Adopted by TNRCC: November 2000
Adopted with Revisions: June 2002
Approved by EPA: May 2003

Two Total Maximum Daily Loads for Total Dissolved Solids and Sulfate in E.V. Spence Reservoir

For Segment 1411

Prepared by:
Strategic Assessment Division, TNRCC
Colorado River Municipal Water District

Distributed by the
Total Maximum Daily Load Team
Texas Natural Resource Conservation Commission
MC-150
P.O. Box 13087
Austin, Texas 78711-3087

TMDL Project Reports are also available on the TNRCC Web site at:
http://www.tnrcc.state.tx.us/water/quality/tmdl/

Two Total Maximum Daily Loads for Total Dissolved Solids and Sulfate in E. V. Spence Reservoir

Introduction

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

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

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

The ultimate goal of these TMDLs is to reduce pollution from total dissolved solids (TDS) and sulfate in the E. V. Spence Reservoir in order to restore and maintain general water quality uses.

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA) implementing regulations (40 Code of Federal Regulations, Section 130) describe the statutory and regulatory requirements for acceptable TMDLs. The TNRCC guidance document, *Developing Total Maximum Daily Load Projects in Texas* (GI-250, 1999), further refines the process for Texas. This TMDL document has been prepared in accordance with those guidelines, and is composed of the following six elements:

- Problem Definition
- Endpoint Identification
- Source Analysis

- Linkage Between Sources and Receiving Waters
- Margin of Safety
- Pollutant Load Allocation

These TMDLs were prepared by:

- Colorado River Municipal Water District (CRMWD) in Big Spring, Texas,
- Freese and Nichols, Inc. in Fort Worth, Texas, and
- the TMDL Team in the Strategic Assessment Division of the Office of Environmental Policy, Analysis, and Assessment of the TNRCC.

They were adopted by the Texas Natural Resource Conservation Commission on June 14, 2002. Upon adoption, the TMDLs became part of the state Water Quality Management Plan. The TNRCC will use this document in reviewing and making determinations on applications for wastewater discharge permits and in its nonpoint source pollution abatement programs.

Based on the TMDL, an implementation plan will be developed. An implementation plan is a detailed description and schedule of the regulatory and voluntary management measures necessary to achieve the pollutant reductions identified in the TMDL. The plan is a flexible tool that governmental and non-governmental agencies involved in TMDL implementation will use to guide their program management. Actual implementation will be accomplished by the participating entities by rule, order, guidance, or other appropriate formal or informal action. The implementation plan, combined with the TMDL, establishes a Watershed Action Plan (WAP). A WAP provides local, regional, and state organizations with a comprehensive strategy for restoring and maintaining water quality in an impaired water body. The TNRCC has ultimate responsibility for ensuring that water quality standards are restored and maintained in impaired water bodies.

Background Information

E.V. Spence Reservoir was constructed by the CRMWD for water supply purposes. CRMWD is permitted to draw 50,000 acre-feet of water from the reservoir each year for municipal, mining, and industrial uses. E.V. Spence Reservoir is an important source of drinking water for the surrounding region and provides a portion of the water for approximately 305,000 residents of the cities of Big Spring, Coahoma, Midland, Odessa, Robert Lee, San Angelo, and Stanton.

The 15,893 acre reservoir is located in the upper Colorado River Basin, approximately two miles west of Robert Lee. The reservoir was completed in June 1969 and is managed by the CRMWD. Inflow into the reservoir is partially regulated by Lake J.B. Thomas, Lake Colorado City, and Champion Creek Reservoir. The lake is widely known for its striped bass, which lure large numbers of fishermen to the region each year.

The E. V. Spence Reservoir watershed includes a 15,278 square mile area of Texas and New Mexico and is characterized by mesquite covered rolling plains in the lower portion of the basin and high plains grasslands in the upper portion. A majority of this drainage area, 10,260 square miles, is part of the High Plains Region and does not normally contribute runoff to the main stem of the Colorado River above the reservoir. Figure 1 illustrates the 5,018 acres of contributing drainage area above E. V. Spence Reservoir evaluated in this project. The designated water quality segments in this drainage area include E. V. Spence Reservoir (Segment 1411), and the Colorado River below J. B. Thomas Reservoir (Segment 1412).

Problem Definition

E. V. Spence Reservoir was placed on the 1998 CWA Section 303(d) List because sulfate and total dissolved solids (TDS) concentrations exceeded the segment standards criteria of 450 milligrams per liter (mg/L), and 1,500 mg/L, respectively. Recently, chloride concentrations in the reservoir have also been approaching the Texas surface water quality standard criteria of 950 mg/L. Since 1992, water quality in the reservoir has continued to deteriorate, partly due to the most severe drought conditions that the region has experienced since the reservoir began impounding water in 1969. Toward the end of March 2000, a single rainfall delivered over 47,000 acre-feet of badly needed water to the reservoir, more than doubling its content, and improving its water quality. However, lake levels remain at critical levels and more rainfall is needed to end the drought and help restore water quality in the lake to existing standards. Historic lake levels and chloride concentrations are shown in Figures 2 and 3.

In April 1999, the TNRCC and the CRMWD agreed to develop TMDLs for sulfate and total dissolved solids in the E.V. Spence Reservoir. The two-year TMDL project was funded by the TNRCC and administered by the CRMWD. Data analysis and modeling activities were subcontracted to Freese and Nichols, Inc. Evaluation of the watershed for purposes of these TMDLs was limited to the 5,018 square-mile contributing area.

Stakeholder contributions to the TMDL project were achieved through a 14 member Watershed Steering Committee. The Steering Committee was the major decision-making body throughout the two-year study. Members of the Steering Committee represented the general public, environmental interests, municipalities, industry, agriculture, water districts, river authorities, and state and federal agencies. A Technical Subcommittee consisting of several members of the Steering Committee was formed to evaluate technical issues such as modeling, and to provide recommendations to the Steering Committee.

The objective of the E.V. Spence Reservoir TMDL project is to characterize the sources of chloride, sulfate and TDS to the reservoir from the watershed and identify water quality targets necessary to restore and maintain usable water quality in the reservoir.

Endpoint Identification

Texas Surface Water Quality Standards (TSWQS) are rules (Texas Water Code §26.023) developed by the TNRCC to establish goals for water quality throughout the state and to provide a basis on which regulatory programs are carried out. Four categories are defined by TNRCC to describe the way that water bodies in the state are used. These include aquatic life use, contact recreation, public water supply, and fish consumption. Each use category is associated with a suite of standards and criteria developed to protect the continued use of each water body. The specific designated uses assigned to E. V. Spence Reservoir include high quality aquatic life use, contact recreation, and public water supply.

The limits of acceptable site-specific conditions presented in the TSWQS are described by numeric and narrative criteria. Statewide criteria are applied to each segment unless the results of targeted studies support the development of segment-specific criteria. Segment-specific criteria may either be more or less restrictive than statewide criteria, depending on the natural conditions of the water body and the contributing watershed. Segment-specific standards have been assigned to E. V. Spence Reservoir because of the naturally saline conditions of the region. The numeric criteria for the reservoir are 450 mg/L for sulfate and 1,500 mg/L for TDS.

All TMDL projects must identify a quantifiable water quality target for each constituent appearing on the CWA Section 303(d) list. For the E. V. Spence Reservoir TMDLs, the water quality targets are readily available from the secondary constituent levels published in the TSWQS (Title 30, Texas Administrative Code, Chapter 290). In acknowledgment of the effects that drought conditions can impose in this region of Texas, an exceedance probability approach is applied to the water quality targets. These TMDLs are designed to achieve and maintain the current respective segment-specific standards for sulfate and TDS, i.e. 450 and 1,500 mg/L, at least 80% of the time. The load reduction scenario suggested in these TMDLs is also expected to mitigate the recent increases in reservoir chloride concentrations.

Source Analysis

Several sources contribute to the load of sulfates, TDS, and chlorides entering E.V. Spence Reservoir. The only point sources of dissolved solids to the watershed are from municipal wastewater treatment plants. The nonpoint sources from the subwatersheds of E.V. Spence Reservoir include a combination of natural and man-made pollution loads. Surface water traveling across mineral beds, dissolution of natural underground mineral deposits, and concentrating effects of evaporation and transpiration from plants are natural sources of salt loads. The most commonly cited man-made pollution source is nonpoint pollution resulting from oil production practices, such as improper brine disposal, leaking oil well casings, and over-pressurization of downhole formations.

The remainder of this section addresses specific E.V. Spence Reservoir watershed sources in each of the point source, man-made nonpoint source, and natural nonpoint source categories.

Point Sources

Two municipalities, the City of Big Spring and the City of Snyder, discharge wastewater effluent to tributaries of the Colorado River upstream of E.V. Spence Reservoir (Segment 1412). Both facilities are upstream of CRMWD water quality diversions on Beals Creek and the Colorado River. Other municipal wastewater producers in the watershed employ land application as their primary disposal method, resulting in no contaminant loading or discharge of fresh water to streams in the reservoir watershed. Municipal discharge permits for the cities of Big Spring and Snyder currently do not require monitoring of sulfate or total dissolved solids in treated effluent. However, the CRMWD has conducted monitoring just downtream of the discharge outfalls for both cities.

Man-made Nonpoint Sources

Leaking Oil Wells

Oil exploration was established as a major industry in the E.V. Spence Reservoir watershed in the early 1920's. The Texas Railroad Commission (TRC) reported that total production in 1998 from fields in Mitchell, Scurry and Howard Counties, which comprise the major portion of the E.V. Spence watershed, was 17,917,877 barrels (TRC, 1999). The production of oil is always accompanied by the production of brine, which occurs in the same strata as the oil. During primary production of oil, the ratio of salt water to oil is usually less than 1:4. As the well ages, the ratio of salt water to oil becomes closer to 1:1 and may be as high as 10:1. As the ratio increases, the well becomes unprofitable to operate and is usually abandoned. Many of these abandoned wells have been found to develop cracks and leaks which may eventually reach the surface and contaminate ground water and surface water.

Brine Pits

Historically, operators disposed of brine in large, shallow unlined pits where water would be lost due to evaporation and seepage. Records for Scurry County indicate that, in 1961, more than 3.7 million barrels of brine were placed in open disposal pits (155.4 million gallons). It is estimated that approximately five percent of water placed in disposal pits is lost through evaporation which is retarded by films of oil and microorganisms (TRC, 1966; Slade and Buszka, 1994). When brine is evaporated, dissolved solids are left behind as salt, which can infiltrate to the shallow subsurface and local ground water. Brine disposal pits were used extensively in areas of oil production until 1969, when a state-wide ban was placed on their use.

Brine Injection

In 1969, the Texas Legislature passed a law prohibiting open pit disposal of brine, causing a shift of disposal techniques from surface to subsurface. By March 1987 about 184 brine disposal projects in the area were issued permits, each of which included one to several hundred disposal wells. The permitted disposal rates for each project ranged from 100 to 10,000 barrels per day. Approximately 40.9 million barrels of brine were injected into disposal wells during 1987 (Slade and Buszka 1994).

The practice of injecting brine into subsurface strata is used for both disposal of excess salt water and for recovering oil from under-pressurized formations. There are over 2,500 wells in the TRC GIS database of wells in the E.V. Spence watershed which are classified as injection wells. As technology has improved and the costs associated with injection has decreased, the volume of brine disposed of by injection has increased.

Many disposal wells inject brine into formations immediately below shallow aquifers. This relatively shallow disposal presents a higher risk of migration into groundwater and surface water bodies at formation outcrops. Injection into the Coleman Junction Limestone member of the Putnam Formation was banned by the TRC because of the demonstrated risk of migration. The permits for five injection wells in the Coleman Junction Limestone were rescinded in 1977 for this reason.

Brine used for secondary recovery of oil from producing wells is injected into production formations located much deeper than those used for disposal. The pathway for contamination of freshwater from secondary recovery activities is back up the well itself. TRC data compiled by Slade and Buszka (1994) indicate that, compared to the sheer number of permitted wells, relatively few secondary recovery projects pose a risk to shallow ground water or surface water bodies.

Surface and subsurface contamination associated with injection wells is often traced to cracked casings, leaking boreholes, or wells which are not operated properly. Documented cases of leaking injection wells have been reported by Reed (1961), Rawson (1982) and in other unpublished investigations by the TRC for locations in the vicinity of the Colorado River above Colorado City. A study by the TRC identifies leaking injection wells as being the probable cause of contamination of Beals Creek at the Snyder Oil Field in eastern Howard County.

Industrial Facilities

A magnesium plant is located approximately seven miles west of the city of Snyder at FM1606 and FM1607. The plant is situated on the side of a slope approximately 3,000 feet west of Bluff Creek and approximately 1,000 feet north of an unnamed tributary to Bluff Creek. The site contains buildings of various sizes and in various states of disrepair, a tank farm, and several ponds for storage and catchment. The facility has been abandoned since 1986.

The TNRCC regional office has documented unauthorized discharges of high chloride water during 1976, 1983, 1985, 1986, 1987, and twice during 1988. Chloride concentrations of discharged water ranged from 6,000 mg/L to 164,000 mg/L. In January of 1998, water samples were collected by CRMWD staff from a well near the property line and from a seep down-slope from the well. Chloride concentrations of the samples were 15,200 mg/L and 15,100 mg/L, respectively. Discharge from the seep was not measured, but was sufficient to cause a small flow across a nearby county road. An apparent kill zone was noted on both sides of the county road. The location of the site presents a clear threat to the water quality of Bluff Creek and eventually to Colorado River. The CRMWD estimates that chloride loads from the abandoned plant could be as much as 61.6 tons per month on average.

Natural Nonpoint Sources

In 1994, the U.S. Geological Survey (USGS) published a report (Slade and Buszka, 1994) which investigated the sources of salinity in surface waters between Lake J.B. Thomas and the O.H. Ivie Reservoir. The study incorporated surface and ground water data collected between 1969 and 1990. Chemical characteristics of surface and shallow aquifer waters in the study area were compared to the predicted characteristics of water that would result from evapotranspiration by phreatophytic plants such as salt cedar and mesquite, mineral dissolution of natural deposits, and mixing of water with brine from deep aquifers.

Using the computer model SNORM for salt-norm analysis, four categories of water were identified, including meteoric-sulfate and gypsum which represent naturally-occurring sources of ions, brine which represents man-made or produced water, and brine-mixed which indicates the reaction of brine with naturally-occurring shallow aquifer minerals. The study concluded that, for nine stream samples collected in the O.H. Ivie watershed, 56 percent of the dissolved solids were from naturally-occurring sources and 44 percent was determined to be caused by dissolution of halite or mixing with deep-aquifer water, indicating anthropogenic (man-made) origins.

Of the 86 sites (streams, springs, or wells) analyzed using salt-norm analysis, 45 were located in the E.V. Spence Reservoir watershed. Eight sites represented surface water bodies, including the Colorado River and Beals Creek, while thirty-seven sites represented ground water, including alluvial ground water and shallow aquifers. The percent halite data from each combination of water body type and salt-norm classification at sampling sites within the E.V. Spence Reservoir watershed, show an apparent distinction between the groups representing man-made and naturally-occurring sources.

Phreatophytic Brush

The proliferation of invasive species of brush into the western portions of Texas are a recognized problem in water management. Three species which occur in the E.V. Spence Reservoir watershed are salt cedar, juniper, and mesquite. These plants have a high water consumption rate compared to most native vegetation and easily out-compete most native species in disturbed areas. All have extensive root systems, robbing the soil of moisture to a depth impenetrable by most other species. Salt cedar is especially detrimental to water quality because of its ability to transport salts from ground water to its leaves. Because salt cedar is a deciduous plant, salt stored in the leaves is concentrated at the soil surface when leaves are dropped in the fall. Salt cedars can tolerate chloride concentrations as high as 35,000 mg/L, much higher than most plant species.

Natural Dam Lake Spill

Natural Dam Lake is an approximately 54,000 acre-foot reservoir on Beals Creek. Unusually heavy rainfall conditions from 1986 through 1989 caused highly saline water to spill from Natural Dam Lake to Beals Creek and the Colorado River from June 1986 through July 1987, and again from July 1988 through May 1989. These spills have significantly degraded the water quality and usability of the E. V. Spence Reservoir on the Colorado and contributed to the current violation of E. V. Spence Reservoir’s water quality standard for sulfate and TDS. Between 1989 and 1994, the CRMWD enlarged the dam of Natural Dam Lake and constructed Sulphur Draw Reservoir in its watershed. These modifications were designed to prevent future spills from Natural Dam Lake.

Salt Deposits

The surface geology of the watershed includes significant areas of Permian gypsum such as the Cloud Chief Gypsum formation. Leifeste and Lansford (1968), Green (1977), and Rawson (1982) concluded that, in addition to contamination from oil fields, natural salt deposits could not be ruled out as a significant source of elevated salinity in the Colorado River and its tributaries. The salt deposits contribute to the load by surface water traveling across mineral beds or by dissolution of natural underground mineral deposits into ground water that discharges to the surface.

Climatological Effects
The gradual accumulation and concentration of dissolved solids over time during extended dry periods exacerbate water quality problems in the reservoir. The common pattern in the reservoir is for water quality to improve dramatically immediately after a large rainfall, and gradually deteriorate as arid conditions persist.

A fundamental problem for the E.V. Spence Reservoir is the amount of runoff it receives relative to its size. Reservoirs in most watersheds fill to capacity and spill fairly regularly, and this process helps maintain a fresh supply of water within the reservoir. But water supply reservoirs in arid regions may rarely experience spills. The E.V. Spence Reservoir has not experienced a natural spill since its construction in 1969. Thus the flushing process that helps maintain water quality in most reservoirs has not occurred for Spence.

Subwatershed Analysis

Although water quality of the upper Colorado River has been studied for many years, the lack of water quality data associated with identified pollutant sources such as seeps, leaking oil wells, and brine pit disposal precludes the quantitative determination of pollutant loadings from these sources. The widespread nature of potential nonpoint sources of dissolved solids in the Spence watershed also makes the identification of specific sources difficult. For this reason, a subwatershed approach was used to evaluate loadings in the E.V. Spence Reservoir watershed, with subwatersheds delineated from USGS gages in the watershed and loadings based on stream monitoring data from those locations.

The spatial distribution of the total historical chloride loadings to E.V. Spence Reservoir (since construction) is shown in Figure 4. Historically, most of the chloride loads to E.V. Spence Reservoir originated from the Beals Creek Watershed because of extremely deleterious spills from Natural Dam Lake, in 1986-88.

Linkage Between Sources and Receiving Water

Poor quality inflows and the natural concentrating effect of reservoir evaporation have combined to create poor water quality conditions in E.V. Spence Reservoir. In 1983, a FORTRAN model of E.V. Spence Reservoir was created that predicted the concentration of chlorides in the reservoir over an extended period (CRMWD, 1983). The model required estimates of chloride concentrations from the watershed, and predicted chloride concentrations in the reservoir resulting from alternative reservoir operation simulations. The predictions of the 1983 water quality model were based on volumetric and mass balance algorithms for the system and assumed a completely mixed reservoir.

For the E.V. Spence Reservoir TMDL study, the 1983 water quality model was updated to include water quality data through March 2000 and expanded to include total dissolved solids and sulfates, in addition to chlorides. The model was also upgraded to account for stratified differences in reservoir surface and release concentrations. The updated E.V. Spence Reservoir water quality model predicts reservoir concentrations of chloride, sulfate, and TDS based on estimates of monthly pollutant loads from the watershed, inflows, net reservoir evaporation rates, demand, and releases. The model was initially calibrated to the historical chloride concentrations in the reservoir rather than sulfate or TDS, because of the relative abundance of chloride data available for the entire period of record.

Through a linear regression analysis of the calibrated model's output with historically observed chloride concentrations, Figure 5 shows the relative accuracy of the model's predictive abilities. The results show a strong relationship ($R^2 = 0.8742$) between the measured and predicted chloride concentrations. Figure 6 illustrates the predicted and measured reservoir chloride concentrations, plotted for the entire period of record, using the calibrated model.

Figures 7 and 8 show the results of model simulations for sulfate and TDS concentrations, compared with historical measurements from the USGS and TNRCC. While the historical sulfate and TDS databases are not as extensive as the chloride database, the chloride-calibrated model produces relatively accurate estimates for sulfate and TDS, also. For this reason, the model was not recalibrated for the prediction of sulfate and TDS. As shown in all the comparison figures, the E.V. Spence Reservoir water quality model explains much of the variability in the observed values for the full range of concentrations throughout the entire period of record. The model simulates large short-term changes in the water quality resulting from large inflows such as those that occurred at several times in the 1980's, and it accurately simulates the gradual long-term changes such as those experienced in the 1970's and 1990's, resulting from extended drought.

Natural Dam Lake Spills

Freese and Nichols used the Spence Reservoir water quality model to quantify the impacts of Natural Dam Lake spills on the quality of water in E.V. Spence Reservoir. The model used historical hydrologic records with adjustments to account for flows and loads originating from Natural Dam Lake to predict the reservoir concentrations and content during the study period.

For this analysis, the flows and mass loads passing the Beals Creek near Westbrook gage (#08123800) were naturalized to remove the known anthropogenic (man-made) influences (e.g. Big Spring wastewater treatment plant). For months when Natural Dam Lake was spilling, mass loads from the Natural Dam watershed were estimated by taking the difference between the total naturalized load passing the Westbrook gage and the estimated load from the normal contributing watershed.

To estimate the impact of the Natural Dam Lake spill on the water quality of Spence Reservoir, the estimated flow and mass loads originating from Natural Dam Lake were removed from the hydrologic input of the Spence Reservoir water quality model. With historic input, the model accurately predicted historic concentrations of chloride (Figure 5). When the Natural Dam Lake estimated spills were removed from the historic hydrology, the concentration of chloride in Spence Reservoir in March 2000 was predicted to fall approximately 330 mg/L from an estimated concentration of 1,070 mg/L to a new estimate of 740 mg/L.

Figure 9 shows the results of the water quality simulation for lake content, and Figure 10 shows the chloride concentrations that would have resulted in Spence Reservoir without Natural Dam Lake spills. The figures show that mass loads from the Natural Dam Lake spill still impair water quality in the reservoir, to the present day. However, as the reservoir contents have dropped through the 90's drought, the magnitude of the impact of Natural Dam Lake spill has diminished. All of the subsequent evaluations of water quality management practices incorporate the Natural Dam modifications, by removing flows and loads originating from the Natural Dam watershed from the hydrologic period of record. These adjustment are critical for understanding the current Spence Reservoir watershed conditions.

Full Potential Loads, Natural Loads, and Existing Management Conditions

Once the Natural Dam Lake effects were removed from the water quality model, the model was then used to simulate salt concentrations that would result in E.V. Spence Reservoir without any future management of the watershed. The results of this worst-case scenario are shown in Figures 11, 12, and 13. The figures also show estimates of the natural loadings impacts to E.V. Spence Reservoir. These estimates were derived by applying the USGS hypothesis that 56% of the full potential loadings occur naturally (Slade and Buszka, 1994). In either scenario the current standards are not maintained throughout the entire period of record. Future management of the watershed may reduce loadings received by the reservoir from the full potential loadings, but the legacy of oil production activities in the basin makes it impossible to completely eliminate man-made loadings to the reservoir in the foreseeable future.

There are few regulatory controls currently available to mitigate TDS and sulfate loadings in the E.V. Spence Reservoir watershed. The CRMWD has spent over $25 million addressing the pollution problems of the E.V. Spence Reservoir basin. Their existing management practices attempt to improve water quality in the reservoir without targeting specific polluters. Instead, CRMWD's efforts have included several diversions of high salinity water from the Colorado River above Colorado City and Beals Creek upstream of Moss Creek, as well as improvements to Natural Dam to avoid future spills. Without these historical management efforts, water quality in E.V. Spence Reservoir would be much worse than it currently is, and it would be impossible to maintain water quality in the reservoir. Figure 14 shows the subwatershed distribution of chloride loadings to E.V. Spence under the current management of the watershed, also referred to as the “base case.” Figures 15, 16, and 17 show the simulated chloride, sulfate, and TDS concentrations, under the existing management conditions.

Evaluation of Load Reduction Scenarios

Figures 15, 16, and 17 also show the expected chloride, sulfate, and TDS concentrations, respectively, that result from a simulation of the management measures considered by the E.V. Spence Steering Committee, along with an additional reduction from man-made nonpoint sources. Figure 18 shows the frequency of exceeding the existing standards if all of these management measures are implemented. As shown in Figure 18, the load reduction scenario produces reservoir TDS concentrations that meet the existing standard approximately 80% of the time. When compared with the existing management conditions (i.e. “base case”) scenario, this corresponds to a 39.6% reduction in the 80th percentile TDS concentration. The same load reduction scenario also produces reservoir sulfate concentrations that meet the existing standard approximately 90% of the time. This corresponds to a 38.9% reduction in the 80th percentile sulfate concentration.

Margin of Safety

These TMDLs include an implicit margin of safety that has significance but is not specifically quantifiable. The margin of safety is embodied in two aspects of the technical analysis and modeling executed during the TMDL development.

First, a significant amount of chloride monitoring data has been collected by the CRMWD and was used in the calibration of the E.V. Spence Reservoir water quality model. Through use of this large data set, the resulting calibrated model explains much of the variability in the observed values for the full range of concentrations throughout the entire period of record. As shown in Figures 5-8, the model accurately simulates large short-term concentration changes resulting from large inflows as well as gradual long-term changes such as those experienced during extended drought periods. Because of this accurate calibration, the uncertainty associated with the modeling effort is minimized.

A second factor effecting margin of safety is the model simulation uncertainty associated with the limitations of the TMDLs to optimize specific simulations and account for potential modifications to existing operations procedures that could improve the management of the system. CRMWD's water quality diversions are managed to maintain and enhance the water quality of Spence Reservoir. The basic model assumption that municipal wastewater treatment plants discharge at their full permitted levels severely compromises the ability of the downstream water quality diversions to effectively capture natural high salinity/low flows. The assumption creates large base flows, unlike any projected to occur, that dilute the diversions. This uncertainty in the simulation is unique from uncertainty that may be inherent to the Spence water quality model, but could lead to significant simulation error. From this perspective, it may be argued that the Spence water quality model has been applied conservatively and that Margin of Safety could be reduced to reflect the sub-optimal operation of the water quality diversions that are assumed for all the simulations.

Some allowance for future growth (FG) is also embodied in these TMDLs. The full permitted wastewater discharges and loads assigned to the point sources represent much more growth than is anticipated for either of the cities’ facilities. Because the permitted discharges from the municipal wastewater treatment plants are much larger than the current and projected discharges, no additional future growth or margin-of-safety was considered in the implicit allocation.

Pollutant Load Allocation

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

The loading allocation process in a TMDL study partitions the potential loading received by the reservoir between several different terms. Equation 1 shows a typical formulation of the load allocation equation.

$$TMDL = L_{pt\ src} + L_{npt\ nat} + L_{npt\ anthro} + FG + MOS \tag{1}$$

where $L_{pt\ src}$ is the loading from point sources, $L_{npt\ nat}$ is the nonpoint source loading from natural sources, $L_{npt\ anthro}$ is the nonpoint source loading from anthropogenic sources, FG is a loading value assigned for future growth considerations, and MOS is Margin-Of-Safety. Alternatively, the FG and MOS could be included implicitly in each of the loading components. Implicit inclusion of the FG and MOS components reduces the loading allocation equation to three terms, as such:

$$TMDL = (L + FG + MOS)_{pt\ src} + (L + FG + MOS)_{npt\ nat} + (L + FG + MOS)_{npt\ anthro} \tag{2}$$

Management measures implemented by these TMDLs will focus on reducing dissolved solids loadings from nonpoint sources. Loading from other sources is not anticipated to change significantly due to the TMDLs. Some of the management measures, such as brush control and TRC mitigation activities, will target specific natural or man-made nonpoint sources. Others, such as increased diverted flows at CRMWD diversion locations, will affect loadings from both natural and man-made sources.

Since mass loadings to a reservoir-type water body typically have long residence times, the incremental loads that are received by the reservoir within any single time step (e.g. month) do not constitute the total loads that determine standards compliance for that time step. For this reason, it is important to consider the *loading capacity* of the reservoir, which is the load that would result in a concentration equal to the water quality standard. The sum of the loads from different sources cannot exceed the loading capacity without violating the water quality standard.

Reservoir loading capacity is calculated very differently from the loading capacity of a stream. A stream's loading capacity varies in time as a function of only the stream's flow rate. If the flow rate increases, the stream's loading capacity at that moment increases proportionally. A reservoir's loading capacity also varies in time, but it is a function of the mass inflow, as well as the volume and concentration present in the reservoir.

Reservoir loading capacity can be expressed mathematically as

$$LC = L + (C_{standard} - C_{eom}) * V_{eom} \tag{3}$$

where LC is the monthly reservoir loading capacity, L is the mass received during the month, $C_{standard}$ is the water quality standard, C_{eom} is the end-of-month concentration, and V_{eom} is the end-of-month reservoir volume. The second term in the equation represents the additional load that may be received by the reservoir and still remain within the water quality standard. The loading capacity of a reservoir can appear negative when the standards are exceeded. The loading capacity may also be expressed in other units (e.g. tons per day, tons per year), by varying the time step of the mass received (L). It is important to note that reservoir loading reductions, as may be achieved through application of management measures, result in corresponding loading capacity increases.

Monthly chloride, sulfate, and TDS loading capacities over the 28-year period of record were estimated using the updated E.V. Spence Reservoir water quality model. Once the series of loading capacities was established, the loading capacity values were ranked in order of magnitude. In recognition of the climatological limitations associated with this portion of Texas, the 80th percentile loading capacity, i.e. the loading capacity that would be present in the reservoir 80% of the time, was selected as the target loading capacity.

Monthly estimates of the point source loads in the watershed were derived from the permitted flows for each facility and monitoring data, collected by CRMWD just downstream of the discharge outfalls. For each parameter, the difference between the target loading capacity and the point source loads represents the allowable loading contribution from nonpoint sources, with 44% of that remainder assigned to man-made sources and 56% assigned to natural sources, in accordance with the USGS assessment (Slade and Buszka, 1994). Table 1 shows the distribution of the 80th percentile loading capacities to each of these source categories.

Based on output shown in Table 1, if the reduced loading and management goals associated with the load reduction scenario were fully achieved, reservoir loading capacities for chloride, sulfate, and TDS would be approximately 1,427 tons/day, 268 tons/day, and 438 tons/day, respectively. These loading capacity estimates represent the minimum values that would be present during 80% of the 28-year period of record. It is important to note that, for years when rainfall runoff contributes to less than the 80th percentile reservoir content, smaller (and sometimes negative) loading capacities would exist.

It should also be noted that the above approach tends to overestimate the relative effects of point source loads in the watershed since the full permitted flows are assumed, since there is no consideration of what influent dissolved solids concentrations may be at each of the facilities, and since the approach assumes that no fraction of the point source loads are diverted at any of the CRMWD’s downstream water quality diversions. In reality, wastewater flows are of much higher quality than the background flows in the watershed and typically provide dilution effects to the reservoir.

Table 2 shows the corresponding parameter concentrations associated with the 80th percentile loading capacities. For comparative purposes, the 80% parameter concentrations associated with the existing management conditions, or "base case" scenario, are also shown in Table 2. By comparing these two scenarios, the load allocation can be described in terms of the total percent reduction required for each parameter in order to achieve all water quality standards at least 80% of the time.

The reductions necessary to meet the loads allocated to nonpoint sources, both natural and man-made, will be achieved through the development of an implementation plan. The plan will include the following components:

(1) a description of the control actions and management measures that will be implemented to achieve the water quality target;
(2) legal authority under which control actions and management measures will be carried out and whether they are enforceable;
(3) the development of a schedule for implementing specific activities determined necessary to achieve TMDL objectives;
(4) a follow-up surface water quality monitoring plan to determine the effectiveness of the control actions and management measures;
(5) reasonable assurances that the implementation of voluntary management measures will achieve the load allocations for nonpoint sources; and
(6) measurable outcomes for determining whether the implementation plan is properly executed and water quality standards are being achieved.

Implementation will be achieved through coordination with partnering agencies including the Texas State Soil and Water Conservation Board, the Railroad Commission of Texas, and the Colorado River Municipal Water District.

References

Colorado River Municipal Water District (CRMWD). 1983. Evaluation of the improvement of water quality in E.V. Spence Reservoir. CRMWD, Big Spring, Texas.

Green, M.G. 1977. An investigation of sources of salt pollution in the upper Colorado River Basin, Texas. Thesis report for the University of Minnesota, Master of Geomechanics.

Leifeste, D.K., and M.W. Lansford, 1968. Reconnaissance of the chemical quality of surface waters of the Colorado River Basin, Texas. Report 71. Texas Water Development Board, Austin, Texas.

Rawson, J. 1982. Source areas of salinity and trends of salt loads in streamflow in the upper Colorado River, Texas. Geological Survey Water Supply Paper 2084, U.S. Army Corps of Engineers, Alexandria, Virginia.

Reed, E.L. 1961. A study of salt water pollution of the Colorado River, Scurry and Mitchell Counties, Texas. CRMWD, Big Spring, Texas.

Slade, R.M., Jr. and P.M. Buszka. 1994. Characteristics of streams and aquifers and processes affecting the salinity of water in the upper Colorado River Basin, Texas. Water-Resources Investigations Report 94-4036. U.S. Geological Survey, Austin, Texas.

Texas Railroad Commission (TRC). 1966. Inspection and Pollution Report of Salt-Water Disposal Pits - Howard, Mitchell, and Sterling Counties, TX. Texas Railroad Commission, Oil and Gas Division, District VIII, Midland, Texas.

Texas Railroad Commission (TRC). 1999. ACTI Texas Oil and Gas Production, [Online] May, 1999. Available URL: http://driller.rrc.state.tx.us/cgi-bin/WebObjects/acti

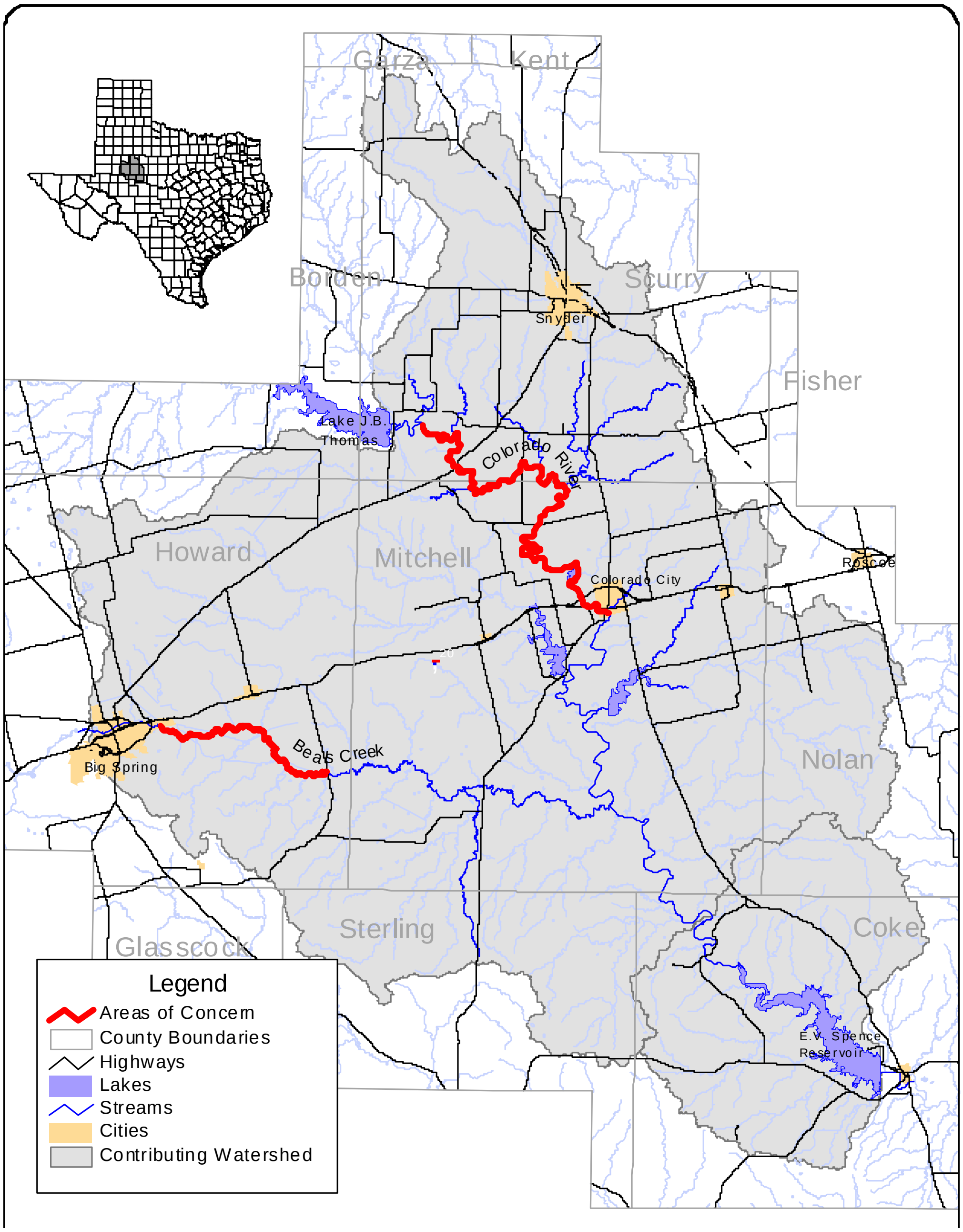

Figure 1 - TMDL Study Area

Figure 2 - Historic E. V. Spence Reservoir Content

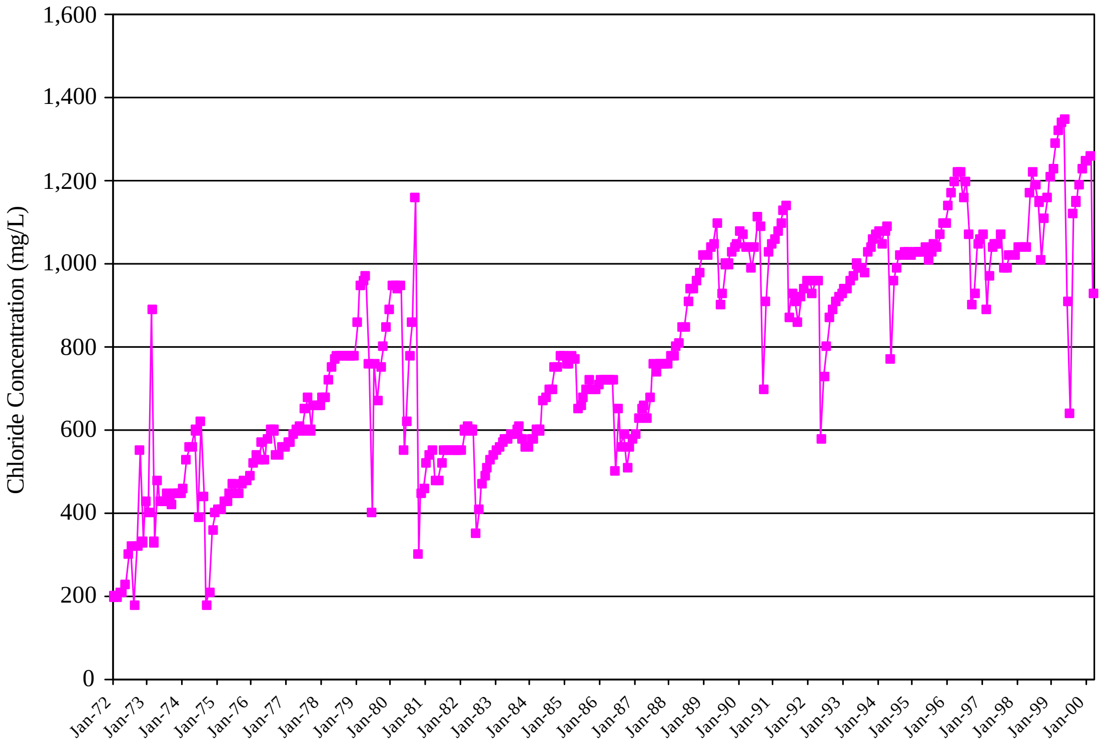

Figure 3 - Historic E. V. Spence Reservoir Chloride Concentrations

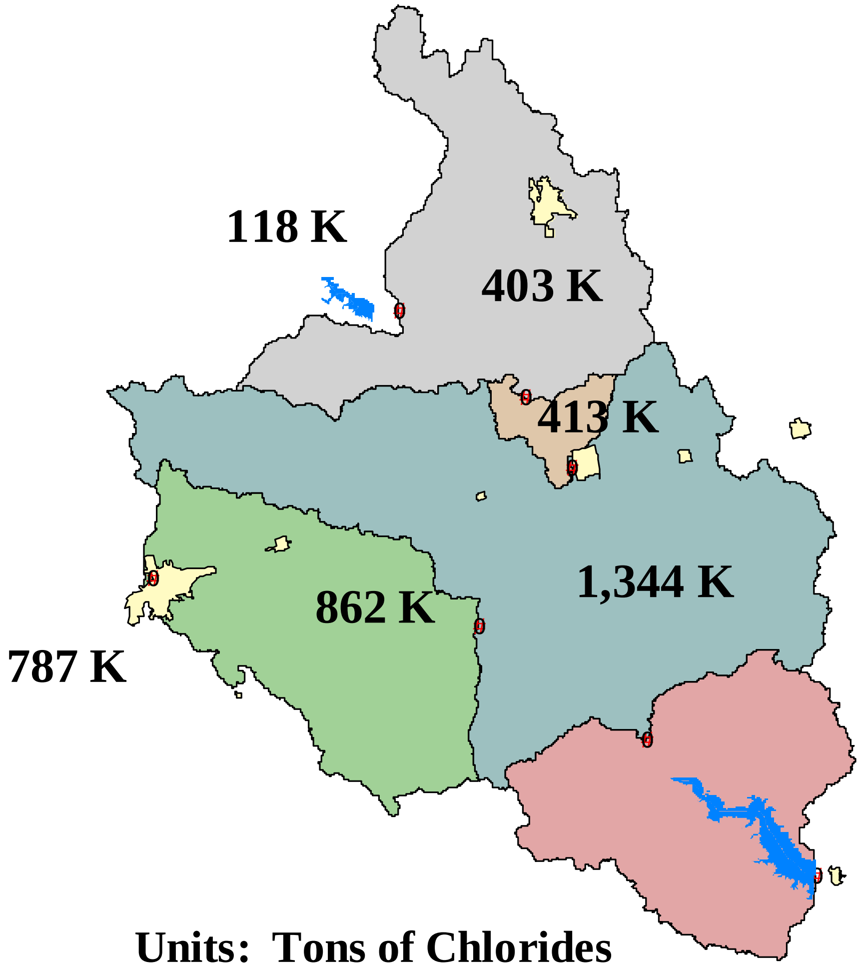

Figure 4 - Subwatershed Distribution of Total Chloride Loads Received by E.V. Spence Reservoir under Historical conditions

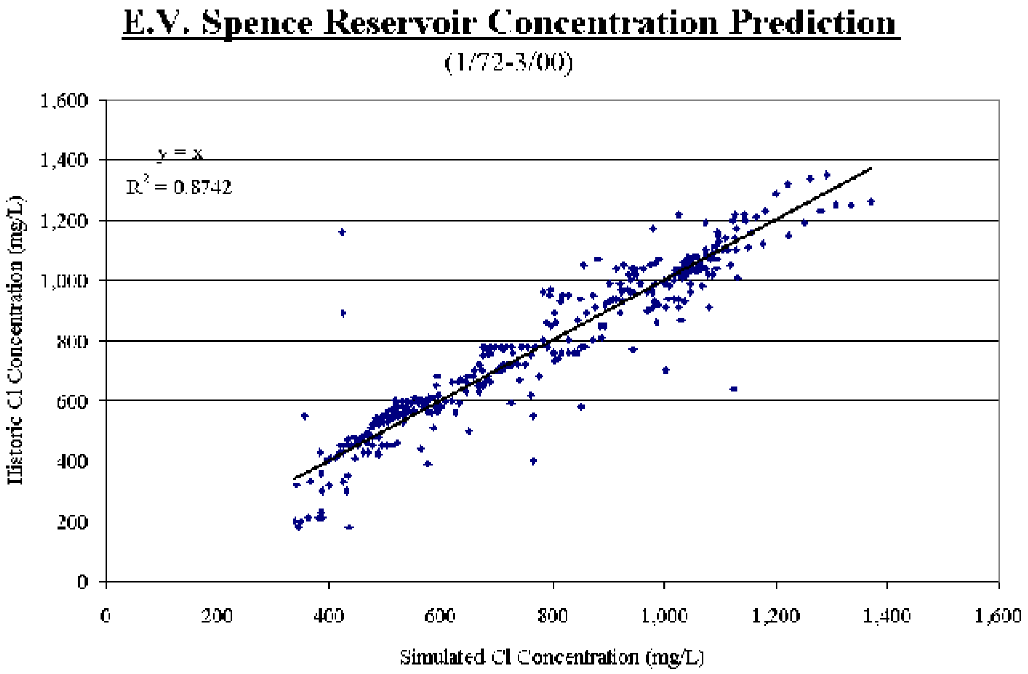

Figure 5 - Comparison of the Calibrated E.V. Spence Reservoir Water Quality Models's Simulated Output with Historically Observed Chloride Concentrations

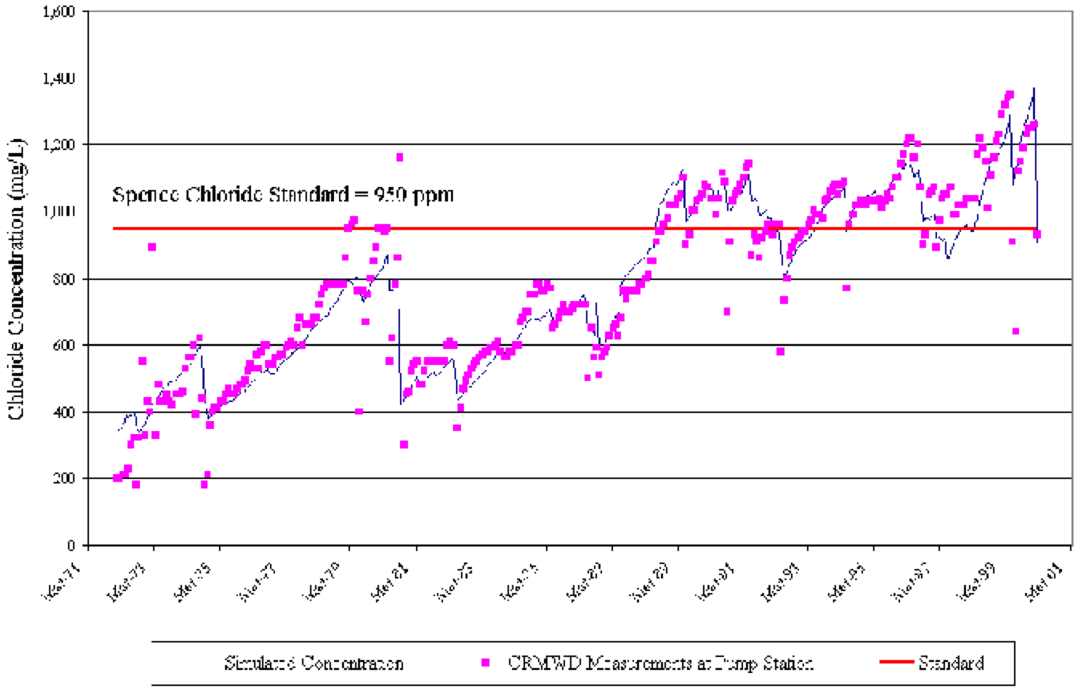

Figure 6 - Historical Chloride Simulation in E.V. Spence Reservoir

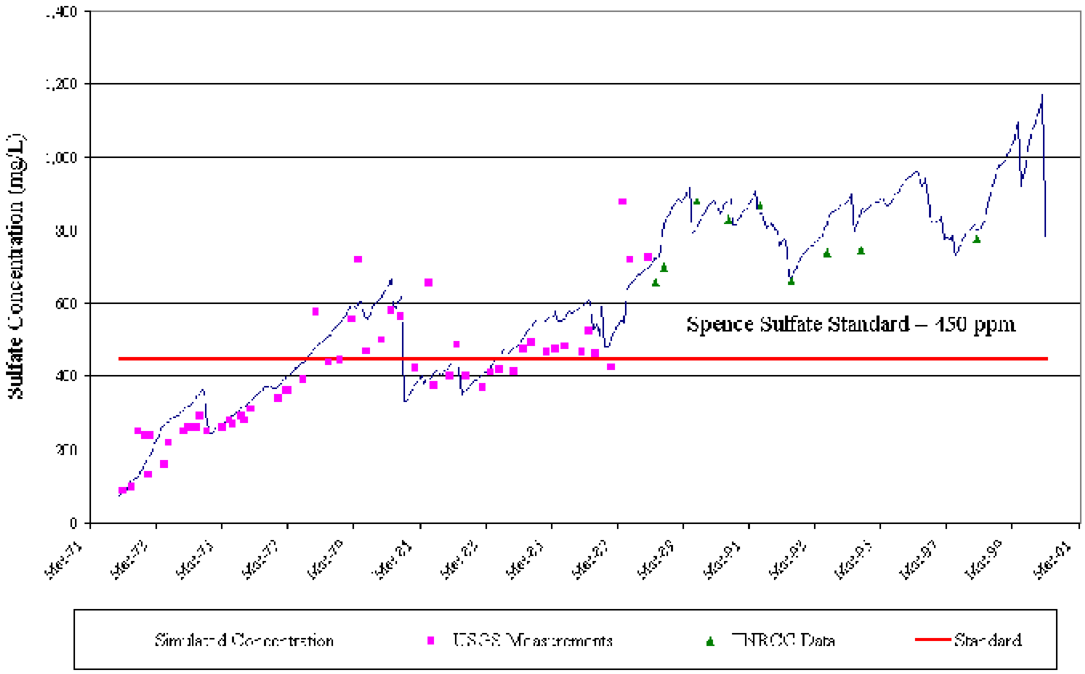

Figure 7 - Historical Sulfate Simulation in E.V. Spence Reservoir

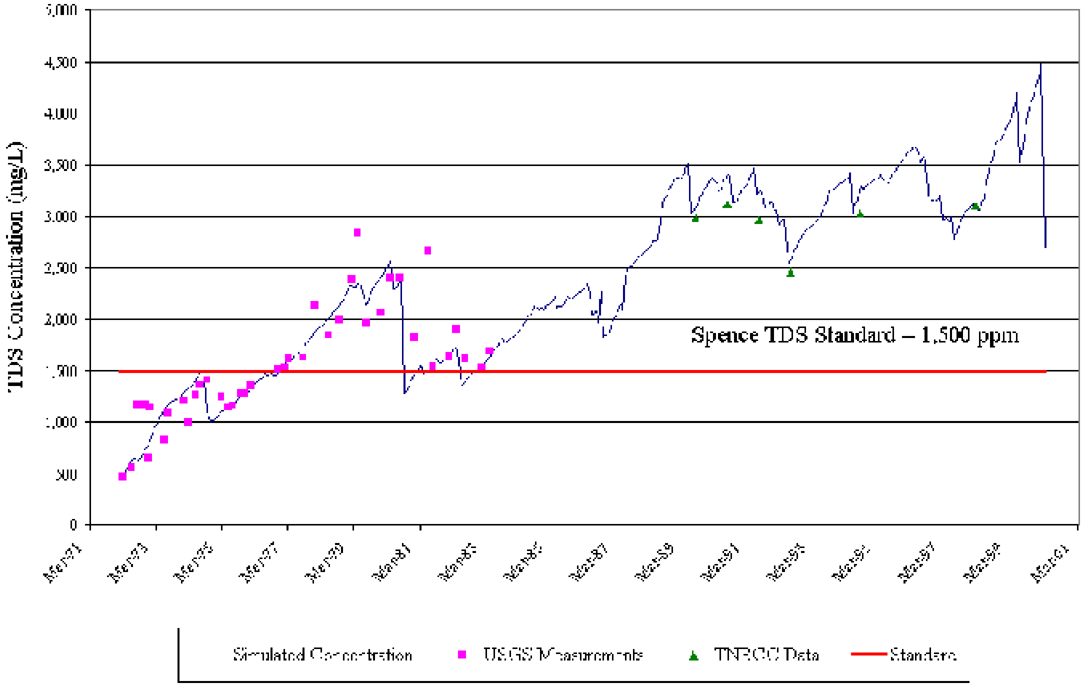

Figure 8 - Historical TDS Simulation in E.V. Spence Reservoir

Figure 9 - Impact of Natural Dam Spill on E. V. Spence Reservoir Content

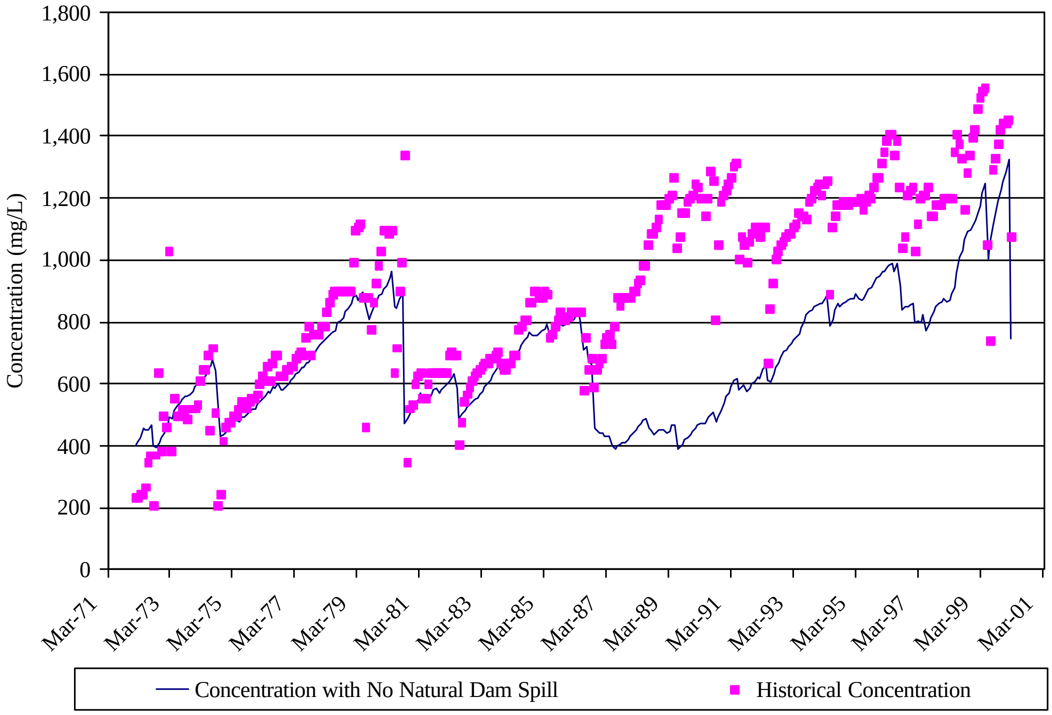

Figure 10 - Impact of Natural Dam Spill on E. V. Spence Reservoir Chloride Concentrations

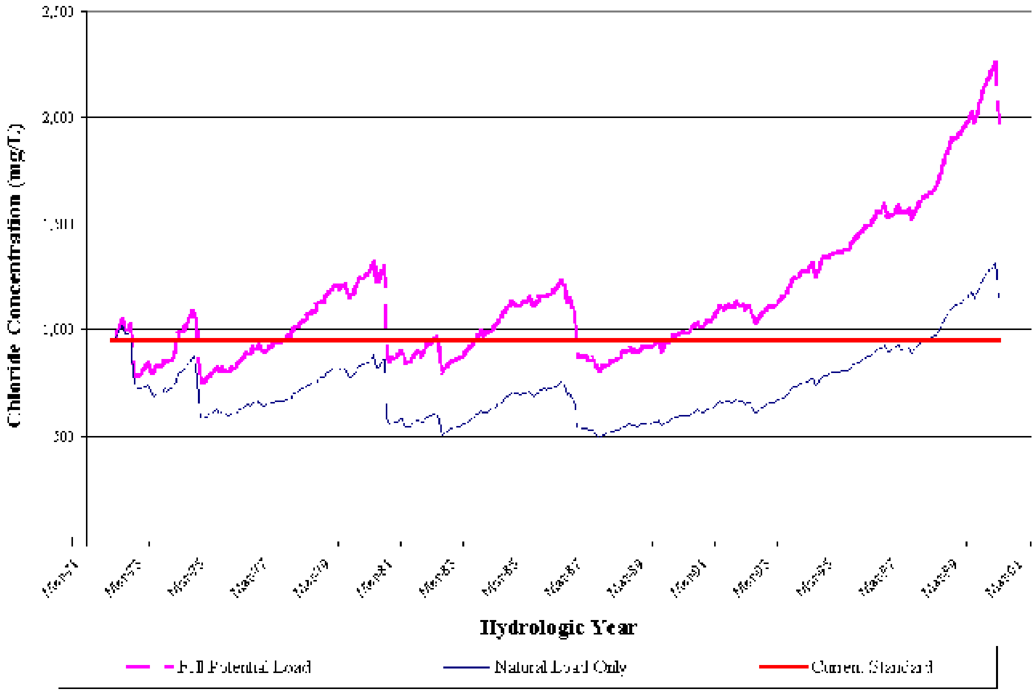

Figure 11 - Chloride Simulation in E.V. Spence Reservoir without Future Management

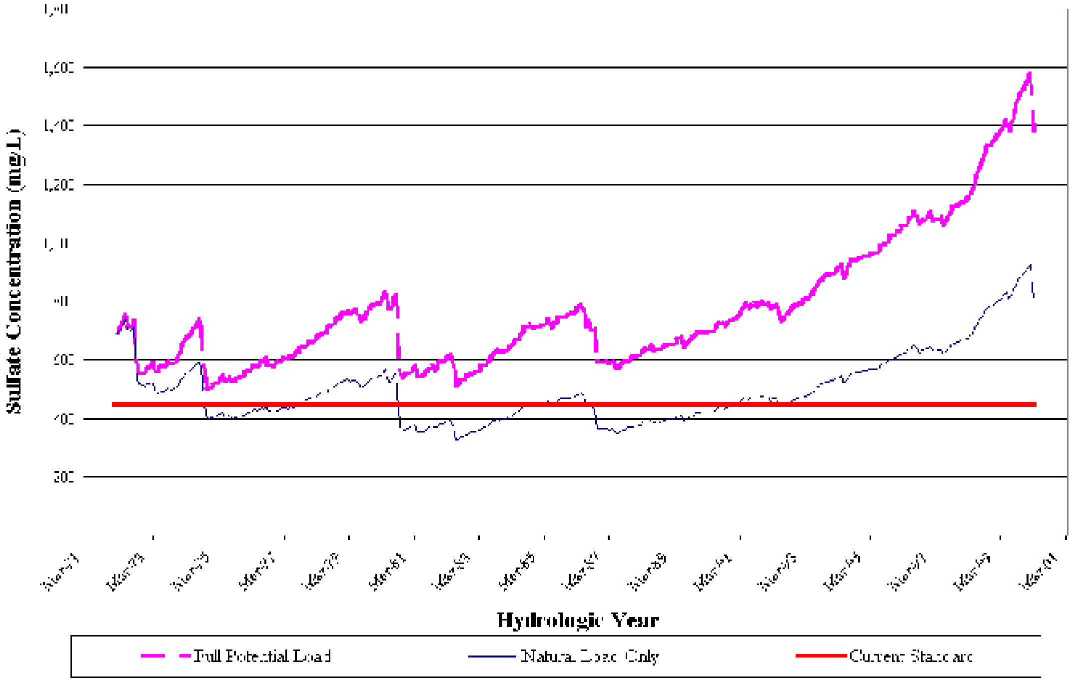

Figure 12 - Sulfate Simulation in E.V. Spence Reservoir without Future Management

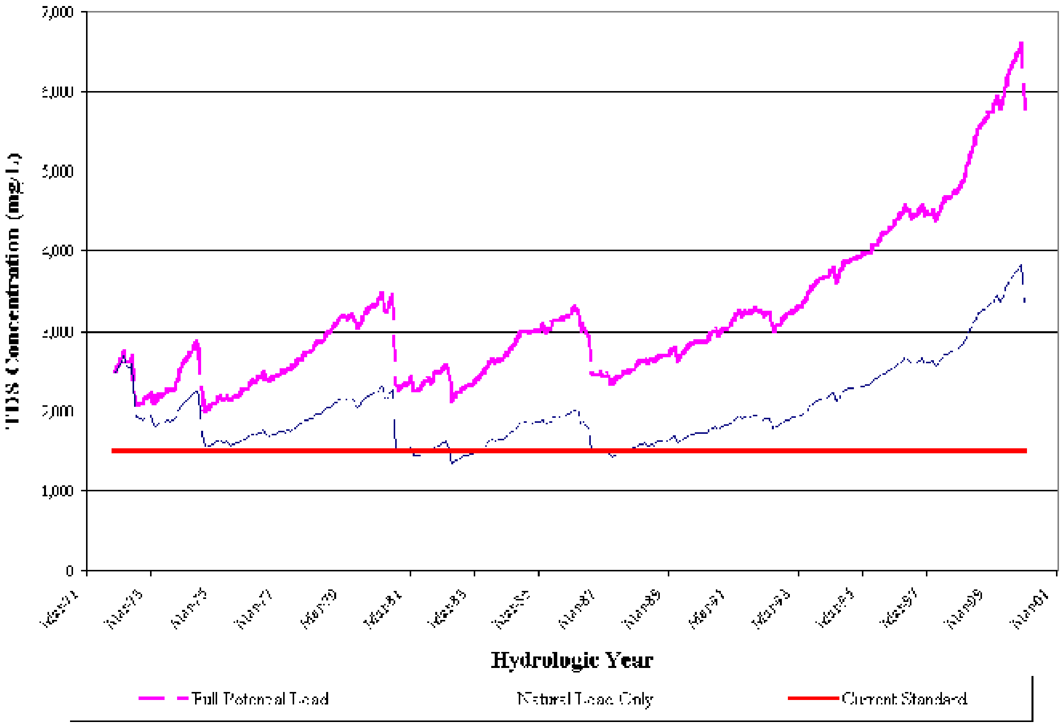

Figure 13 - TDS Simulation in E.V. Spence Reservoir without Future Management

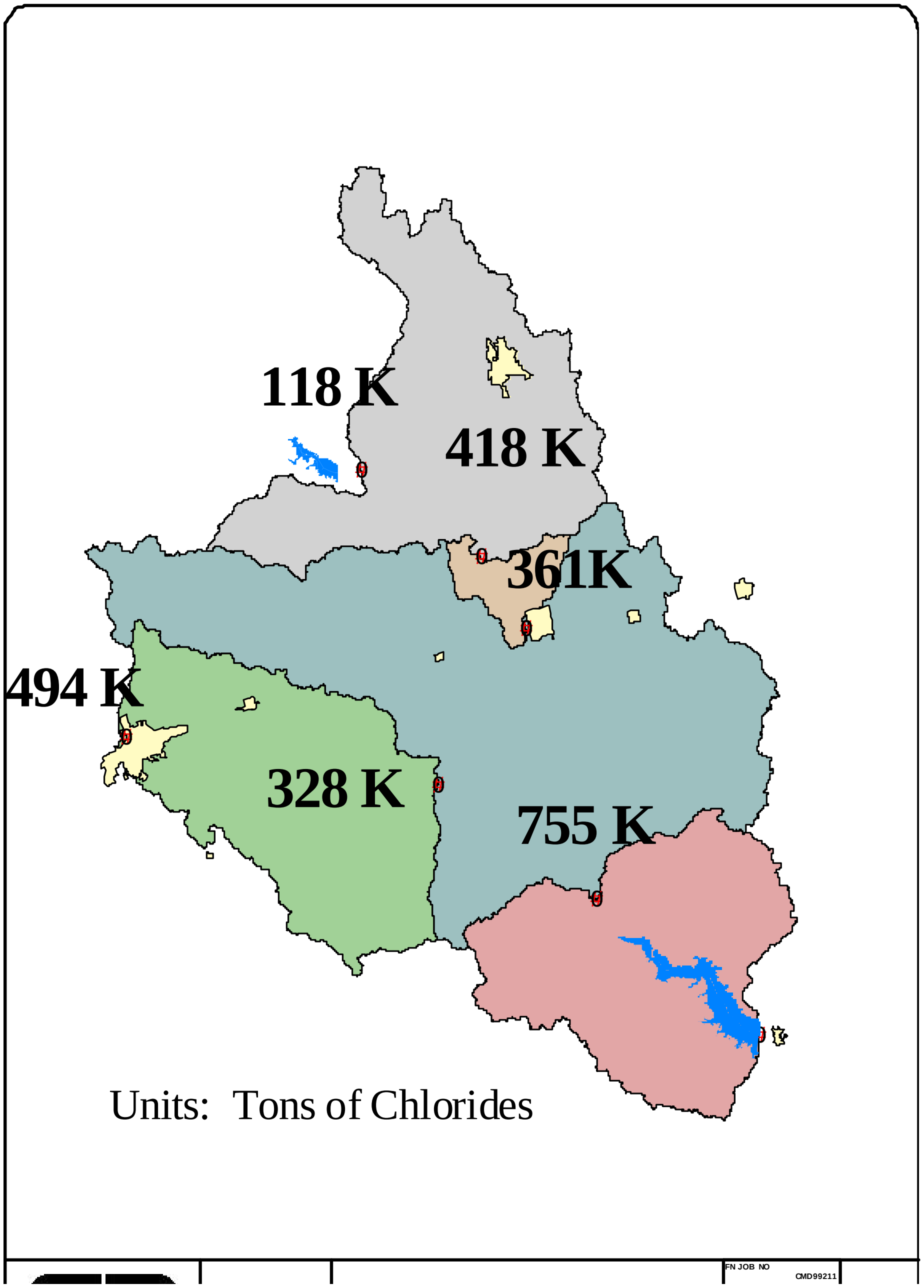

Figure 14 - Subwatershed Distribution of Total Chloride Loads Received by the E.V. Spence Reservoir under Existing Management (Base Case) Conditions.

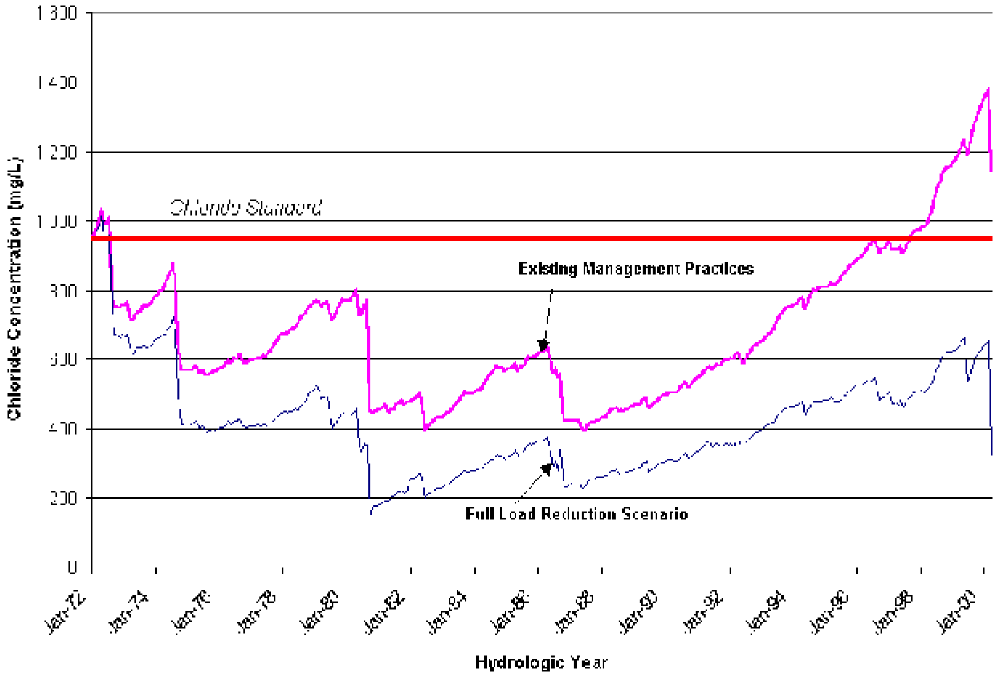

Figure 15 - E.V. Spence Reservoir Chloride Concentrations under Load Reduction Modeling Scenario

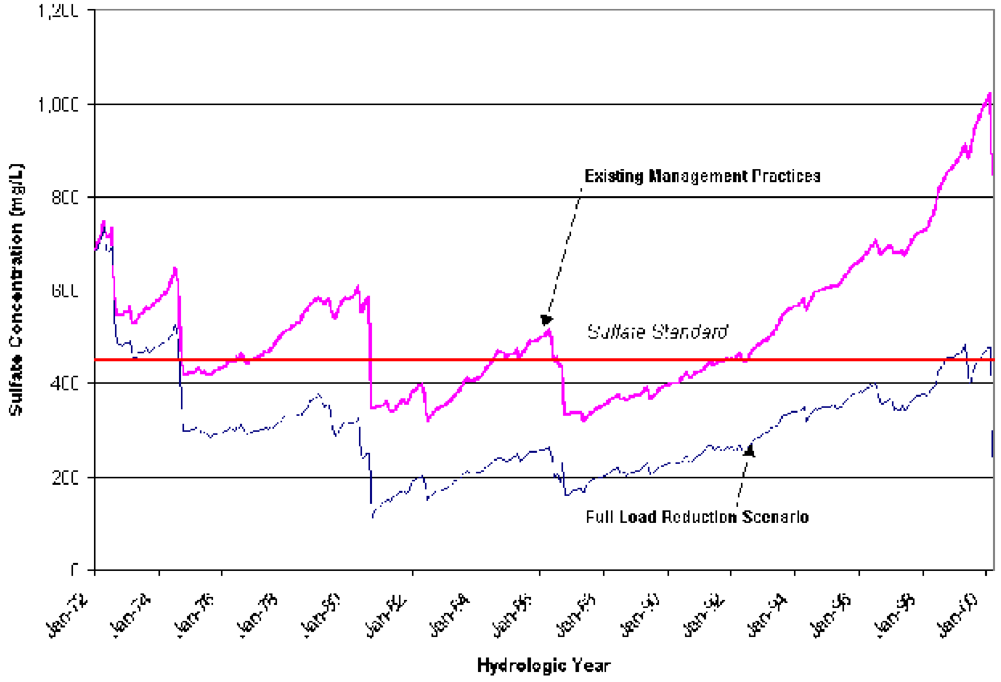

Figure 16 - E.V. Spence Reservoir Sulfate Concentrations under Load Reduction Modeling Scenario

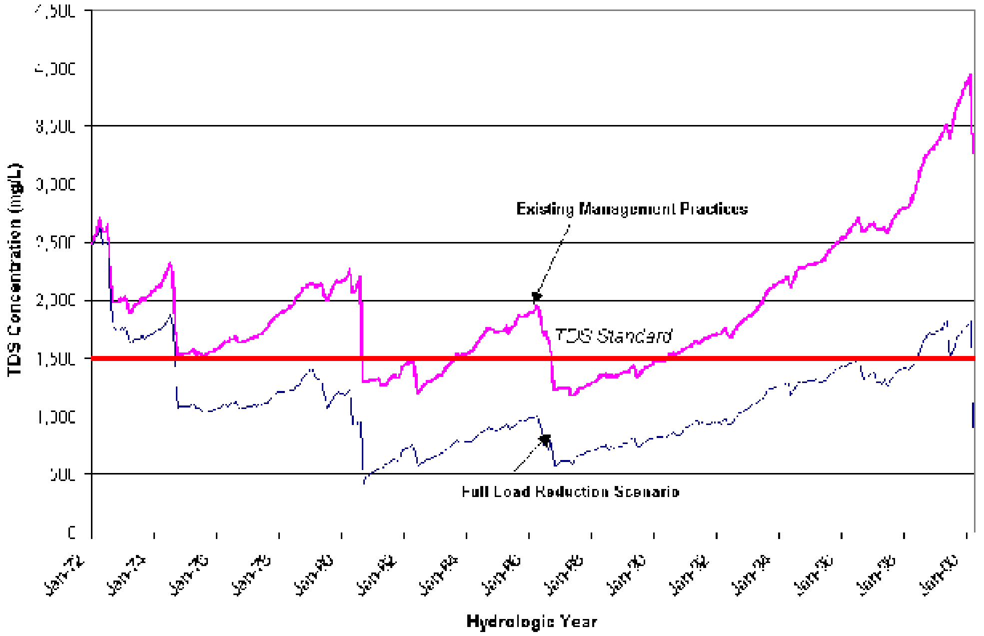

Figure 17 - E.V. Spence Reservoir TDS Concentrations under Load Reduction Modeling Scenario

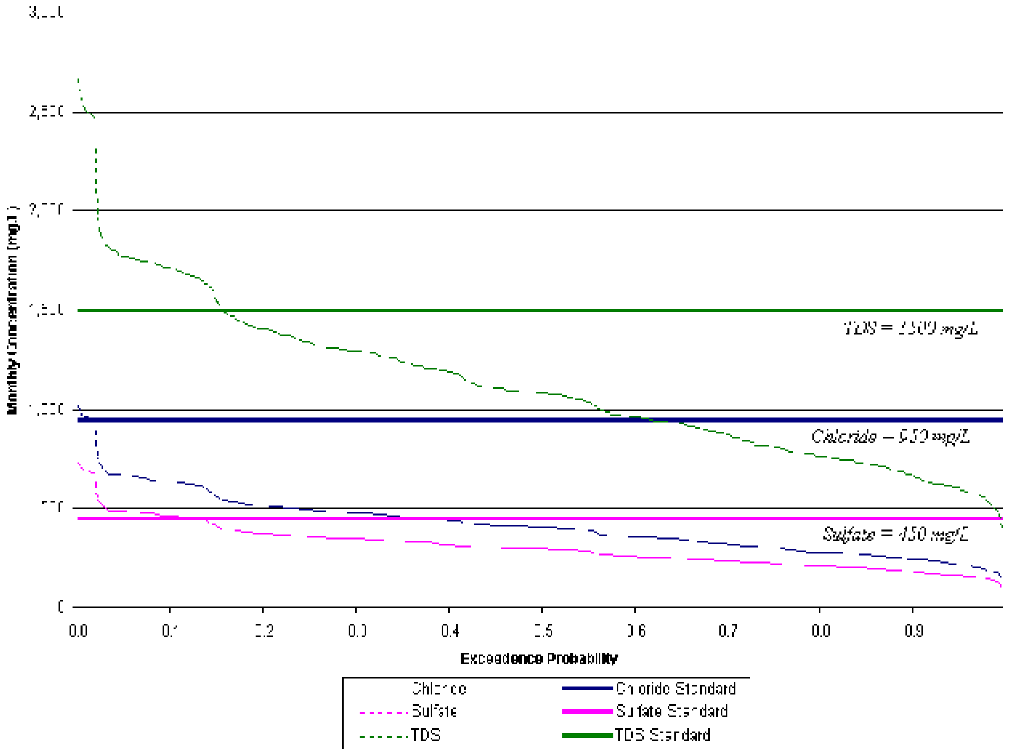

Figure 18 - Exceedence Frequencies for the Load Reduction Scenario

Constituent	E.V. Spence Reservoir Water Quality Standard (mg/L)	80% Simulated Loading Capacity (tons/day)	Loading Allocation to Big Spring WWTP (tons/day)	Loading Allocation to Snyder WWTP (tons/day)	Loading Allocation to Natural Nonpoint Sources (tons/day)	Loading Allocation to Man-made NPS (tons/day)
Chloride	950	1,427	17.44	2.12	788	619
Sulfate	450	268	9.04	0.96	144	114
TDS	1,500	438	40.27	5.21	220	173

Table 1 - Loading Allocation for Source Categories in the E.V. Spence Reservoir Watershed under the Load Reduction Modeling Scenario

Constituent	E.V. Spence Reservoir Water Quality Standard (mg/L)	80% Concentration For Full Load Reduction Scenario (mg/L)	80% Concentration For Existing Management Conditions (mg/L)	Total Percent Reduction
Chloride	950	513	833	38.4%
Sulfate	450	376	615	38.9%
TDS	1,500	1,405	2,326	39.6%

Table 2 - Comparison of 80th Percentile Concentrations for the Load Reduction and Existing Management Conditions Modeling Scenarios