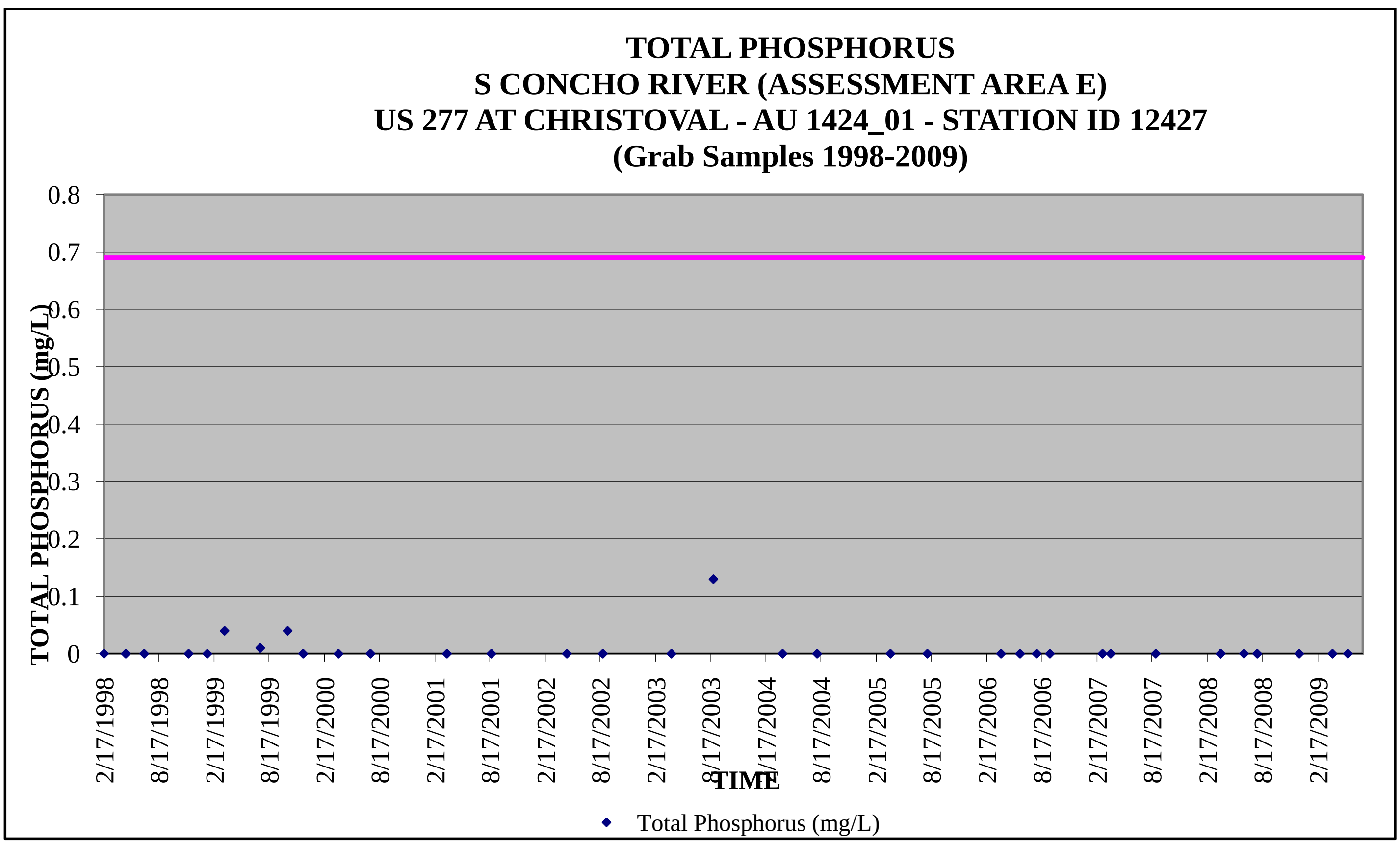

TOTAL PHOSPHORUS
TWIN BUTTES RESERVOIR, SOUTH POOL (ASSESSMENT AREA E)
RIVER CHANNEL NEAR DAM - AU 1423_02 - STATION ID 12425
(Grab Sample Data 1998 thru 2009)
TOTAL PHOSPHORUS (mg/L)
TIME
Total Phosphorus (mg/L)

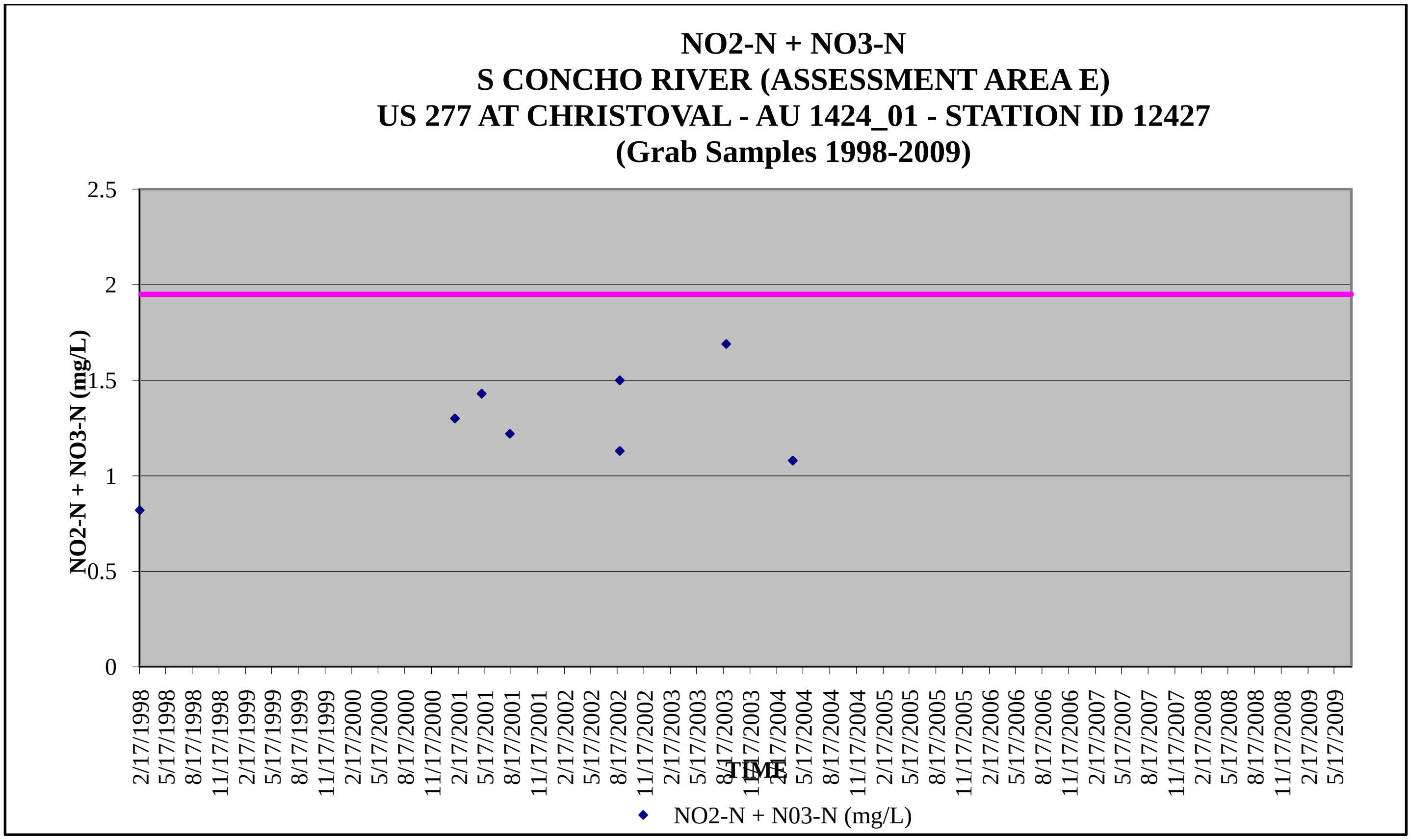

NO2-N + NO3-N
TWIN BUTTES RESERVOIR, SOUTH POOL (ASSESSMENT AREA E)
RIVER CHANNEL NEAR DAM - AU 1423_02 - STATION ID 12425
(Grab Sample Data 1998 thru 2009)
NO2-N + NO3-N (mg/L)
TIME
NO2-N + NO3-N (mg/L)

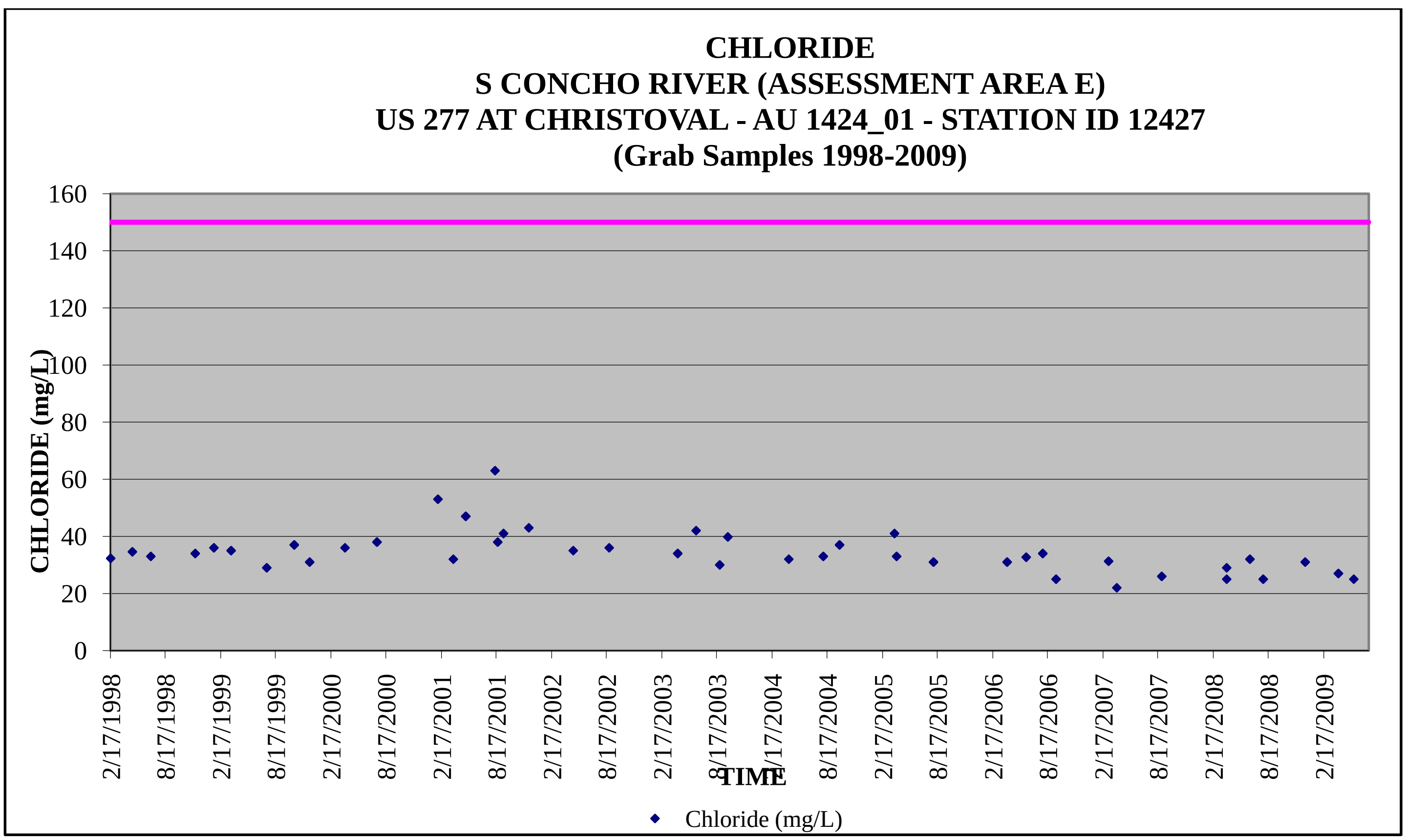

CHLORIDE
TWIN BUTTES RESERVOIR, SOUTH POOL (ASSESSMENT AREA E)
RIVER CHANNEL NEAR DAM - AU 1423_02 - STATION ID 12425
(Grab Sample Data 1998 thru 2009)
CHLORIDE (mg/L)
250
200
150
100
50
0
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
TIME
Chloride (mg/L)

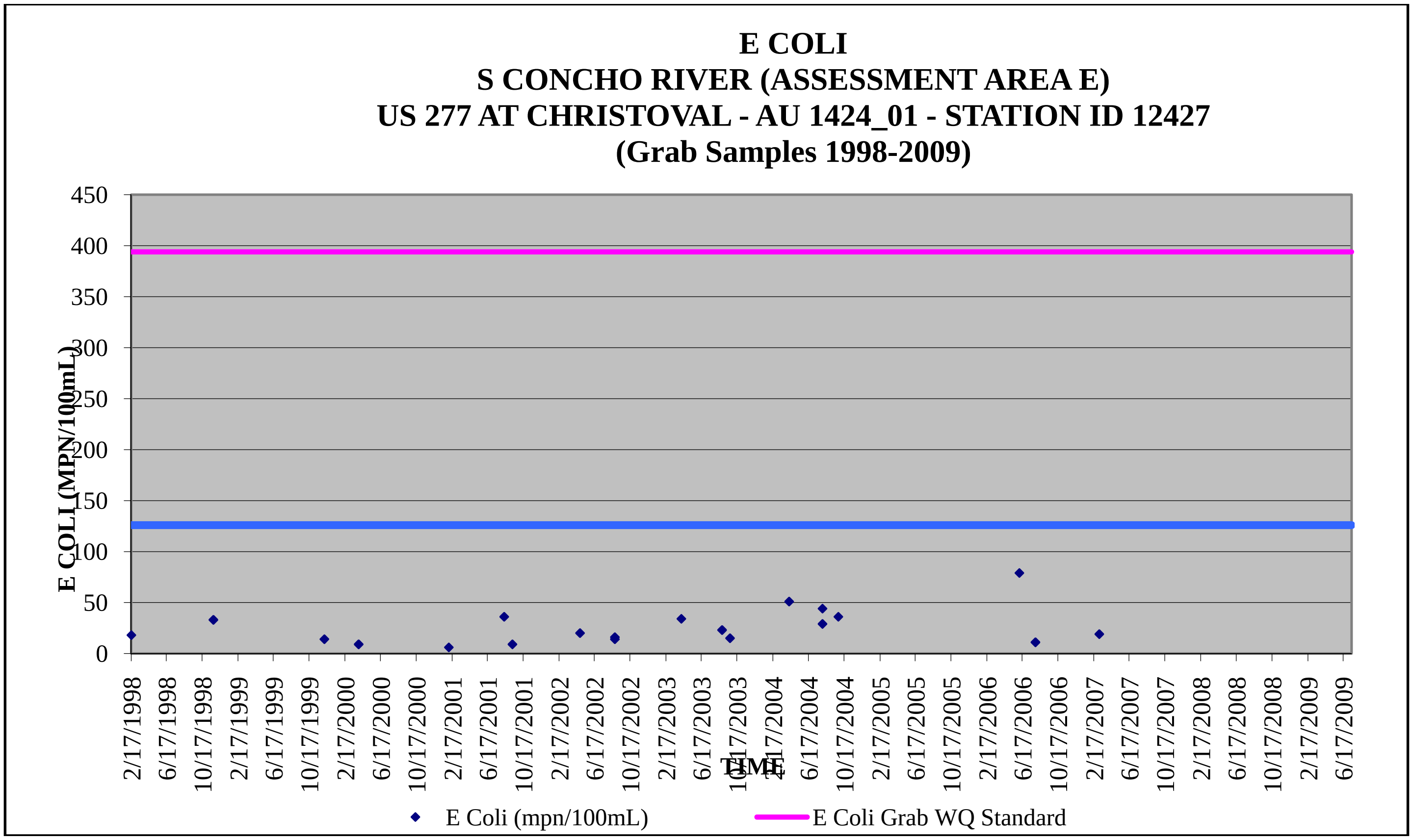

E COLI
TWIN BUTTES RESERVOIR, SOUTH POOL (ASSESSMENT AREA E)
RIVER CHANNEL NEAR DAM - AU 1423_02 - STATION ID 12425
(Grab Sample Data 1998 thru 2009)
E COLI (MPN/100mL)
450
400
350
300
250
200
150
100
50
0
5/6/1998
11/6/1998
5/6/1999
11/6/1999
5/6/2000
11/6/2000
5/6/2001
11/6/2001
5/6/2002
11/6/2002
5/6/2003
11/6/2003
5/6/2004
11/6/2004
5/6/2005
11/6/2005
5/6/2006
11/6/2006
5/6/2007
11/6/2007
5/6/2008
11/6/2008
5/6/2009
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

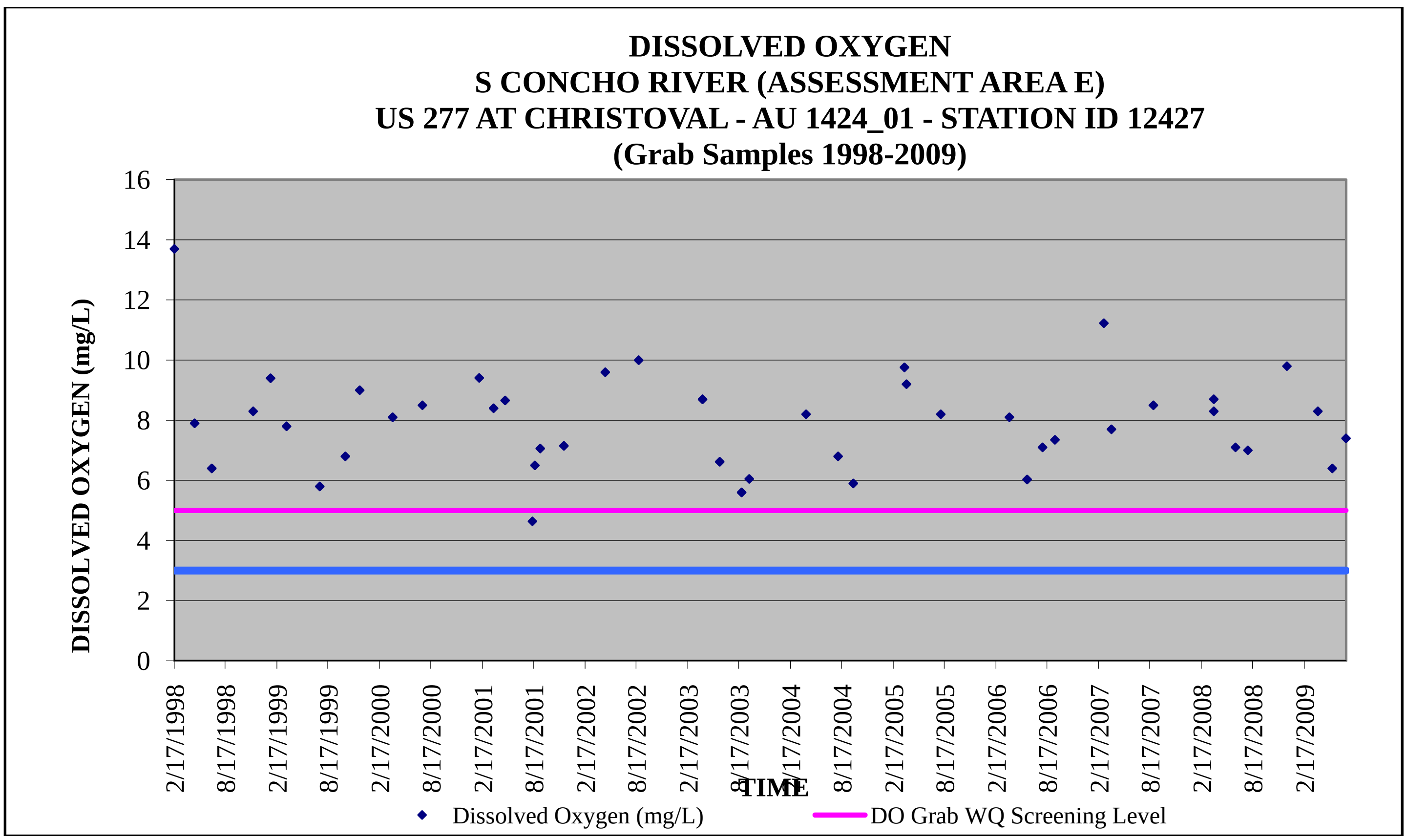

DISSOLVED OXYGEN
TWIN BUTTES RESERVOIR, SOUTH POOL (ASSESSMENT AREA E)
RIVER CHANNEL NEAR DAM - AU 1423_02 - STATION ID 12425
(Grab Sample Data 1998 thru 2009)
DISSOLVED OXYGEN (mg/L)
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level


TOTAL PHOSPHORUS
S CONCHO RIVER (ASSESSMENT AREA E)
US 277 AT CHRISTOVAL - AU 1424_01 - STATION ID 12427
(Grab Samples 1998-2009)
TOTAL PHOSPHORUS (mg/L)
TIME
Total Phosphorus (mg/L)


NO2-N + NO3-N
S CONCHO RIVER (ASSESSMENT AREA E)
US 277 AT CHRISTOVAL - AU 1424_01 - STATION ID 12427
(Grab Samples 1998-2009)
NO2-N + NO3-N (mg/L)
2.5
2
1.5
1
0.5
0
TIME
NO2-N + N03-N (mg/L)

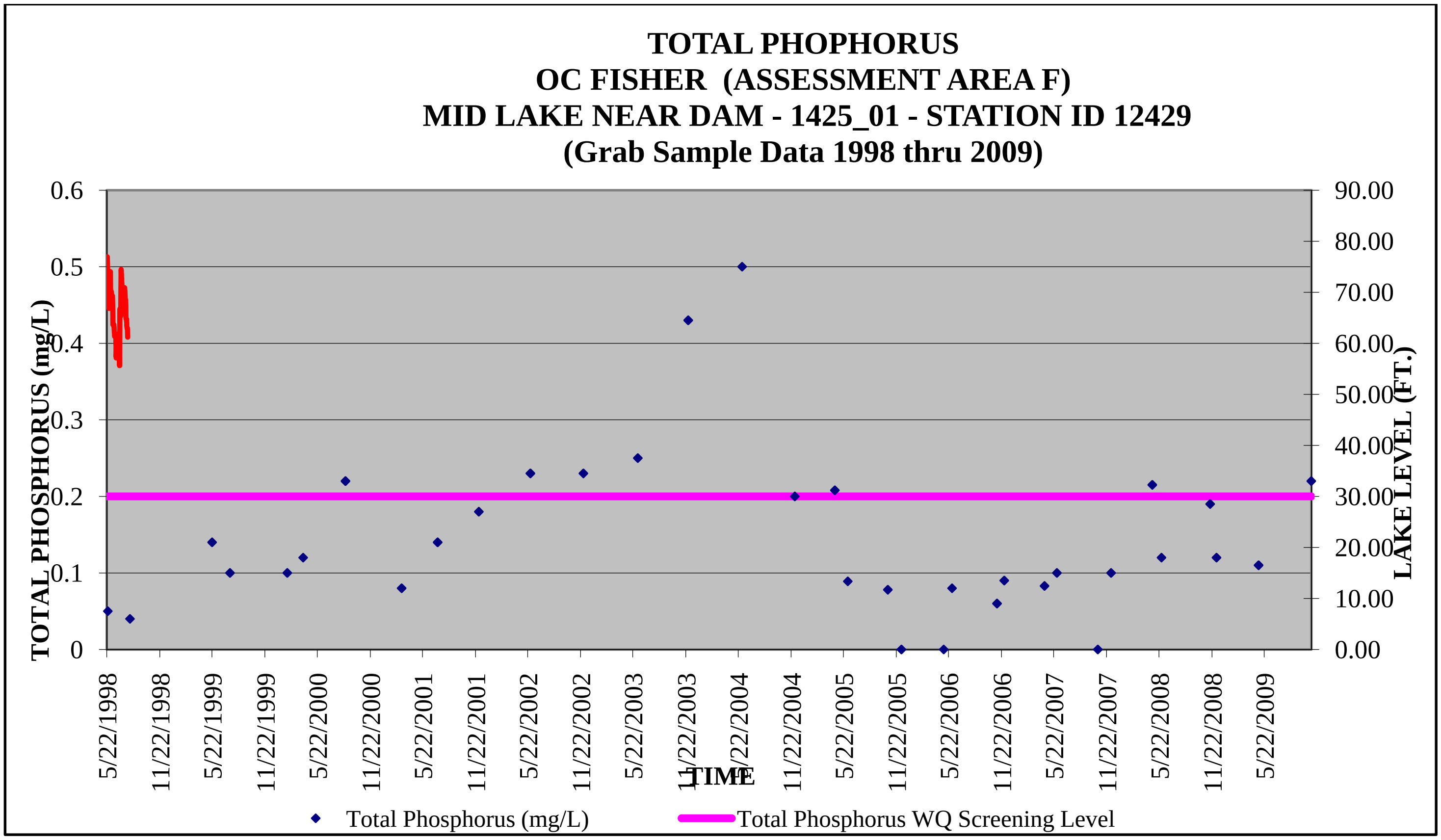

CHLORIDE
S CONCHO RIVER (ASSESSMENT AREA E)
US 277 AT CHRISTOVAL - AU 1424_01 - STATION ID 12427
(Grab Samples 1998-2009)
CHLORIDE (mg/L)
160
140
120
100
80
60
40
20
0
TIME
Chloride (mg/L)


E COLI
S CONCHO RIVER (ASSESSMENT AREA E)
US 277 AT CHRISTOVAL - AU 1424_01 - STATION ID 12427
(Grab Samples 1998-2009)
E COLI (MPN/100mL)
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

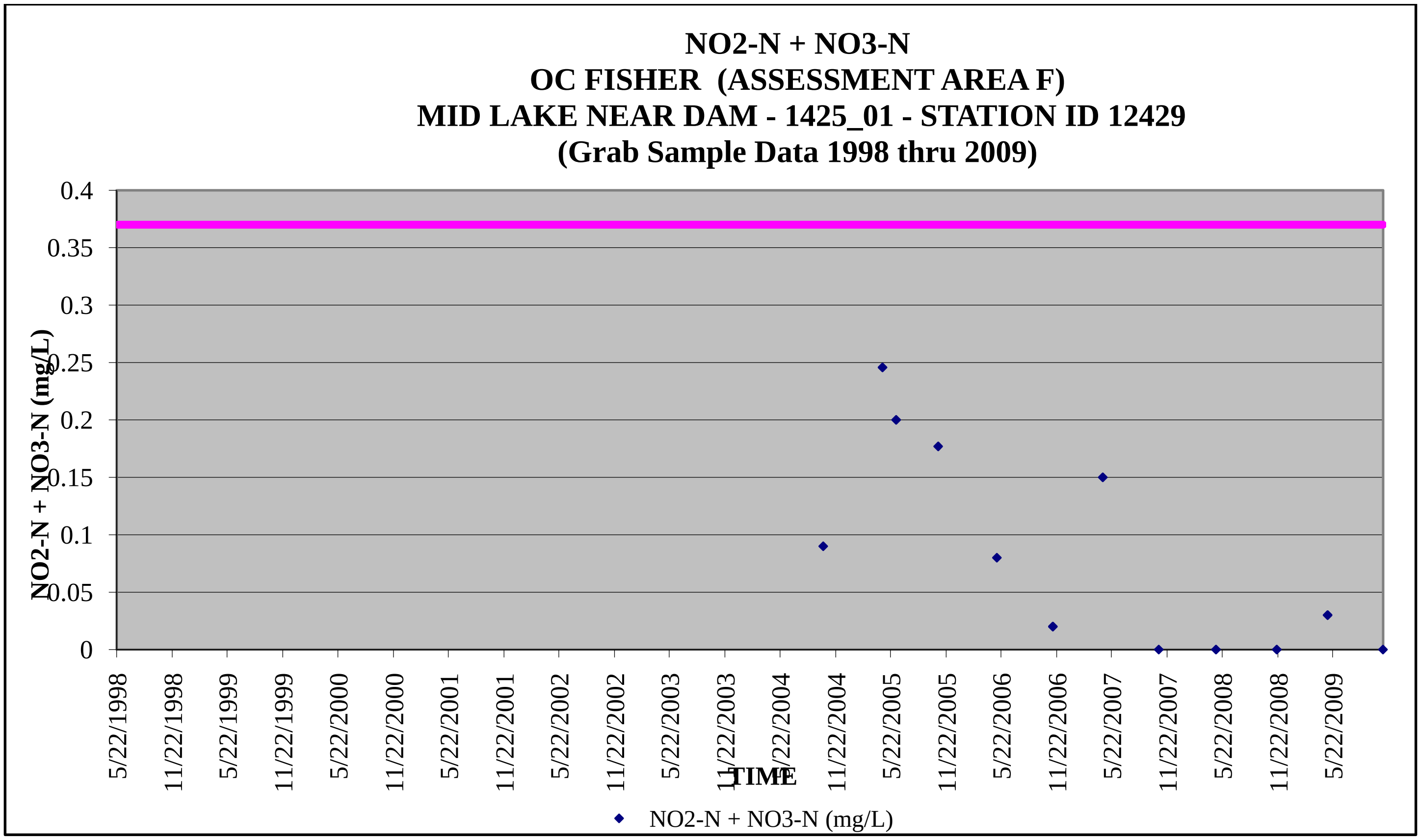

DISSOLVED OXYGEN
S CONCHO RIVER (ASSESSMENT AREA E)
US 277 AT CHRISTOVAL - AU 1424_01 - STATION ID 12427
(Grab Samples 1998-2009)
DISSOLVED OXYGEN (mg/L)
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level

APPENDIX F

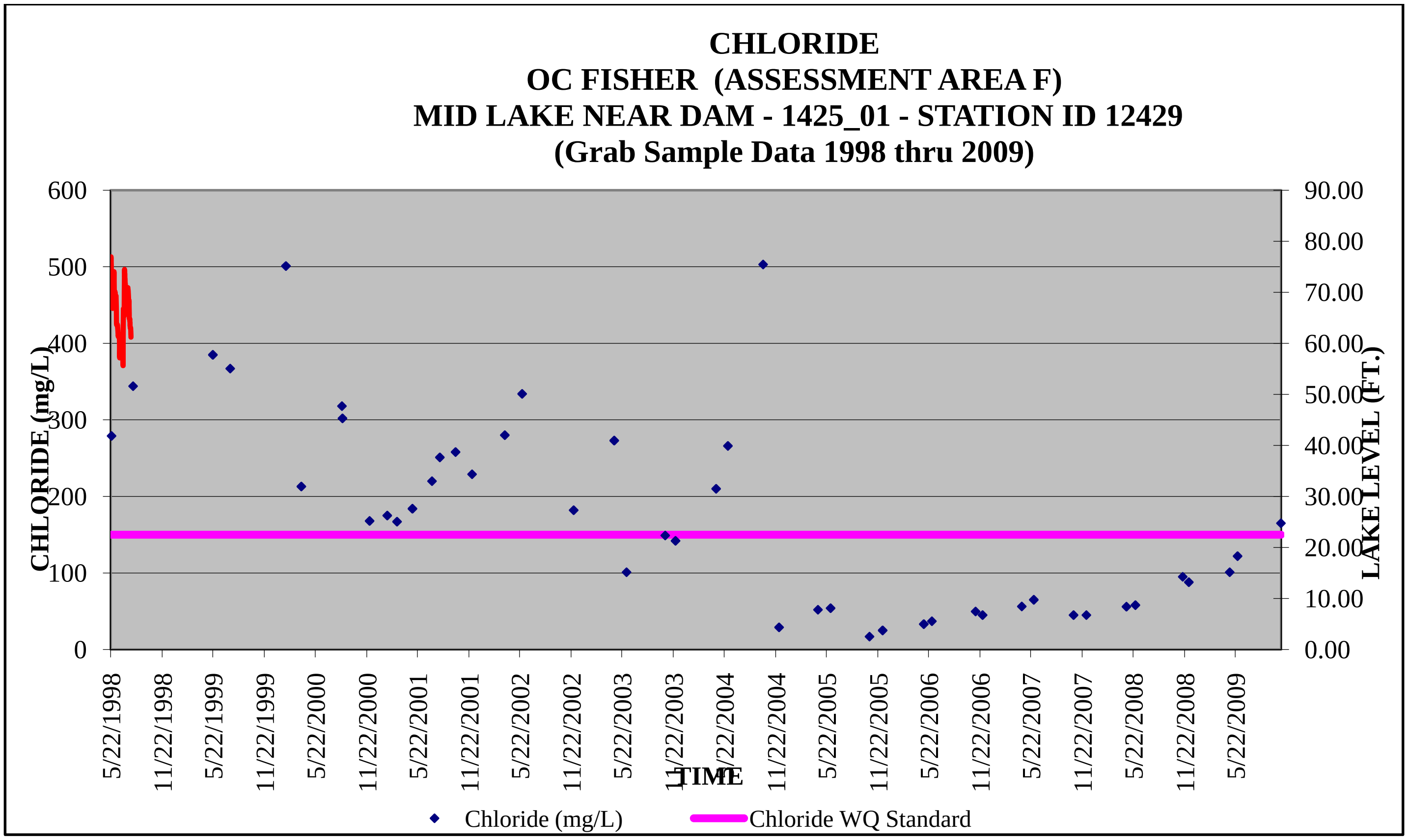
Assessment Area F Supporting Data

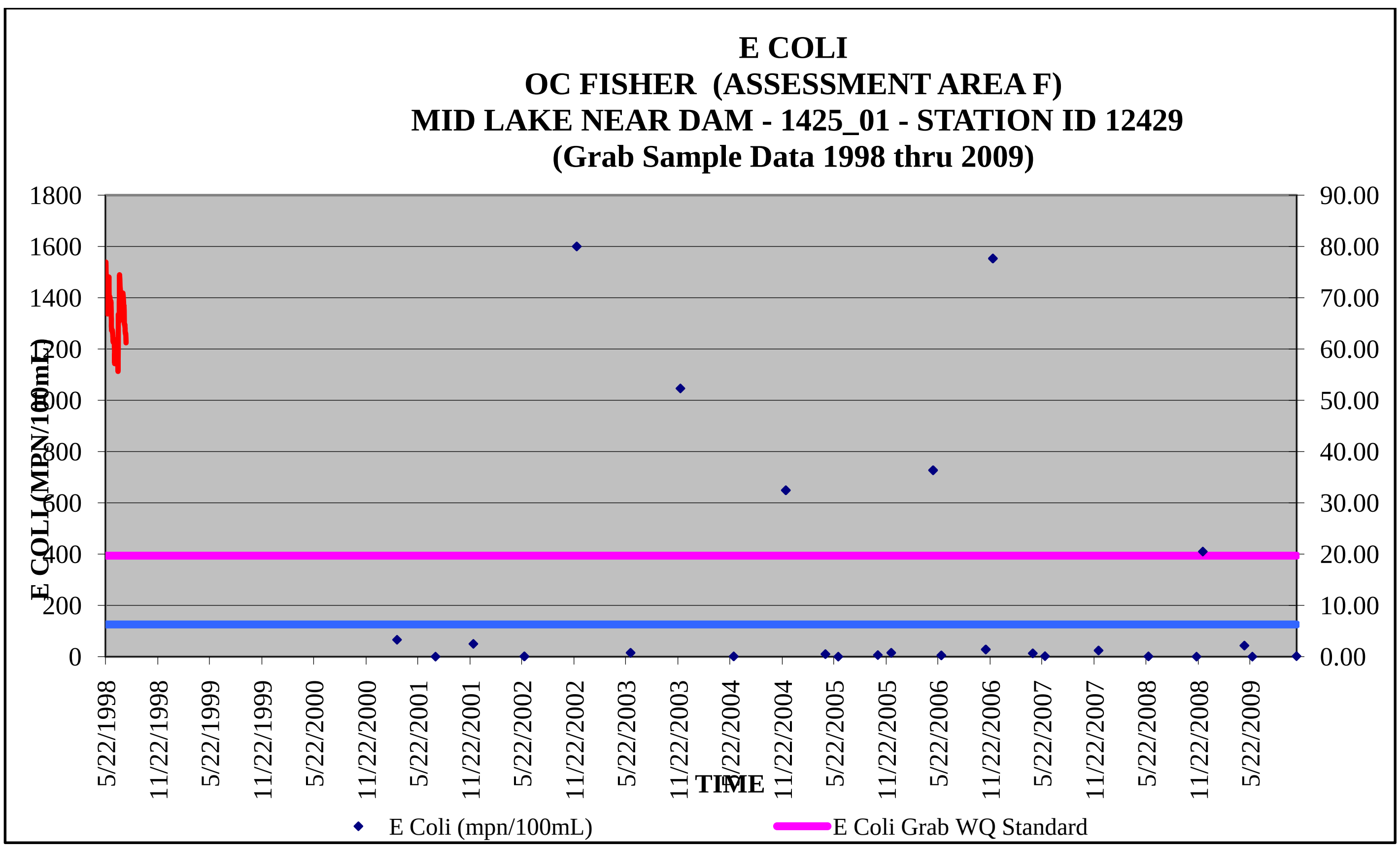


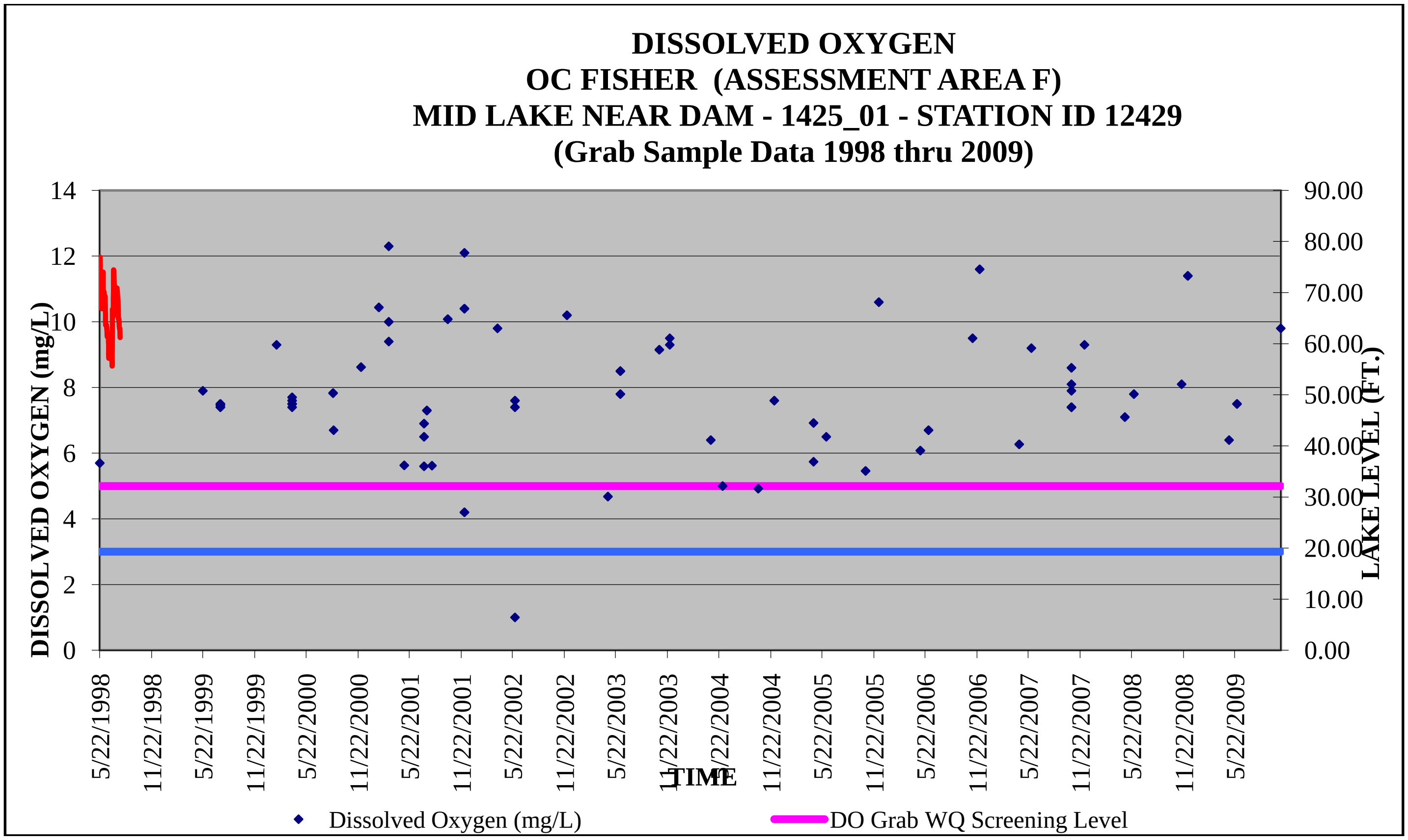
TOTAL PHOPHORUS
OC FISHER (ASSESSMENT AREA F)
MID LAKE NEAR DAM - 1425_01 - STATION ID 12429
(Grab Sample Data 1998 thru 2009)
TOTAL PHOSPHORUS (mg/L)
LAKE LEVEL (FT.)
TIME
0.6
0.5
0.4
0.3
0.2
0.1
0
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
5/22/1998
11/22/1998
5/22/1999
11/22/1999
5/22/2000
11/22/2000
5/22/2001
11/22/2001
5/22/2002
11/22/2002
5/22/2003
11/22/2003
5/22/2004
11/22/2004
5/22/2005
11/22/2005
5/22/2006
11/22/2006
5/22/2007
11/22/2007
5/22/2008
11/22/2008
5/22/2009
Total Phosphorus (mg/L)
Total Phosphorus WQ Screening Level

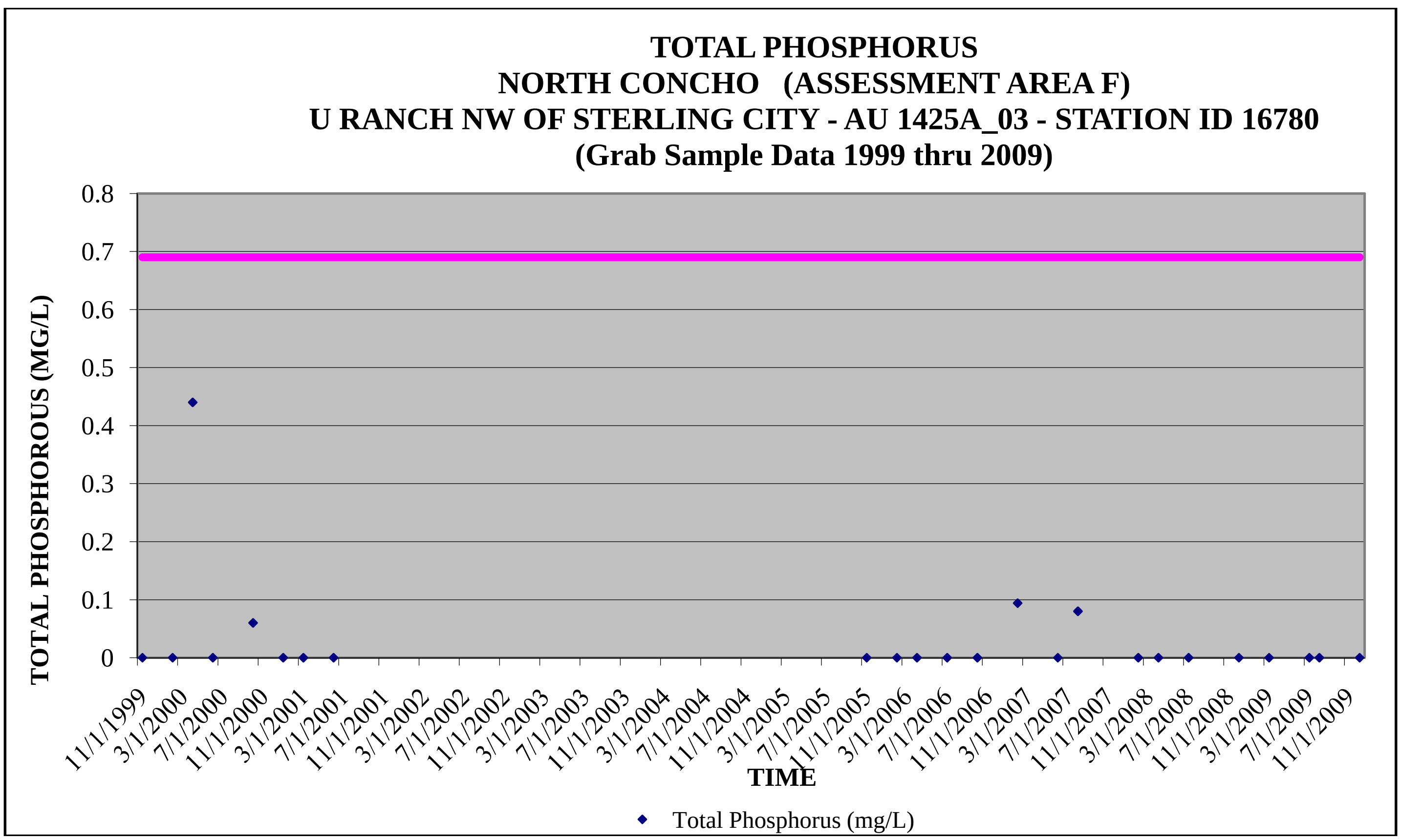


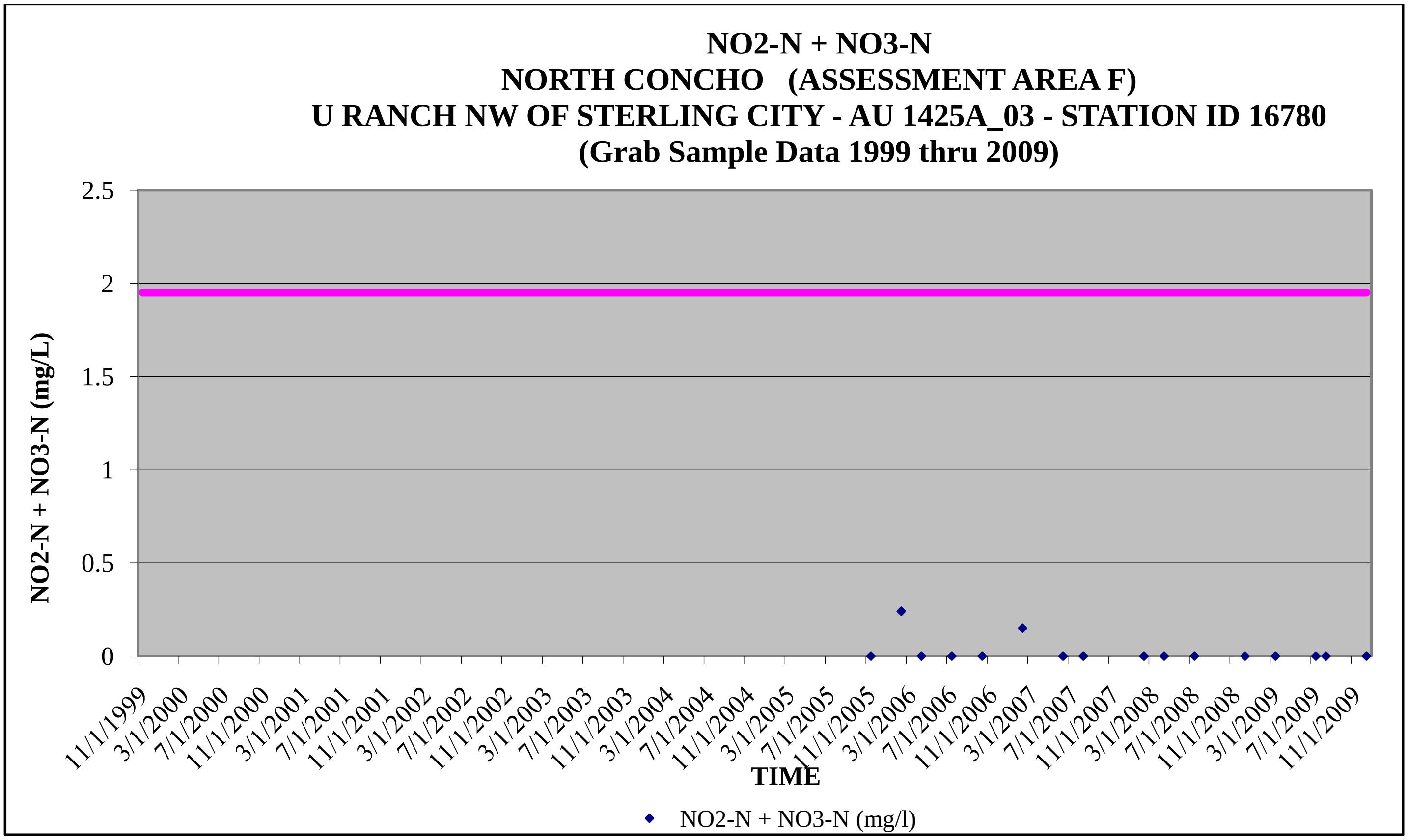
NO2-N + NO3-N
OC FISHER (ASSESSMENT AREA F)
MID LAKE NEAR DAM - 1425_01 - STATION ID 12429
(Grab Sample Data 1998 thru 2009)
NO2-N + NO3-N (mg/L)
TIME
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
5/22/1998
11/22/1998
5/22/1999
11/22/1999
5/22/2000
11/22/2000
5/22/2001
11/22/2001
5/22/2002
11/22/2002
5/22/2003
11/22/2003
5/22/2004
11/22/2004
5/22/2005
11/22/2005
5/22/2006
11/22/2006
5/22/2007
11/22/2007
5/22/2008
11/22/2008
5/22/2009
NO2-N + NO3-N (mg/L)

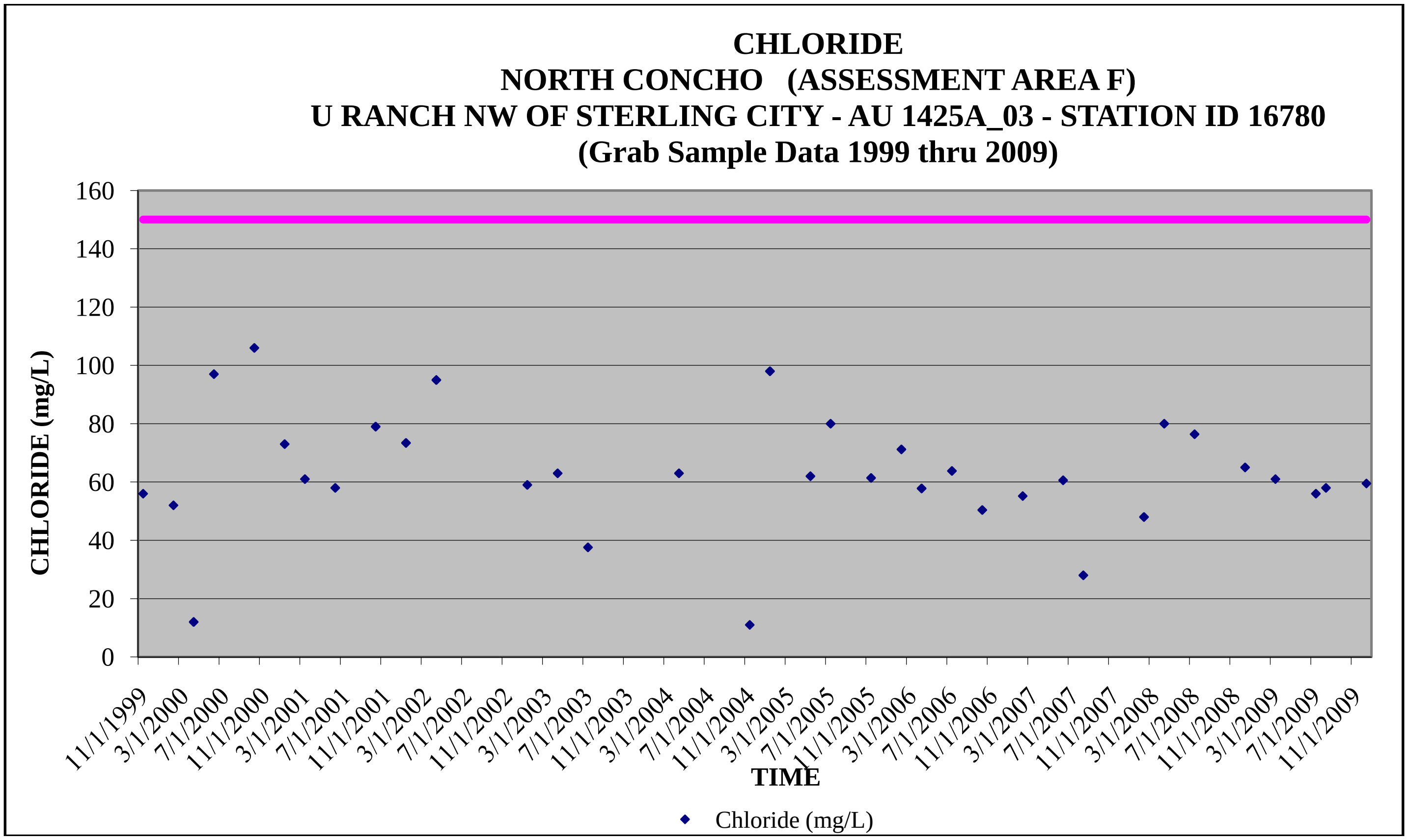

CHLORIDE
OC FISHER (ASSESSMENT AREA F)
MID LAKE NEAR DAM - 1425_01 - STATION ID 12429
(Grab Sample Data 1998 thru 2009)
CHLORIDE (mg/L)
LAKE LEVEL (FT.)
TIME
Chloride (mg/L)
Chloride WQ Standard

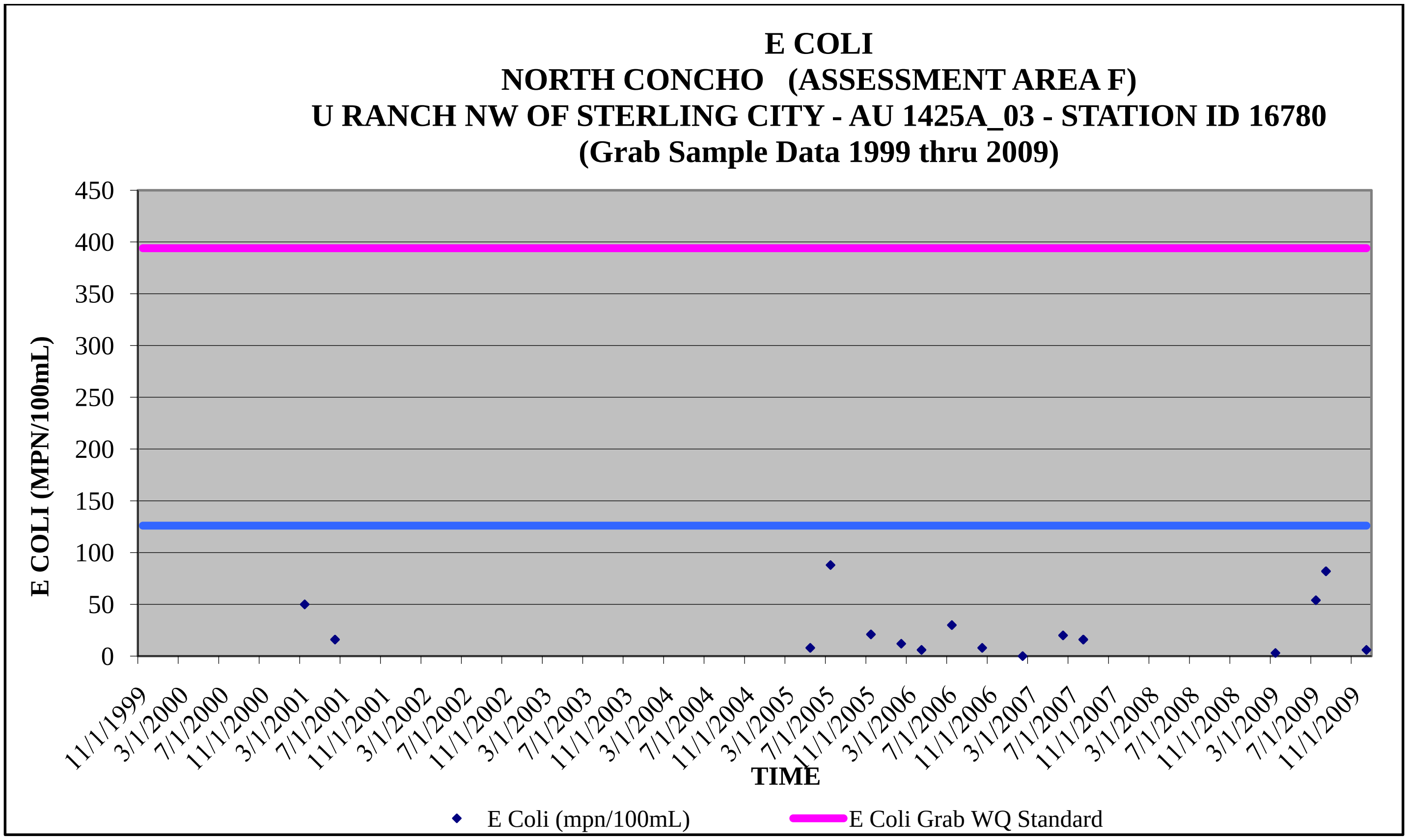

E COLI
OC FISHER (ASSESSMENT AREA F)
MID LAKE NEAR DAM - 1425_01 - STATION ID 12429
(Grab Sample Data 1998 thru 2009)
E COLI (MPN/100mL)
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard

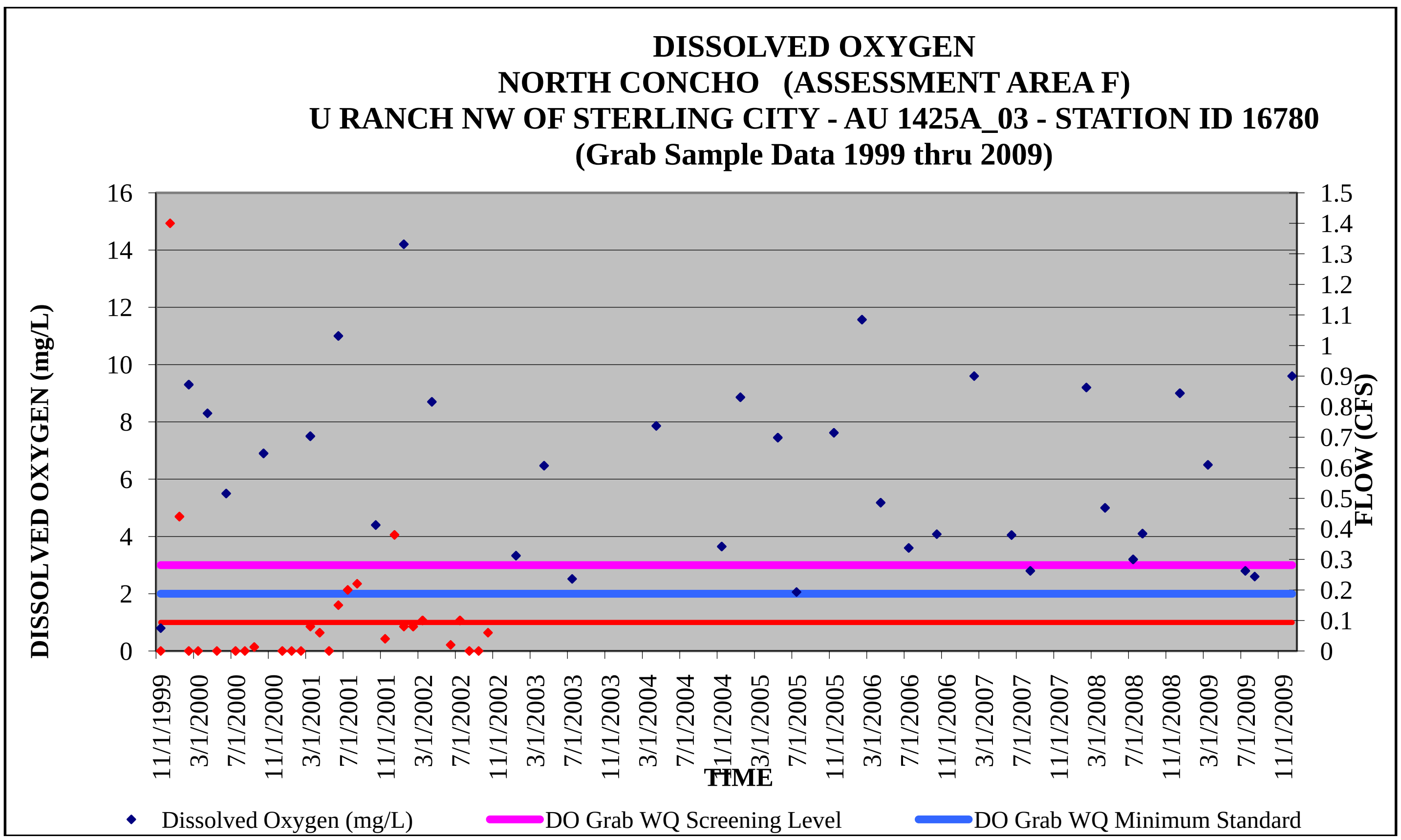

DISSOLVED OXYGEN
OC FISHER (ASSESSMENT AREA F)
MID LAKE NEAR DAM - 1425_01 - STATION ID 12429
(Grab Sample Data 1998 thru 2009)
DISSOLVED OXYGEN (mg/L)
LAKE LEVEL (FT.)
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level


TOTAL PHOSPHORUS
NORTH CONCHO (ASSESSMENT AREA F)
U RANCH NW OF STERLING CITY - AU 1425A_03 - STATION ID 16780
(Grab Sample Data 1999 thru 2009)
TOTAL PHOSPHOROUS (MG/L)
TIME
Total Phosphorus (mg/L)


NO2-N + NO3-N
NORTH CONCHO (ASSESSMENT AREA F)
U RANCH NW OF STERLING CITY - AU 1425A_03 - STATION ID 16780
(Grab Sample Data 1999 thru 2009)
NO2-N + NO3-N (mg/L)
2.5
2
1.5
1
0.5
0
11/1/1999
3/1/2000
7/1/2000
11/1/2000
3/1/2001
7/1/2001
11/1/2001
3/1/2002
7/1/2002
11/1/2002
3/1/2003
7/1/2003
11/1/2003
3/1/2004
7/1/2004
11/1/2004
3/1/2005
7/1/2005
11/1/2005
3/1/2006
7/1/2006
11/1/2006
3/1/2007
7/1/2007
11/1/2007
3/1/2008
7/1/2008
11/1/2008
3/1/2009
7/1/2009
11/1/2009
TIME
NO2-N + NO3-N (mg/l)


CHLORIDE
NORTH CONCHO (ASSESSMENT AREA F)
U RANCH NW OF STERLING CITY - AU 1425A_03 - STATION ID 16780
(Grab Sample Data 1999 thru 2009)
CHLORIDE (mg/L)
160
140
120
100
80
60
40
20
0
11/1/1999
3/1/2000
7/1/2000
11/1/2000
3/1/2001
7/1/2001
11/1/2001
3/1/2002
7/1/2002
11/1/2002
3/1/2003
7/1/2003
11/1/2003
3/1/2004
7/1/2004
11/1/2004
3/1/2005
7/1/2005
11/1/2005
3/1/2006
7/1/2006
11/1/2006
3/1/2007
7/1/2007
11/1/2007
3/1/2008
7/1/2008
11/1/2008
3/1/2009
7/1/2009
11/1/2009
TIME
Chloride (mg/L)


E COLI
NORTH CONCHO (ASSESSMENT AREA F)
U RANCH NW OF STERLING CITY - AU 1425A_03 - STATION ID 16780
(Grab Sample Data 1999 thru 2009)
E COLI (MPN/100mL)
TIME
E Coli (mpn/100mL)
E Coli Grab WQ Standard


DISSOLVED OXYGEN
NORTH CONCHO (ASSESSMENT AREA F)
U RANCH NW OF STERLING CITY - AU 1425A_03 - STATION ID 16780
(Grab Sample Data 1999 thru 2009)
DISSOLVED OXYGEN (mg/L)
FLOW (CFS)
TIME
Dissolved Oxygen (mg/L)
DO Grab WQ Screening Level
DO Grab WQ Minimum Standard

APPENDIX G

Published Evapotranspiration Paper

Effect of brush control on evapotranspiration in the North Concho River watershed using the eddy covariance technique

A. Saleh, H. Wu, C.S. Brown, F.M. Teagarden, S.M. McWilliams, L.M. Hauck, and J.S. Millican

Abstract: This paper reports on a project that was designed to study changes in total water budget with implementation of brush control in two adjacent mesquite-dominated experimental sites, wherein one site received brush control treatment and the other served as an untreated site. The two plots, each consisting of about 80 ha (200 ac), are located within the North Concho River watershed near San Angelo, Texas. Evapotranspiration (*ET*) from the plots was measured with the eddy covariance technique beginning in April 2005. The field data indicated that the measured *ET* at the mesquite-treated site was lower than that of the untreated site during the mesquite growing season (May to October). For instance, the largest difference in *ET* (about 25%) in measured *ET* between the treated and untreated sites was recorded during the peak mesquite growing season in 2008. The higher *ET* measured at the untreated site suggests that there is great potential for increasing water yield by eliminating the water uptake by mesquite trees, through a brush control approach in the North Concho River watershed. For example, based on 952 daily *ET* measurements (from 9:00 a.m. to 6:30 p.m.), the experimental data indicated that during the four-year study, the mesquite-dominated untreated site had a net consumption of over 46 mm (1.8 in) more water than the treated site. In addition, extrapolation of the data set to include all days during the four-year study (1,370 days) indicated that the untreated site had a potential net consumption of about 71 mm (2.8 in) more water compared to the treated site. Truncation of the data set to include measurements obtained during only the months within the mesquite growing season (May to October) indicated that the untreated site had consumed more than 58 mm (2.3 in) more water than the treated site based on 513 daily measurements obtained during the four-year study. Extrapolation of the data set to account for missing values within the growing season (732 days) indicated that water consumption at the untreated site would be expected to potentially exceed that of the treated site by 90 mm (3.5 in) during the growing season months over the four year period.

Key words: brush control—eddy covariance—evapotranspiration—mesquite—North Concho River watershed

Consumptive water use of surface and subsurface waters in the western United States exceeds recharge. This imbalance of supply and demand has led to a significant depletion of aquifers and stream flows throughout much of the region (Bidlake 2000; Thurow et al. 2000). It is believed that if a site is dominated by grass instead of brush, then water yield from rangeland will be significantly greater (Hinnert 1983). Therefore, brush control programs are being considered by policymakers as a way to relieve regional water shortages, based on the belief that improved water yields from suitable range sites will raise groundwater levels and/or increase stream flow in the region thus benefiting off-site water users (Thurow et al. 2000).

In Texas, water supply is a crucial issue because of projected population growth, combined with Texas' vulnerability to drought (Texas Water Development Board 2006). The growing Texas population, and associated municipal and industrial growth, is placing greater demands on the state's water supply. The issue of available water supply becomes particularly acute during times of drought, as recent experience during the drought of the late 1990s to 2001 suggests (Wilcox et al. 2005). Brush in Texas uses about 12.3 billion m^3 (10 million ac ft) of water per year, compared with human usage of 18.5 billion m^3 (15 million ac ft) a year, as estimated by the USDA Natural Resources Conservation Service (Walker et al. 1998). Therefore, brush control will affect water resources by enhancing surface water supplies, the recharge of groundwater aquifers, and spring flows.

Honey mesquite (*Prosopis glandulosa* Torr.), one of the dominant brush species growing in Texas, is known as a high water user. The root system of a mature mesquite tree, consisting of lateral roots and tap roots, makes it possible for it to utilize both shallow and deep soil moisture (Ansley 2005). Mesquite's shallow lateral roots compete for water with grasses, while mesquite's deep tap roots are used to obtain water from the underground water table. This root structure enables the plant to avoid drought (Ansley et al. 1990). Thus, prolonged drought conditions could reduce perennial forage and favor mesquite survival (Warren et al. 1996). In addition, mesquite establishes under a wide range of conditions and withstands repeated top removal, because it is a prolific producer of long-lived seeds that germinate readily after scarification (Laxson et al. 1997). The density and distribution of mesquite have been increasing. The factors that are associated with this increase usually include (1) rangeland management practices, (2) enhanced seed distribution, (3) reduced grass competition as a result of livestock grazing, (4) suppression of naturally occurring fires, and (5) climate changes and increasing atmospheric carbon dioxide (Ansley et al. 2001). The invasion of mesquite has also negatively influenced the density and production of native grasses, which are the principal ground cover and forage for livestock (Tiedemann and Klemmedson 2004).

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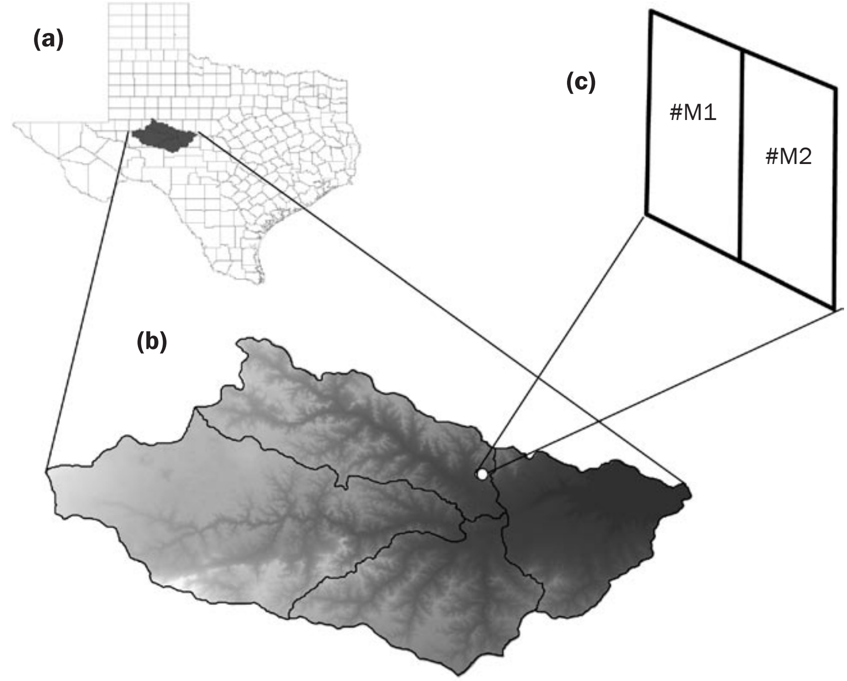
Figure 1

Location map for the Concho River Basin near San Angelo, Texas. (a) Texas county map with Concho River Basin. (b) Concho River Basin map. (c) Paired mesquite watersheds and station locations (number signs). M1 denotes the treated site; M2 denotes the untreated site.



The North Concho River (NCR) watershed, located in West Central Texas, is one of the watersheds in which water resources are affected by growing brush levels. This watershed encompasses more than 380,000 ha (939,000 ac) within Tom Green, Sterling, Glasscock, and Coke Counties. The NCR is dammed to form O.C. Fisher Reservoir, which is a major water supply for the city of San Angelo. However, "more than 130 million mesquite trees and more than 100 million junipers thrive in the watershed," and "the trees' tentacle roots act like straws to suck water from the watershed," according to Johnny Oswald, project manager for the Texas State Soil and Water Conservation Board. Selectively removing these types of trees is, therefore, expected to increase underground water resources for ranchers and farmers and divert more water into the NCR and ultimately into O.C. Fisher Reservoir (Smith 2000).

Studies have shown that brush control can increase surface water flows and ground water recharge through reductions in evapotranspiration (*ET*) and possible interception by resident plants (Griffin and McCarl 1989). In 1998, a study funded by the Texas Water Development Board, was conducted by the Texas State Soil and Water Conservation Board, Texas A&M Research and Extension Center, and the Upper Colorado River Authority on the NCR watershed to determine potential water yields from a comprehensive brush control program. The study estimated that a brush control program in the NCR watershed could improve the water yield of the river by 40.7 million m^3 y^{-1} (33,000 ac ft yr^{-1}), a five-fold increase (Smith 2000).

The rationale for using brush management to increase water yield is based on the premise that shifting vegetation composition from species associated with high *ET* potential (e.g., trees and shrubs), to species with lower *ET* potential (e.g., grasses) will increase the likelihood of water yield from the site in forms such as runoff and/or deep drainage (Thurow et al. 2000). Although evaporation from the soil may increase because of less shading and more air movement, the net result of the conversion to grasses is to reduce water use. Wu et al. (2001) concluded that in semiarid rangelands, *ET* can account for 80% to 95% of the water loss. Thus, changes in woody cover in semiarid rangelands can significantly alter *ET* losses, which in turn will generally increase the amount of water that percolates below the root zone into groundwater.

This study was conducted to evaluate the effect of brush control on the water budget by measuring *ET* from two plot study facilities located in Tom Green County and within the NCR watershed. The main objective of this study was to investigate reductions in *ET* as a result of the removal of mesquite trees, by determining statistically significant differences in *ET* between mesquite-treated and untreated sites. The results of this study are important in that they will provide an estimate of the quantity of water that could be saved by brush control for this and similar locations within the United States.

Materials and Methods

Study Area and Brush Treatment. The study area is located within the southeast portion of the NCR watershed (figures 1a and 1b), near San Angelo, Texas, in a flat mesquite-dominated area with relatively deep soils in northern Tom Green County. Climate in the study area is semiarid. Long-term average annual precipitation is 566 mm (20.9 in), average daily maximum temperature is 25°C (77°F), and average daily minimum temperature is 11°C (51.7°F) (NWS 2008). The study area consists of two adjacent plots, each covering approximately 80 ha (200 ac) (figure 1c). Mesquite is the dominant land cover at this site, and major land use is a light grazing cow/calf operation. The paired plots are in an area of very low relief with an absence of discernible pathways for surface water flow. Based on a field survey, the mesquite density of the study area was about 4,520 trees ha^{-1} (1,830 trees ac^{-1}).

On June 1, 2002, the herbicides Remedy (triclopyr) and Reclaim (clopyralid) were sprayed over the mesquite trees in one of the plots. The trees were defoliated within two weeks, representing the initiation of the brush treatment phase of the project. There was no land management imposed on the other mesquite-dominated plot (M1), referred to as untreated (M2) in this paper (figure 1c). Photographs of the treated and untreated sites are shown in figures 2a and 2b, respectively, and were taken in June 2008.

Micrometeorological Data Collection Techniques. A 10 m (33 ft) flux tower was established at each site in 2000. The coordinates of the towers were 31°36'20.24" and 100°30'55.84" at the treated site and 31°36'12.16" and 100°30'33.71" at the untreated site. The two towers were equipped with identical instruments. The Bowen Ratio technique was initially employed, intending to obtain approximately three years of pretreatment data to establish the baseline data, which was necessary for application of the paired plot approach. However, various complications and failures of instrumentation with the Bowen Ratio system resulted in the collection of less than a complete set of reliable data.

Because of the unreliability in the data collection with the Bowen Ratio technique, a three-dimensional eddy covariance (EC) system (Campbell Scientific, Inc, Logan, Utah) was mounted to the tower for the untreated site in April 2004 and for the treated site in April 2005. The EC technique is based on direct measurements of the product of vertical velocity fluctuations and scalar concentration fluctuations, resulting in an estimate of sensible heat flux (*H*) and latent heat flux (*LE*), assuming the mean vertical velocity is negligible (Twine et al. 2000). The EC system, mounted at a height of 8 m (26 ft) above the ground and oriented toward the south to take advantage of the predominant wind direction, measured the surface fluxes above the canopy, which has an average height of about 3 m (10 ft).

According to the eddy covariance theory, the *LE* (W m^{-2}) is determined as follows:

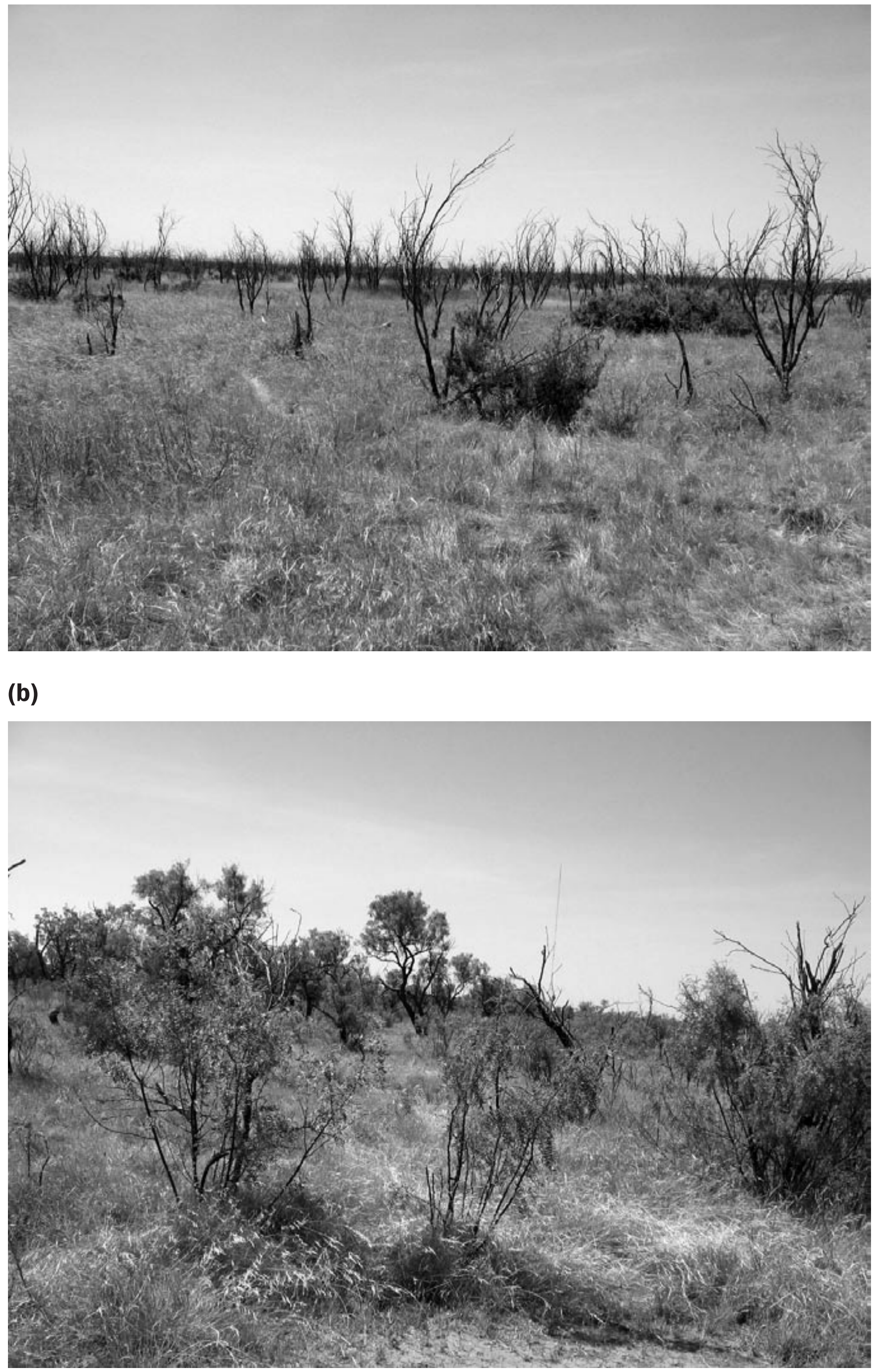
$$LE = L_v \overline{w'\rho'_v}\,, \qquad (1)$$

where L_v (kJ kg^{-1}) is the latent heat of vaporization for water, w' is the instantaneous deviation of vertical wind speed from the mean, and ρ'_v is the instantaneous deviation of the water vapor density from the mean. The quantity $\overline{w'\rho'_v}$ is the covariance between the vertical wind speed and vapor density.

With the EC technique, vertical wind speed was measured by a three-dimensional sonic anemometer (model CSAT3; Campbell Scientific, Inc), and vapor density was measured by a krypton hygrometer (model KH20; Campbell Scientific, Inc). The fluctuations were sampled at 10 Hz, and the covariance between the vertical wind speed and vapor density was computed every 30 minutes. The measurements were recorded on a datalogger (model CR5000, Campbell Scientific, Inc). The *LE* was computed using

$$LE = \frac{2{,}400 \times \overline{w'(\ln V_h)'}}{-xk_w}\,, \qquad (2)$$

Figure 2
Study site photographs taken in June 2008. (a) Treated site (M1). (b) Untreated site (M2).



(a)

(b)

where $\ln V_h$ is the natural log of the signal voltage from the hygrometer, x (1.210 cm [0.048 in] for the treated site and 1.295 cm [0.051 in] for the untreated site) is the path length of the hygrometer used in this study, and k_w (0.146 m^3 g^{-1} cm^{-1} [371.27 ft^3 oz^{-1} in^{-1}] for both treated and untreated sites) is the absorption coefficient for water vapor.

Then, the *LE* was converted to a rate of *ET* as

$$ET = \frac{LE}{L_v}\,, \qquad (3)$$

Figure 3
Photographs of untreated study site taken (a) sortly after the fire that occurred on January 19, 2006, and (b) during the following growing season on July 8, 2006.

(a)

(b)

where L_v changes with sonic temperature (T_s), which is measured by the 3-D sonic anemometer. The linear regression between the two is

$$L_v = 2{,}500 - 2.359T_s \, , \tag{4}$$

which is from Jones 1983.

In addition, a temperature and relative humidity probe was installed at a height of 1.8 m (5.9 ft) (model HMP45C, Vaisala Inc), and a tipping bucket rain gage was installed at a height of 1.5 m (4.9 ft) (model TE525, Campbell Scientific, Inc) at each site. With the availability of additional funding in March 2008, more sensors were installed at both sites to collect microclimate variables, including net radiation at a height of 5.3 m (17 ft) above the ground (model NRLite; Kipp & Zonen), soil heat flux at a depth of 8 cm (3.2 in) below the ground (model HFT3; REBS Inc), soil moisture at a depth of 2.5 cm (1 in) (model CS615; Campbell Scientific Inc), and soil temperature at depths of 2 cm (0.8 in) and 6 cm (2.4 in) (model TCAV; Campbell Scientific Inc). Through these additional measurements, an energy budget for each study site was established to validate the fluxes measured with the EC technique.

Post-Field Data Processing and Energy Balance Closure Assessment. Before the *ET* data were computed through equations 1 to 4, the following corrections were made to the measured *H* and *LE*: (1) correction of the krypton hygrometer data for ultraviolet absorption by oxygen (van Dijk et al. 2003); (2) correction of the sonic temperature for the effect of moisture (Schotanus et al. 1983); (3) two-dimensional rotations to transform the measured fluxes from the sonic anemometer's coordinates into the natural coordinate system (Kaimal and Finnigan 1994; Lee et al. 2004); and (4) Webb-Pearman-Leuning correction to the water vapor flux for the fluctuations of temperature and water vapor (Webb et al. 1980).

Using the corrected *H* and *LE*, the energy balance closure (*D*) was assessed by

$$D = \frac{H + LE}{R_n - G - S} \, , \tag{5}$$

where R_n is net radiation (W m^{-2}), *G* is soil heat flux (W m^{-2}), and *S* is heat storage in soil (W m^{-2}).

Grass Cover Index. To monitor the changes of the surface grasses during the study period, four 1 m^2 (3.28 ft^2) plots were randomly selected at each of the treated and untreated sites. Within each plot, grass-related data, including percentage of overall grass cover, percentages of dead and live grass, grass height, and species, were recorded and photographed beginning in July 2005. The observed grasses at the study area included Texas winter grass (*Stipa leucotricha*), woolly croton (*Croton capitatus*), wildrye (*Elymus sp.*), pepper weed (*Lepidium virginicum*), paleseed plantain (*Plantago virginica*), and western ragweed (*Ambrosia psilostachya*).

To quantitatively reveal the grass cover collected at the mesquite sites, the Grass Cover Index (*GCI*) was developed as follows for each plot in this study:

$$GCI = OGC \times LGC \times (GH/GH_{max}) \,, \quad (6)$$

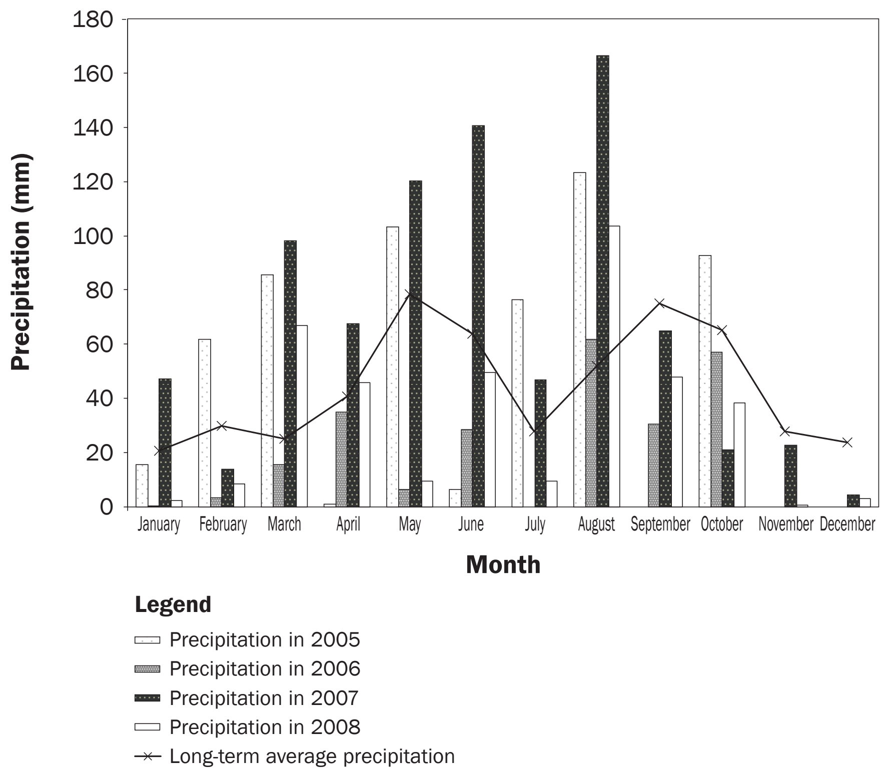
where *OGC* is the percentage of overall grass cover, *LGC* is the percentage of live grass cover, *GH* is grass height, and GH_{max} is maximum grass height during the entire survey period. Therefore, GH/GH_{max} is scaled from 0 to 1. The *GCI* for each site was presented as the average of the four plots.

In addition, several mesquite trees randomly selected within the study area were photographed along with the grass survey to monitor growing stages of the trees.

Data Quality-Control Procedures. Although great effort was taken to assure the quality of the data, incidents led to interruptions in the consistency of data collection. For example, during a severe drought, the untreated site was burned by a quickly spreading fire on January 19, 2006. As a result of the fire, winter grass cover was destroyed, and approximately 90% to 95% of the mesquite trees were partially affected. Some of the EC equipment, including battery and wires, was also damaged, resulting in a loss of 24 days of data. However, due to the resilience of mesquite trees and the relatively short duration of the fire, the mesquite root systems along with above-ground biomass were not completely destroyed. Figure 3a shows a picture of a portion of the untreated site right after the fire on January 19, 2006; while figure 3b shows a picture taken of the same location during the following growing season on July 8, 2006. Regrowth of leaves and tree branches of the affected trees occurred during the next growing season (i.e., July 2006). However, the ground surface grass cover was much less compared to the same area in 2005. For instance, the average overall grass cover of the four plots at the untreated site was about 100% in July 2005 but dropped to 40% in July 2006. This slow regrowth of grass cover was due to drought conditions that occurred following the fire (figure 4). Other factors that resulted in the presence of some unreliable or missing values within the *ET* dataset included precipitation events, power supply interruptions, instrument malfunction, and various electrical problems.

Figure 4

Monthly precipitation totals during 2005 through 2008 at the study area are shown along with the long-term average at San Angelo, Texas. The 2007 data were obtained from the National Weather Service Forecast Office at San Angelo.

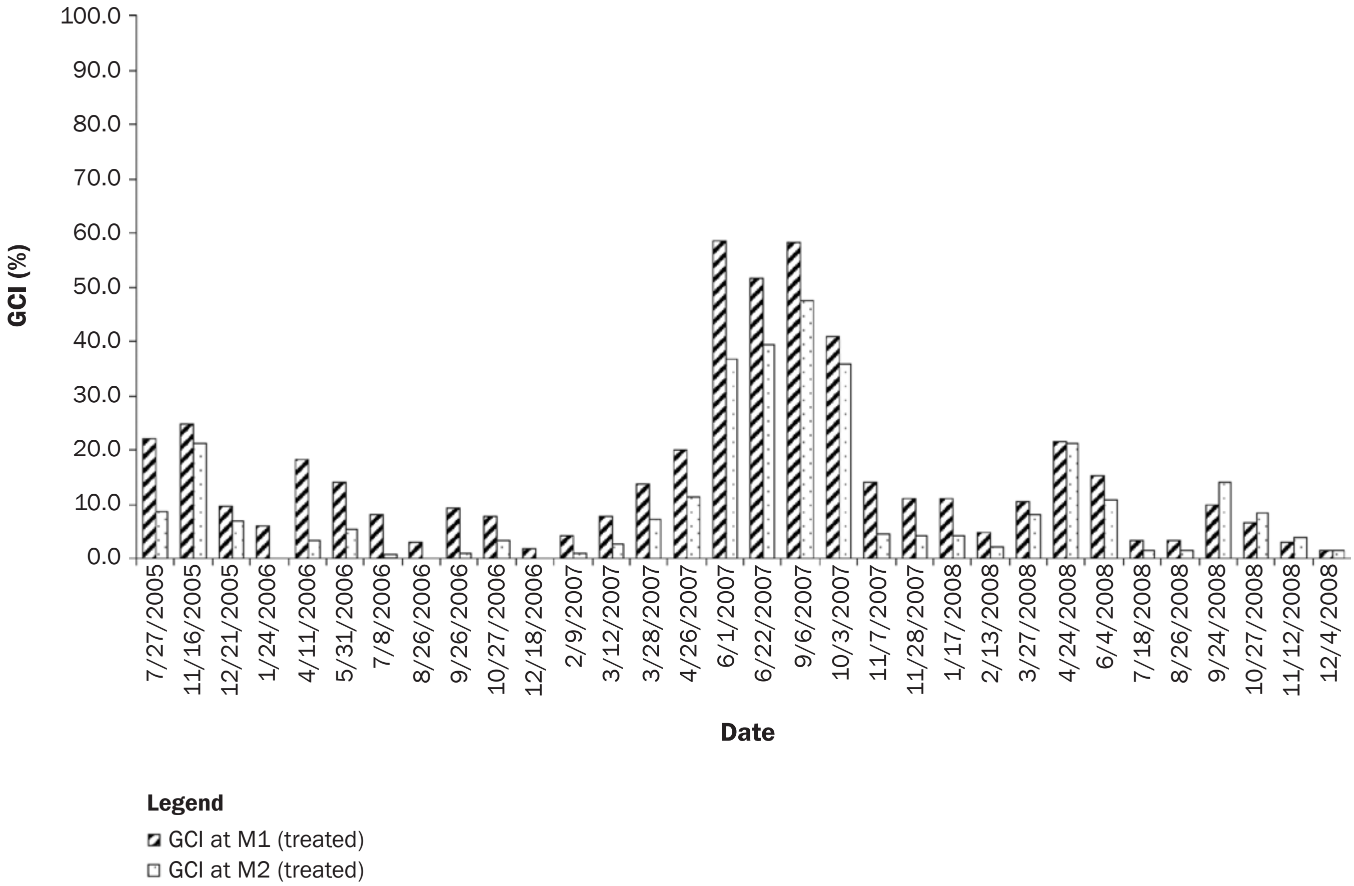


In June 2007, the EC sensors and data loggers were shipped to Campbell Scientific Inc for recalibration, resulting in a three-month interruption of *ET* data collection. The sensors and data loggers were calibrated under identical laboratory conditions by Campbell Scientific Inc, and the calibration data provided by Campbell Scientific Inc indicated that there were no statistically significant differences between instruments. When the sensors and dataloggers were ready for reinstallation in September 2007, the calibrated sensors were exchanged between the two sites. The differences in *ET* recorded between the two sites continued to be similar to what had been recorded prior to shipping the instruments for calibration. This verified that the observed differences in treated and untreated sites were a representation of observed field conditions and not a function of instrumentation.

In this study, the data from periods of weak turbulent mixing (friction velocity less than 0.35 m s^{-1} [1.14 ft sec^{-1}] [Su et al. 2008]) were discarded. Next, an effective approach to identify questionable *ET* data was a comparative analysis in which the concurrently collected EC data and rainfall data from the treated and untreated sites were plotted and compared by visual inspection. Rainfall events helped identify the problem sources (from instrument malfunction or weather). If over any time interval (1) the paired data had large discrepancies, (2) either site had missing data, or (3) either site had out-of-range data, the calculated ET data for that time interval at both sites were rejected, since this was a paired plot study. If the questionable data were from a single 30-minute interval record, and the data immediately preceding and following were good, the questionable data were interpolated from the before and after data points.

Cumulative Evapotranspiration at Different Time Scales. To demonstrate the difference in *ET* between the two sites over various time scales, the estimated 30-minute interval *ET* data were converted into daily, weekly, and monthly time scales. The cumulative *ET* values were calculated using data obtained during an optimum period of *ET* activity from 9 a.m. to 6 p.m. Central Standard Time (when net radiation > 0 W m^{-2}), rather than a complete 24-hour period

Figure 5
Grass Cover Index (GCI) during 2005 through 2008.



of record. Cleverly et al. (2002) set criteria to determine whether to estimate daily ET with missing data. Similarly, the daily, weekly, or monthly *ET* would not be computed if the missing data exceeded 50% of the corresponding time period. It is important to note that the daily, weekly, and monthly *ET* values presented in this study are for comparison purposes only, and the data do not represent the actual measured daily, weekly, and monthly *ET* values, because questionable data were rejected, and missing records occurred.

Statistical Analyses on Evapotranspiration Data. The nonparametric matched-pair statistical test (Helsel and Hirsch 2002) was performed using the PROC UNIVARIATE program within Statistical Analysis Systems (SAS Institute, Inc, Cary, North Carolina, USA) to determine whether the *ET* data at the untreated site were statistically significantly ($\alpha = 0.05$) different from those at the treated site. A nonparametric method was employed because the distribution of the *ET* values used in this study was unknown.

Results and Discussion

Precipitation and Grass Cover Index during Study Period. Precipitation records obtained from onsite rain gages and supplemented by the NWS gages were compared to the long-term average annual precipitation of 566 mm (22.3 in) for the San Angelo area (figure 4). This comparison revealed that the study period included a nearly normal rainfall year in 2005 (566 mm [22.3 in]), two dry years in 2006 (267 mm [10.5 in]) and 2008 (386 mm [15.2 in]), and a wet year in 2007 (814 mm [32.0 in]).

Figure 5 illustrates the distribution of the *GCIs* computed by equation 6 during the study period. Overall, the Grass Cover Indexs (*GCIs*) at the treated site were greater than at the untreated site. The greater *GCIs* recorded at the treated site are due to the lack of competition for water and sunlight from active shallow lateral roots of mesquite trees and associated canopy cover (Ansley et al. 2004). The *GCI* at the untreated site in January 2006 was zero because of the fire event during that month. However, the new grasses started to grow back in the spring. In addition to the fire, 2006 was very dry, leading to the *GCIs* at both sites to be much lower than in 2007, in which moisture supply was abundant. Similar to 2006, low *GCI* values were observed in 2008 for both sites due to below average rainfall.

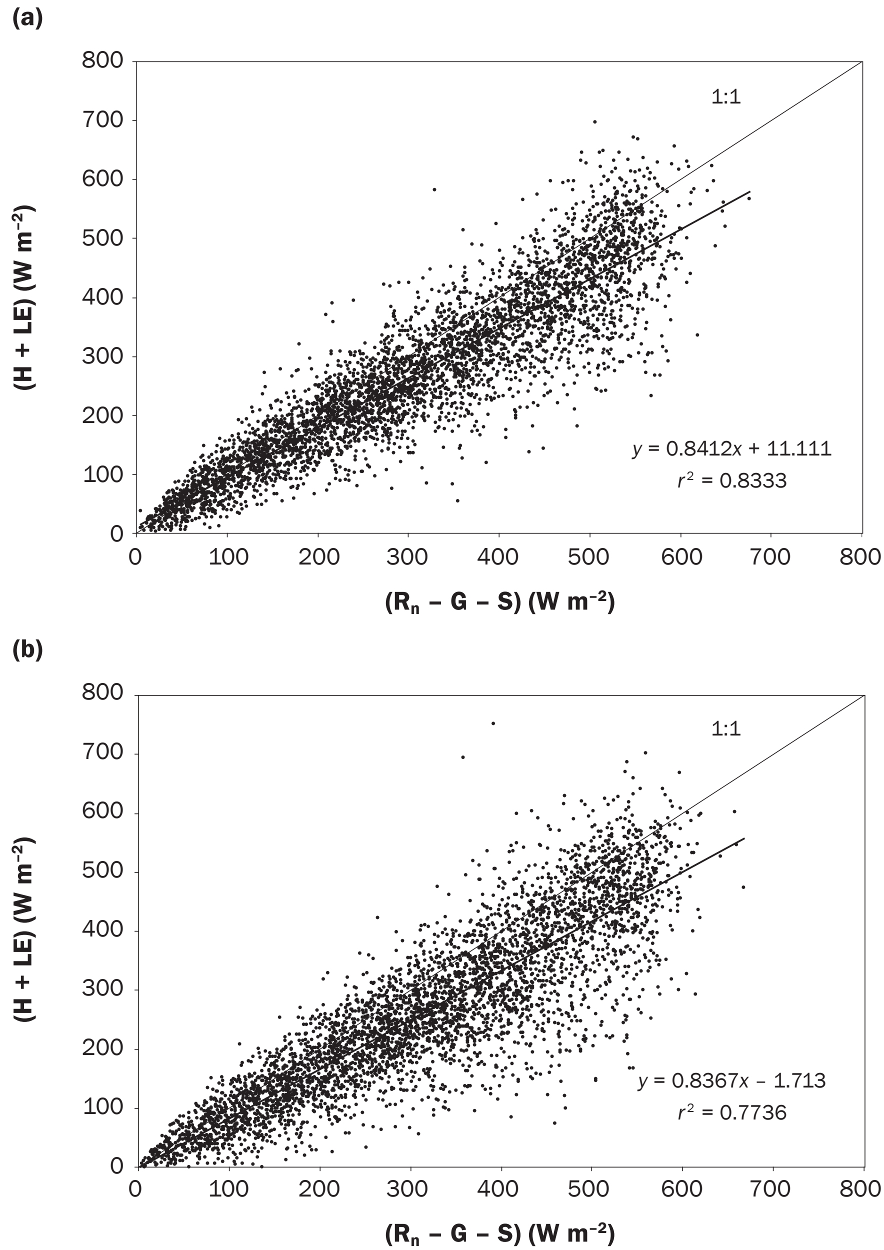
Energy Balance Closure Evaluation. The straight-line regressions between $H + LE$ and $R_n - G - S$ at the treated and untreated sites during daytime (9 a.m. to 6 p.m.) when the *ET* data were considered in this study, from March through December 2008, are displayed in figures 6a and 6b. The intercept and slope between $H + LE$ and $R_n - G - S$ were 0.84 and 11.1 W m^{-2} and 0.84 and 1.71 W m^{-2} for the treated and untreated sites, respectively. The r^2 was 0.83 for the treated site and 0.77 for the untreated site. The average daytime closure rate was 0.90 for the treated site and 0.83 for the untreated site. Even though energy balance closure information was not collected prior to March 2008, the newly obtained energy balance closure data indicate that the *ET* measured by EC at the treated and untreated sites are acceptable, and thus, the measured fluxes from the two sites can be used to perform comparisons.

Evapotranspiration Comparison at Daily Scale. The paired *ET* data accumulated at a daily scale from the two sites during the observation period, along with the corresponding daily rainfall, are illustrated in figures 7a, 7b, 7c, and 7d for each year. Any breaks along the graph lines represent missing data for that specific period (e.g., day). The operation of the EC system at both sites started on April 7, 2005, when the winter grasses at both sites were still alive and the mesquite trees at the untreated site had started to leaf out, resulting in the fairly high *ET* rates recorded during this time (figure 7a). The first autumn freeze occurred on November 16, 2005. As a result, the *ET* rate fell rapidly because the mesquite trees started to lose leaves due to freezing temperatures and go dormant during the winter. Also, the *GCI* values decreased from 20% in mid-November to less than 10% in late December at both sites. Similar results were reported by Scott et al. (2000). In 2006, the last spring freeze was recorded on March 24, and the first autumn freeze was on November 16, which resulted in significant variations in *ET* rates (figure 7b). In 2007, March 4 was the last spring freeze, and November 22 was the first fall freeze (figure 7c). December 2007 data were missing due to an equipment problem at the treated site. The last spring freeze in 2008 was March 8 (figure 7d).

Based on the measured daily *ET* during the four-year study period, *ET* values at both sites were low but similar during the first three months of each year. However, during the start of the growing season (April), the *ET* at the treated site exceeded the untreated site for a brief period. This is attributable to a lack of mesquite tree leaf emergence at both sites and higher surface grass cover at the treated site (indicted by higher *GCI* at this site as compared to the untreated site) during this period. The month of May was a transition time, in which the *ET* at the untreated site gradually surpassed the treated site as mesquite trees became very active in water use. The higher values of *ET* at the untreated site,

Figure 6

(a) Surface energy balance closure at the treated site (M1) for the period of March through December 2008. (b) Surface energy balance closure at the untreated site (M2) for the period of March through December 2008.



with living mesquite trees, as compared to that of treated site with dead trees, increased during the June to September time period. According to Ansley et al. (1997), the annual growth cycle of mesquite trees starts with a six-week period of leaf emergence and twig elongation from April and May, followed by a period of radial stem growth. Thus, by June, mesquite tree leaves were fully mature, resulting in a high transpiration rate. During July to August 2006 when severe drought occurred in the study area, vegetative growth of the mesquite subsided with the onset of summer drought (Mooney et al. 1977). Thus, it was observed that *ET* values from both sites were unusually low (below 0.5 mm [0.02 in]). However, due to more water consumption by mesquite trees, *ET* at the untreated site still consistently exceeded that of the treated site. After the growing season

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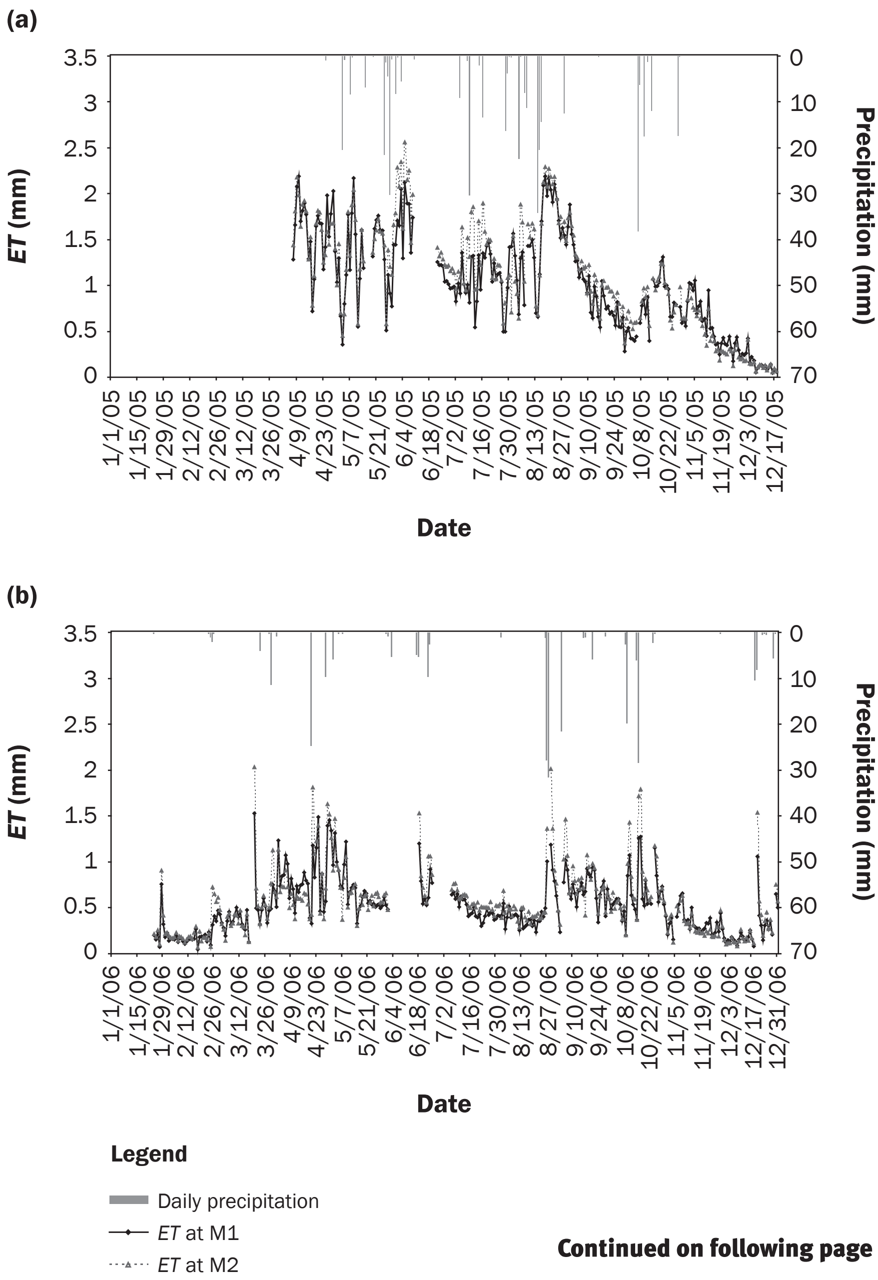
Figure 7

(a) Evapotranspiration (*ET*) accumulated at a daily scale at the treated (M1) and untreated (M2) sites and the precipitation in 2005. (b) Evapotranspiration accumulated at a daily scale at the M1 and M2 sites and precipitation in 2006. (c) Evapotranspiration accumulated at a daily scale at the treated M1 and untreated M2 sites and precipitation in 2007. (d) Evapotranspiration accumulated at a daily scale at the treated M1 and untreated M2 sites and precipitation in 2008.



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was over, once again the *ET* values dropped and became similar at both sites. In addition, it was observed that the *ET* values increased following significant rainfall events, and the differences in *ET* between the untreated and treated sites increased in most cases.

During September 2007, the EC systems were switched between the sites. As shown in figures 7c and 7d, *ET* at the untreated site exceeded the treated site most of the time during September and early October 2007, and the overall tendency of *ET* values went down as the end of the growing season approached. The comparison pattern in *ET* for the first half of 2008 was similar to the previous years.

Evapotranspiration Comparison at Weekly Scale. Figure 8 displays the paired *ET* accumulated at a weekly scale at both sites during the study period. Before June 2005, the *ET* values were similar at the two sites. As the mesquite trees became the dominant vegetation at the untreated site during the period of June to mid-October 2005, the measured *ET* values at the untreated site exceeded the treated site in most weeks. In November, the *ET* at the treated site was slightly higher than the untreated site. By this time, the mesquite growing season was over and trees went into dormancy. The only source of transpiration was from the grasses, which were more abundant at the treated site ($GCIM_1$ = 25%; $GCIM_2$ = 21%) (figure 5). During December, *ET* at the treated site was either slightly higher or the same as compared with the untreated site; where *GCI* at the treated site was 10%, it was only 7% at the untreated site. From January to March 2006, *ET* rates at both sites were very similar. However, *ET* at the untreated site was lower than the treated site in April and became higher than the treated site in May. From June through October 2006, the weekly *ET* at the untreated site was consistently higher than that of the treated site. In November 2006, *ET* at the treated site was slightly higher. During the first two weeks of December 2006, *ET* of the two sites was about the same. However, *ET* became slightly higher at the untreated site during the last two weeks of December 2006. It is believed that the unusually high rainfall (about 20 mm [0.79 in]) prior to and during the last two weeks caused a high bare soil evaporation at the untreated site. This was because the major portion of surface vegetation, which was destroyed by the fire, recovered at a much lower rate under severe drought during the growing season.

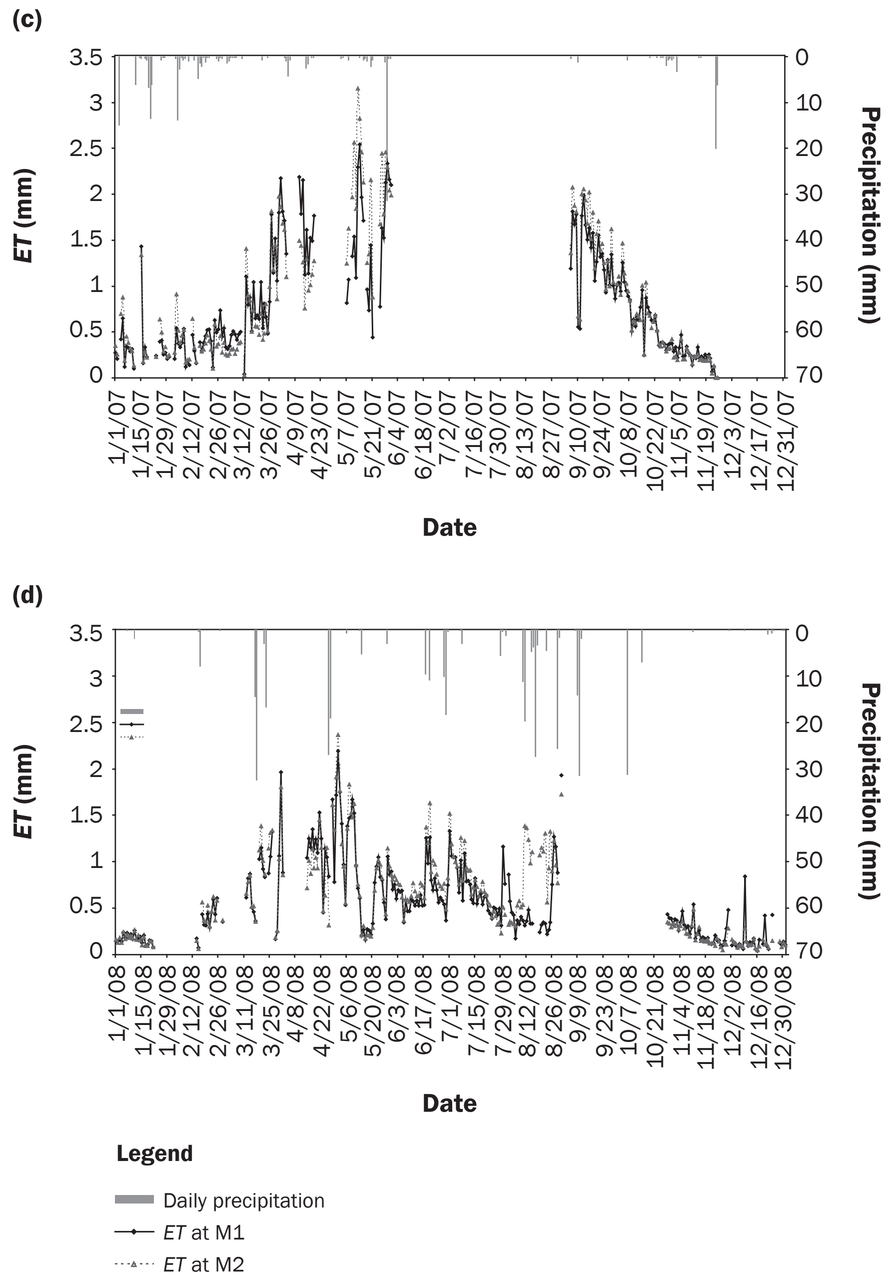
In January and February 2007, the *ET* at the untreated site either slightly exceeded or equaled the treated site. In March and April, *ET* at the treated site surpassed the untreated site because the surface grass cover, as indicated by *GCI* values, was higher at the treated site than at the untreated site (the average *GCI* was 14% at the treated site, as compared to 7% at the untreated site). In May when the mesquite trees became more active in transpiration, *ET* at the untreated site surpassed that of the treated site again. After the exchange of EC systems between the treated and untreated sites in September 2007, similar to past years, *ET* rates at the untreated site were greater than at the treated site at the end of the season and became similar during the mesquite dormant season.

Evapotranspiration Comparison at Monthly Scale. Figure 9 illustrates the variation of accumulated differences in *ET* ($\Delta ET = ET_{M2} - ET_{M1}$) at a monthly scale during the study period. The differences exhibited large variations over the seasons. During the mesquite dormant season, the differences in *ET* were small in magnitude (either positive or negative, and most were less than 2 mm [0.08 in] per month). During the mesquite growing season, the differences were of a larger positive magnitude (all were greater than 2 mm [0.08 in] per month, and the largest difference reached more than 10 mm [0.39 in] per month in August 2008).

Evapotranspiration Comparison at Yearly Scale. Figures 10a to 10d show the annual cumulative *ET* for both sites. From early April through the end of May 2005, a negligible difference in *ET* was obtained for both sites (ΔET = 1 mm [0.04 in]) (figure 10a). From June through October of 2005, field observations and measured data indicated that mesquite trees became the main source of *ET* at the untreated site as compared to the treated. Correspondingly, the accumulated ΔET reached its maximum (19 mm [0.75 in]) by November 1. By the end of 2005, the net accumulated ΔET was 16 mm (0.63 in). A higher *ET* was measured at the treated site during November to December because of more surface grass growth at the treated site (GCI_{M1} = 24.8% in November and 9.7% in December as compared to GCI_{M2} = 21.3% and 6.9%). The effect of the fire that occurred in January 2006 was apparent in that from January 1, 2006, to the end of May, the accumulated ΔET was only about 2 mm (0.08 in) (figure 10b). Beginning in June, the differences consistently became greater until early November of 2006, when the ΔET reached its maximum (13.3 mm [0.52 in]). This increase in ΔET is the result of regrowth of mesquite and grass at the untreated site during the growing season following the fire.

The accumulated ΔET was about 7.5 mm (0.30 in) in mid-October (figure 10c). This was lower than expected mainly because of the lack of measurements from June to early September while the equipment was being

Figure 7
Continued.



recalibrated. The *ET* at the untreated site exceeded the *ET* at the treated site by about 7 mm (0.28 in) by the end of December 2008 (figure 10d).

Seasonal Change in Evapotranspiration Differences. To reflect the differences in *ET* during different growing stages, the individual months were grouped into five periods: dormancy period (January to March), pregrowing period (April), growing period (May to October), peak-growing period (June to September), and dormancy period (November to December). Table 1 summarizes the total *ET* for each site, total precipitation, and the overall differences in *ET* between the two sites over the five periods. The total difference in *ET* between untreated and treated sites for the entire growing season of 2005 was 19.4 mm (0.76 in). Thus, *ET* at the untreated site was about 10% higher than at the treated site. The percentage difference increased slightly to 12% during May to October 2006. The total precipitation in the same period was 402 mm

Figure 8

Evapotranspiration (*ET*) accumulated at a weekly scale at the treated (M1) and untreated (M2) sites and precipitation during 2005 to 2008.

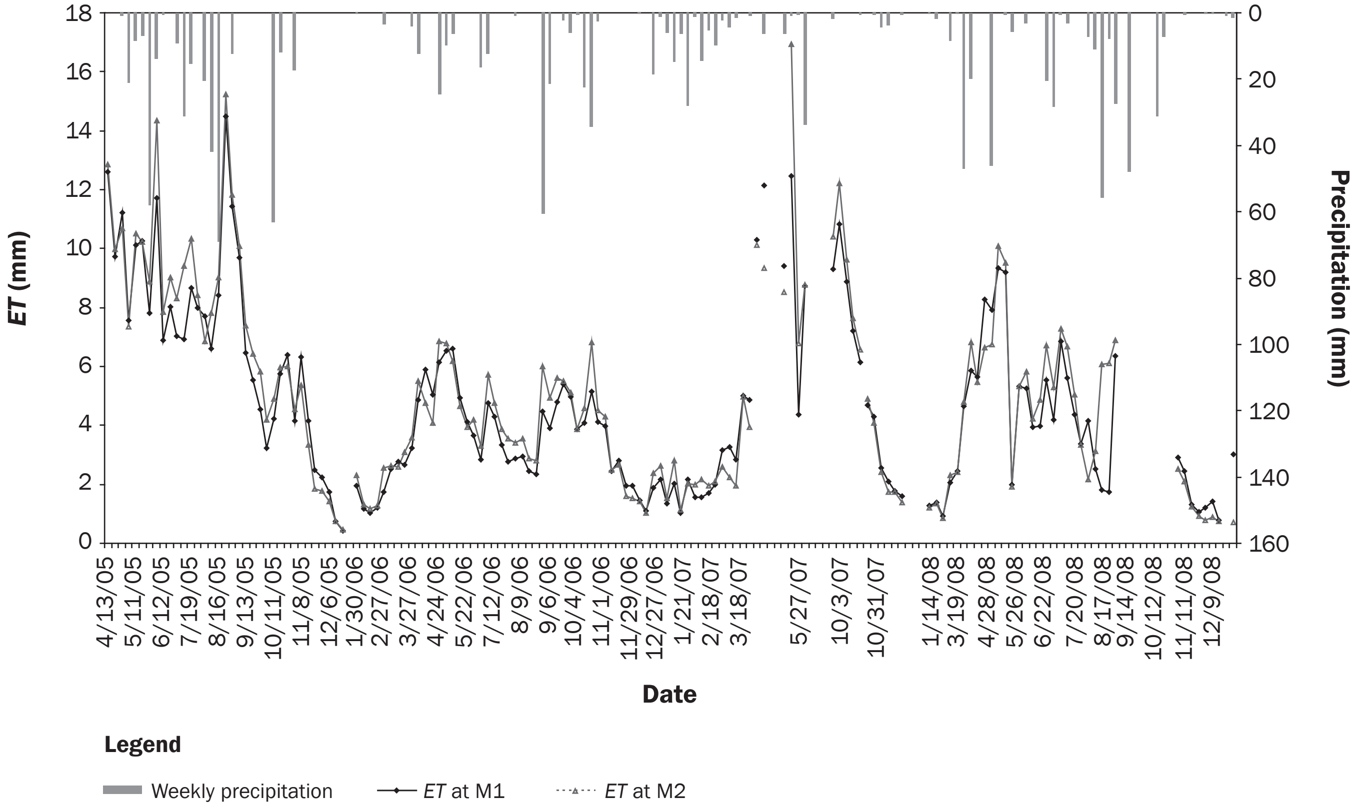


Figure 9

Difference in evapotranspiration ($ET_{M2} - ET_{M1}$) accumulated at a monthly scale during 2005 to 2008.

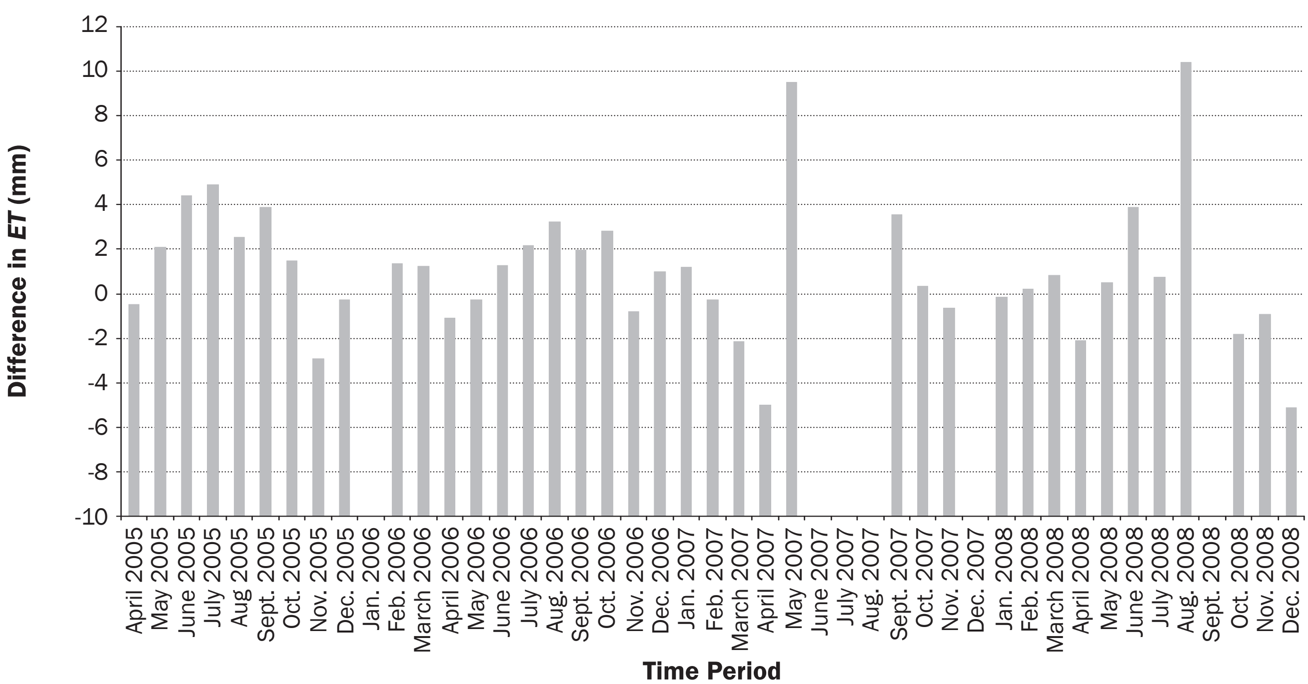


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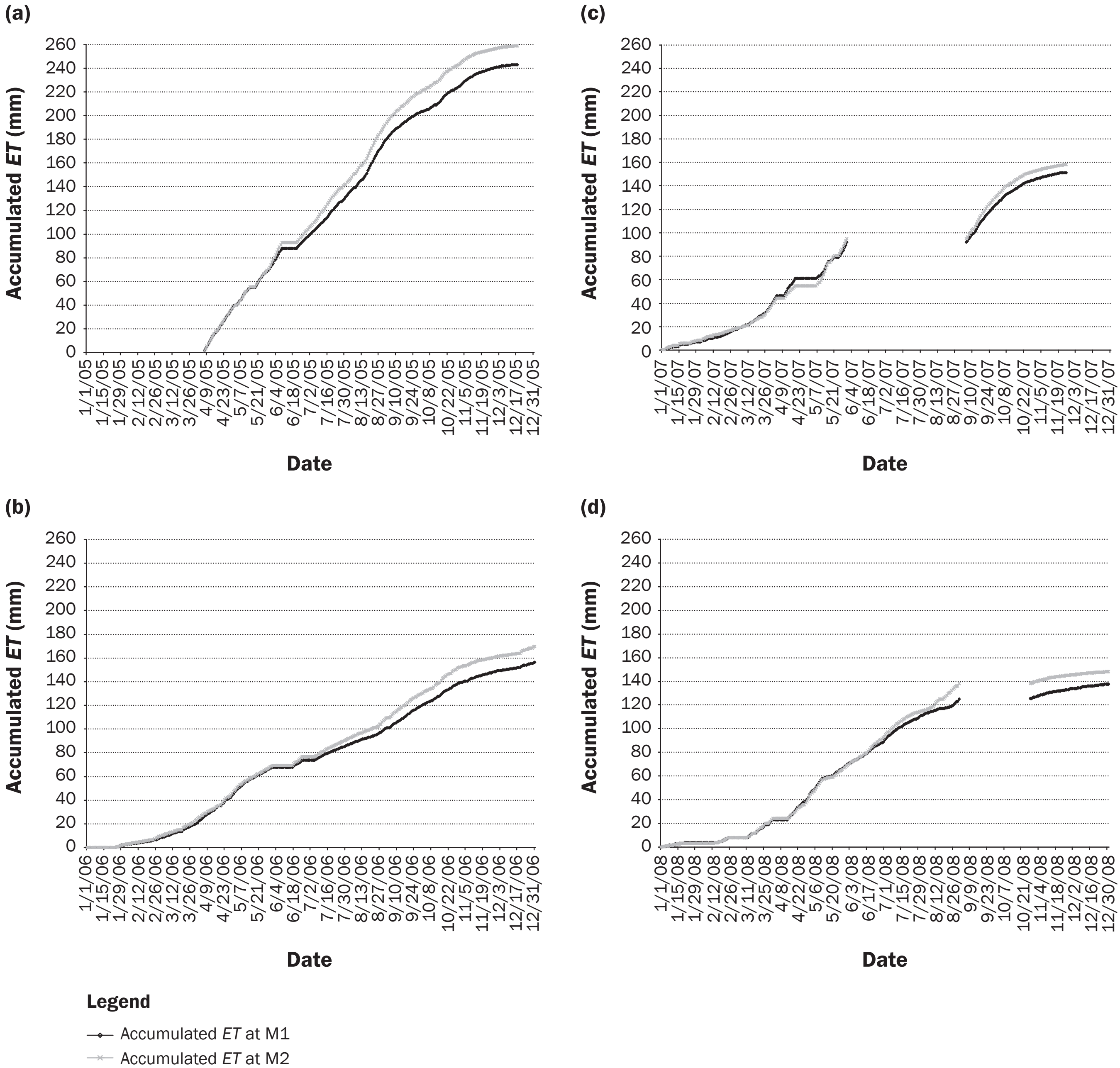
Figure 10

(a) Accumulated evapotranspiration (*ET*) in 2005. (b) Accumulated *ET* in 2006. (c) Accumulated *ET* in 2007. (d) Accumulated *ET* in 2008.



(15.8 in) in 2005 and 187 mm (7.36 in) in 2006. Measurement obtained during the peak mesquite growing season revealed that the *ET* at the untreated site was about 12% higher in 2005, 17% higher in 2006, and 25% higher in 2008 as compared to what was measured at the treated site. Recorded precipitation during the peak mesquite growing season was 299 mm (11.8 in) in 2005, 121 mm (4.76 in) in 2006, and 163 mm (6.42 in) in 2008. This indicates that during dry periods when surface grass growth is limited (e.g., dormant) the mesquite trees seem to become the dominant agent of water uptake from the soil profile.

In 2007, although data during the critical periods of the growing season were missing, the total difference in *ET* during the months of May, September, and October was 13 mm (0.51 in), indicating *ET* at the untreated site was 16% higher than at the treated site with precipitation of 49 mm (1.93 in) during this short period.

During the peak growing season of 2008, the largest observed difference in *ET* between sites was recorded. The difference in *ET* during this period was approximately 13.6 mm (0.54 in), which represents a difference in *ET* of 25%.

Based on 952 daily measurements obtained throughout the four-year study, the experimental data indicated that the mesquite-dominated untreated site had a net consumption of over 46 mm (1.8 in)

Table 1
Summary of measured *ET* and rainfall over various time periods for treated and untreated sites. Time periods were divided into five groups based on the growing periods: dormancy period (January to March), pregrowing period (April), growing period (May to October), peak-growing period (June to September), and dormant period (November to December).

Year	Time period	Total rainfall over the time period (mm)	Total ET over the period (mm) Treated	Untreated	*ET* difference ($ET_{M2} - ET_{M1}$) (mm)	Number of measured days and (potential days)
2005	Pregrowing	0.90	38.0	37.6	−0.40*	24 (30)
	Growing	402	186	206	19.4	164 (184)
	Peak-growing	206	131	146	15.7	109 (122)
	Dormant	0	19.0	15.8	−3.20*	48 (61)
	Total of 2005	403	243	259	15.8	236 (275)
2006	Dormancy†	19.3	18.5	21.1	2.60	57 (90)
	Pregrowing	35.1	24.7	23.6	−1.10*	30 (30)
	Growing	187	93.8	105	11.3	155 (184)
	Peak-growing	121	52.7	61.4	8.70	94 (122)
	Dormancy	25.9	17.3	17.5	0.20	58 (61)
	Total of 2006	267	154	167	13.0	300 (365)
2007	Dormancy	89.4	39.3	38.1	−1.20*	76 (90)
	Pregrowing	11.2	21.8	16.9	−4.90	13 (30)
	Growing‡	48.5	84.5	97.9	13.4	76 (184)
	Dormancy‡	30.7	5.7	5.0	−0.70*	23 (61)
	Total of 2007	180	151	158	6.60	188 (365)
2008	Dormancy‡	69.1	17.8	18.5	0.70	38 (90)
	Pregrowing	46.0	19.6	17.5	−2.10*	17 (30)
	Growing	172	83.0	97.2	14.2	118 (184)
	Peak-growing	163	55.8	69.4	13.6	87 (122)
	Dormancy	3.66	11.3	9.02	−2.28*	55 (61)
	Total of 2008	291	132	142	10.5	228 (365)

* Denotes *ET* at treated site is greater than the untreated site.
† Denotes January is not included due to the fire incident.
‡ Denotes months missing due to insufficient data.

more water than the treated site. The results above were obtained from actual days of valid observations and do not represent the total potential water consumed during the entire study period. In an effort to obtain an estimate of the total potential difference, the actual recorded difference between sites was extrapolated to the total potential number of days within the study period of April 2005 through December 2008 (1,370 days). Extrapolation of the data to include every day of the four-year study period indicated that the mesquite-dominated untreated site yielded a net usage of about 71 mm (2.8 in) more water than the treated site. Truncation of the data set to include only measurements obtained during the months within the mesquite growing season indicated that water consumption at the untreated site was 58 mm (2.3 in) higher than at the treated site and is the sum of 513 daily measurements. The extrapolation of the data set to include every potential day within the growing season (732) resulted in an estimated potential of 90 mm (3.5 in) of water use by the untreated site as compared to the treated site, assuming measurements of *ET* were obtained each day of the 184-day growing season during each of the four years. When quantifying how much groundwater was being used by sacaton grassland and mesquite trees, Scott et al. (2000) confirmed that grasses relied primarily on the near surface water from recent precipitation, while the mesquite trees could obtain water from deeper in the soil profile. During the dry period when the surface lacks moisture, most of the surface grasses, therefore, become inactive, and the live mesquite trees become the dominant consumers of water.

Nonparametric Matched-pair Test. The monthly nonparametric matched-pair test results, including *p*-values, means of differences, and conclusions based on the *p*-values and means, are summarized in table 2. From June through September, during the peak mesquite growing season, *ET* at the untreated site was consistently statistically significantly greater (at $\alpha = 0.05$) than at the treated site, with the exception of July 2008. On the other hand, *ET* at the treated site always was statistically significantly greater than at the untreated site in November when the surface grasses at the treated site were more abundant than at the untreated site and mesquite trees were dormant. For the remaining months, no consistent trends were detected.

Summary and Conclusions

A study was conducted on two adjacent plots within the North Concho River watershed, located in West Central Texas. The goal of this study was to investigate changes in the total water budget with implementation of brush control. Field *ET* values were measured with the eddy covariance technique from two 80 ha (200 ac) mesquite-dominated plots. On the treated plot, mesquite trees were killed with herbicide, while no herbicide application occurred at the untreated plot. The study period included a year with nearly normal precipitation (2005), two years with much lower than average precipitation (2006 and 2008), and a year with abundant precipitation (2007).

The *ET* comparative analyses at various time scales throughout the years showed that differences in *ET* between the untreated and treated sites were negligible during the dormancy season of the mesquite trees. The results also showed that the *ET* values at the untreated site exceeded the *ET* values at the treated site typically during the period from May to October. As mesquite trees became more active in transpiration, the maximum cumulative ΔET ($ETM_2 - ETM_1$) was typically measured by the end of October or early November. Quantitatively, for the paired data available, the *ET* at the untreated site was about 10% higher than the treated site for the entire growing season of 2005, with precipitation of 402 mm (15.8 in). The percentage increased to 12% in 2006, with lower precipitation of 187 mm (7.36 in). During the peak mesquite-growing period in 2005, the *ET* at the untreated site was about 12% higher than the treated site, with precipitation of 299 mm (11.8 in). During this same time period in 2006, *ET* at the untreated site was about 17% higher than at the treated site with precipitation of only 121 mm (4.76 in). The results also showed that based on partial growing season observations, *ET* at the untreated site was 16% higher than at the treated site during 2007. The highest recorded percent difference in *ET* between sites was 25% and occurred in 2008 during the peak growing season in which the measured *ET* was 14 mm (0.55 in) more at the untreated site. The nonparametric matched-pair test results indicated that the *ET* at the untreated site was statistically significantly greater than the treated site from June through September at a 95% confidence level.

Table 2
Results of nonparametric matched-pair test (α = 0.05).

Time period	Mean of difference (per day)	*p*-value	Conclusion
April 2005	−0.01888	0.97793	ns
May 2005	0.07837	0.00744	+
June 2005	0.24578	0.00001	+
July 2005	0.15853	0.00002	+
August 2005	0.08521	0.00554	+
September 2005	0.12937	0	+
October 2005	0.05386	0.00878	+
November 2005	−0.09768	0	–
December 2005	−0.01397	0.26453	ns
January 2006	0.04453	0.01563	+
February 2006	0.04832	0.00054	+
March 2006	0.04225	0.5054	ns
April 2006	−0.03639	0.05012	ns
May 2006	−0.00898	0.65962	ns
June 2006	0.14419	0.00781	+
July 2006	0.0846	0	+
August 2006	0.10836	0.00006	+
September 2006	0.06853	0.0007	+
October 2006	0.09396	0.00084	+
November 2006	−0.02779	0.00226	–
December 2006	0.03485	0.08145	ns
January 2007	0.05742	0.00297	+
February 2007	−0.01123	0.48708	ns
March 2007	−0.07127	0.01213	–
April 2007	−0.38439	0.00024	–
May 2007	0.4748	0.00003	+
September 2007	0.14331	0	+
October 2007	0.0109	0.55222	ns
November 2007	−0.0277	0.0001	–
January 2008	−0.00692	0.03859	–
February 2008	0.01944	0.2334	ns
March 2008	0.04935	0.08865	ns
April 2008	−0.12279	0.03052	–
May 2008	0.01711	0.3866	ns
June 2008	0.12832	0	+
July 2008	0.0257	0.056	ns
August 2008	0.3470	0.0019	+
October 2008	−0.0553	0.2500	ns
November 2008	−0.0388	0	–
December 2008	−0.1707	0.2880	ns

Notes: + = $ET_{untreated}$ is statistically significantly greater than $ET_{treated}$. – = $ET_{treated}$ is statistically significantly greater than $ET_{untreated}$ ns = *ET* between the two sites is not statistically significantly different.

Based on a total of 952 daily measurements obtained during the fouryear study period, the mesquite-dominated untreated site had consumed over 46 mm (1.8 in) more water than the treated site. Extrapolation of the data to include every potential day that *ET* could have been recorded during the study period (1,370 days) indicated that the untreated site had a potential net consumption of about 71 mm (2.8 in) more water over the four-year period than the treated site. Truncation of the data set to include only the 513 daily values recorded during the mesquite growing season for each year indicated that the untreated site had consumed approximately 58 mm (2.3 in) more water than the treated site. Extrapolation of the growing season dataset to include every day of the 184-day growing season (732 days) over the four-year period indicated that the total potential water consumption at the untreated site would exceed that of the treated site by about 90 mm (3.5 in).

Although efforts to collect *ET* data during the pretreatment period failed, and the results presented here were obtained after imposition of the treatment, the seasonal *ET* variations demonstrate that the reduced *ET* at the treated site was caused by killing of living mesquite trees rather than systematic differences in *ET* between the two sites. The consistency of the field observations with measured values by the EC technique indicates the dependability and accuracy of this method. It is also believed that the accumulated *ET* values for each site and the overall *ET* differences between the two sites could be actually larger than the values presented in this paper. This is because questionable data were not taken into account in the statistical analyses. The results from this study are consistent with the fact that mesquite trees can take advantage of their shallow lateral roots to compete for surface moisture with grasses, and of their deep roots to take up water from lower in the soil profile and shallow groundwater when the surface becomes very dry during drought and typical Texas summers. The consistency of field observations with *ET* values measured by the EC system indicates the dependability and accuracy of this system. Ultimately, this study suggests that a brush control approach has great potential for increasing water yield in the Concho River Watershed, which could support the further development and sustainability of San Angelo and its surrounding communities.

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