APPENDIX A

Devils Lake, North Dakota

Final
Integrated Planning Report
and
Environmental Impact Statement

Hydrology, Hydraulics, and Water Quality

TABLE OF CONTENTS

INTRODUCTION

The Hydrology and Water Quality Appendix is comprised of twelve sections.

Section 1, **"Reasons for Stochastic and Scenario Analysis**," gives a general overview of each method, why they were chosen, and strengths and weaknesses of each. References are provided for additional investigation.

Section 2, "**Devils Lake Emergency Flood Plan, EIS Scenario/Strategy**," describes the nature of the flood emergency, objectives, and key decisions made for providing an appropriate degree of protection.

Section 3, "**Overview of USGS Devils Lake Outlet Simulation M**odel," describes the hydrologic and water quality model that was used for Devils Lake and developed by the U.S. Geological Survey (USGS) on contract with the St. Paul District. This model was used to develop the stochastic and scenario analysis input for economic evaluation and water quality impacts within-lake and downstream. Lake elevation-frequency that is required in the economic evaluation was determined by the stochastic analysis. Lake levels for with- and without- project were fed into the Feature Analysis Model (FAM) developed by Barr Engineering, Company, (also on contract with the St. Paul District) for the economic evaluation. Alternative outlet flows and water quality were fed into the HEC-5Q model for downstream impact assessment. This section references a more detailed USGS report for further study.

Section 4, "**Devils Lake, ND, Downstream Water Quality Impacts Model, HEC-5Q**," describes the model that was used to evaluate flow and water quality effects downstream on the Sheyenne River and Red River of the North. The St. Paul District did it with contract assistance from the Hydrologic Engineering Center in Davis, CA, and RMA Associates. The results from this model were used in both the economic and environmental evaluations. Results of this model were also fed into the Downstream User's Model, developed by Barr Engineering Company. Output from the HEC-5Q model was also provided to other consultants on contract to the St. Paul District for the EIS evaluation.

Section 5, **"Hydrologic Impacts**," describes the hydrologic effectiveness for each of the alternatives based on the stochastic and scenario analysis. It also presents the flow impacts downstream. The USGS model determined outflow from Devils Lake and the HEC-5Q model determined downstream river flows.

Section 6, "**Water Quality Impacts**," describes the water quality impacts for within-lake and downstream. The USGS model determined the within-lake impacts and the HEC-5Q model determined the downstream impacts.

Section 7, "**Downstream User's Model,**" was developed by Barr Engineering Company to determine the economic impact of users of Sheyenne River and Red River. The HEC-5Q model provided input to this model. Output was used in the economic evaluation. This section references a more detailed Barr Engineering Company report for further study.

Section 8, "**Upper Basin Storage**," describes this alternative in more detail. West Consultants, Inc. in San Diego, CA and Polaris Group, Minneapolis, MN did this study. It uses a GIS analysis of the upper watershed to determine potential benefits of additional storage. Output of this study was in turn provided to the USGS model as input into the Devils Lake model to assess effects and changes on lake level. Output was then given to the FAM model for economic evaluation. This section references a more detailed West Consultants/Polaris Group report for further study.

Section 9, "Sheyenne River Hydraulics Model and Flooded Outline Analysis." The St. Paul District performed this study. HEC-RAS models were developed for a range of flows from 100 to 7,000 cfs. Water surface profile output from these models were then combined with the digital terrain model (DTM) to delineate the area flooded for each profile. The area flooded was verified with comparisons to aerial orthophotos of historic floods. This information was then used in the evaluation of environmental impacts and economics.

Section 10, "Sheyenne River Erosion Study." This study evaluated the impact of Devils Lake pumping on erosion in the Sheyenne River. It was done by WEST Consultants, INC.

Section 11, "Upper Basin Management Measures." This section provides additional information besides section 8 on Upper Basin Storage. It provides a land use analysis for the basin and addresses other options/alternatives such as change in farming practices and irrigation.

Section 12, "Dry Lake Diversion." This section presents the Dry Lake Diversion feature as part of the outlet plan. It discusses the reason for its inclusion in the outlet alternative by showing it's hydrologic effectiveness with and without this feature and it's corresponding economic justification.

Section 1 - Reasons For Stochastic and Scenario Analysis

Introduction

The U.S. Water Resource Council (WRC) guidelines specify the use of "expected" annual flood damage. Expected damage accounts for the risk of various magnitudes of flood damage each year, weighing the damage caused by each flood by the probability of occurrences. According to ER 1105-2-101 (Risk-Based Analysis for Evaluation of Hydrology/Hydraulics, Geotechnical Stability, and Economics in Flood Damage Reduction Studies, 1 March 1996) **(reference 1)**, the National Economic Development (NED) plan will be the scale of the flood damage reduction alternative that reasonably maximizes "expected" net benefits. The stochastic analysis for Devils Lake is designed to calculate expected net benefits. The scenario analysis can calculate net benefits for an assumed future but not "expected" net benefits. For this study, the stochastic analysis would therefore represent the method that best fits with the standard approach used by the Corps for determination of probability-weighted damages.

The WRC guidelines do not generally specify what model to use. In riverine studies, the Log-Pearson Type III frequency distribution is commonly applied. However, because Devils Lake is a terminal lake, previous lake levels will affect lake levels in any given year. Therefore, the set of annual lake levels are not <u>independent</u> and a standard riverine-type analysis of lake levels cannot be applied. As a result, the USGS developed a stochastic simulation model that can be used to generate future lake levels and water quality of Devils Lake in response to future precipitation, evaporation, surface-water inflow, and potential outlet discharges. The simulation model consists of three parts: (1) A statistical time series model for generating future precipitation, evaporation, and inflow for Devils Lake and Stump Lake and future discharges for the Sheyenne River; (2) a water and chemical mass-balance model for generating future volumes and sulfate concentrations in Devils Lake and Stump Lake in response to future precipitation, evaporation, and inflow; and (3) an outlet simulation model for generating daily outlet discharges and sulfate concentrations to meet downstream water-quality and water-quantity constraints in the Sheyenne River. The USGS simulation model is described in more detail in the **Section 3.**

An important assumption of the stochastic model is that climate is <u>stationary</u> or time-invariant; that is, climatic conditions in the Devils Lake Basin in the "recent" past are representative of climatic conditions during the future project-planning period. The Devils Lake hydrologic record may not be subject to a stationary climate or a "constant system of chance causes." As indicated below, climate in the Devils Lake Basin changed significantly during the late 1970's, but has remained relatively homogenous from 1980 to the present. Therefore, the "recent" past is defined as the period 1980-99. Although it is unknown exactly how long the current wet conditions may persist, or if even wetter conditions may be in store in the future, according to University of North Dakota, Regional Weather Information Center (**reference 2**) the climate during the next 10-15 years is likely to be similar to climate during 1980-99.

Climate in the Devils Lake Basin may be nonstationary for a variety of reasons, such as the existence of natural climate cycles caused by global ocean and atmospheric circulation patterns or the existence of global warming due to anthropogenic causes. Residents adjacent to a terminal lake such as Devils Lake would be some of the first to experience the impact of a small change in climate.

Even small changes in precipitation or evaporation can have significant synergistic effects on lake level because these changes are integrated over 3,800 square miles. Small changes in precipitation and evaporation are not significant considerations for hydro-meteorological phenomenon such as riverine flood peak hydrology. Consequentially, WRC guidelines assume climate invariance **(reference 3)**. However, for hydroclimatological phenomenon such as a terminal lake, these considerations are very important for assessing lake level frequency because they are also cumulative in their impact and are subject to persistent weather patterns.

Hurst Phenomenon

A separate but related concept to nonstationarity is long-range dependence, which is the tendency for hydrologic processes such as annual streamflow volumes to have autocorrelations that decay at a slow rate as the time lag becomes large. Processes with long-range dependence are said to posses "infinite memory." Long-range dependence is sometimes referred to as the Hurst phenomena (**reference 4**). The Hurst coefficient is a parameter that is estimated from geophysical time series (e.g. tree rings, varves, annual runoff) and indicates the degree of persistence within the record. It not only is an indicator of drought potential but it can also be an indicator of extended high runoff potential.

Based on long-term hydrologic time series data such as Nile River annual discharge, Hurst demonstrated that for a long record:

$$R/S = (n/2)^H$$

Where:

R = range of cumulative departures from the mean of a time series
S = standard deviation of the series.
n = length of record in years.
H = the Hurst coefficient

Theoretically H = 0.5 for a stationary process with finite memory. However, Hurst found that for many natural time series H is in fact greater than 0.5 averaging 0.72 with a standard deviation of 0.09.

However, there has been much controversy amongst researchers as to the cause of the Hurst phenomenon. According to Bras and Rodriguez-Iturbe **(reference 5**), there are presently three main lines of thought explaining this phenomenon:

1. “The Hurst phenomenon is a transitory behavior. The argument is that our series are simply not long enough to test the steady-state behavior of R, which according to the argument is the square-root law. This period of transition can be reproduced by Markov-autoregressive models. On the basis of a very long time series, Mandelbrot and Wallis (1968) **(reference 6**) effectively argue against this explanation.”
2. “The Hurst phenomenon is due to nonstationarities in the underlying mean of the process. This argument claims that a low-frequency, slowly time-varying mean explains the Hurst behavior (Klemes, 1974; Potter, 1976; Boes and Salas, 1978).” (**reference 7, 8, and 9**).
3. “The Hurst phenomenon is due to stationary processes with very large memory. That is, stationary processes that have correlation functions that decay very slowly in time, much slower than Markov-Gaussian-autoregressive processes. In the limit, this argument claims infinite memory for natural processes.”

The last explanation is a problem in that there is no known identifiable watershed process that is endowed with infinite memory. Of these explanations the second one seems the most plausible. A form of nonstationarity in the mean would be a “shifting level process” or a shift in the central tendency of a hydrologic process due to climatic variation. This follows the concept put forth by Lorenz (1970) **(reference 10**) called ‘Almost-Intransitivity.’ This concept is used to explain the non-linear behavior in the atmospheric processes. An almost-intransitive system such as the atmosphere-ocean-earth system will exist for some time at one level or regime such that the general circulation will persist until by chance it acquires a state that permits a jump to another level or regime in a short period of time (**reference 8**). An obvious shift in the Devils Lake hydrologic record can be observed in the period before and after approximately the year 1940 and perhaps more recently with the rapid rise in elevation in the 1990’s. It is unlikely that such shifts are due to man-made origins.

According to Charles Stockton and William Boggess of the Laboratory of Tree-Ring Research at the University of Arizona in a publication for the U.S. Army Coastal Engineering Research Center (**reference 12**), the fact that Hurst’s work demonstrates that H > 0. 5 is considered to be, by some hydrologists, climatically induced and that climate is not a random function of time. Stockton and Boggess, using tree-ring chronologies for the period 1600-1962, developed maps showing isolines of the H coefficient for the United States. For the Red River of the North Valley a coefficient of 0.75 extended from North to South.

The St. Paul District updated H values for annual streamflow runoff for: the Red River at Grand Forks, Minnesota River at Mankato, and the Mississippi River at St. Paul, and found H values to be 0.82, 0.81, and 0.81 respectively. **Figure A1-1** shows the elevation history of Devils Lake and **Figure A2-2** shows plots of the accumulated departure of the mean of annual runoff divided by the standard deviation for the river stations. Another terminal lake (lake without an outlet at lower elevations) in the region is Waubay Lake in South Dakota. Waubay Lake is at a smaller scale than Devils Lake with a drainage area and surface area of 206 square miles and 28 square miles (at elevation 1803.6 feet msl), respectively compared to Devils Lake drainage area of 3,373 square miles and 195 square miles (at elevation 1447.0 ft. msl), respectively. **Figure A1-3** shows a lake elevation plot for Waubay Lake. By comparing **Figures A1-1** through **A1-3**, one can see that the patterns of variation of streamflow/elevations are similar and are a regional phenomenon that can only be attributed to large-scale atmospheric circulation patterns that are near hemispherical in magnitude **(reference 13 and 14)**. In regards to Devils Lake levels, the Hurst values indicate that in this region there is a tendency for extended high runoff potential or high drought potential.

Vecchia (2002) demonstrates that the geologic history of lake-level fluctuations of Devils Lake for the past 2,500 years is consistent with a climatic history consisting of two "quasi-stationary" climatic states – a wet climate state similar to 1989-99 and a normal climate state similar to 1950-78. transitions between the two states occur at random times and the durations of the wet periods are much shorter, on average, that the durations of the normal periods. Thus, the geologic history of lake-level fluctuations is consistent with a "shifting-level" process for climate. The duration of the current wet cycle is a random variable that cannot be predicted using standard statistical techniques. However, as indicated in the next section, long-term climate models indicate that the current wet cycle is likely to continue at least until 2015.

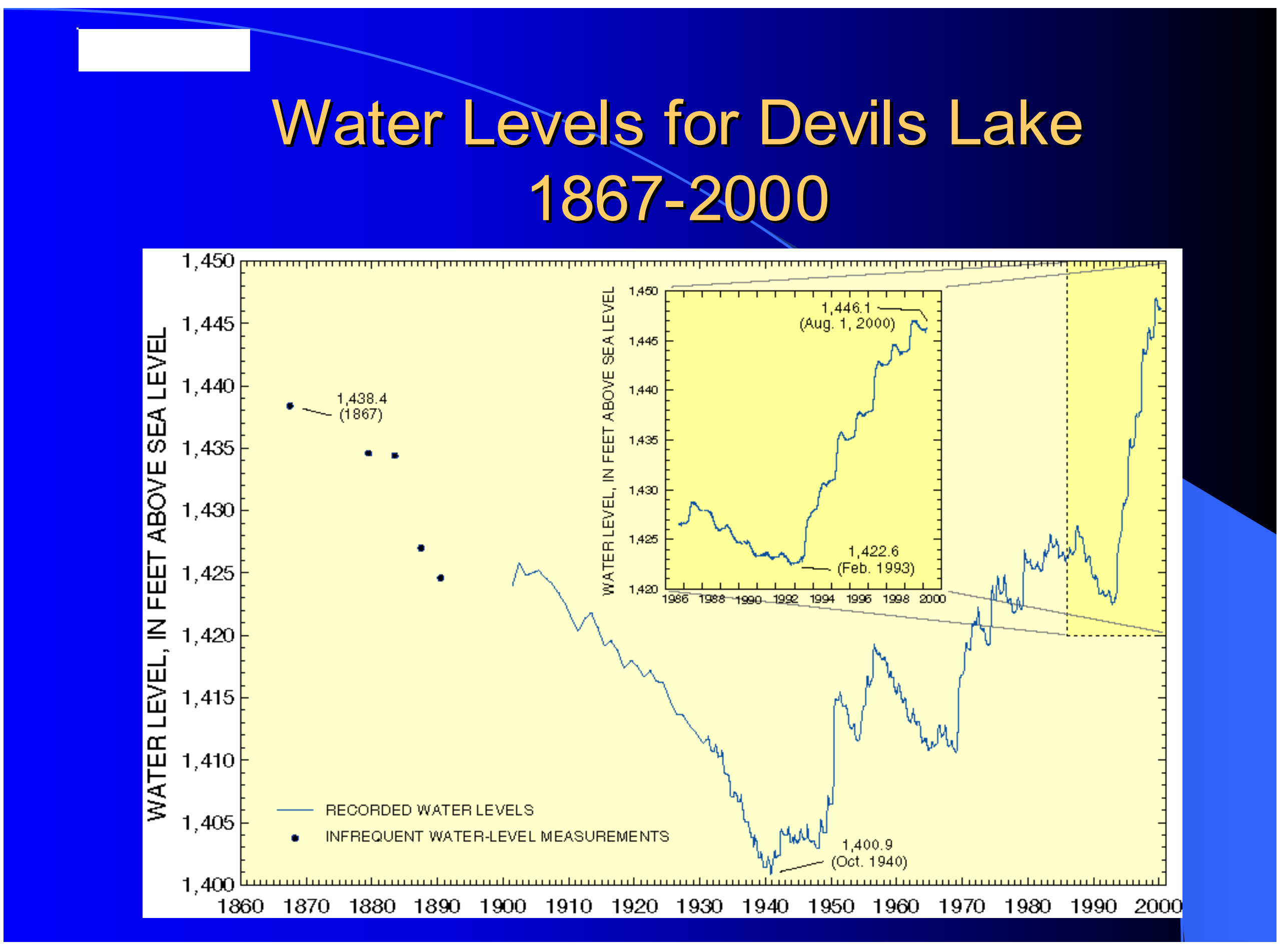


FIGURE A1-1

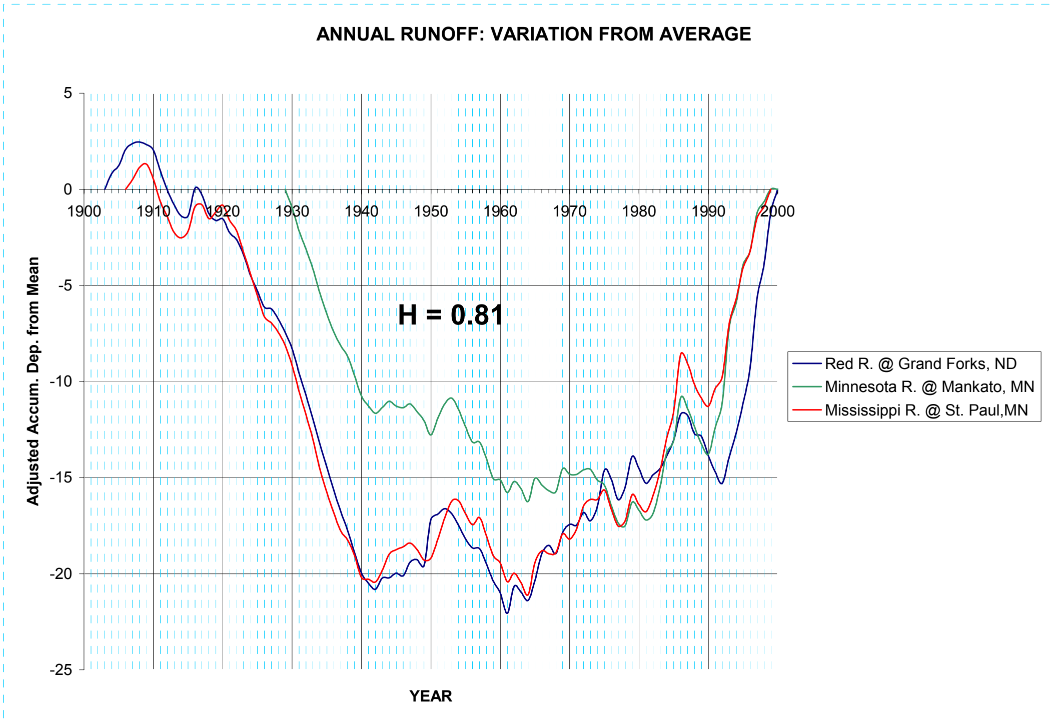
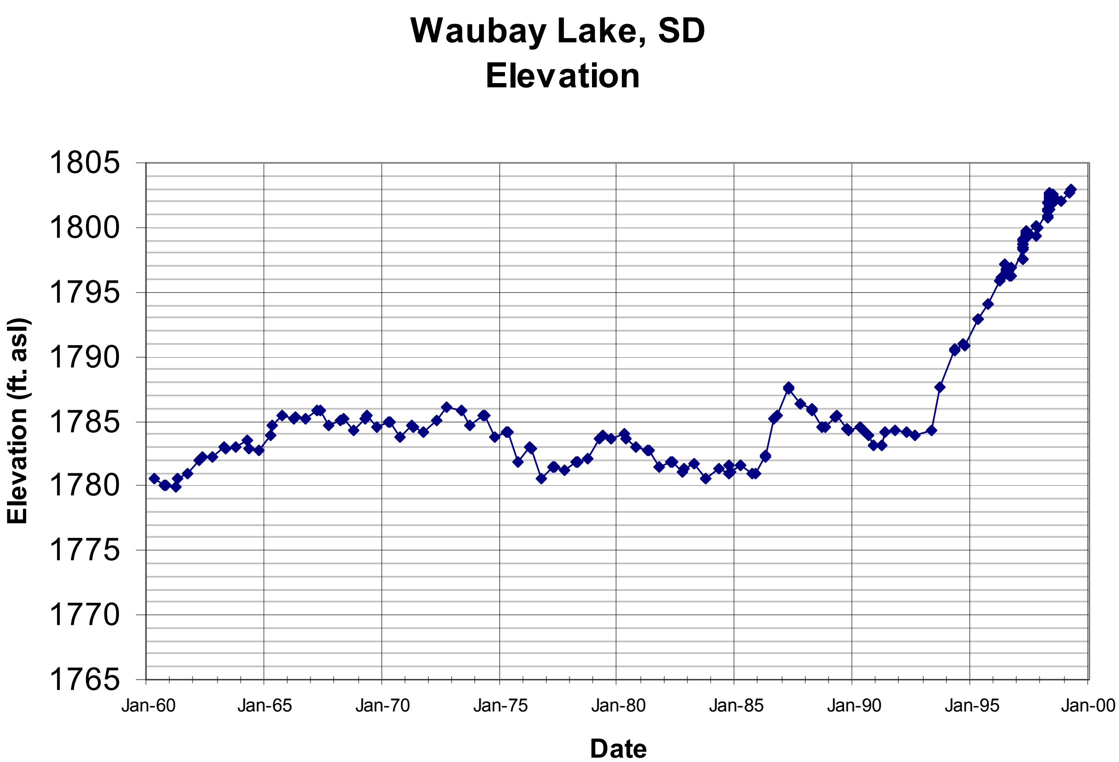

ANNUAL RUNOFF: VARIATION FROM AVERAGE
5
0
-5
-10
-15
-20
-25
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Adjusted Accum. Dep. from Mean
YEAR
H = 0.81
Red R. @ Grand Forks, ND
Minnesota R. @ Mankato, MN
Mississippi R. @ St. Paul,MN

FIGURE A1-2


Waubay Lake, SD
Elevation
1805
1800
1795
1790
1785
1780
1775
1770
1765
Elevation (ft. asl)
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Date

3

Climatology

The following discussion on climatic variability specific to the Devils Lake basin is taken verbatim from the USGS publication, "Climatology, Hydrology, and Simulation of an Emergency outlet, Devils Lake Basin, North Dakota **(reference 15**)."

Nature of Climate Variability

According to the University of North Dakota Regional Weather Information Center **(reference 2**), Devils Lake responds directly to climate variability across the region. This climate variability generally can be regarded as the movement of the jet stream from season to season and from year to year. The jet stream, which is a ribbon of high-velocity air located about 30,000 ft. above the Earth's surface, exists because of temperature differences between air masses at the Earth's poles and at the equator. The movement of weather systems along the jet stream determines the distribution of precipitation about the globe. Climate variability results from a long-term shift in circulation patterns of the jet stream. As the circulation patterns shift, precipitation and temperature patterns also shift. Devils Lake has an enhanced sensitivity to long-term shift in global circulation patterns as the level of the lake depends on many years of antecedent precipitation, runoff, and evaporation. If at any time precipitation, runoff, or evaporation is dominant, a corresponding dramatic response occurs in the lake level.

Global atmospheric circulation patterns are driven predominantly by variations in sea-surface temperatures. The most noticeable of these variations, known as El Niño, occurs in the equatorial Pacific and accounts for the dramatic variations in precipitation patterns along the western equatorial regions of South America. Across the plains of the northern United States and southern Canada, El Niño and its cold counterpart - La Niña - produce variations in precipitation and temperature pattern primarily in the winter months (**reference 16**). However, long-term variations in annual precipitation and temperature patterns across the region also occur as a result of variations in the tropical sea-surface temperatures. These long-term variations often span decades and are instrumental in the occurrence of flood and drought conditions across the Devils Lake Basin and elsewhere.

When the position of the jet stream across the western United States shifts to the southwest, strong storm systems move predominantly from the southwest at upper levels. These storm systems typically referred to as Colorado Lows (**Figure A1-4**), cause unstable conditions across the Devils Lake Basin because warm, moist air from the Gulf coast interacts with cool, dry air from Canada. The net result is a high frequency of both warmer and wetter conditions across the Devils Lake Basin than during more stable periods. When the position of the jet stream shifts to the northwest, the Devils Lake Basin experiences a high frequency of Alberta Clippers, which are associated with cold, dry conditions in the basin. When the position of the jet stream shifts to a more westerly flow, referred to as a zonal pattern, the Devils Lake Basin generally experiences more normal precipitation and temperature patterns (patterns close to long-term seasonal average precipitation and temperature patterns).

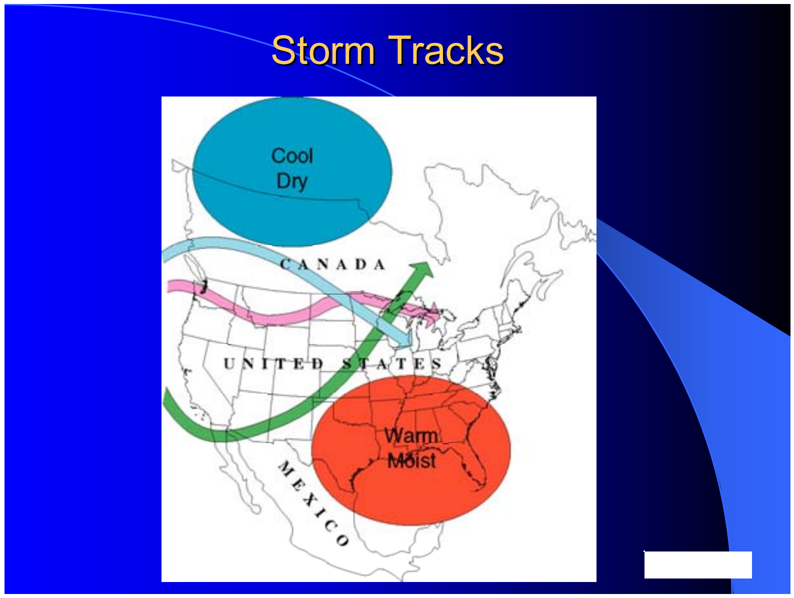


FIGURE A1-4

Recent Atmospheric Weather Patterns

In a study by Baldwin and Lall (**reference 17**), long-term trends in local climate parameters such as precipitation, temperature, and sea level pressure (SLP) were examined relative to the seasonal changes in Devils Lake volume (**Figure ckb1**). It was found that two key transistion months of mass balance in Devils Lake were implicated in the recent increase in volume. Typically, July is the transition month between increases in lake volume earlier in the year and decreases in lake volume later in the year. An examination of long-term July precipitation indicated a dramatic increase since 1980, with a concomitant decrease in (SLP) and temperature more pronounced in the later period (**Figure ckb2**). Also present are changes in October precipitation and SLP. Although these increases in monthly precipitation are not clearly visible in annual totals of precipitation, the impact of the increases is highly nonlinear because the change in these key transition months simultaneously increases the inflow and reduces the amount of time available for net decreases in lake volume through evaporation. Thus, it is the change in summer and fall precipitation, evaporation and cloud cover, rather than the winter precipitation that may be largely responsible for the trends in Devils Lake. This suggests that a rather different mechanism than the winter jet stream may need to be understood to resolve the mystery.

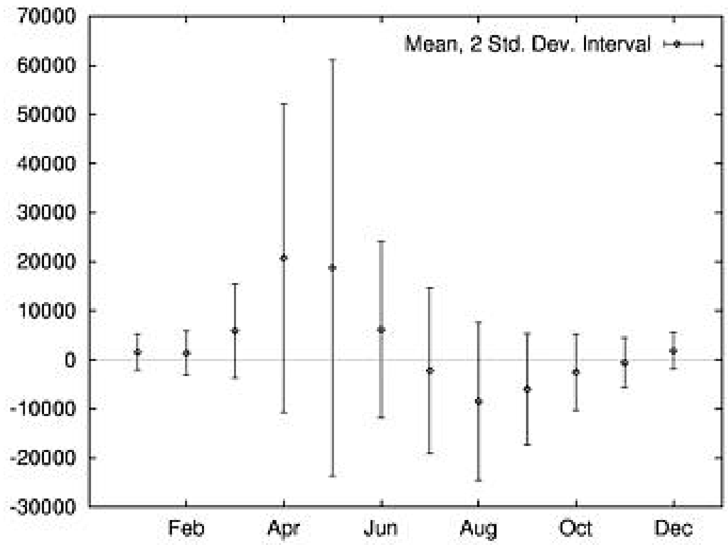


Figure ckb1. Climatology of monthly lake volume changes. Based on monthly lake volume data from October 1941 to May 1998.

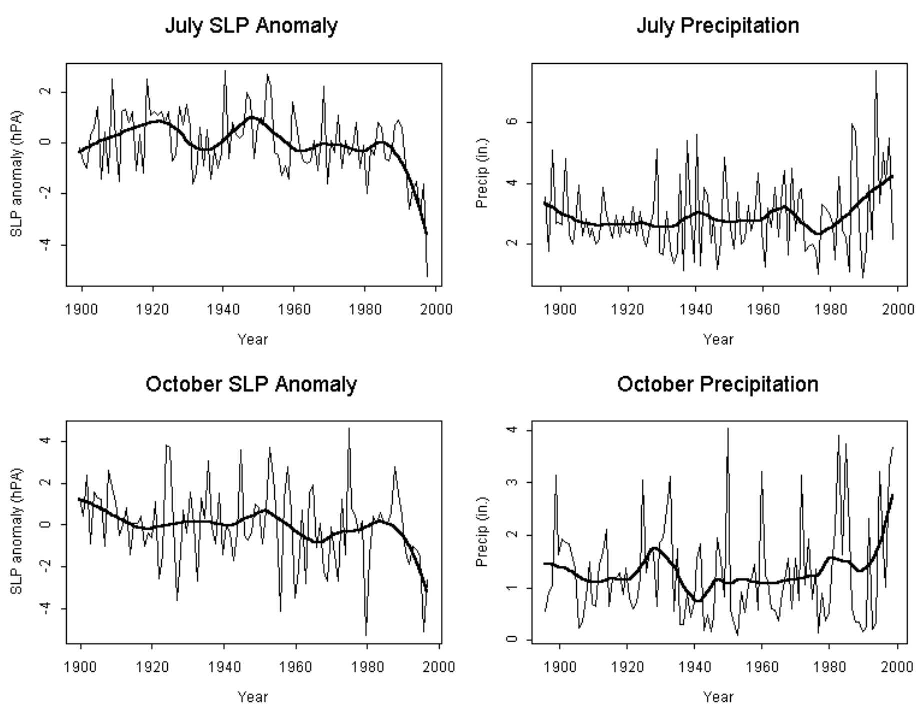


Figure ckb2. Sea level pressure (SLP) anomaly and Langdon precipitation time series plots for July and October. The heavy line is a 20 year Loess smooth of the raw data (light solid). Note the recent large decrease in SLP in both months and the associated increase in precipitation. The summer SLP values in 1992-98 correspond to a 6-8 m average reduction in the height of the regional 700 mb geopotential surface.

Another demonstration of this is the July-December precipitation record between 1950 and 1999. Some have surmised that before the late 1970's the relatively subdued activity of El Niño and La Niña resulted in a low frequency of wet years in the Devils Lake Basin (**Figure A1-5)**. Average

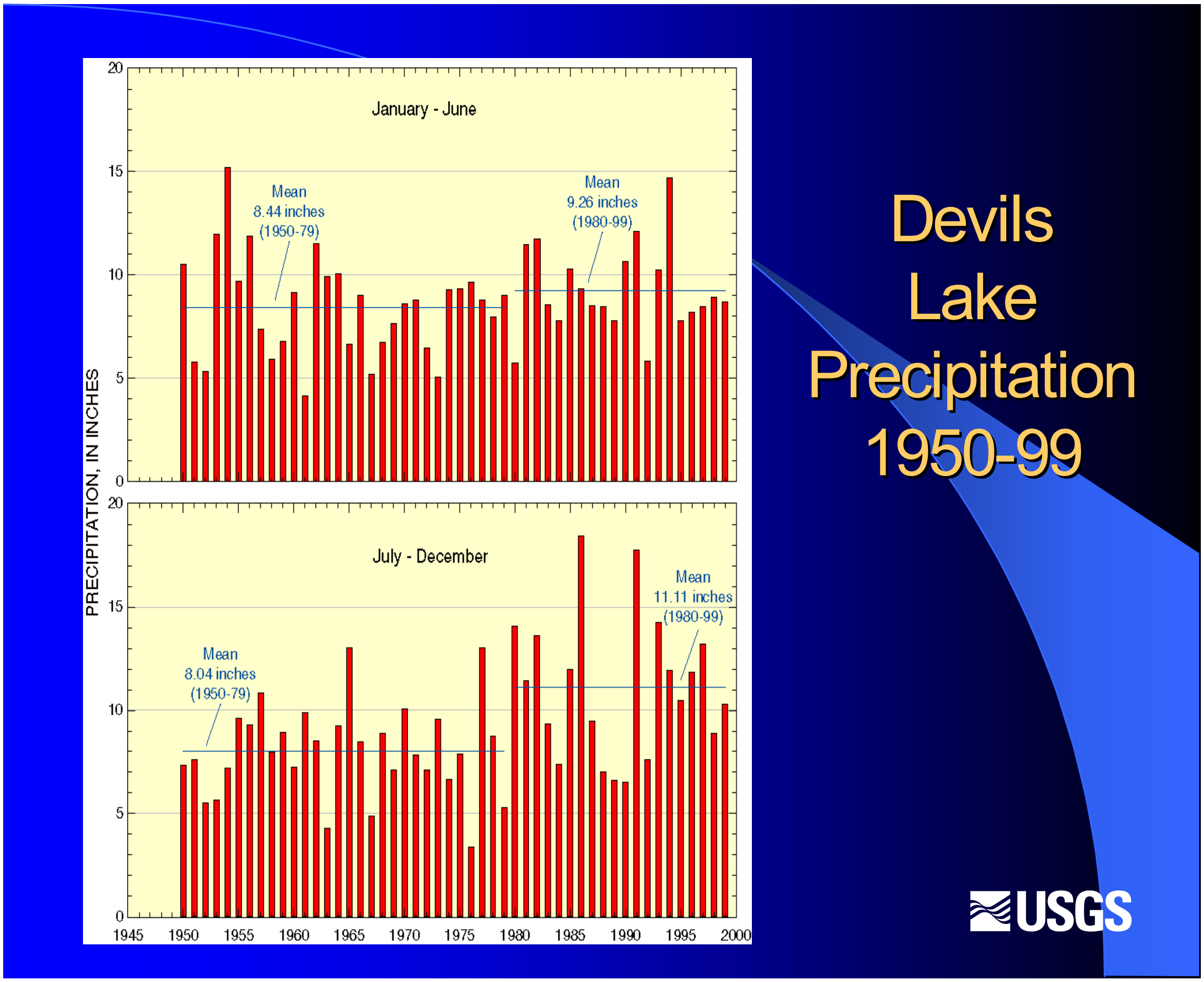


FIGURE A1-5

seasonal precipitation values from the 1950's into the late 1970's varied from year to year, but precipitation amounts, particularly during July-December, generally were less than amounts since the late 1970's. This is consistent with a more even distribution of storm systems from the northwest, west, and southwest. Average annual temperatures from the 1950's into the late 1970's were relatively warm compared to temperatures from the late 1970's to the present, and a sharp temperature contrast occurred between the winter and summer extremes.

Since the late 1970's, the activity of El Niño has been greater than at any other time during the 20th century. Investigations by Baldwin and Lall **(reference 17**) indicate that El Niño is not an isolated climatic cause, but only one part of the picture. There is evidence to suggest that the unique climatic conditions that have led to the rise in Devils Lake are influenced by more broad changes in sea surface temperature patterns in both the northern Pacific and Atlantic Oceans. El Niño is indeed the most prominent and visible named phenomenon but is not likely the sole cause. These global circulation patterns have resulted in an increased frequency of storms bearing Gulf of Mexico moisture across the Devils Lake Basin, causing a higher frequency of wet years in the basin (**Figure A1-5**). Since the late 1970's, the movement of the mean jet stream position over time has resulted in warmer late winter and early spring temperatures. However, the annual average temperature for the region has decreased slightly since the mid-1980's associated with greater cloud cover and precipitation. Since the early 1990's, unusually high precipitation amounts have occurred during May and June and again during the early fall.

Future Atmospheric Weather Patterns

The duration of the recent wet conditions cannot be determined definitely because of the complex interactions between global weather factors. According to estimates by the Regional Weather Information Center, University of North Dakota, the present wet conditions are expected to continue beyond the first decade of the new century into 2015 **(reference 2**). During this period, the recent tendency for a high frequency of wet years, punctuated by occasional dry years, probably will continue. La Niña conditions through the summer of 2000 brought some periodic relief from the persistent, high precipitation of the past 8 years, although long-range climate models indicated generally wet conditions during the following fall and winter. Also, because the factors causing the recent wet conditions across the northern plains are global in scale, the transition from wet conditions to dry conditions may require years. Therefore, climatic conditions in the Devils Lake Basin during the next 15 years should be well represented by the historic conditions from the late 1970's to the present. Still, this forecast must be understood in the light of the National Academy of Sciences (**reference 18**) conclusion that no one can know or predict climate with confidence 50 years into the future.

Assumptions Regarding Climatology

In the simulation model used by the USGS in the previous study **(reference 15**), the time-series model for generating precipitation, evaporation, and inflow values was calibrated using data for 1950-93. The entire period of record was used because no statistical evidence was available at that time to indicate climatic conditions were not stationary.

The simulation model was updated in 1999 after 6 more years of data were recorded (1994-99). A detailed examination of this longer precipitation record indicated a shift toward wet conditions occurred in the late 1970's **(Figure A1-5**), particularly in the fall. The change appears to be rather abrupt, and the recent wet conditions do not appear to be statistically different than conditions during 1980-92. To better reflect the wet conditions, the time-series model for generating precipitation, evaporation, and inflow values for Devils Lake and future Sheyenne river discharges was recalibrated using data for 1980-99 (data for the late 1970's were not included to avoid any possible transition period between the dry and wet conditions). As indicated by the regional Weather Information Center, climatic conditions during 2000-15 are expected to be similar to conditions during 1980-99.

Utah Water Research Laboratory

The U.S. Army Corps of Engineers, Institute of Water Resources (IWR), contracted to the Utah Water Research Laboratory (UWRL) to evaluate the hydroclimatic influences on Devils Lake and also the utility of existing methods to forecast Devils Lake levels and associated flood risk **(reference 17**). They investigated the teleconnections of Devils Lake level fluctuations with interannual and longer regional and global climate fluctuations. The study identified key trends in hydroclimatic variables in the Devils Lake region relative to large-scale hydroclimatic fluctuations. Slowly varying sea surface temperature conditions that are known to be associated with interannual to interdecadal atmospheric circulation pattern changes are relevant for understanding the fluctuations of Devils Lake. Hypotheses regarding the causative factors of the recent rise in lake levels were developed and evaluated. For example, a key point is made that there seems to be a threshold, that when crossed, the lake will experience rapidly rising or falling lake levels. Presumably, this is directly related to the fact that the contributing drainage area changes with climate state. The chain of lakes above Devils Lake and prairie potholes store water during dry periods, but during protracted wet periods they will contribute runoff. "This change in drainage area may be a key explanation for the dramatic changes in the lake's volume, subsequent to moderate changes in the climate signal."

Two types of long-range forecasts were investigated. One was for inter-annual periods (1-5 years) and the other for conditional probabilities for inter-decadal periods (over 30-years). For the shorter inter-annual periods, nonlinear times series analysis methods were tried using Devils Lake volumes and climate indices as predictors. For the longer-term forecasts, the study investigated alternatives to the USGS model. One was the Fractionally Integrated Autoregressive Moving Average model (ARFIMA). Another was the Bayesian autoregressive modeling approach (ARCOMP) that considers uncertainty in both the model parameters and coefficients. The study did not have success with these models.

The main conclusion of the study was that direct application of existing time series are not suitable for development of forecasts of Devils Lake levels. It essentially declared the lake level behavior as a nonstationary response to climate. The study noted the similarity of the pattern of variation in lake levels with variations in hydrologic variables seen elsewhere such as the Mississippi River at Clinton, Iowa. However, it was not certain if these variations are due to natural long-term climatic variability or represent climate change due to global warming. Consequently, although the study was able to relate the recent rise in lake level to hydroclimatic factors, predicting or assessing the conditional probabilities of long-term lake levels was beyond the state-of-the-art.

National Academy of Sciences; (Contemporary Uncertainty Analysis: The State of the Art)

No one can know or predict with confidence climate 50 years into the future. The National Academy of Sciences (NAS) provided guidance for another study (**reference 18**) on analysis when the future is uncertain. They warn that, "Failure to deal explicitly with uncertainty leads the unwary to have far too much confidence in the resulting forecast and analysis, which can lead to bad public decisions…" The NAS then lists several methods that should be weighed when evaluating project alternatives (this also applies to assumed economic futures for the base condition).

Sensitivity analysis is one method to address uncertainty. By specifying a full range of future values one can test the significance of assumptions. It can help isolate the most important variables and crucial values of these variables.

A second method for addressing uncertainty is Monte Carlo analysis. This is analogous to the stochastic analysis applied to Devils Lake. It specifies a probability distribution function (distribution) (PDF) for each uncertain variable such as precipitation, evaporation, or inflow that is deemed to be representative of future conditions. Unlike the sensitivity analysis, which specifies a range of values, this method samples from a representative probability distribution of these values and places probability estimates on values within the range. The Monte Carlo analysis is then used to develop estimated probabilities of future events. This is the standard approach outlined in Corps planning and guidance **(reference 3**).

If there were general agreement on the PDF adopted for the variables, then it would give Congress useful information as to the likelihood that a given alternative is a good investment. For example, there is a 90% chance that a project would be feasible. It places confidence in the assumed PDF.

Although the Devils Lake model used a stochastic analysis, it was not feasible or practicable to incorporate uncertainty analysis based on current Corps guidelines because of the nature and complexity of the stochastic model and the Feature Analysis Model used for economic analysis. However, the model did provide a limited form of sensitivity analysis. The current version generates precipitation, evaporation, and inflow data similar to the period 1980 to 1999 to generate lake levels for 2001- 2015. For the remainder of the simulation period (2016 – 2050), the data are generated based on the 1950 –1999 period of record. The previous version of the model generated input data based on historical data for 1950 to 1996 for the entire simulation period. (Only records since 1950 were used because of the lack of available evaporation data.) To compare the effect on the B/C ratio, this comparison was made: for the West Bay 300 cfs constrained pump alternative the previous value was 0.13. For the current version of the model (using 1980 to 1999) the B/C ratio is 0.28 (assuming same costs; however, for the final study costs have increased resulting in a lower B/C ratio of 0.19 for the Pelican Lake alternative). Not all of this increase is due to the change in record. The earlier study used a starting water surface elevation of 1444.2, whereas, the current study began with 1446.0 based on the most recent elevation at study initiation. There were some additional minor differences as well. Apparently, the B/C ratio is fairly robust regarding assumptions about whether the past (or portion of the past) is truly representative of the future. It provides insight on the issue that the more recent past is more likely to continue and that the B/C ratio would otherwise be biased. It does not address the issue of climatic nonstationarity, however. To address this a scenario approach could be used.

This method was the third method presented by the NAS. It is also referred to as conditional forecasts. Scenarios were needed for Devils Lake so that downstream impacts could be evaluated. It was not practicable to simulate 10,000 traces through the HEC-5Q model that was used for downstream simulation.

The scenarios for Devils Lake included the WET future, the moderate trace 1455, an even more moderate trace 1450, and a DRY future. The WET future assumes that the years 1993 to 1999 would occur for two cycles. At this point the lake would reach the overflow elevation of 1459 in the year 2014. The period 1993 to 1999 is repeated again to generate overflow and then the years 1980 to 1999 and then 1980 to 1990 to finish out 50-yrs. The WET future was necessary to assess the impacts of a natural overflow from Stump Lake to the Sheyenne River. The moderate traces represent actual traces from the USGS stochastic model that were representative of cases where the lake would migrate up to elevation 1455 or 1450 within the next 15 yrs. These scenarios were needed to assess the degree of impact of pumping where there may not be as much water available for dilution as in the WET future. They represent a more probable and perhaps detrimental scenario. The DRY future is an actual trace that reflects declining lake levels.

Based on these assumptions, benefits were calculated and compared with costs. Although the probability of any of these scenarios occurring exactly as assumed is zero, probability estimates could be assigned to them by indexing them to a class of traces. **Table A1-1** shows the percent of 10,000 traces are represented by each of the given scenarios. **Table A1-2** lists characteristics for these traces.

TABLE A1-1
Classes of Traces for Evaluating Downstream Impacts of Outlet

Class	Peak lake level during 2001-2050, with no outlet	Percent of traces (out of 10,000)	Average peak lake level	Average time of peak (range)*	Average pump volume** (range)*
1	1,447.0 to 1,449.0	35.6	1,448.1	2004 (2001-2013)	576 (174-1,046)
2	1,449.1 to 1,452.0	29.9	1,450.2	2014 (2002-2034)	1,292 (582-1,975)
3	1,452.1 to 1,459.0	25.0	1,454.9	2021 (2008-2042)	2,443 (1,627-3,399)
4	1,459.1 to 1,465.0	9.5	1,461.1	2021 (2010-2041)	4,034 (2,854-5,483)

* interval containing 80 percent of the traces in the given class

** total volume discharged during 2001-2050, in thousands of acre-feet, assuming 480 cfs unconstrained outlet from West Bay

TABLE A1-2
Representative Traces for Evaluating Downstream Impacts of Outlet

Class	Trace number	Peak lake level during 2001-2050	Time of peak	Pump volume*
1	52	1,448.6	2003	698
2	211	1,450.1	2014	1,133
3	36	1,454.9	2014	2,294
4	Wet	1,460.6	2019	5,954

* total volume discharged during 2001-2050, in thousands of acre-feet, assuming 480 cfs unconstrained outlet from West Bay

Each scenario can also be a way of thinking about the future. It is more qualitative than it is quantitative. The scenario analysis in this study indicates that for the outlet alternatives, feasibility is likely for a future lake level rise of at least 1458 or higher within the next 15 years. This does not imply that a "wait and see" approach should be adopted until the lake reaches a trigger elevation of 1458 because the intervening damages to that elevation would be "sunk." If one knew the lake would rise to at least this elevation now then the outlet could capture enough benefits to exceed costs.

The fourth approach outlined by the NAS is the "wait and see." This would be a possibility if it were not necessary to make a final decision today. The benefits and costs of deciding today are weighed with the benefits and costs of deciding in the future when there is more information. Costs of delaying the decision could be lowered by adopting alternatives in steps or based on trigger elevations. Because of the continued emergency nature of perpetual flooding around Devils Lake immediate action is required.

The fifth method that NAS presented was, "Finding Robust Strategies." The essence of this method is to adopt a policy whereby selection is based on the alternative that best produces favorable outcomes under the full range of plausible futures. It therefore, begins with a scenario analysis to define the range of likely hydroclimatic futures

These methods or a combination of methods are useful for projects with uncertain futures. The Devils Lake approach included some of these methods to some degree. The NAS guidance also warns that a major problem in uncertainty analysis is that analysts may tend to be overconfident of their assessment of the future. "In many situations, actual events turn out to be outside the range of forecast futures." This could be applicable for Devils Lake as well

Summary

Because the economic formulation of any Devils Lake project is directly dependent on how the proposed project would perform under expected future climatic conditions (next 50 years), it is important to be able to accurately forecast or assess the likelihood of these conditions. The Corps' standard economic approach generally ties flood damage reduction benefits with the probability that they would occur. Unfortunately estimates of future climate are uncertain. Furthermore, existing methods assume climate to be stationary. Recent research indicates that climate is probably not stationary and that it has changed in the 20th century. At present there is no model or technique available that can explicitly quantify the climate shift. To do that one would need to know how climate is nonstationary or how wet is wet and when the wet trend would end **(reference 19**). The lake could very easily continue to rise. On the other hand, climate could easily turn the lake around without the help of any structural assistance and do it abruptly. The USGS model is the best that can be done within the state of the art. However, considering the high potential for extended runoff as reflected in the Hurst coefficient, the nonstationarity in the precipitation record identified by the USGS, the climate study by the North Dakota Regional Weather Information Center associating teleconnections to Devils Lake level rise, the importance of hydrologic persistence, and the hydroclimatic studies by the Utah Water Research Laboratory, estimates of the probability or likelihood of future lake levels are most uncertain and therefore, additional methods such as sensitivity and scenario analyses were done so that wise decisions can be made regarding Devils Lake.

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Section 2 – Devils Lake Emergency Flood Plan EIS Scenario/Strategy

The Emergency Flood Plan addresses two emergencies – downstream and in-lake. It also addresses the proposed basis of design and degree of protection adopted as appropriate for this project. For the special case of a terminal lake, there are actually two types of "degree of protection."- hydrometeorological and hydroclimatological. Hydrologists sometimes refer to the meteorological event as the "super flood" or "Noah" event. It is focused on extreme events within a given year. Hydroclimatologal events are sometimes referred to as "Joseph" events **(reference 1**)." The term refers to those events whereby precipitation or runoff is well above or well below average for extended periods of time. This section describes the hydrometeorological basis for design. Corresponding degree of protection from a hydroclimatological perspective is discussed in the later section of this Appendix. This section is applicable only for outlet alternatives.

Downstream Emergency

The purpose of a flood control project in regards to the downstream emergency is to protect downstream interests from an uncontrolled overflow via Tolna Coulee. The volume that would be generated in a single year from a Standard Project Flood (SPF) has been adopted as the appropriate degree of protection for this event. At elevation 1454.2 ft. msl, there is enough storage available up to the overflow elevation of 1459 ft. msl to store the SPF volume (1,152,000 ac.-ft.). This is approximately 40 % of the Probable Maximum Flood (PMF) (2,880,000 ac.-ft.). (Generally the SPF varies between 40 % and 60 % of the PMF depending on many hydro-meteorological factors. As a sensitivity analysis, if the SPF were estimated to be 60 % of the PMF, this would result in a lower drawdown elevation of 1451.2 ft. msl). The study approach is analogous to treating Devils Lake as a "flood control reservoir," whereby the Tolna Coulee outlet is the "emergency spillway." The flood control pool in typical Corps studies is traditionally, economically optimized as the National Economic Development (NED) plan. In this case the District has adopted "flood control" storage to be equal to the SPF volume. However, the degree of protection provided to downstream interests would actually be less than the SPF because there may be less than SPF volume available by the following year due to restricted outlet capacity. This would occur for large events whereby the volume that is consumed within the lake could not be evacuated by an outlet by the following year.

In-Lake Emergency

In regards to the upstream emergency, the design event adopted for the outlet was the continuation of the wet hydroclimatic conditions of the last seven years (1993-1999). There are two objectives of an outlet alternative. One objective is to prevent the lake from rising above approximately <u>elevation 1453 ft. msl.</u> A pump size of 480 cfs operating unconstrained would accomplish this. This pump size was adopted on 20 September 1999 in a teleconference call between the St. Paul District and the Assistant Secretary of the Army (ASA). (Originally it was based on <u>elevation 1447 ft. msl for the average</u> of the last seven years so that no further damage would occur as the lake was at elevation 1447 at that time). However, since 1999, the lake reached 1448 ft. msl. In addition, the USGS readjusted monthly precipitation and evaporation estimates through recalibration of the Devils Lake model. The lake would reach an elevation of 1453 ft. msl before the evaporation at this level in conjunction with the outlet capacity would stabilize the lake. In addition, the earliest the pump could go into operation would be May 2005. Based on the WET future, the lake would then be at elevation 1452 ft. msl).

The 480 cfs pump will not keep the lake from rising absolutely. It is possible to have hydro-climatic conditions that are wetter than the last 7-yrs, which would cause the lake to rise further, although this is improbable.

Similarly, the 480 cfs pump will not keep the lake from rising if the last 7-yrs continue and the lake is at an elevation lower than 1453 ft. msl. This is because the lake would have a smaller surface area and corresponding evaporation would be less, thereby requiring more pump capacity.

The second objective is to provide enough storage below elevation 1447 ft. msl to store the 1-% event. The 1-% event has been selected as an appropriate degree of protection to prevent further damages above elevation 1447 ft.msl. This decision was made in the same teleconference call of September 1999 with ASA. The 1-% event is the annual inflow event that was generated by the USGS and is equal to 606,000 ac.-ft. This is the long-term value. The short-term value would be higher based on wet antecedent moisture conditions and hydrologic persistence. The required elevation to meet this criterion is 1441.4 ft. msl. It assumes that the volume in Stump Lake has filled before pumping starts or that Stump Lake elevation is low and very little flow has made it to Stump Lake from East Devils Lake. This is the more conservative assumption regarding how low the target elevation must be for this adopted degree of protection. This elevation therefore has special significance as the target elevation. Once the lake reaches 1441.4 ft. msl the pumps will be shut off and will not operate again until the lake rises above this elevation with definite forecasted inflow volume.

The 1-% event degree of protection clearly is the overriding degree of protection. At an elevation of 1441.4 ft. msl there is enough available storage to prevent an SPF uncontrolled natural overflow at elevation 1459 ft. msl but also enough storage to prevent an inflow PMF volume from overflow. This elevation would be 1442.8 ft. msl assuming Stump Lake's storage is not available. Since this determination was made the lake rose to a peak elevation of 1448.0 ft. msl in July of 2001. Therefore the target drawdown elevation was adjusted upwared to1443.0 ft. msl.

Regarding selection of design pumping capacity, downstream water quality considerations appear to be the more limiting factor. This is based on downstream water quality simulations with various outlet capacities, meetings with respective agency officials, and concern expressed by the Governor of North Dakota (**reference 2**) for minimizing impacts downstream. A maximum outlet capacity of 300 cfs, constrained for downstream water quality and channel capacity goals, appears to be the most effective in providing lake level drawdown capability and concurrently minimizing downstream impacts. Results from these alternatives are presented in later sections of this Appendix.

Inflow Probable Maximum Flood (PMF) and Standard Project Flood (SPF)

The Probable Maximum Flood (PMF) is that flood which would result from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. The Standard Project Flood (SPF) represents the flood that can be expected from the most severe combination of meteorologic and hydrologic conditions that are considered reasonably characteristic of the geographic region involved, excluding extremely rare combinations. SPFs on detailed studies usually are about 40 to 60 percent of the Probable Maximum Flood for the same basin (**reference 3**).

Devils Lake inflow volume PMF was determined based on interpolation with PMFs at two adjacent and hydrologically similar drainage areas; Pembina River at Walhalla, ND and Sheyenne River at Baldhill Dam. The Probable Maximum Precipitation used to generate these floods was developed using the procedures and data presented and described in Hydrometeorological Report No. 48, "Probable Maximum Precipitation and Snowmelt Criteria for the Red River of the North above Pembina and Souris River above Minot, North Dakota," dated May 1973, commonly called H.M. Report 48 (**reference 4**). **Table A2-1** shows the drainage areas, inflow volume, and peak discharge at each of these locations including the contributing area to Devils Lake. The critical season for the Pembina and Sheyenne Rivers is the15 March event. Other storms that were studied include the 01 April, 15 April, and the all-season storms. **reference 5** and **6** document more detailed analysis for derivation of the two PMFs on which Devils Lake was based.

The PMF volume for the Devils Lake basin was interpolated as 2,880,000 ac.-ft. For the Pembina River and Sheyenne River PMF studies, the SPF was adopted as 40 percent of the PMF; therefore, 40 % was adopted for the Devils Lake basin resulting in an SPF volume of 1,152,000 ac.-ft.

TABLE A2-1
PMF, Drainage Area, Volume, and Peak Discharge

Location	Drainage Area (sq.mi.)	Volume (ac.-ft.)	Peak Discharge (cfs)
Pembina River @ Walhalla, ND	3,310	2,879,000	109,100
Sheyenne River @ Baldhill Dam	3,350	2,875,000	106,800
Devils L. Contributing Drainage area	3,810	2,880,000	N/A

1-Percent Event

The event duration that would cause the highest elevation for Devils Lake (i.e. critical duration) for the 1-percent event was assumed to be approximately 1-year. One-percent events with durations that are shorter or longer were assumed to be not as critical; therefore, this event was adopted for analysis. The 1-percent duration was estimated by using the USGS stochastic model. Based on an assumed starting water surface elevation and then performing a statistical analysis on the next years inflow volume, resulted in a 1-percent volume of 606,000 ac.-ft. for average conditions as representative of conditions from 1950 to 1996 and 1,124,000 ac.-ft. for wet antecedent moisture conditions as currently exist within the basin.

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Section 3 – Overview of USGS Devils Lake Outlet Simulation Model

The lake level, outlet discharge, and water quality data used to evaluate the various proposed outlet options is generated using an outlet simulation model developed by the U.S. Geological Survey (USGS), in cooperation with the Corps. A detailed description of the USGS outlet simulation model is provided in a separate report (**Vecchia, 2002**). A brief overview of the model is provided in this section.

The outlet simulation model consists of three components: (1) A water and sulfate mass-balance model for generating volumes and sulfate concentrations in Devils Lake and Stump Lake in response to precipitation, evaporation, and inflow; (2) a model for generating daily outlet pumping volumes to meet downstream water-quantity and water-quality constraints, and (3) a statistical time-series model for generating future precipitation, evaporation, and inflow values for Devils Lake and Stump Lake and future ambient (with no outlet) discharges for the Sheyenne River.

A schematic of the first two components of the outlet simulation model is shown in **Figure A3-1.** The water and sulfate mass-balance model is used to compute the change in volume and sulfate concentration in each of five major storage compartments – West Bay, Main Bay, East Bay, East Devils Lake, and Stump Lake – in response to precipitation, evaporation, inflow, and outflow from each compartment. The storage compartments are referred to as the lake “boxes.” The first box (West Bay) is comprised of two parts – West Bay north of Highway 19 and West Bay south of Highway 19. When Devils Lake exceeds 1430 ft msl, the north part of West Bay includes Pelican Lake and when Devils Lake exceeds 1445 ft msl, the north part of West Bay also includes Lakes Alice and Irvine. When Devils Lake exceeds 1459 ft msl, water spilling from Stump Lake through the natural outlet to the Sheyenne River is controlled by a flow rating developed by the Corps. The natural outlet is assumed to be “armored” in most of the future simulations. However, a sensitivity analysis was done for the wet scenario in which erosion of the outlet channel is modeled.

In addition to computing the flux of sulfate into or out of each box due to inflow or outflow, the model also computes the benthic flux of sulfate into or out of bottom sediments. The benthic flux of sulfate is an important control on the sulfate mass balance of the lake (**Lent and Lyons, 1995**). Sulfate concentration in the pore-water of the bed sediment increases from West to East and from the lake-pore water interface to the deeper sediments. Thus, each of the bed sediment “boxes” consists of five layers extending from the shallow to deep sediments and each layer consists of a series of several lake sections from west to east (the actual number of sections varies depending on the lake box). The flux of sulfate from the shallow sediments to the lake and from the deep sediments to the shallow sediments is controlled by the concentration gradient and by the porosity of the bed sediments.

Another important control on the sulfate mass-balance is exchange of sulfate between lake boxes due to wind- and buoyancy-driven exchange flows. The work of Prof. Joe Manous of the U.S. Military Academy at West Point (**Manous, 2000**) was used to estimate the rate of wind-driven exchange flow and exchange flow due to buoyancy differences between the various lake boxes as a function of lake elevation and time-of-year. Coefficients controlling mixing efficiency, along with flux coefficients controlling the bed-sediment flux rates, were estimated using a nonlinear regression model to minimize differences between recorded in-lake sulfate concentrations and estimated in-lake sulfate concentrations for the model calibration period (1980-99).

Given the lake volumes (or, equivalently, lake levels) and sulfate concentrations generated as described previously, the outlet simulation model is used to determine the volume and sulfate concentration of daily outlet discharges for various proposed outlet alternatives described elsewhere in this report. The West Bay outlet discharges water from south West Bay to the Sheyenne River. For this outlet configuration, current basin conditions are assumed to hold in the future, in particular, Channel A flows are not diverted into West Bay and a Highway 19 control structure is not built. Outlet discharges for the 300 cfs pump option are constrained so that the combined outlet discharge and ambient Sheyenne River streamflow is less than 600 cfs and the combined sulfate concentration is less than 450 mg/L. Outlet discharges for the 480 cfs pump option are not subjected to these constraints. Outlet discharges for both the 300 cfs and 480 cfs options can occur only during May 1 to November 30 of each year, beginning in the year 2005.

The Pelican Lake outlet discharges water from north of Highway 19. In this alternative, Channel A flows are diverted into West Bay to increase the amount of relatively fresh water available for the outlet. However, if the outlet discharge causes the level of Pelican Lake to decrease below the level of West Bay, water is allowed to flow from West Bay to Pelican Lake to equalize the lake levels north and south of Highway 19. Pump discharges for the 300 and 480 cfs options were constrained as described above for the West Bay outlet. Additional runs were made for the Pelican Lake outlet with sulfate constraints of 350 mg/L and 250 mg/L to reduce adverse impacts of the outlet on downstream water quality. It was determined that a Pelican Lake outlet with a sulfate constraint of 350 mg/L was nearly as effective as a West Bay outlet with no sulfate constraint, and that the downstream water-quality impacts of the Pelican Lake outlet were much less severe than the impacts of a West Bay outlet. However, the Pelican Lake outlet with a 250 mg/L sulfate constraint was much less effective for controlling rising lake levels.

A modified Pelican Lake outlet alternative also was considered. This alternative is the same as the Pelican Lake outlet alternative described previously, except that Highway 19 is used as a control structure to prevent the flow of water from south to north. Thus, the outlet can draw down the level of Pelican Lake below the level of West Bay. However, water is discharged from Pelican Lake into West Bay whenever inflow causes the level of Pelican Lake to rise above the level of West Bay. The modified Pelican Lake outlet with a 250 mg/L sulfate constraint was nearly as effective as the West Bay outlet with no sulfate constraint and the downstream water-quality impacts of the modified Pelican Lake outlet were minimal.

The East Devils Lake outlet alternative discharges water from East Devils Lake, and was considered only for the 480 cfs unconstrained outlet option. The downstream water-quality impacts of the East Devils Lake outlet are severe and thus this alternative was not considered a viable option.

The inputs to the water and sulfate mass-balance model consist of starting volumes and sulfate concentrations for each lake box, starting sulfate concentrations of the bed sediments, and time series of future precipitation, evaporation, inflow volumes and sulfate concentrations, and Sheyenne River discharges and sulfate concentrations. Sulfate concentrations of inflows and Sheyenne River discharges are computed using regression equations relating sulfate concentration to discharge that were calibrated using historical sulfate concentrations for Big Coulee, Channel A, and the Sheyenne River near Warwick, ND. Bias correction factors are used to ensure that estimated sulfate loads for lake inflows are unbiased estimates of true loads.

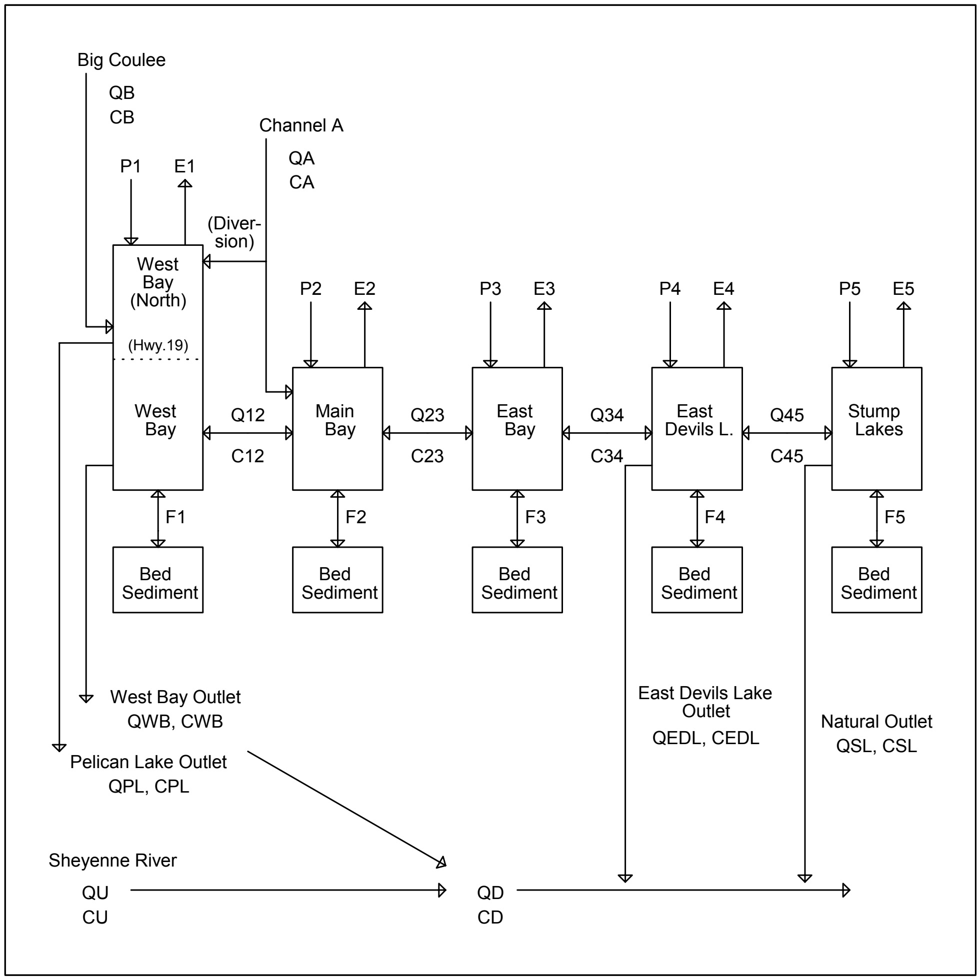
Simulation of potential futures, or "traces" from the outlet simulation model requires only starting conditions and future values of precipitation, evaporation, inflow, and Sheyenne River discharge. All of these future inputs to the model are, of course, subject to a great deal of stochastic uncertainty. There were two approaches used to generate future inputs: a scenario approach and a stochastic approach. In the scenario approach, future inputs are assumed to consist of a specified sequence of historical inputs. There is no need to generate inputs outside of the range of historical values and there is no probability attached to a particular trace obtained from the scenario approach. In the stochastic approach, a statistical time series model is developed for generating realistic sequences of future inputs. Each sequence is selected "at random" and represents one possible future trace that could occur. Future inputs outside of the range of historical inputs can be generated. By generating a large number of potential future traces (10,000 traces were used for this study) the probability of any future event can be estimated. For example, if in 940 out of 10,000 traces with no outlet (existing conditions), Devils Lake continues to rise and spill to the Sheyenne River sometime before 2050, then there is a 9.4 percent chance of a spill sometime during the next 50 years. Each of the 10,000 traces can be input to the economic model to determine a distribution of possible benefits and costs associated with each outlet alternative.

The time series model used to generate inputs is a particular type of first-order Markov model, which means that precipitation, evaporation, inflow, and Sheyenne River discharge for the current year depend on antecedent conditions during the previous year and a sequence of randomly generated noise. The model maintains the historical probability distributions of the inputs as well as cross-correlation between inputs and serial correlation in the inputs. Inflows in particular are not independent from year-to-year, and wet (or dry) starting conditions can affect inflows for many years into the future because of storage of water in upper basin soil, wetlands, and lakes.

The estimated probabilities associated with the stochastic approach depend on the period of record used to calibrate the statistical time series model. Thus, it is important that climatic conditions during the model calibration period provide a reasonable representation of future climatic conditions. According to estimates by the Regional Weather Information Center, University of North Dakota, climatic conditions similar to the past 20 years (1980-99) will probably continue beyond the year 2015 (**Osborne, 2000; Wiche and others, 2000**). Furthermore, climatic conditions from 1900 to the late 1970's are generally drier and less variable than conditions during the past 20 years. Thus, the period 1980-99 was selected to calibrate the time series model and the resulting model was used to generate inputs for 2001-2015. It is not known whether climate after 2015 will be similar to the recent wet period, revert back to a climate similar to the more stable period 1950-79, or change to an entirely different regime. Therefore, the time series model also was calibrated using the entire available historical period of 1950-99, and the resulting model was used to generate inputs for the remainder of the simulation period (2016-50). There was much more variability in the generated inputs for 2016-50, reflecting more uncertainty in the climatic conditions for that time period.

The stochastic outlet traces and most of the scenario-based traces were generated assuming existing conditions in the upper Devils Lake Basin, thus the potential effects of upper basin storage restoration were not considered. However, WEST consultants, under contract from the Corps, developed a detailed precipitation-runoff model for the upper basin that is described in detail in a separate report **(reference 6)**. Data from that report were used to develop a regression relation between basin runoff with existing conditions and basin runoff under various levels of upper basin storage restoration. The regression relation was used to adjust inflows generated from the time series model to reflect inflows that would occur with a storage restoration level of 50 percent by volume.

Schematic of Devils Lake water and sulfate mass-balance model



QB - Inflow for Big Coulee
CB - Sulfate concentration of QB
QA - Inflow for Channel A
CA - Sulfate concentration of QA
Pi - Precipitation on surface of ith box
Ei - Evaporation from surface of ith box
Qij - Flow of water between box i and box j
Cij - Sulfate concentration of Qij
Fi - Flux of sulfate between box i and bed sediment
QWB - Discharge from West Bay outlet
CWB - Sulfate concentration of QWB
QPL - Discharge from Pelican Lake outlet
CPL - Sulfate concentration of QPL
QEDL- Discharge from East Devils Lake outlet
CEDL- Sulfate concentration of QEDL
QU - Discharge for Shey. R. upstream of outlet
CU - Sulfate concentration of QU
QD - Discharge for Shey. R. downstream of outlet
CD - Sulfate concentration of QD
QSL - Discharge from Stump L. natural outlet
CSL - Sulfate concentration of QSL

FIGURE A3-1

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Section 4 - Downstream Water Quality Impacts Model HEC-5Q

Introduction

Congress has authorized the US Army Corps of Engineers to plan, engineer, and design an emergency outlet from Devils Lake to help alleviate flooding in the basin. As part of emergency outlet planning, the Corps is required to determine potential effects of an outlet on downstream water quality, downstream reservoir operations, and the future lake levels and water quality in Devils Lake. The U.S. Geological Survey (Bismarck, ND, office) was contracted by the Corps to develop a lake level/water quality model for Devils Lake. The model, known as the "5-box model" **(reference 1)**, is a water mass-balance model that simulates future volumes and sulfate concentrations in Devils Lake with and without outlet operation. The 5-Box Model's output, in terms of outlet flow rate and water quality released to the Sheyenne River, is input to HEC-5 and HEC-5Q models developed by the Corps to determine the effects of outlet operation on the receiving waters (the Sheyenne River and Red River of the North). This section summarizes the Corps efforts in developing the HEC-5 and HEC-5Q models.

Corps Water Quality Modeling Objective

The objective of the Corps effort was to develop a model (or models) to predict relative effects on water quality in the Sheyenne River and Red River of the North from operating the proposed Devils Lake outlet. The modeled reaches include the Sheyenne River from the insertion point at the confluence of Peterson Coulee and the river to the Sheyenne River's confluence with the Red River of the North, then down the Red River of the North to the Canadian Border at Emerson. The model should have reservoir operation capability for the Lake Ashtabula reservoir and should allow travel times to vary with hydrologic conditions.

Background - Previous Corps Spreadsheet Model

In 1996, a spreadsheet model was developed to assess the effects of a proposed Devils Lake outlet on the Sheyenne River and Red River of the North. The modeled outlet was operated to meet a sulfate standard of 450 mg/l at the insertion point on the Sheyenne River. Baseline and pumping options were run for several combinations of pumping and channel capacities. River flow data from water years 1985 thru 1995 were used to estimate the pumping that could be accomplished and the resulting downstream sulfate concentrations. The spreadsheet model assumed constant travel times or lags between stations and assumed Lake Ashtabula was operated as a constant volume reservoir throughout the year.

Sulfate was the only parameter modeled in the spreadsheet model. Model runs indicated that operation of a Devils Lake outlet would result in minor increases in the magnitude, frequency, and duration of exceedances of the sulfate standard and, by inference, the total dissolved solids (TDS) standard on the Red River of the North. The model, though useful, needed improvements so that travel times and effects of reservoir operations on downstream water quality could be estimated.

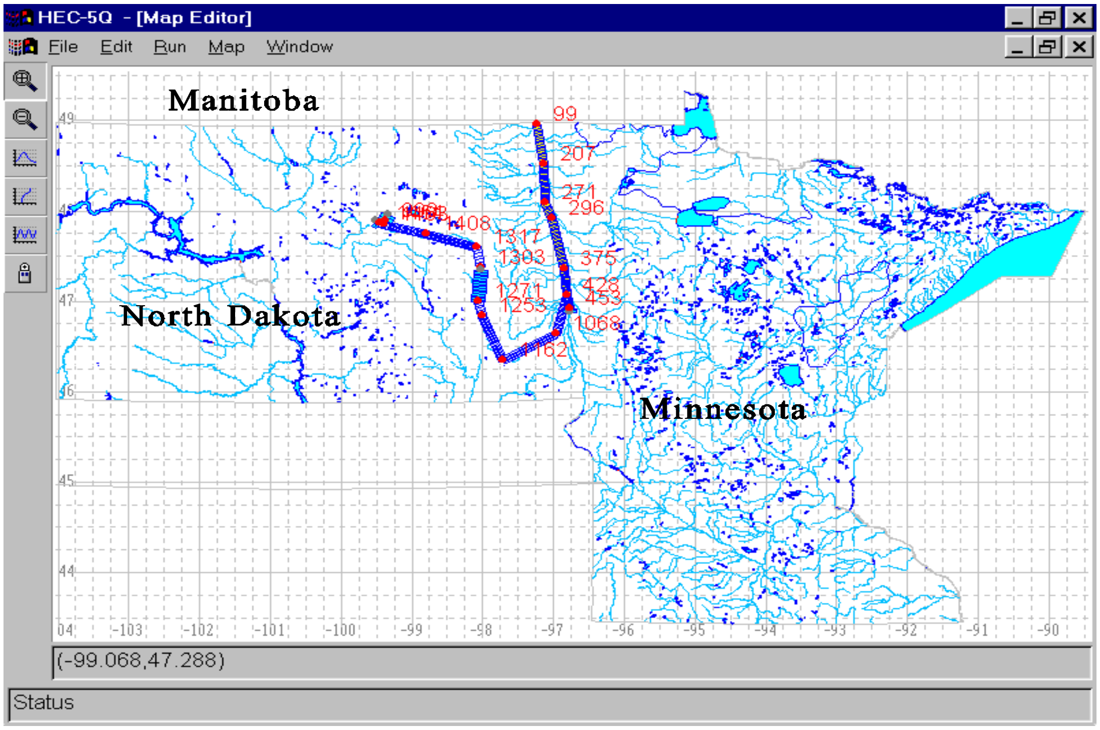


FIGURE A4-1. Example of 5Q Project Map.

Model Selection

The selection of a new model to simulate hydrologic and water quality conditions on the Sheyenne River and Red River of the North was based on the following criteria:

- The model must include water quality constituents
- The model must be a hydrologic model
- The model must have reservoir regulation capability (required since Lake Ashtabula is a significant re-regulator of Devils Lake flow that could have downstream impacts)
- The model must have database management capability to handle the large amounts of data used in the simulations
- The model must be able to vary travel times with hydrologic conditions
- The model should have a post processor to graphically display output

The HEC-5 and HEC-5Q models were selected for modeling the effects on Sheyenne River and Red River of the North water quality from operating the proposed Devils Lake outlet: They are the only models which met the above criteria. The models can regulate reservoirs for a specified rule curve and allow use of the Hydrologic Engineering Center's (HEC) Data Storage System (DSS) for easy manipulation and analysis of large amounts of data. In addition, HEC-5Q can write output to a graphical user interface (GUI) developed by Resource Management Associates, Inc. (RMA) under contract to the U.S. Army Corps of Engineers HEC, Davis, CA.

The HEC-5Q GUI allows graphical representation of model results. The interface displays a schematic representation of the model on a map display (see above). The map is used to select locations along the modeled reach where results are to be plotted. Longitudinal and time series plots can be created. Time series plots (see below) display non-animated model results for a user-selected constituent and location(s) for the time series. Longitudinal plots (see below) display results for a user-specified constituent along one or more reaches of the model; the user may invoke the animation option to observe output over any period of time.

Background - Devils Lake Simulation

The USGS conducted the hydrologic and water quality analyses for Devils Lake for various outlet operating plans using its "5-box model" (**reference 1**). Each analysis involved the determination of future lake levels and water quality characteristics for 10,000 50-year traces. The model stochastically generates precipitation, inflow, and evaporation, and inputs these components into a water mass-balance analysis to determine resulting lake levels. The stochastic simulations were necessary to determine a statistically valid lake level-frequency relationship for with- and without-project conditions. The model also simulates water quality by accounting for constituent loadings from inflows, evaporation-related concentration of those constituents, and sediment flux/water column interactions. The model divides Devils Lake into compartments (boxes) -- West Bay, Main Bay, East Bay, East Devils Lake, and the Stump Lakes -- to replicate the lake's west-to-east salinity gradient.

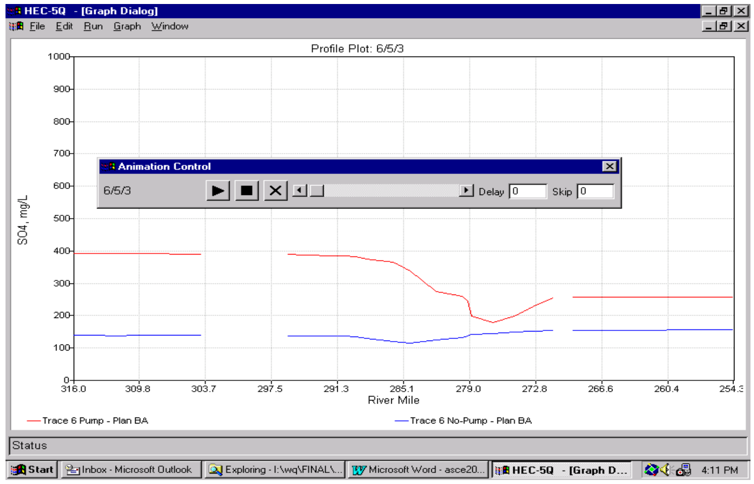


FIGURE A4-2. Example of Reach Profile SO4 Plot

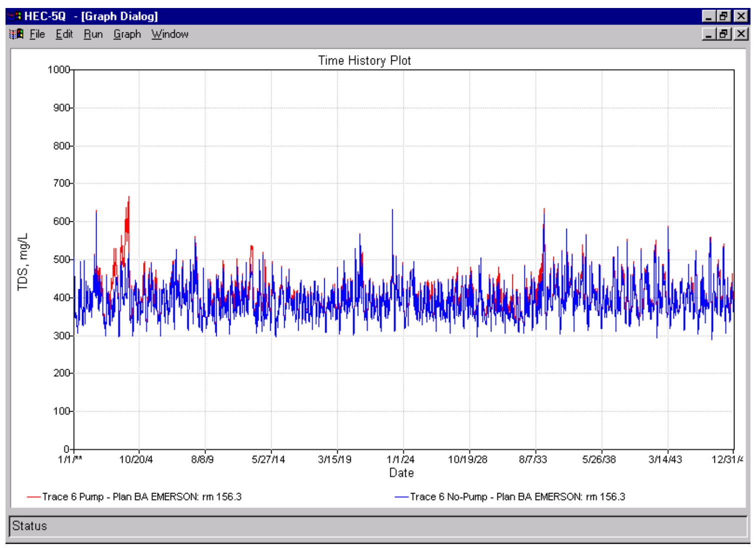


FIGURE A4-3. Example of Time Series Plot of TDS at a Specified Location

Linking Models

To link the 10,000 stochastically generated traces to the downstream water quality impact study, three of the 10,000 traces were selected to reflect the range of possible future lake behavior. Each trace reflects 50 years of data on a daily time interval -- flow (Q), total dissolved solids (TDS), sulfate (SO_4), chloride (CL), total hardness (HRD), and non-carbonate hardness (NCHRD) -- with and without Devils Lake outlet operation. The USGS traces were 50 years in duration (October 1, 2000 - September 30, 2050). It was assumed that outlet operation would start in May 2005 which is the earliest the pump could begin operation. The prior years were used to establish baseline conditions in the system. In addition to the four traces a synthetic (design trace) was also selected.

The selected traces reflect the following situations:

Description of Traces

<u>WET Future</u>

The WET future is a 50-yr trace beginning October 1, 2000 and extends to September 30, 2050 and is represented by historic years. The years are based on precipitation, evaporation, and inflow for the last 7-yrs of record (1993 -1999). The sequence begins with these 7-yrs and then repeats until the lake reaches the natural overflow elevation of 1459 in the year 2014. It repeats once more so that the impacts of the natural overflow through Tolna Coulee can be simulated downstream on the Sheyenne River. The historic years 1981 – 1999, and 1981 – 1990 are then used in the sequence to fill the remaining years for a total of 50-yrs. **Table A4-1** lists the simulation water year and the corresponding historic water year for this scenario.

The corresponding in-lake elevation traces for without- project conditions are shown in **Figure A4-4**. For the without-project condition, the lake will peak in the year 2019 at elevation 1460.6 with a peak outflow of approximately 550 cfs. Natural overflow ends in year 2024. **Figures A4-5** shows the natural overflow hydrograph.

For the most pumping alternatives, pumping begins May 1, 2005 and occurs throughout the 50-yrs. For other Pelican Lake alternatives, pumping begins May 1, 2006. Pumping is terminated when the lake reaches 1441.4 and will begin again if the lake rises above this elevation.

<u>Moderate Trace 1455</u>

This is an actual 50-yr trace from the 10,000 stochastic traces generated for Devils Lake. It is trace number 36. It represents the case whereby the lake elevation migrates up to elevation 1455 within the first 15 years. This is referred to as a more "moderate" trace relative to the WET future and was selected to assess more likely and perhaps more significant water quality impacts compared to the WET trace because conditions downstream are not as wet and therefore do not have as much dilution to attenuate impacts.

Corresponding flows downstream of Devils Lake were associated with the synthetic trace in Devils Lake by "tagging" each year with a historic year multiplied by a factor. In this way the flows downstream are "in phase" with hydrologic conditions that are being simulated in Devils Lake. In this scenario the lake reaches a peak elevation of 1454.9 in the year 2014. The years after the first 15 years tend to be dry and appear to be drier than average conditions of the last 50-years.

Figure A4-4 shows the in-lake elevation trace for Devils Lake for without- project conditions. There is no natural overflow through Tolna Coulee for this scenario. Pumping terminates near the middle of the 50-yr period when the lake reaches 1441.4.

<u>Moderate Trace 1450</u>

This is the second “moderate” trace and is an actual 50-yr trace from the 10,000 stochastic traces generated for Devils Lake. It is trace number 211. It represents the case whereby the lake elevation migrates up to elevation 1450 within the first 15 years. In this scenario the lake reaches a peak elevation of 1450.1 in the year 2014. The years after the first 15 years tend to be dry.

Figure A4-4 shows the in-lake elevation trace for Devils Lake for without- project conditions. There is no natural overflow through Tolna Coulee for this scenario. Pumping terminates near the middle of the 50-yr period when the lake reaches 1441.4.

<u>DRY Trace</u>

This trace represents the case whereby the lake level decreases and no pumping occurs. It is needed for economic evaluation. It is an actual 50-yr trace from the 10,000 stochastic traces generated for Devils Lake. It is trace number 52. In this scenario the lake reaches a peak elevation of 1448.6 in the year 2003 and then falls continuously.

Figure A4-4 shows the in-lake elevation trace for Devils Lake for without- project conditions. There is no natural overflow through Tolna Coulee for this scenario. Pumping terminates near the middle of the 50-yr period when the lake reaches 1441.4.

TABLE A4-1.
WET SCENARIO SIMULATION
WATER YEAR WITH CORRESPONDING
HISTORIC WATER YEAR

Simulation Year	Historic Year	Simulation Year	Historic Year
2001	1993	2026	1985
2002	1994	2027	1986
2003	1995	2028	1987
2004	1996	2029	1988
2005	1997	2030	1989
2006	1998	2031	1990
2007	1999	2032	1991
2008	1993	2033	1992
2009	1994	2034	1993
2010	1995	2035	1994
2011	1996	2036	1995
2012	1997	2037	1996
2013	1998	2038	1997
2014	1999	2039	1998
2015	1993	2040	1999
2016	1994	2041	1981
2017	1995	2042	1982
2018	1996	2043	1983
2019	1997	2044	1984
2020	1998	2045	1985
2021	1999	2046	1986
2022	1981	2047	1987
2023	1982	2048	1988
2024	1983	2049	1989
2025	1984	2050	1990

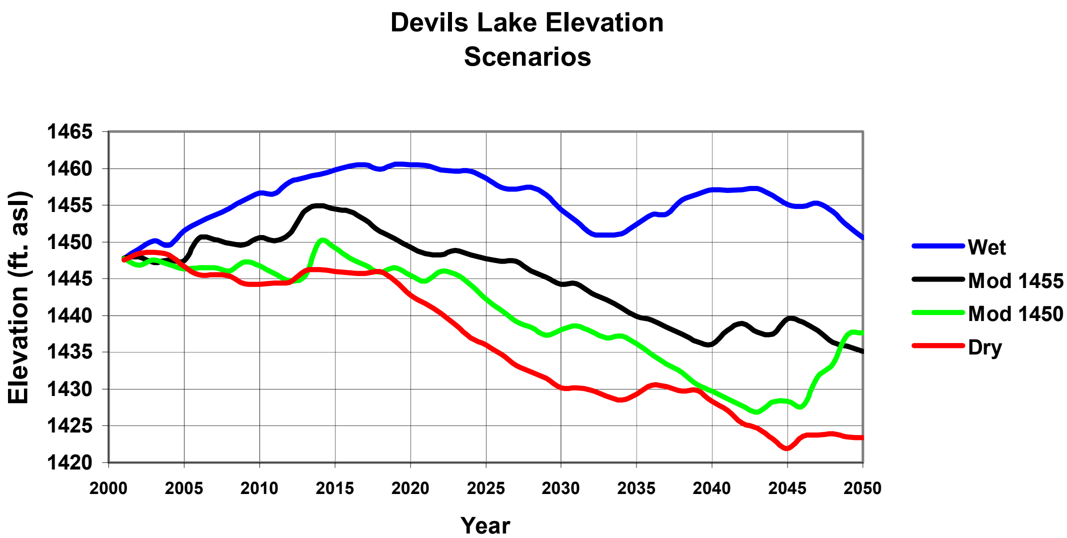


FIGURE A4-4

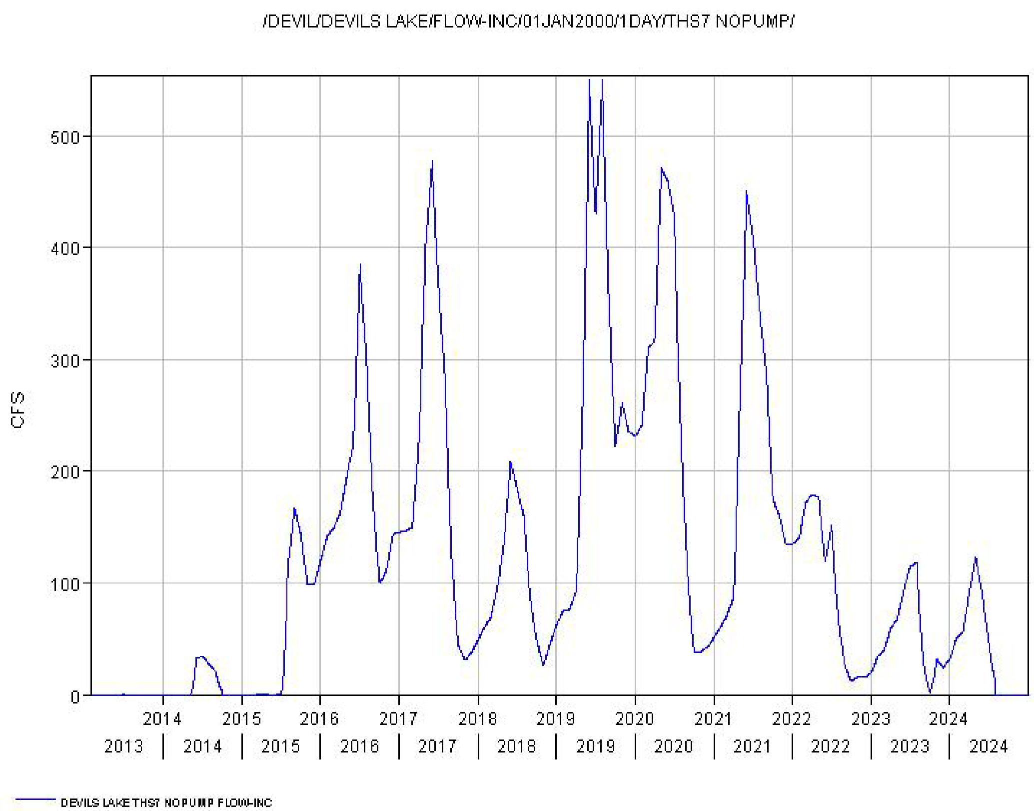


FIGURE A4-5

Table A4-2 and A4-3 show the classes that each trace represents and additional characteristics associated with each trace. The percent of traces out of the total 10,000 was used to weight the downstream benefits/disbenefits for determination of the B/C ratio in the stochastic analysis. **Figure A4-4** shows plots of the traces selected for use in the Devils Lake model.

TABLE A4-2.
Classes of Traces for Evaluating Downstream Impacts of Outlet

Class	Peak lake level during 2001-2050, with no outlet	Percent of traces (out of 10,000)	Average peak lake level	Average time of peak (range)*	Average pump volume** (range)*
1	1,447.0 to 1,449.0	35.6	1,448.1	2004 (2001-2013)	576 (174-1,046)
2	1,449.1 to 1,452.0	29.9	1,450.2	2014 (2002-2034)	1,292 (582-1,975)
3	1,452.1 to 1,459.0	25.0	1,454.9	2021 (2008-2042)	2,443 (1,627-3,399)
4	1,459.1 to 1,465.0	9.5	1,461.1	2021 (2010-2041)	4,034 (2,854-5,483)

* interval containing 80 percent of the traces in the given class
** total volume discharged during 2001-2050, in thousands of acre-feet, assuming 480 cfs unconstrained outlet from West Bay

TABLE A4-3.
Representative Traces for Evaluating Downstream Impacts of Outlet

Class	Trace number	Peak lake level during 2001-2050	Time of peak	Pump volume*
1	52	1,448.6	2003	698
2	211	1,450.1	2014	1,133
3	36	1,454.9	2014	2,294
4	Wet	1,460.6	2019	5,954

* total volume discharged during 2001-2050, in thousands of acre-feet, assuming 480 cfs unconstrained outlet from West Bay

A daily time interval simulation for pumping from Devils Lake to the Sheyenne River was necessary because of the highly variable daily flow on the Sheyenne River. For the constrained outlet alternatives, outlet operation was limited to a 7-month window (1 May - 30 November) and was constrained by the most restrictive of the following requirements -- not exceeding the design maximum pumping capacity (300 cfs), not allowing the blend of ambient Sheyenne River flow and outlet releases to exceed maximum channel capacity of the Sheyenne River in the vicinity of the insertion point (600 cfs), and not exceeding SO_4 limits at the insertion point which were varied for alternative plans of operation up to the North Dakota State standard of 450 mg/l. The 480 cfs plans are unconstrained for either water quality or channel capacity.

For each scenario, HEC-5 and HEC-5Q model baseline (no-pump) and pumping options. The daily simulation results for each scenario are stored in DSS for Cooperstown, ND; four locations in the Lake Ashtabula reservoir; Valley City, ND; Kindred, ND; the confluence of the Sheyenne River and Red River of the North; Halstad, MN; Grand Forks, ND; Oslo, MN; Drayton, ND; and Emerson, Manitoba. Five-day simulation results are stored in an output file which can be viewed by the HEC-5Q GUI. A 5-day interval was utilized to reduce file size while maintaining enough data points to reasonably view and interpret model results. Output is used to assess the effects of Devils Lake releases on downstream water quality, specifically, the frequency, duration, and severity of exceedances of downstream water quality standards above the modeled baseline condition. In addition, model results were be used to estimate impacts on and potential mitigation costs for downstream water users due to increased hardness, chloride, TDS, and sulfate concentrations.

Streamflow Stations

Table A4-4 lists the USGS streamflow stations used in the study and their period of record.

TABLE A4-4.
USGS STREAMFLOW GAGING STATIONS

LOCATION	USGS ID NO.	DRAINAGE AREA (sq. mi.)	PERIOD OF RECORD
SHEYENNE RIVER BASIN			
Sheyenne R. @ Warwick, ND	05056000	2,070 1,310 non-contributing	Oct 1949 - present.
Sheyenne R. @ Cooperstown, ND	05057000	6,470 5,200 non-contributing; includes 3,800 closed basin	Oct 1944 - present
Sheyenne R. @ Baldhill Dam, ND	05058000	7,470 5,560 non-contributing; includes 3,800 closed basin	Oct 1949 - present
Sheyenne R @ Valley City, ND	05058500	7,810 5,700 non-contributing; includes 3,800 closed basin	Mar - Aug 1919, Mar - Jun 1939, Aug 1938 - Sep 1975, Oct 1979 - present
Sheyenne R. @ Lisbon, ND	05058700	8,190 5,700 non-contributng; includes 3,800 closed basin	Sep 1956 - present
Sheyenne R. @ Kindred, ND	05059000	8,800 5,780 non-contributing; includes 3,800 closed basin	Jul 1949 - present
Maple R. @ Enderlin, ND	05059700	843 47 non-contributing	May 1956 - present

LOCATION	USGS ID NO.	DRAINAGE AREA (sq. mi.)	PERIOD OF RECORD
RED RIVER OF THE NORTH BASIN			
Red River of the North @ Fargo, ND	05054000	6,800	May 1901 - present
Red River of the North @ Halstad, MN	05064500	21,800 3,800 includes closed basin	Apr 1936 - Jun 1937 (no winter records), Apr 1942 - Sep 1960 (spring and summer months only), May 1961 - present
Red River of the North @ Grand Forks, ND	05082500	30,100 3,800 includes closed basin	Apr 1882 - present
Red River of the North @ Oslo, MN	05083500	31,200 3,800 includes closed basin	Apr 1936 - Jun 1937, Apr 1941 - Apr 1943, and Mar 1945 - Sep 1960, 1974 - 1976
Red River of the North @ Drayton, ND	05092000	34,800 3,800 includes closed basin	Apr 1936 - Jun 1937, and Apr 1941 - present
Red River of the North @ Emerson, Man.	05102500	40,200 3,800 includes closed basin	Mar - Nov 1902 (stage only), May 1912 - Sep 1929 (monthly discharge), and Oct 1929 – present

HEC-5 and HEC-5Q Models

The HEC-5/HEC-5Q model is a two-part model with the standard HEC-5 model **(reference 2**) providing the flow data for use by the HEC-5Q water quality model. Input files required for this model are as follows:

● HEC-5	Flow regulation model
● HEC-5Q	Water quality model
● Meteorological file	Provides meteorological input
● Stream hydraulic file	Provides hydraulic elements for the river
● Tributary file	Provides information on the water quality of the tributaries
● DSS files	Provides input for flow and water quality parameters

HEC-5

The HEC-5 model begins simulation with three required dummy reservoirs -- Devils Lake; Highway 30 (HWY 30), representing the headwaters of the Sheyenne River, the watershed upstream of the insertion point; and Fargo, representing the headwaters of the Red River of the North. Control points include:

- Peterson Coulee (insertion point of pumped Devils Lake water to the Sheyenne River)
- Warwick*
- Cooperstown*
- Into Ashtabula (required as upstream end of reservoir in 5Q model)
- Baldhill Dam*
- Valley City*
- Lisbon*
- Kindred*
- Junction (confluence of Sheyenne River and Red River of the North)
- Halstad*
- Grand Forks*
- Oslo*
- Drayton*
- Emerson*

* Observed flows at USGS gages

Observed flows were input to the HEC-5 model for each control point where possible. At the remaining control points or at partial record stations, flow was computed by multiplying the observed flow at another control point by a ratio of respective drainage areas. Because water quality data were limited to the period 1971-1999, that period was adopted as the baseline period for both water quality and water quantity input data for the HEC-5 and HEC-5Q models.

The HEC-5 model was then used to calculate incremental local flows. The incremental local flow at each control point is the basic input for the final HEC-5 simulation runs. A DSS file was then established that included incremental local flows for each control point in the system for the years 1971-1999.

Because the USGS analysis produces synthetic, stochastic traces, the downstream simulation using incremental local flows had to be in "hydrologic phase" with the 5-box model's inflows generated for Devils Lake for the corresponding period. Therefore, incremental local flows downstream on the Sheyenne River and Red River of the North had to be cross-correlated with inflows occurring in the Devils Lake basin. When high precipitation and inflows were generated in the Devils Lake 5-box model, high flows should also be occurring on the Sheyenne River and Red River of the North. Likewise, when low precipitation and inflows were generated in the Devils Lake 5-box model, then low incremental local flows should be occurring on the Sheyenne River and Red River of the North. This part of the analysis was accomplished by "tagging" each year of the Devils Lake traces with a similar year from the base period 1971-1999, adjusted if necessary with a multiplier. Once every year in each trace was identified in this way, a flow series was developed with the incremental local flows using a DSS macro.

Lake Ashtabula

Lake Ashtabula is formed by the 1,650-foot, earth-filled Baldhill Dam. Storage began on July 30, 1949, and the dam was completed in September 1949. Usable capacity is 69,100 acre-feet between the invert of the outlet conduit (elevation 1,238.0) and normal pool level (elevation 1266.0). Dead storage below elevation 1,238.0 is 1,500 acre-feet. Maximum pool elevation is 1278.5 with the recent project at Baldhill to increase flood control capacity. This pool raise increased the storage capacity to a total of 157,500 acre-feet. Low flows are controlled by two sluice gates 3 feet in diameter. The spillway crest is 120 feet long at elevation 1,252.0, surmounted by 3 tainter gates, each 15 feet high and 40 feet long. The dam has an 880-foot-long, ungated overflow auxiliary spillway with a crest elevation at 1271.0. The reservoir is operated to increase low-water flow and for flood control.

HEC-5 Reservoir Regulation

HEC-5 was used to simulate operation of Lake Ashtabula in conservation and flood control mode. **Table A4-5** shows the simplified operation goals in order of priority for flood control and conservation. Reservoir operation criteria used in the model are as follows:

a. Releases are made within the flood control pool to draw the reservoir to the top of conservation pool without exceeding the channel capacity at the reservoir or at control points for which the reservoir is being operated.

b. Releases are made equal to or less than the non-damaging channel capacity until the top of flood control pool is exceeded, then all excess floodwater is dumped if sufficient outlet capacity exists by Modified Puls routing.

c. The current release is never greater (or less) than the previous period's release plus (or minus) a percentage of the channel capacity at the damsite unless the top of flood pool is exceeded.

d. Releases are always equal to or greater than the minimum specified flow, if possible. Desired flows are released if the reservoir is above the buffer storage. Only required releases are made if the reservoir is in the buffer storage.

e. Releases are not made (as long as flood storage remains) which would contribute to flooding occurring at one or more specified downstream locations during a predetermined number of future periods except to satisfy minimum flow and rate of change of release criteria. The number of future periods is based on the number of downstream local flow forecast periods from input data.

f. Releases are made, where possible, to exactly fill the downstream channel (assuming local flow times a contingency) as long as no flooding will result during any of the fixed future periods.

TABLE A4-5.
OPERATION GOALS

Flood Control
1. Do not endanger the dam.
2. Do not contribute to downstream flooding.
3. Do not unnecessarily store water in the flood control pool.
4. Evacuate flood control storage as quickly as possible by filling downstream channel capacity.

Conservation
1. Maintain releases for all demands while in conservation pool.
2. Maintain reduced demands while in buffer pool.
3. Make no releases when below top of inactive pool.

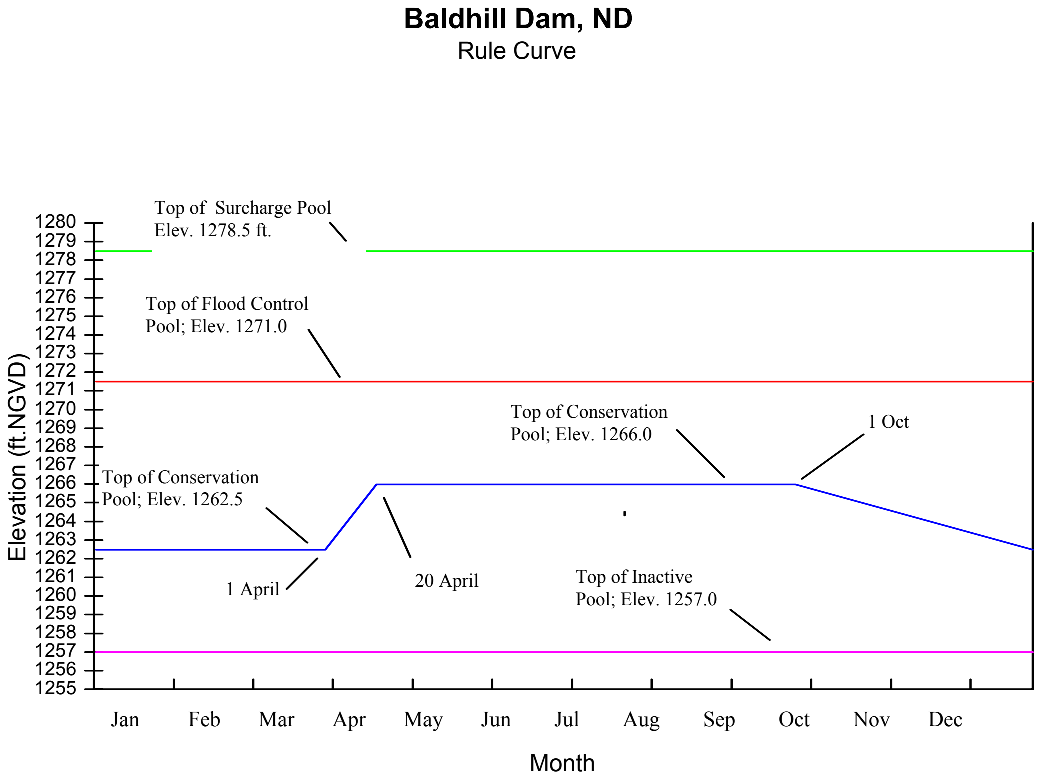
Simulation was made in conservation and flood control mode based on a daily time interval. Two reservoir operating plans were tested, designated Plan A and Plan B. **Table A4-6** shows specific reservoir information used in this study. **Figure A4-6** shows the Lake Ashtabula rule curve.

TABLE A4-6.
RESERVOIR INFORMATION

Reservoir Storage	Level	Summer Storage (ac.-ft.)	Summer Elev. (ft. NGVD 1929)	Spring Storage (ac.-ft.) Plan	Spring Elev. (ft. NGVD 1929) Plan
Top of Inactive Storage Pool	1	31,000	1257.00	31,000	1257.00
Top of Buffer Pool	2	32,600	1257.50	32,600	1257.50
Top of Conservation Pool	3	70,600	1266.00	52,250	1262.50
Top of Flood Control Pool	4	104,550	1271.50	104,550	1271.50
Top of Induced Surcharge Pool	5	157,500	1278.50	157,500	1278.50

Operating Criteria

Forecasting ability	2 days
Contingency in forecast	10 %
Maximum allowable rate of change in release	(0.0125)(channel capacity)



Baldhill Dam, ND
Rule Curve
Top of Surcharge Pool
Elev. 1278.5 ft.
Top of Flood Control
Pool; Elev. 1271.0
Top of Conservation
Pool; Elev. 1266.0
1 Oct
Top of Conservation
Pool; Elev. 1262.5
1 April
20 April
Top of Inactive
Pool; Elev. 1257.0
Elevation (ft.NGVD)
1280
1279
1278
1277
1276
1275
1274
1273
1272
1271
1270
1269
1268
1267
1266
1265
1264
1263
1262
1261
1260
1259
1258
1257
1256
1255
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

FIGURE A4-6

HEC-5 Conservation Operation

Conservation simulation was based on a daily time interval. **Table A4-7** shows the demands at specified control points that the reservoir was operated for. Monthly evaporation was not input into the reservoir simulation. Net evaporation was incorporated into the analysis in the calculation of inflows to the reservoir via "reverse routing." Therefore to have included evaporation in the reservoir scheme would have double accounted for this variable. Lake Ashtabula was operated for the Valley City control point with a minimum required flow of 13 cfs and minimum desired flow of 10 cfs.

Table A4-7.
Lake Ashtabula Conservation Data

Days	Month	Valley City Channel Capacity cfs	Minimum Desired Flow @ Valley City, cfs	Minimum Required Flow @ Valley City, cfs
31	Oct	2500	13	10
30	Nov	2500	13	10
31	Dec	2500	13	10
31	Jan	2500	13	10
28	Feb	2500	13	10
31	Mar	3000	13	10
30	Apr	3500	13	10
31	May	3500	13	10
30	Jun	2500	13	10
31	Jul	2500	13	10
31	Aug	2500	13	10
31	Sep	2500	13	10

HEC-5 Flood Control Operation

Baldhill Dam was operated for the downstream control point at Valley City with a channel capacity that varied between 2500 cfs and 3500 cfs as shown in **Table A4-7.** Above the top of flood control pool elevation 1266.20, the reservoir was programmed to make releases based on the induced surcharge envelope curve. Because the outlet's downstream water quality simulation interval is based on 1 day, the gate regulation feature was not used in the HEC-5 model. Releases based on the induced surcharge envelope curve were, therefore, input as maximum outlet capacity values on the HEC-5 model's RQ record.

The new emergency spillway has a crest elevation at 1271.0. This discharge capacity was added to the induced surcharge envelope curve flows in the RQ records.

Lake Ashtabula was longitudinally segmented into 16 volume elements to simulate the water quality dynamics of the reservoir. The segmentation was based on previous sediment range surveys conducted for the reservoir.

Routing

Routing for all reaches between control points was based on the Modified Puls method except for the reach between the HWY 30 and Peterson Coulee control points and Baldhill Dam and Valley City control points. These reaches had travel times that were less than the 1-day simulation time interval; therefore, a no route option was used. Modified Puls routing values were derived from water surface profile computer runs using HEC's River Analysis System (HEC-RAS; **reference 5**). Storage and corresponding outflow values for the reaches between control points were determined using a range of flow values in the RAS model. The number of routing steps (NSTPS) was determined by calculating the average velocity at channel capacity for each reach between control points. The average velocity was then multiplied by 1.3 to estimate the flood wave velocity. Dividing the total reach length by the flood wave velocity gives the flood wave travel time, and dividing the flood wave travel time by the 1-day simulation time interval and rounding yields the NSTPS.

DSS and input files

Vast amounts of data are conveniently handled by the HEC's Data Storage System (HECDSS). HECDSS is used to preprocess the data for input to HEC-5Q and to post-process the data from HEC-5Q for analysis. For each scenario, baseline (no pump) and pump (pumping allowed) options are modeled. The daily simulation results for each scenario are stored in DSS for each control point, which are: Cooperstown, four locations in Ashtabula Reservoir, Valley City, Kindred, the confluence of the Red and Sheyenne Rivers, Halstad, Grand Forks, Oslo, Drayton, and Emerson.

Meteorological Data

The HEC-5Q computer program requires the use of surface airways meteorological data to compute water surface heat exchange. Weather stations in this region which record surface airways data are Fargo, Bismarck, Minot, and Williston in North Dakota; International Falls and St. Cloud in Minnesota; and Aberdeen in South Dakota. The Fargo (Hector Field) station was chosen as being representative of the Sheyenne River and Red River of the North basins. The entire modeling area was treated as a single meteorological zone.

Hourly data for wind speed, sky cover, and dry bulb and dew point temperatures were obtained from a CD-ROM data base for the period January 1959 through October 1999. The CD-ROM data base and interface software is considerably refined from the raw data available from the National Climatic Data Center (NCDC). Use of the unrefined data is not recommended because of the high cost of processing it into a usable format. The data sets were created in 1-year increments to facilitate their use with the annual lake elevation traces provided by the USGS. The data had to be further manipulated to obtain the proper format for use with the HEC-5Q program. This was done with two proprietary computer programs (PRE and EQT) provided by RMA Engineering.

Using the 1971 to 1999 base period, the MET files were configured to be in the same sequence as the "tagged years" used in the incremental local flow file. The sequential years were determined by the USGS so that downstream conditions are in "phase" with hydro-meteorological conditions for Devils Lake.

Geometric and Hydraulic Data for Flow Simulation

Channel geometric and hydraulic data are needed to represent the physical characteristics of the river segments at and between control points. Characteristics for this study defined using HEC-5Q's S3 records are cross section location (nearest control point and river mile) and, for various river flow elevations, the flow, cross-sectional area, 2/3 power of the hydraulic radius, top width, and Manning's roughness coefficient.

The data were obtained from the output of the HEC-RAS water surface profile computer program. A special feature was added the program by HEC for this project to write output tables in S3 format. Cross section data for HEC-RAS input were imported from existing HEC-2 models for the Red River of the North and for the Sheyenne River from Kindred to the confluence with the Red River of the North. Cross section data for the Sheyenne River from Kindred upstream to the proposed insertion point were obtained by scanning (digitizing) plotted sections from Corps of Engineers surveys from 1940-1944. A recent channel capacity study by the North Dakota State Water Commission (**reference 6**) for several locations on the Sheyenne River upstream of Lake Ashtabula determined that the cross section data were not significantly different than more recent surveys. The Sheyenne River HEC-RAS model was run with 14 discharge values from 10 to 10,000 cubic feet per second (cfs). The Red River of the North HEC-RAS model was run with 15 discharge values from 50 to 100,000 cfs. Manning's roughness coefficients were adopted and/or estimated from the HEC-2 models.

Travel times used for routing parameters in the HEC-5Q model were also obtained from the HEC-RAS runs. Channel distance and channel velocity were used to compute travel times for approximate bank-full flows for the Sheyenne River and Red River of the North.

The input stream cross section file is called S3REV.DAT.

HEC-5Q Modeling Assumptions/Development

The water quality simulation module (HEC-5Q) was developed so that temperature and conservative and non-conservative water quality constituents could be readily included as a consideration in system planning and management. Using daily average historical and/or synthesized flows, HEC-5Q computes the distribution of temperature and other water quality constituents in the reservoirs and streams.

HEC-5Q can be used to simulate concentrations of various combinations of water quality constituents. Two sets of water quality parameters were evaluated as part of the Devil's Lake project and model development was accomplished in two phases. In the first phase the HEC-5Q model was developed to model the major ions as conservative substances. Routing of conservative substances represents the worst-case scenario, i.e., the environment is assumed not to assimilate or degrade any of the constituents.

Phase 1 modeling included the following constituents:

- Water Temperature
- Sulfate
- TDS
- Chloride
- Total Hardness
- Non-Carbonate Hardness
- Devils Lake tracer

Sulfate is modeled since it appears to be the limiting constituent for meeting water quality standards on the Sheyenne River. In addition, sulfate, TDS and chloride are modeled since they appear to be limiting constituents for meeting water quality standards on the Red River of the North and for meeting objectives at the US/Canada border. Total and non-carbonate hardness are modeled to evaluate the effect on downstream water treatment costs related to outlet operation. The Devils Lake tracer, a virtual dye, was used to determine the percentage of Devils Lake water present at any location due to outlet operation. The virtual dye output was useful for estimating water quality constituents that were not directly modeled including calcium, magnesium, sodium, and SAR (sodium adsorption ratio).

Phase 2 modeling was accomplished to investigate potential eutrophication effects in Lake Ashtabula and the increase in mass phosphorus transport downstream. Outlet operations would introduce a new source of phosphorus and nitrogen into the Sheyenne and Red Rivers potentially affecting the productivity and abundance of algae and aquatic plants in downstream environments. The HEC-5Q nutrient model is designed to estimate downstream ambient concentrations and loadings of phosphorus based on materials routing that includes hydraulic routing and general representation of the major physical and biological pathways that nutrients follow. The model is not intended to directly predict algal blooms or other nuisance aquatic plant problems since information on critical site specific and time variable conditions is not available. It can however provide valuable information if phosphorus is known or suspected of limiting plant or algal growth in the base condition. Parameters modeled in the Phase 2 model include:

- Temperature
- Conservative tracer / TDS
- Ammonia (NH_3) - Nitrogen
- Nitrate (NO_3) - Nitrogen
- Phosphate (PO_4) - Phosphorus
- Phytoplankton
- Dissolved oxygen
- Dissolved organic material (DOM)
- Particulate organic material (TSS)
- Benthic algae
- Chloride
- Alkalinity
- Total inorganic carbon, CO_2 and pH

With the exception of benthic algae, all of these parameters are assumed passively transported by advection and diffusion. All rate coefficients regulating the parameter kinetics are first order and temperature dependent. A brief description of the processes affecting each of these parameters is provided below. Refer to the HEC-5Q users manual (HEC, 2001a) for a more complete description of the water quality relationships of the model.

Temperature

The external heat sources and sinks that are considered in HEC-5Q are assumed to occur at the air-water interface and at the sediment-water interface. The method used to evaluate the net rate of heat transfer utilizes the concepts of equilibrium temperature and coefficient of surface heat exchange. The equilibrium temperature is defined as the water temperature at which the net rate of heat exchange between the water surface and the overlying atmosphere is zero. The coefficient of surface heat exchange is the rate at which the heat transfer process progresses. All heat transfer mechanisms, except short-wave solar radiation, are applied at the water surface. Short-wave radiation penetrates the water surface and may affect water temperatures several meters below the surface. The depth of penetration is a function of adsorption and scattering properties of the water as affected by particulate material (i.e. phytoplankton and suspended solids). The heat exchange with the bottom is a function of conductance and the heat capacity of the bottom sediment.

Conservative tracer / TDS

The conservative parameter is unaffected by decay, settling, etc. Mass continuity is confirmed by setting the quality of all inflows to a constant value and then checking to see that the simulation results do not deviate from that value. During calibration and alternative evaluation, the conservative parameter was TDS.

Ammonia – Nitrogen (NH_3)

Ammonia is a plant nutrient and is consumed with phytoplankton and benthic algae growth. The remaining ammonia sink is decay. Sources of ammonia include phytoplankton and benthic algae respiration, TSS and DOM decay, and aerobic and anaerobic release from bottom sediments.

Nitrate – Nitrogen (NO_3)

Nitrate is a plant nutrient and is consumed with phytoplankton and benthic algae growth. The remaining nitrate sink is denitrification associated with suboxic processes that occur at low dissolved oxygen levels. Decay of ammonia provides a source of nitrate (intermediate nitrite formation is considered rapid relative to the model time step and is included as a component of NO_3).

Phosphate – Phosphorus (PO_4)

Phosphorus is the third plant nutrient considered in the model and is consumed with phytoplankton and benthic algae growth. Phosphates tend to sorb to suspended solids and are subject to loss by settling. Sources of phosphorus include phytoplankton and benthic algae respiration, TSS and DOM decay and aerobic and anaerobic release from bottom sediments.

Carbon Dioxide – carbon (CO_2)

Carbon is the final plant nutrient considered in the model and is consumed with phytoplankton and benthic algae growth. Sources of carbon dioxide include phytoplankton and benthic algae respiration, TSS and DOM decay and aerobic and anaerobic release from bottom sediments. Exchange of CO_2 at the water surface is a function of the ambient and saturation concentrations and surface exchange (reaeration) rate that is determined by wind speed in reservoirs and hydraulic characteristics in streams. Carbon dioxide is a component of total inorganic carbon (TIC) and the CO_2 concentration is calculated as a function of alkalinity and pH. Refer to the alkalinity, TIC and pH section below for further details of the CO_2 computations.

Phytoplankton

Photosynthesis acts as a phytoplankton source that is dependent on the concentration of phosphate, ammonia, nitrate and carbon dioxide. Photosynthesis is therefore a sink for these nutrients. Conversely, phytoplankton respiration releases phosphate, ammonia and CO_2. Phytoplankton is an oxygen source during photosynthesis and an oxygen sink during respiration. Phytoplankton growth rates are a function of the limiting nutrient (or light) as determined by the Michaelis-Menten formulation. Respiration, settling and mortality are phytoplankton sinks.

Dissolved Oxygen (DO)

Exchange of dissolved oxygen at the water surface is a function of the ambient and saturation concentrations and surface exchange. Phytoplankton and benthic algae photosynthesis is a source of DO. Sinks for DO include ammonia, DOM, and TSS decay, phytoplankton and benthic algae respiration, and benthic uptake.

Dissolved and Particulate Organic Material (DOM and TSS)

Sources of DOM and TSS include a component of phytoplankton and benthic algae respiration and mortality. DOM and TSS sinks include decomposition to phosphate, ammonia and CO_2. TSS is also subject to settling. DOM is partitioned into labile and refractory components having different decay and transformation characteristics.

Inorganic Particulate Material

Inorganic particulate material is conservative except for settling and impacts light attenuation, affecting reservoir temperature, and phytoplankton and benthic algae growth.

Benthic Algae

Benthic algae biomass is not explicitly modeled, but is input as a spatially and temporally varying benthic algae standing crop. Growth of benthic algae produces DO, and consumes PO_4, NH_3, NO_3 and CO_2. Respiration mortality of benthic algae consumes DO, and releases PO_4, NH_3, CO_2, DOM, and TSS. Growth rate and related nutrient uptake rates are a function of ambient temperature and nutrient concentration.

Alkalinity, Total Inorganic Carbon (TIC) and pH

Alkalinity is considered conservative. Total inorganic carbon includes all components of the carbonate system including CO_2 (i.e., TIC = [CO2-C] + [CO3-C]). The sources and sinks are described in the CO_2 section. The component concentrations are computed according to equilibrium theory considering $CO3^{--}$, $HCO3^{-}$, CO2, OH^{--} and H^{+}. The pH reflects the molar H^{+}.

Model Schematic

A graphical depiction of the model is shown in **Figure A4-1**. Control points for the model are depicted by small red circles and identifying number. The control point names and identifying numbers are the Devils Lake outlet (999), Sheyenne River headwaters (1464), Peterson Coulee (insertion point, 1463), Warwick (1408), Cooperstown (1317), Upper Lake Ashtabula Reservoir (1303), Baldhill Dam (1271), Valley City (1253), Lisbon (1162), Kindred (1068), Fargo (representing the Red River of the North headwaters (453)), junction of the Sheyenne River and Red River of the North (428), Halstad (375), Grand Forks (296), Oslo (271), Drayton (207), and Emers9). The identifying numbers represent river mile (from the mouth of the river), with 1000 added to the Sheyenne River numbers to prevent confusion with similar numbers on the Red River of the North; the Devils Lake outlet and Emerson identifying numbers, 999 and 99 respectively, are "dummy values" with no physical significance.

In **Figure A4-1**, a series of volume elements, depicted by the small rectangles, connect the control points in the model. The clear rectangles represent stream elements, and the shaded rectangles represent reservoirs. Three dummy reservoirs (Devils Lake outlet -- 999, Sheyenne River headwaters -- 1464, and Red River of the North headwaters -- 453) are used to satisfy HEC-5 model requirements. Lake Ashtabula, between control points 1303 and 1271, is the only actual reservoir represented in the system.

Lake Ashtabula is treated as a layered and longitudinally segmented reservoir. Flow velocities are assumed uniform over depth and parallel to the direction of flow in each layer. Mass transport between vertical layers in the reservoir is represented by diffusion. Vertical stratification is affected by chemical (TDS) and temperature related density functions. The reservoir consists of 16 longitudinal segments with each longitudinal segment represented by 10 vertical layers. Vertical layer thickness is determined by a factor times the area of the cross section. Each element is assumed to be fully mixed in the lateral direction. Corps of Engineers monitoring data indicates that intermittent stratification occurs in the lower segment of the reservoir.

Phase 1 daily water quality and flow data for the Sheyenne River headwaters and Devils Lake outlet were developed by the USGS. Constituents include sulfate, TDS, total hardness, non-carbonate hardness, and chloride. Data development methods are described in **Reference 1**. For the Sheyenne River headwaters, sulfate was related to flow magnitude and Julian date (to account for seasonal variations) and the other constituent concentrations (TDS, total and non-carbonate hardness, and chloride) were related to the sulfate concentrations using proportionality equations with a seasonal cycle. Sulfate concentrations at the Devils Lake outlet were determined for each trace using the 5-box model, and the other Devils Lake water quality constituents were related to the Devils Lake sulfate concentration using proportionality equations appropriate for Devils Lake water.

All tributary loadings in the conservative model, with the exception of the Sheyenne River Headwaters and Devils Lake Outlet, are computed using mean monthly constituent concentration for the tributary (tributary concentration varies by month, not by flow). The Corps developed mean monthly tributary data where they were available for tributaries to the Sheyenne River and Red River of the North below Warwick.

In the phase 2 (nutrient model) the nutrient loadings were computed based available information. Generally there was much less data available on nutrients than on parameters such as TDS and sulfate, making calibration and modeling more difficult. Daily flow data developed by the USGS for Devils Lake pumping and the Sheyenne River Headwaters was utilized from the phase 1 model. Nutrient concentrations were loaded as mean monthly or constant values except for temperature, algae, dissolved oxygen, and suspended material that were computed from various general relationships.

Lake Ashtabula is operated as a water supply and flood control reservoir. Releases are made according to the current rule curve. Lake Ashtabula's operation is not altered to meet water quality objectives below the dam.

The majority of the time Lake Ashtabula is well mixed. Intermittent stratification does occur however in the lower end of the reservoir during favorable climatic conditions (high air temperatures, calm winds). Since stratification is intermittent, no gate or wet well operations are used to meet water quality objectives downstream.

Ice Cover

In 2001 the 5Q model was revised to simulate the effects of ice cover. Ice cover is considered important because ice growth and melting and significantly influence the mass routing of dissolved solids. Specifically, the ice algorithm was added to HEC-5Q to account for the freeze-fractionation of water during ice formation and dilution during the spring thaw. Specific ice formation schedules were developed for Lake Ashtabula, the Red River from Fargo to Grand Forks, and the Red River from Grand Forks to Emerson. On Lake Ashtabula, 1985 thru 2000 Project ice thickness database records were used to compute average ice thicknesses and the corresponding dates of occurrence (Reference http://www.mvp-wc.usace.army.mil/projects/Baldhill.shtml). River ice thickness schedules were developed from the 1990 thru 2000 Corps St Paul District Ice Reconnaissance Team database. The database did not include ice on and off dates so these were estimated through consultation with Corps project staff and professional judgment. The ice routine was not utilized on the Sheyenne River due to channel geometry, winter flow characteristics, and tributary loading assumptions. Calibration data indicate the Sheyenne River was representative of winter conditions without the ice algorithm. Average ice conditions were deemed an appropriate level of detail for the purpose of this model. For investigation of non-typical years the user can specify ice thickness using a calendar date format for each year modeled. **Table A4-8** shows ice development and degradation schedules utilized in the model.

Table A4-8
Ice Thickness Schedule

	Ice Thickness (inches)			
Julian Day	Lake Ashtabula	Julian Day	Red River (Fargo to Grand Forks)	Red River (Grand Forks to Emerson)
0	17.0	1	12	14
4	18.8	15	16	18

14	21.5	35	18	21
24	24.0	50	21	24
34	25.8	65	18	21
44	26.5	85	10	12
54	26.3	95	0	0
64	25.0	320	0	0
74	22.3	366	12	14
84	18.5			
94	13.0			
104	5.5			
114	0			
320	0			
330	3.5			
340	8.0			
350	11.8			
360	15.2			
366	17.0			

Reservoirs

All of the reservoirs (except Lake Ashtabula) are modeled as longitudinally segmented reservoirs. The reservoirs are assumed to be well mixed in the vertical direction and vary only longitudinally. Three dummy reservoirs are used in the model to satisfy HEC-5 and HEC-5Q model requirements. The dummy reservoirs are the Sheyenne River headwaters, Devils Lake[1], and Red River of the North Headwaters. These are all operated as constant volume reservoirs and essentially are inflow points to the system.

Initial Reservoir Conditions

Initial water quality conditions in the three dummy reservoirs (Sheyenne River headwaters, Devils Lake, and Red River of the North headwaters) and Lake Ashtabula are relatively unimportant. HEC-5Q model runs have an extended (>1year) baseline startup period prior to the initial pumping event. This allows all the dummy reservoirs (which have minimum volumes) and Lake Ashtabula to stabilize or set up prior to operation of the proposed Devils Lake outlet. Initial conditions in Ashtabula were set at fall 1997 levels at four locations in the reservoir where the Corps and North Dakota Department of Health conduct water quality sampling.

[1] The Devils Lake Dummy Reservoir represents inflow for pumped Devils Lake water into the Sheyenne River system. It does not represent the actual lake, only the flow and water quality of water pumped from Devils Lake into the Sheyenne River. Flow and water quality in Devils Lake are determined using the USGS 5-box model.

Tributary Loadings/Concentrations

HEC-5Q tributary water quality data is stored in a separate data file allowing the input of water temperature and quality data. The tributary data file specifies coefficients to be used in water temperature computations, DSS pathnames storing daily tributary water quality data, or other relationships that define an inflow water quality data record for each constituent modeled. The data record, or collection of data records and/or relationships developed describing how a tributaries water temperature and constituent concentrations vary over time is called a "tributary water quality type" and is assigned a tributary type number (TT1, TT2, etc.). Once a tributary type is defined it can be used to describe the water quality of any tributary inflow point in the model assuming that tributary has a similar water quality relationships as the development tributary.

For the Phase 1 Devils Lake model, a tributary water quality type identifies a relationship or record of tributary water temperature and constituent concentrations (Devils Lake tracer, TDS, sulfate, total and non-carbonate hardness, chloride) that can be assigned to any tributary or inflow identified in the system. Individual tributary water quality relationships were initially determined by identifying the major tributaries to the Sheyenne River and Red River of the North. The EPA STORET database was searched to determine tributaries with adequate water quality records for data development. Initially, thirteen individual tributary water quality datasets were identified. Water temperature and constituent relationships were developed for each of these datasets and assigned as tributary types 1 through 13. In addition 2 tributary types were added to describe groundwater sources in the model and identified as tributary types 14 and 15 (TT14 and TT15).

The USGS developed daily water quality data for the Sheyenne River headwaters and the Devils Lake outlet for the phase 1 constituents modeled, with the exception of water temperature. (Reference 1) The daily data sets were read into DSS files and referenced in the tributary data file as tributary water quality types 1 and 2 (TT1 and TT2) respectively. The Corps developed the water temperature relationships for the data set using a procedure described below. The Corps developed 13 additional tributary water quality types to depict tributary inflow water quality to the Sheyenne and Red Rivers of the North. Tributary water quality types included Red River of the North headwaters (TT3), Red Lake River (TT4), Baldhill Creek (TT5), combined North Dakota tributaries to the Red River of the North (TT6), Park River (TT7), Tongue River (TT8), Pembina River (TT9), Forest River (TT10), combined Minnesota tributaries to the Red River of the North (TT11), Warwick local tributaries (TT12), and Cooperstown local tributaries (TT13), local groundwater contribution between Drayton and Emerson (TT14), and local groundwater contribution between Valley City and Lisbon (TT15).

In defining tributary water quality, the Corps explored both flow and seasonal relationships with constituent concentrations. Monthly relationships appeared stronger than flow relationships based on graphical inspection of the data. Flow relationships proved to be very weak unless seasonal data stratification was employed. At the time of development, a combined seasonal/flow relationship was not practical for the model. Mean monthly tributary constituent concentrations were developed and adopted to describe tributary water quality types 3 thru 11.

Water Quality types 14 and 15 were determined during the calibration procedure. During calibration runs, inspection of the low flow data indicated a source of high salinity inflow near Lisbon and between Drayton and Emerson. These sources have been referenced in other publications (Upham 1895, Minnesota Pollution Control Agency 1997, Cowdery 1998).

There were no defined tributaries between Peterson Coulee (the insertion point) and Warwick and between Warwick and Cooperstown. The USGS based their Sheyenne River Headwaters water quality relationships on the Warwick water quality and flow records. Therefore, inflow quality between Peterson Coulee and Warwick was assumed mimic the quality of the Sheyenne River headwaters developed by the USGS and was assigned a daily inflow quality type TT1. Incremental loading between Warwick and Cooperstown (Cooperstown local tributaries - TT13) was determined using a historic mass-balance relationship of flow and water quality records between Warwick and Cooperstown. Mean monthly flows and concentrations were used to compute the mass balance for the reach. The computed incremental inflow concentrations were assumed to be the mean monthly inflow concentrations to the reach.

Mass balance flow/concentration relationships were explored for other reaches of the rivers in an attempt to more accurately describe the net incremental inflow loadings for specific reaches. The results were not favorable, and negative loading values often occurred during low flow periods. Evaporation, water withdrawals from the river, groundwater dynamics, and water quality and flow record compatibility may have affected the relationships. Therefore, tributary water quality is described by mean monthly constituent concentrations developed from USGS STORET water quality records were adopted for the model.

Daily water quality records were developed for the Sheyenne River headwaters upstream of the insertion point (TT1) and Devils Lake outflow constituent concentrations (TT2) by the USGS. The methods for water quality constituent concentrations and flows (Sheyenne River headwaters and Devils Lake releases) are covered in **Reference 1**.

Tributary inflow temperatures are determined using linear regression equations for each of the tributary water quality types. The regression relationship takes the form T = To + k * Tx where Tx is the equilibrium temperature, To is the intercept, and k is the slope. Intercept and slope coefficients were optimized by calibrating to tributaries with existing temperature data. A trial and error process was used to identify the best fit and a depth (RTO) variable was added to smooth daily variations. Minimum and maximum temperatures were set at 0 and 32 degrees Celsius. Temperature calibrations were completed for Baldhill Creek, Buffalo River, Red River at Fargo, Red Lake River, Maple River, and the Wild Rice River. Tributaries with insufficient data for meaningful calibrations adopted the coefficients from a similar calibrated tributary.

The nutrient model (phase 2) adopted the existing tributary water quality types used in the phase 1 model and added two additional loading sources. The two additional loading sources (Tributary Types 16 and 17) represent wastewater and industrial releases. These loading sources were added to account for loadings that were evident in the main stem data but not evident in the tributary data. Wastewater release information obtained from both Minnesota and North Dakota supports the loading assumptions.

Phase 1 conservative parameters were replaced with nutrient data in phase 2 modeling. The nutrient concentrations were computed from available USGS and North Dakota Department of Health data. Phosphorus concentrations were loaded as mean monthly concentrations. Nitrate, ammonia, dissolved organic matter (DOM1 & DOM2), alkalinity, pH, and the tracer were loaded as constant values. Generally the constant values were near the median or mean of the data available for a particular parameter. If data were not available, professional judgment was used to estimate a proper value. Temperature was computed using the linear regression relationship. Algae and DO concentrations were computed using harmonic curve fits. The loading analysis was much simpler than in phase 1 due to the scarcity of large nutrient datasets.

Unlike the "conservative" or phase 1 model, water quality in Devils Lake was not modeled. For the purpose of loading the HEC-5Q nutrient model, Devils Lake nutrient concentrations were assumed constant. Respective concentrations for phosphorus, nitrate, and ammonia concentrations representing the Devils Lake input to the model were 0.29 mg/l, 0.045 mg/l, and 0.04 mg/l respectively, and are assumed to represent the entire lake. Devils Lake water quality was determined using historic data provided by the North Dakota Department of Health. Although some spatial and temporal variability was noted, differences can be associated to the winter season (during non-pumping periods) or natural variability in nutrient cycles within Devils Lake that may or may not have been captured by the sampling activities. Generally, the differences in the median concentrations indicated only small variations in water quality that could be negated by tributary loading assumptions used in the HEC-5Q model.

In the nutrient model, phosphorus loadings were based on mean monthly concentrations from the Sheyenne River at Cooperstown, Baldhill Creek, Red River below Fargo, Red Lake River, Beaver Creek near Finley, and the Pembina River. Mean monthly concentrations developed for these tributaries were then applied to tributaries assumed to have similar quality. Late fall and winter phosphorus concentrations were scarce in most data records, so smoothing of the concentrations was done in an attempt to best represent typical concentrations during the time period.

Nitrate, ammonia, labile and refractory organic material, alkalinity, and pH concentrations were assumed constant throughout the year, but varied somewhat from tributary to tributary. In many cases typical concentrations were adopted to represent tributary concentrations. Minor tributary concentration adjustments were made during the calibration procedure to reproduce a general pattern of response based on main stem monitoring data.

Tributary concentrations for algae and dissolved oxygen were assumed to vary harmonically over the year. The same relationship was used for all tributaries (ie. Concentrations were the same for all tributaries) with the exception of the Devils Lake contribution. Algae were assumed to vary seasonally from Devils Lake and represents concentrations typical of a lake situation. Pumped flows from Devils Lake were assumed to be oxygen deficient, simulating a worst-case condition in which a standing algal crop dies off and exerts a high oxygen demand on the stream. Recovery of dissolved oxygen is apparent in the model output.

Tributary loading of the suspended material components are defined as a function of the local incremental inflow, increasing as flow increases. The slope defined in the equation was adjusted slightly to represent different tributary properties. The relationship was applied generally and was not calibrated to specific tributaries. Loading of material from Devils Lake was assumed constant throughout the year regardless of the flow. The specific relationships used are shown in the example HEC-5Q data set contained in **Exhibit A**.

Except for temperature, Groundwater and local contributions of nutrients representing the wastewater and industrial dischargers (TT16 & 17) were assumed to be constant throughout the year. The concentrations used were based on a general calibration of the model to main stem water quality patterns and supported by permitted discharge data provided by both the Minnesota Pollution Control Agency and North Dakota Department of Health.

Exhibit A contains an example of both a phase 1 and phase 2 HEC-5Q and tributary water quality input data files. Specifically the SI cards in the HEC-5Q input file indicate the distribution of tributary types for each stream reach and the associated tributary water quality file describes the parameter concentration for each tributary type called by an SI card. As mentioned previously, the distribution of tributary types was not altered for the phase 2 modeling, however 2 additional nutrient sources were added to account for wastewater and industrial loadings not captured in the historic tributary data. Please refer to **Reference 10** for further information on input data structure.

Tributary Placement

Tributaries were placed at the river mile where they entered either a reservoir or river. In cases where there were no defined tributaries in a reach, the inflows were assumed to occur near mid-reach. In one instance, two tributaries entered a reach in the same element. This is not allowed in HEC-5Q. To avoid this, the tributaries were combined and modeled as a single tributary to the element. Flow contributions for each tributary were determined based on the incremental percentage of drainage area represented by the individual tributary for the reach. The remaining drainage area (unaccounted-for drainage area) was divided between the tributaries in the reach. This unaccounted-for drainage area was later reassigned in some reaches during the calibration procedure.

Tributary Water Quality Type Selection

Fifteen tributary water quality types were developed to describe all inflow water quality to the Sheyenne River and Red River of the North. All inflows (tributary, local, unaccounted-for inflows, groundwater) are modeled as tributaries and are represented by one of the tributary water quality types. Inflows assigned a tributary water quality type maintain the same water quality type for the duration of the model simulation (the same inflow location cannot switch water quality types during the simulation). Selection of the water quality type assigned to each tributary was a function of tributary location, 1996 spreadsheet model constituent loading assignments, and an iterative calibration procedure. Originally, tributaries with water quality data were assigned the water quality type (a mean monthly water quality record) that was developed based on the data record. If no water quality type was developed for a tributary or inflow, one was assigned based on subbasin characteristics and proximity to the nearest developed water quality type. Inflows on the Sheyenne River between Cooperstown and Kindred were assigned the tributary water quality of Baldhill Creek (TT5), the same convention used in the 1996 spreadsheet model.

The goal of the calibration procedure was to effectively model the general tendencies in the historic water quality records along the Sheyenne and Red Rivers. To check the initial water quality type assignments, the model was run for the historic period January 1971 to January 1996. Simulated results were compared to historic water quality records to determine if the tributary water quality type assignments were adequately representing constituent loadings to the rivers. Tributary water quality type assignments were reviewed and reassigned in reaches where divergences between the simulated and historic records occurred. Water quality types for the major tributaries such as the Red River of the North headwaters and Red Lake River were not altered. The initial tributary water quality types assigned below Kindred did not appear to account for the water quality associated with unaccounted-for drainage areas and groundwater inputs. The iterative process of assigning a water quality type through the calibration process allowed the assignment of a water quality type representative of the entire inflow to a reach. In 2000 several upgrades to the model were made and the calibration process was revisited. The historic record for the recalibration was extended through October 1999. Two groundwater sources of high TDS water were added during this iteration to account TDS increases near Lisbon and Emerson during low flow periods. An ice cover algorithm was also utilized on Lake Ashtabula and the Red River to account for the freeze-fractionation of dissolved salts during the winter. Ice effects on the Sheyenne River were not included due to tributary loading assumptions and channel morphometry. Final tributary water quality assignments are shown in **Table A4-9** and are contained in the example HEC-5Q input file as shown in **Exhibit A**.

The tributary water quality assignments developed during phase 1 modeling were adopted for use in the phase 2 (nutrient) modeling. The parameters modeled and their respective concentrations were changed, but the relative contribution from each tributary type remained the same. The amount and temporal distribution of nutrient data available for developing tributary water quality records was much less than the records used in phase 1 tributary water quality type selection, reducing the actual number of tributary types used in the model (ie. 17 tributary types are listed but several exhibit the same quality records). Due to the lack of data, many tributary types in phase 2 were identical in quality since their quality was based on the same nutrient data record.

Calibration Procedure

Conservative Model (Phase 1)

The Phase 1 HEC-5Q model was calibrated using historical water quality data sets at Cooperstown, below Baldhill Dam, and Kindred on the Sheyenne River and Halstad, Grand Forks, and Emerson on the Red River of the North. Historical medians and percentile concentrations were developed for each station. The model was run for the historic period 1971 thru 1999 and statistics were developed for the output data. The USGS supplied daily sulfate concentrations and flows for the Sheyenne River headwaters for the historical record. TDS, total hardness, non-carbonate hardness, and chloride were related to the sulfate concentrations by regression equations developed by the USGS.

Several factors affected the calibration procedure. The Red River of the North headwaters were represented by mean monthly tributary concentrations. The quality of the Red River of the North headwaters can vary widely due to Corps of Engineers reservoir operations and local runoff from different parts of the basin. Two Corps reservoirs (Lake Traverse and Orwell) are located in the Red River of the North headwaters. These reservoirs (and their watersheds) have substantially different water quality associated with them, and their operations can have substantial effects on downstream water quality for short periods of time. Calibration to individual data records or short-term events would require the Red River of the North headwaters reservoir operations be modeled. This modeling was not done due to time and data constraints; instead, Red River of the North headwaters water quality is represented by mean monthly concentrations, with calibration done to reasonably match the range and median of long-term records.

The historic water quality data used for calibration are from long-term USGS monitoring stations (Cooperstown, ND; below Baldhill Dam, ND; Kindred, ND; Halstad, MN; Grand Forks, ND; and Emerson, Manitoba) and downloaded from STORET. The different stations have different lengths of record and somewhat different sample scheduling. Sampling was generally 4 to 5 times per year. At some of the stations, sampling activity was greater during high flow periods rather than evenly over time, skewing the record toward lower concentrations.

Unaccounted-for drainage areas and groundwater inflows along the Red River of the North did not have associated water quality. Water quality for these areas was originally assumed to be similar to the tributaries in the reach. In actuality, the unaccounted-for drainage areas and groundwater may reflect areas that contribute intermittently (i.e., during large events or extended wet periods) and have runoff and drainage area characteristics that generate water quality dissimilar to the tributaries.

Calibration of the model was an iterative process. Calibration was mainly based on TDS and sulfate. Calibration was limited to varying the tributary water quality types and flow distribution. No adjustments were required in the Upper Sheyenne River, as the selected tributary water quality types appear to mimic historical medians and ranges. Tributary water quality types along the Red River of the North and unaccounted-for drainage area flow distributions were exchanged until acceptable matches of historical medians at Halstad, Grand Forks, and Emerson were achieved. Calibration began with the Halstad station and proceeded downstream. **Table A4-9** illustrates the final tributary water quality type assignments for each reach. **Table A4-10** compares the minimum, maximum, 10th, 50th and 90th percentiles of the simulated dataset (calibrated) to the historical data record.

The use of mean monthly water quality inflow concentrations limits or "smooths" the resulting data record created by model simulation. This smoothing effect increases as you progress downstream and more tributaries contribute loadings to the rivers. The largest such effect occurs at the confluence of the Sheyenne River and Red River of the North. The historical averaging smooths out the effect of reservoir operations in the Red River of the North headwaters. This is especially apparent when reviewing the historical data at the first water quality station below the confluence of the Sheyenne River and Red River of the North at Halstad. Removing several years of data from the Halstad record results in sizeable increase in median TDS and sulfate values. The opposite is true at Grand Forks where the deletion of several years of data results in essentially no change in the historic median. The use of mean monthly inflow concentrations limits the simulated concentrations to a range smaller than the historical record range. Historical maximum and minimum concentrations are not expected to be reflected in the simulated results, only a general range.

The HEC-5Q model was calibrated for TDS and sulfate by adjusting tributary water quality types and unaccounted-for flow distributions. No attempt was made to calibrate for total and non-carbonate hardness or for chloride, although comparisons of the simulated datasets to historical data records were made to ensure reasonableness. The results are shown in **Table A4-10**. Since all parameters are related proportionally to TDS, they are effectively calibrated by calibrating to TDS. Historical data records were much smaller for total and non-carbonate hardness than for TDS and sulfate. In addition, chloride levels are not limiting as far as meeting water quality standards is concerned.

The following paragraphs describe the results of the calibration procedure. All the conservative parameters are proportional to TDS, therefore only the plots of the TDS calibration are provided. Sulfate and other conservative constituent plots revealed similar patterns and are not included for brevity. Non-graphical summary information on calibration results for sulfate, total hardness, non-carbonate hardness, and chloride for each calibration point is included in **Table A4-10**.

No calibration was required above Kindred on the Sheyenne River. The historical TDS median at Cooperstown was higher than the simulated median, but considered acceptable; the sulfate medians were very close. Graphical representation of historical and simulated TDS at Cooperstown revealed that the historical and simulated ranges were similar and very large (See **Figure A4-7**). Differences between simulated and historical TDS medians may have been partially introduced by using mean monthly concentrations for local inflow or possibly due to the Sheyenne River headwaters water quality records being based on sulfate concentrations.

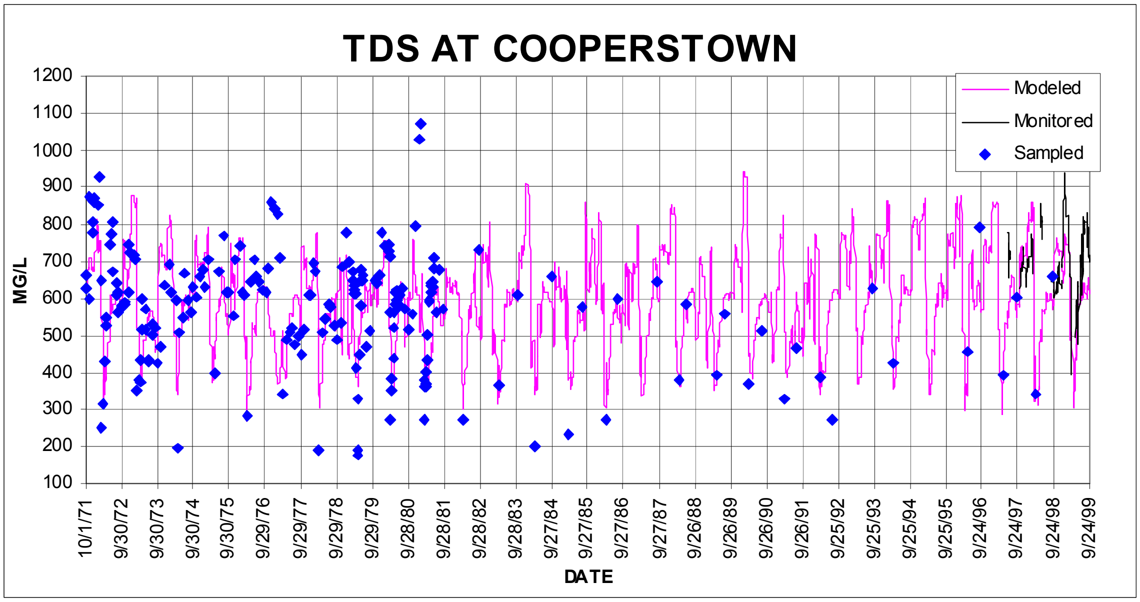


Figure A4-7

The next calibration point was below Baldhill Dam/Valley City. The historic water quality data record is available just below the dam, while model output is at Valley City, approximately 17.5 miles downstream. The distance between the stations is short enough that additional model output was deemed unnecessary for calibration and reporting model results. Comparison of the historic and simulated TDS and sulfate appear reasonable based on model assumptions. Chloride values also appear very close at this site. Hardness values differ and could be affected by historic data availability and/or chemical and biological interactions within the reservoir.

Lisbon was not a defined calibration point, however it was noted that TDS levels were below the historic record, especially during low flow periods. Review of the literature indicated a potential groundwater source of high TDS flow near this location (Upham 1895, Minnesota Pollution Control Agency 1997, Cowdery 1998). A distributed non-point source of high TDS water was added to the model between Valley City and Lisbon to account for higher TDS levels during low flow periods at Lisbon.

Kindred is the third calibration point. The median and range of simulated TDS and sulfate are very close to the historical record. Total hardness appears to be good; however, the simulated chloride and non-carbonate hardness tend to be lower than the historical record. This may be due in part to groundwater effects in the area that may not have been addressed by the tributary loading assumptions. **Figure A4-8** shows the simulated results compared to the historical data.

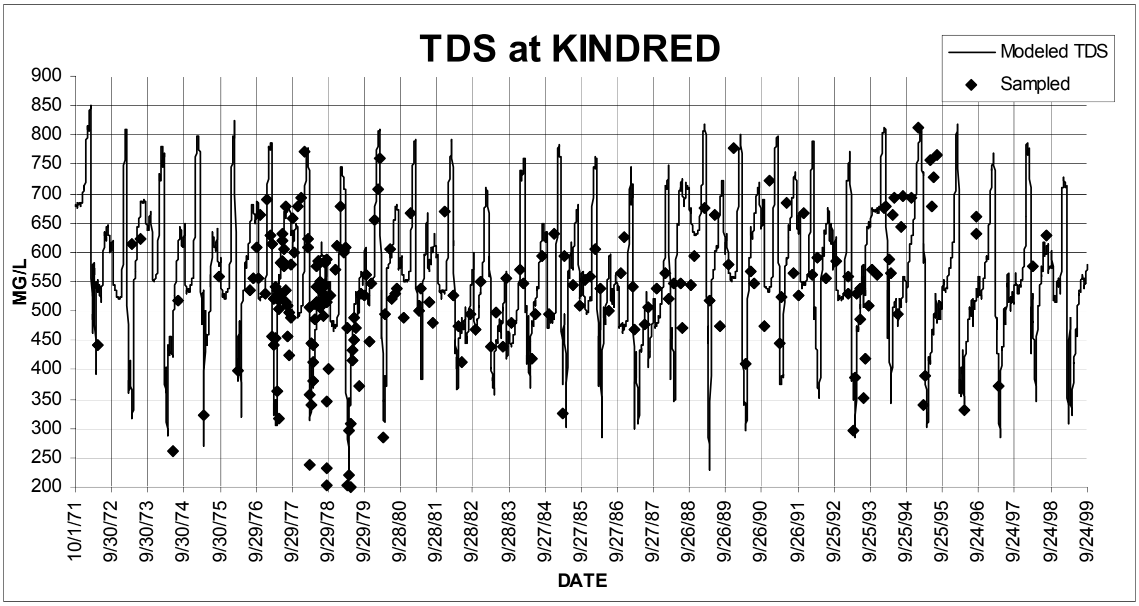


Figure A4-8

The historic and simulated records at Halstad tend to underestimate the historical TDS and sulfate concentrations. **Table A4-10** also indicates a reduction in the simulated range for TDS and sulfate. Differences between the historic and simulated record at Halstad are believed to be an effect of utilizing mean monthly average concentrations for the Red River of the North headwater's inflows. Chloride, total hardness, and non-carbonate hardness all appear to be reasonable at Halstad. The modeled vs. historic data records for TDS at Halstad are shown in **Figure A4-9**.

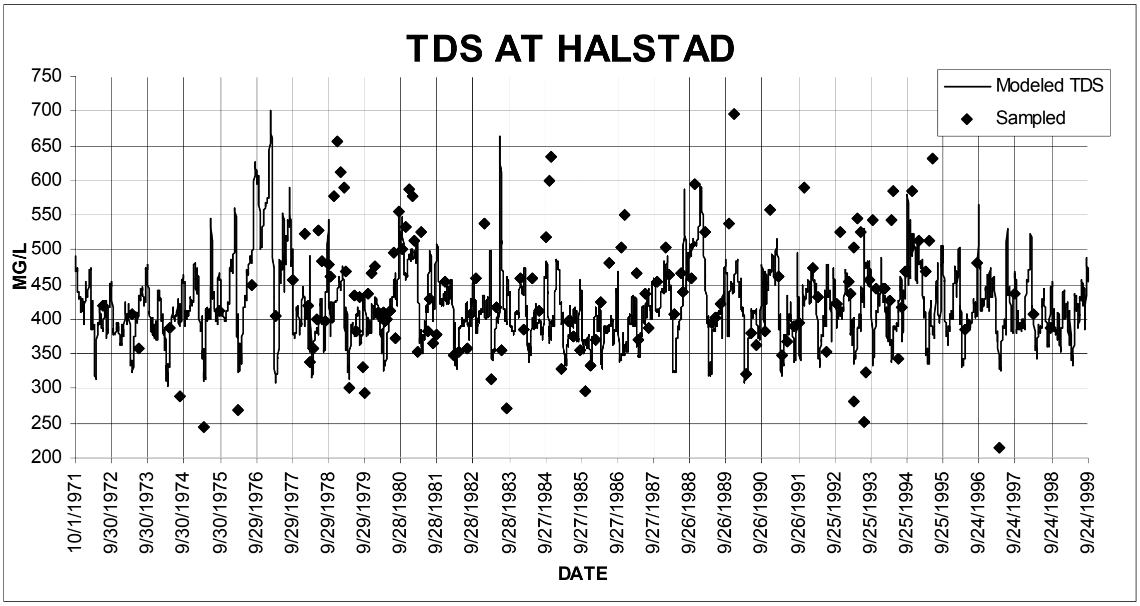


Figure A4-9

Simulated results at Grand Forks slightly overestimate the historical TDS median but essentially match the sulfate median. The ranges, though reduced in the simulated data, appear reasonable based on model assumptions. The simulated chloride and total and non-carbonate hardness values appear reasonable based on the historical record.

The final calibration site is Emerson. The simulated sulfate record appears reasonable compared to the historic record. Originally, simulated TDS appeared to be much lower than the historic record. This may be due in part to unaccounted-for groundwater inflow quality, the representativeness of the historical record, and/or the effect of using mean monthly inflow concentrations. The simulated range appears to miss the higher values for all parameters at Emerson, suggesting an unaccounted-for loading source during low flows, or the effect of averaging inflow concentrations. This was especially apparent in the TDS results. To account for the low flow discrepancies a non-point distributed groundwater source between Drayton and Emerson was added to the model and ice effects were incorporated into the model. With the changes the simulation reasonably mimics historic patterns and trends and is adequate for predicting the relative effects of Devils Lake releases on the Sheyenne River and Red River of the North. **Figure A4-10** shows the measured TDS and the simulated TDS at Emerson.

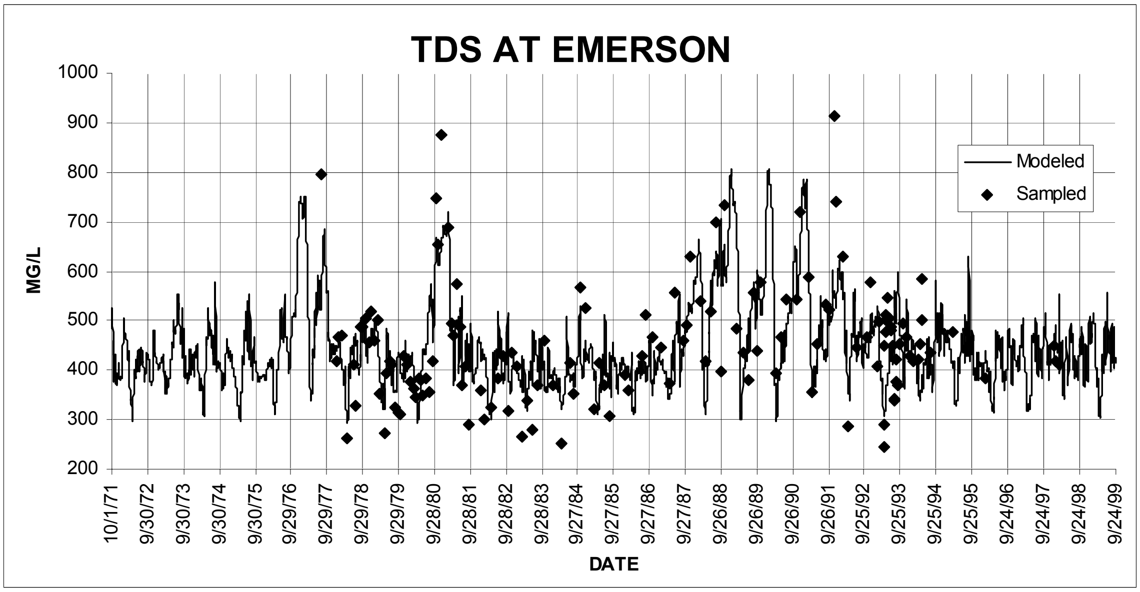


Figure A4-10

Calibration of the model indicates that for the years 1971 thru 1999 a reasonable range of data can be reproduced at each of the calibration sites. Matching extreme high and low values is not possible based on the model assumptions incorporated in the data development process. The model does reasonably predict relative effects on Sheyenne River and Red River of the North sulfate, TDS, total hardness, non-carbonate hardness, and chloride due to the operation of the proposed Devils Lake outlet.

Nutrient Model (Phase 2)

Data availability and loading assumptions limited the amount of calibration possible in the nutrient model. The loading assumptions limited or "smoothed" the resulting data record created by model simulation. This is the same effect described in the conservative model, however concentrations are smoothed to a greater extent since data is generally loaded at a constant or seasonally varying concentration rather than a daily concentration. In addition, available data records were from different time periods, collected at different frequencies, or collected for different reasons. Data was grouped and assumed to be representative of a typical condition. The calibration effort was aimed at mimicking general patterns observed in the data and not necessarily matching the concentrations.

A consideration associated with the loading assumptions was missing the first flush effect. Often significant loadings are realized in these instances. The generalized loading scheme used misses these occurrences. Often these first flush effects can have greater impacts after a series of dry years or be less apparent following wet periods. Therefore, effects due to first flush loadings are not realized in the model output and can bias model output during specific loading events.

Another consideration is the ability of the HEC-5Q to model different algal communities and associated processes. The model used allows for one set of reaction rates thereby specifying a "general" or specific response related to the adopted rate coefficients. The model does not allow for use of secondary rates or an algal community that would be present during winter conditions. Therefore, the model used prioritizes summer time algal species at the expense of early spring, late fall, and winter species. Wintertime algal and associated nutrient reservoir dynamics in Lake Ashtabula are not modeled effectively in this case. Winter effects on the reservoir would require additional data and modeling. The downstream effect of this limitation is thought to be minimal in terms of annual loadings.

Mr. Don Smith of RMA, Inc. completed the initial phase 2 calibration for the model. The model was calibrated in a general nature to data provided by the Corps of Engineers, MPCA, USGS, and NDHD. Mr. Smith set rate coefficients for the various processes in the model to mimic typical conditions in Lake Ashtabula, the Sheyenne River, and the Red River of the North. Once these were set the model was run to check calibrations against available data sets.

Lake Ashtabula was calibrated to the 1994-1999 North Dakota Department of Health and Corps of Engineers datasets. The effort concentrated on mimicking temperature profiles and general nutrient levels present in the reservoir during the period. An adjustment doubling wind speed and halving the diffusion coefficient was required to increase the responsiveness of the model to meteorological conditions and thermal cooling in the fall. The resulting model closely mimicked the available monitoring data. Nutrient data was calibrated in a general nature to best fit the monitoring data available.

Comparison of historic data to simulated data was accomplished by comparing the HEC-5Q GUI output to observed data at Lake Ashtabula monitoring stations A1 (near dam in old channel), A1A (in front of dam outlet), A2, A4, and A7. This proved an effective method for comparing simulated to historic data, however it did not provide a direct method for preparing combined plots of the in-reservoir data. Both the GUI and historic data is available upon request as the combined simulated vs observed plots of in-reservoir data were not prepared for this report. Comparison of the simulated to observed data indicate the general patterns observed in historic reservoir DO and temperature data were effectively simulated using the HEC-5Q model. Algal and nutrient levels were also reviewed to ensure that reasonable estimates were produced. Again, the simulated results produces were to represent general conditions and not to reproduce specific algal blooms that may occur.

Graphical output was produced for Station A1A and is compared to the simulated outflow from the outlet. The nutrient profiles were averaged to produce a single comparison to the simulated outlet concentration. **Figure A4-11** shows the period 1996 through 1999 for average total phosphorus at station A1A compared to the simulated outlet concentration.

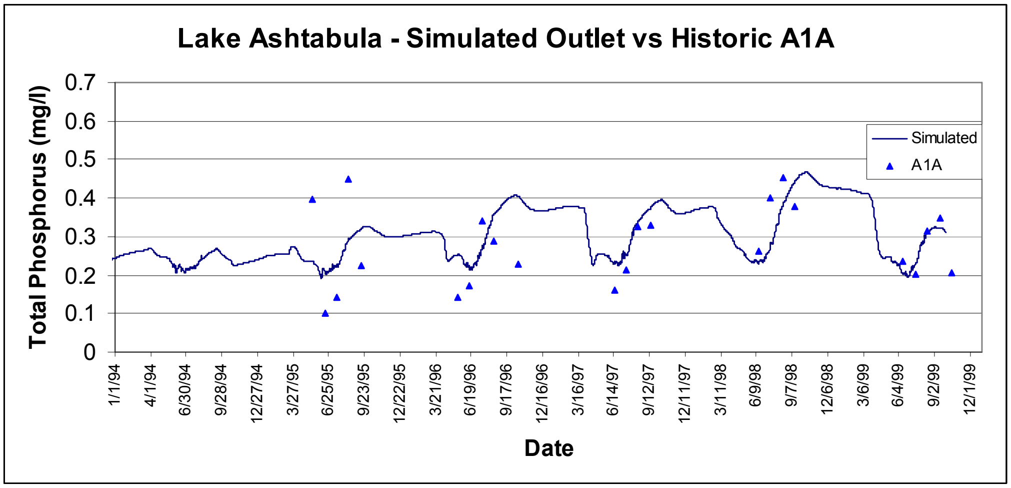


Figure A4-11

Stream segments of the model were also calibrated to mimic general patterns (seasonal) seen in the Sheyenne and Red River monitoring data. No attempt was made to match actual concentrations, only to mimic patterns and the general concentration magnitude was accomplished. Tributary loadings for phosphorus, nitrate nitrogen, ammonia nitrogen, dissolved organic matter (DOM1 &DOM2), Alkalinity, pH, and the tracer were all loaded as constant values. This was deemed reasonable based on the datasets available, and the pumping period. Generally either the mean or median concentration for the period of pumping was adopted for the parameter concentration. Water temperature, algae, DO, and suspended solids were computed by various methods such as harmonic curve fits.

Two additional loading sources were added to account for wastewater discharges by industries and municipalities. This source was not accounted for in the tributary monitoring data, but was evident in the main stem data sets and the loading sources were added as a calibration tool. Permitted discharger data records for North Dakota and Minnesota were obtained to substantiate this.

Calibration of the stream segment of the nutrient model was accomplished at Cooperstown and Kindred on the Sheyenne River and at Halstad and Emerson on the Red River of the North. These stations generally had the best data records and represented the upper and lower ends of both river segments. The calibration was general in nature and not intended to replicate actual concentrations, but mimic general trends in the available data. This is especially important considering the monthly and constant loading assumptions used in the model. Calibration plots of water temperature, total phosphorus, and ammonia are provided for each calibration station. Similar patterns were seen in the other parameters modeled but is not presented in this report. Sufficient historical nitrate data for plotting was available at Cooperstown and Kindred and the general trends are similar to those seen in the ammonia data.

Temperature is simulated very well at all calibration locations as illustrated in **Figure A4-12**. Simulated temperatures matched historical temperatures very well throughout the simulation with the exception of a few peaking temperatures above 80 degrees F. The differences between the simulated and historical peaking temperatures may be attributed to differences between the model computational techniques and historical data measurement techniques. The model computes a daily stream average temperature. Typically the historical data sets represent spot measurements for specific times and locations. Spot measurements can differ significantly from a daily average, often reaching higher temperatures during the late afternoon than an average temperature would indicate.

Figure A4-13 compares the monthly simulated data ranges to the monthly historical data ranges of total phosphorus at Cooperstown, Kindred, Halstad, and Emerson. Total phosphorus does not exhibit a defined pattern consistent throughout the system. Total phosphorus concentrations are highly dependent on local runoff events and operation of the Red River Headwaters Reservoirs. The loading assumptions to the model (mean monthly) smooth out these effects considerably, and matching maximum and minimum concentrations is often not possible. Still, the simulated results show that HEC-5Q is reproducing concentrations typically occurring at each of the calibration stations.

At Cooperstown, the January and February simulated total phosphorus range is very large. This is largely due to extremely low flow periods that are common during the winter in this particular reach of the river. During these extremely low flows the model computes very high phosphorus concentrations. These concentrations cannot be verified since there are is no historical data that corresponds with these particular events. The effect is essentially meaningless however since the flows are extremely small and the effects (as predicted by the model) unnoticeable downstream. The extent of this effect is much smaller at the downstream stations.

Ammonia (and nitrate which is not shown) exhibits a general pattern of higher winter concentrations and lower summer concentrations. The HEC-5Q model simulates this pattern fairly well at each calibration station as shown in **Figure A4-14**. The Kindred and Halstad stations exhibit some high concentrations during April and May, and again at Kindred in August and September. These data points are likely due to specific loading events and runoff of newly applied fertilizer. Modeling of specific runoff events would require much more extensive data to refine the loading assumptions used in model development. Still, HEC-5Q mimics the concentration ranges and general trend of lower summer concentrations and higher winter concentrations well.

Following the general calibration, the model was compared against phosphorus loading estimates at Cooperstown, Below Baldhill Dam, Kindred, Halstad, and Emerson. The Corps computer model, FLUX, was used to determine historic loads at each location for the years 1979 thru 1996. The HEC-5Q model was then run for the historic period 1971 through 1999 and loadings computed at each loading station. At Cooperstown, HEC-5Q predicted phosphorus loads lower than those computed by FLUX during higher flow years. During lower flow years the loading estimates between the models was quite close. The differences are attributable to utilizing the mean monthly tributary concentration in the model and the assumptions used in FLUX. **Figure A4-15** shows the loading estimates between FLUX and HEC-5Q at Cooperstown.

Below Baldhill Dam the loading relationship was the opposite. HEC-5Q predicted phosphorus loads generally higher than the FLUX estimates in all but the higher flow years. This appears to be due to model assumptions during the calibration procedure. Water quality data below Baldhill Dam (1979, 1980, 1981, and 1995) suggests concentrations lower than HEC-5Q computes. The calibration of Lake Ashtabula was accomplished for the period 1994 through 1999. During this time near dam pool phosphorus concentrations are higher than the historic concentrations measured below the dam during other years. Our calibration assumption was to mimic the pool concentrations in the outflow for the 1994 – 1999 period since it represented the period of best data coverage. This in turn resulted in higher loading computations than predicted by flux since flux used the stream phosphorus data for load computations based on fewer data points and a different time period.

Another factor to be considered is the fact that the HEC-5Q model does not model the winter period well. Rate coefficients are temperature based and drop to nearly zero during the winter. Minimal processes are occurring in the reservoir at this time, however in reality different species of algae are growing and dieing off, degradation is taking place, and settlement is occurring which causes chemical stratification to occur. In pool monitoring shows that strong chemical gradients form in the reservoir during the winter that are not reflected in the model. The effect may be biasing the winter release of nutrients based on specific outlet operation (low level withdrawal or epilimnetic withdrawal).

At Kindred the FLUX loading estimates indicate high variability. The HEC-5Q estimate falls within this range consistently throughout the modeled period. **Figure A4-16** compares the modeled load to the load estimated by FLUX.

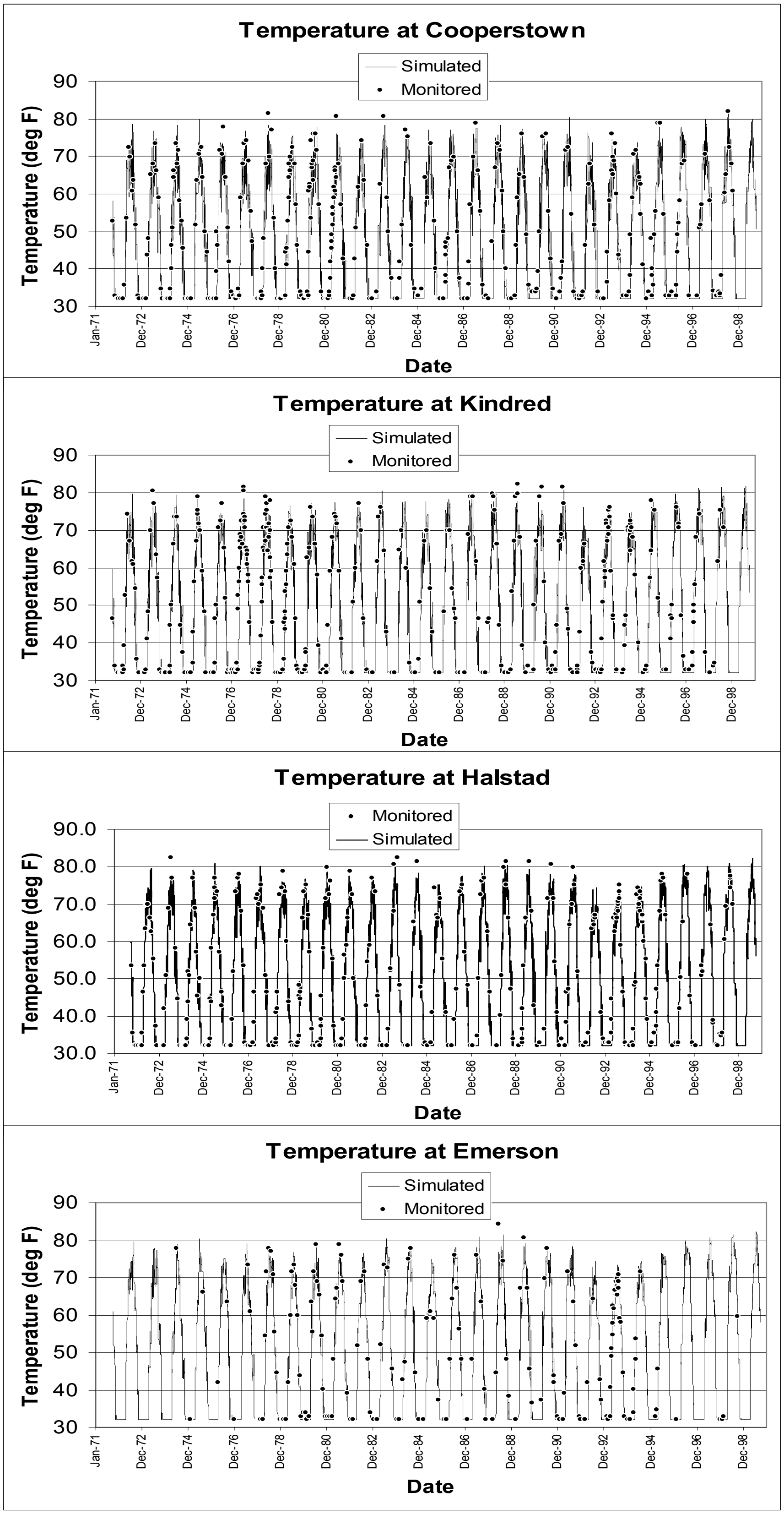
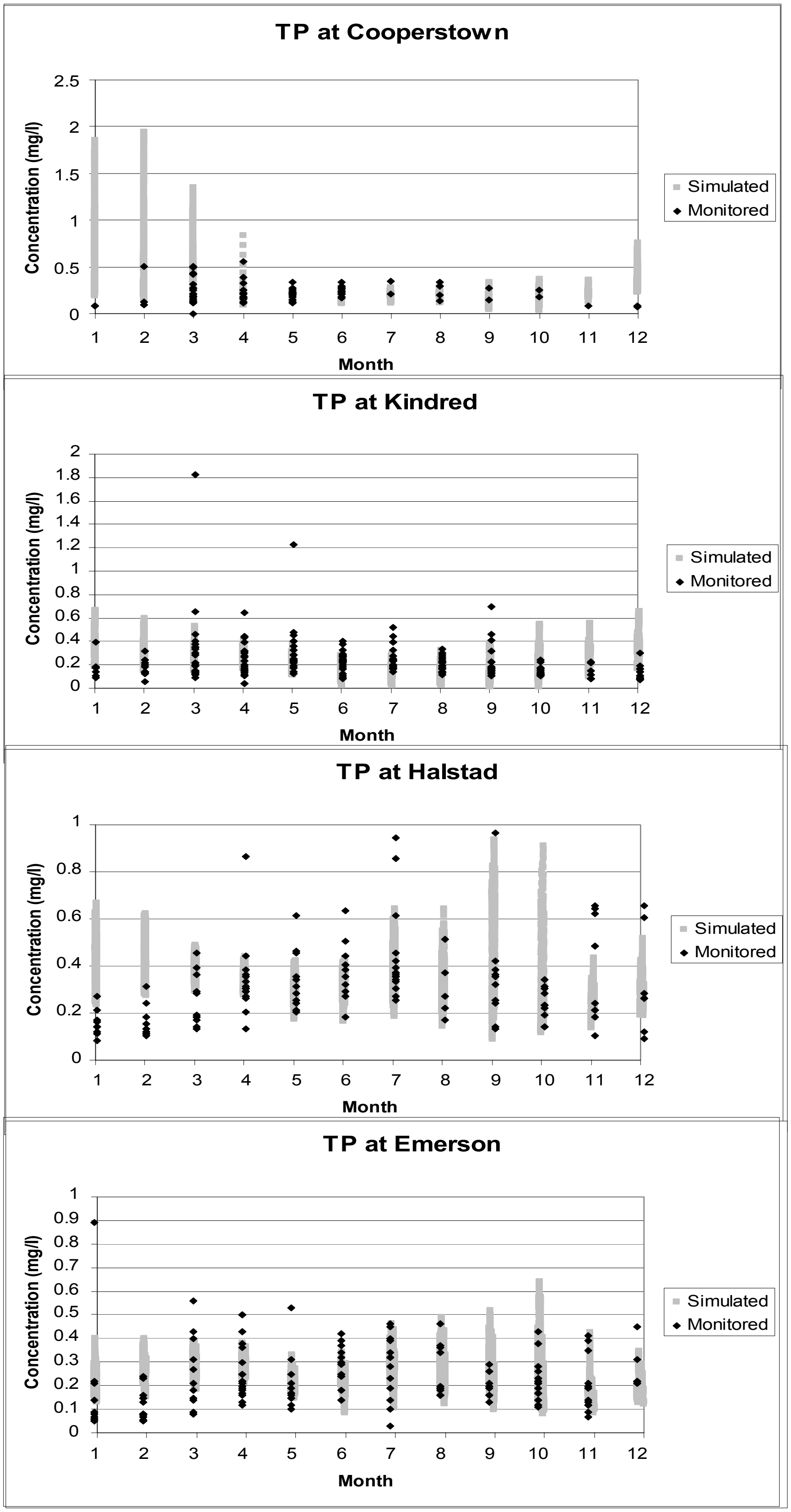
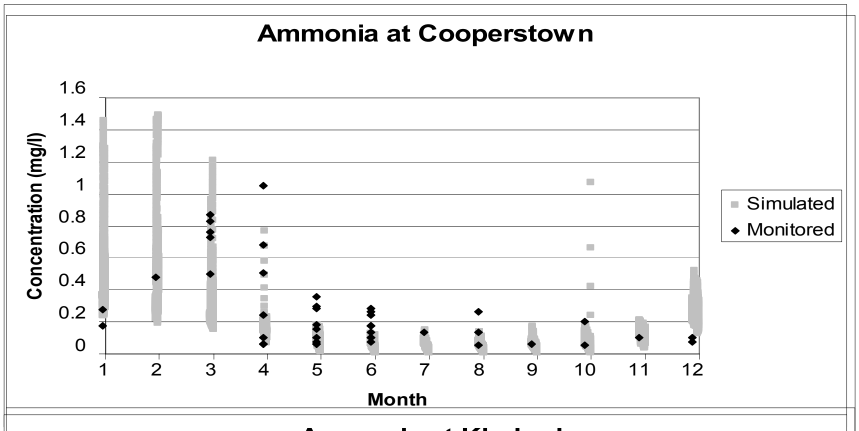

Temperature at Cooperstown
Simulated
Monitored
Temperature (deg F)
90
80
70
60
50
40
30
Jan-71
Dec-72
Dec-74
Dec-76
Dec-78
Dec-80
Dec-82
Dec-84
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Date
Temperature at Kindred
Simulated
Monitored
Temperature (deg F)
90
80
70
60
50
40
30
Jan-71
Dec-72
Dec-74
Dec-76
Dec-78
Dec-80
Dec-82
Dec-84
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Date
Temperature at Halstad
Monitored
Simulated
Temperature (deg F)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
Jan-71
Dec-72
Dec-74
Dec-76
Dec-78
Dec-80
Dec-82
Dec-84
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Date
Temperature at Emerson
Simulated
Monitored
Temperature (deg F)
90
80
70
60
50
40
30
Jan-71
Dec-72
Dec-74
Dec-76
Dec-78
Dec-80
Dec-82
Dec-84
Dec-86
Dec-88
Dec-90
Dec-92
Dec-94
Dec-96
Dec-98
Date

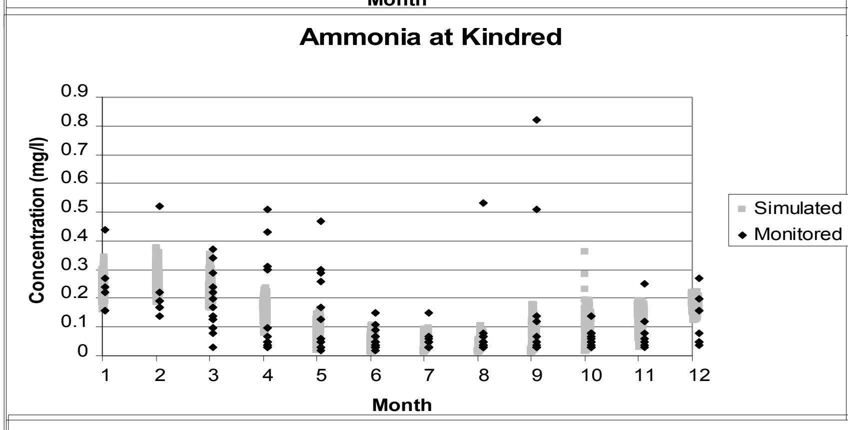
Figure A4-12

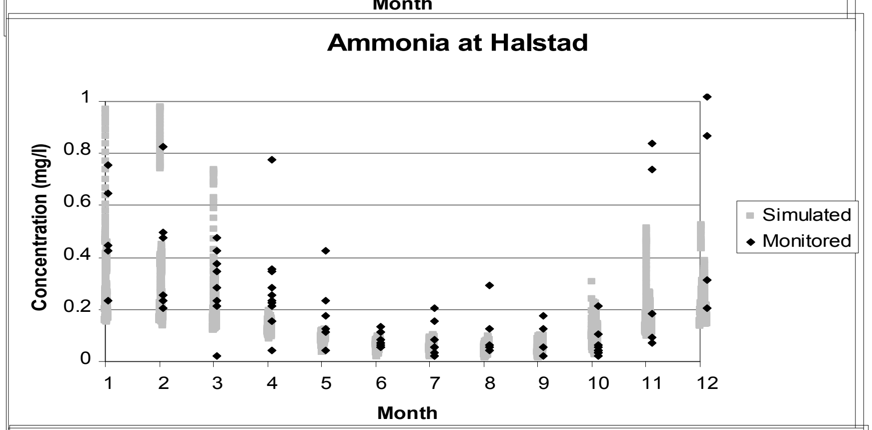


TP at Cooperstown
Concentration (mg/l)
Month
Simulated
Monitored
TP at Kindred
Concentration (mg/l)
Month
Simulated
Monitored
TP at Halstad
Concentration (mg/l)
Month
Simulated
Monitored
TP at Emerson
Concentration (mg/l)
Month
Simulated
Monitored

Figure A4-13


Ammonia at Cooperstown
Concentration (mg/l)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Simulated
Monitored


Ammonia at Kindred
Concentration (mg/l)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Simulated
Monitored


Ammonia at Halstad
Concentration (mg/l)
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Simulated
Monitored

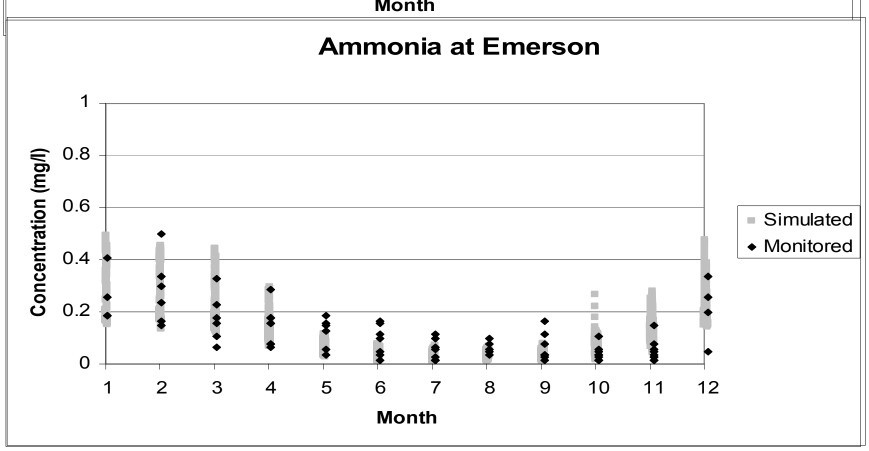

Ammonia at Emerson
Concentration (mg/l)
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12
Month
Simulated
Monitored

Figure A4-14

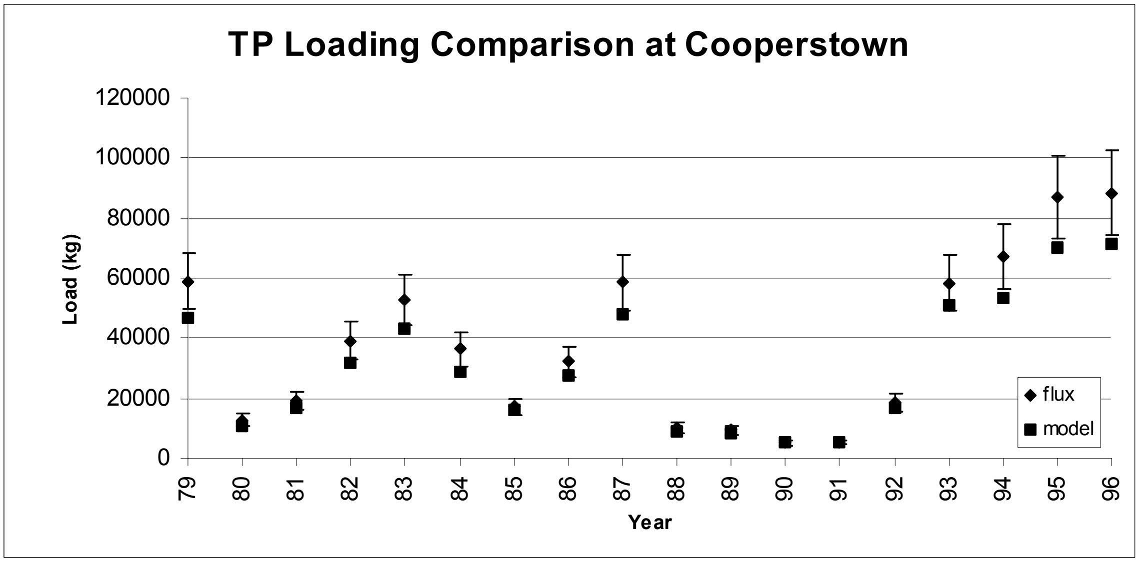


Figure A4-15

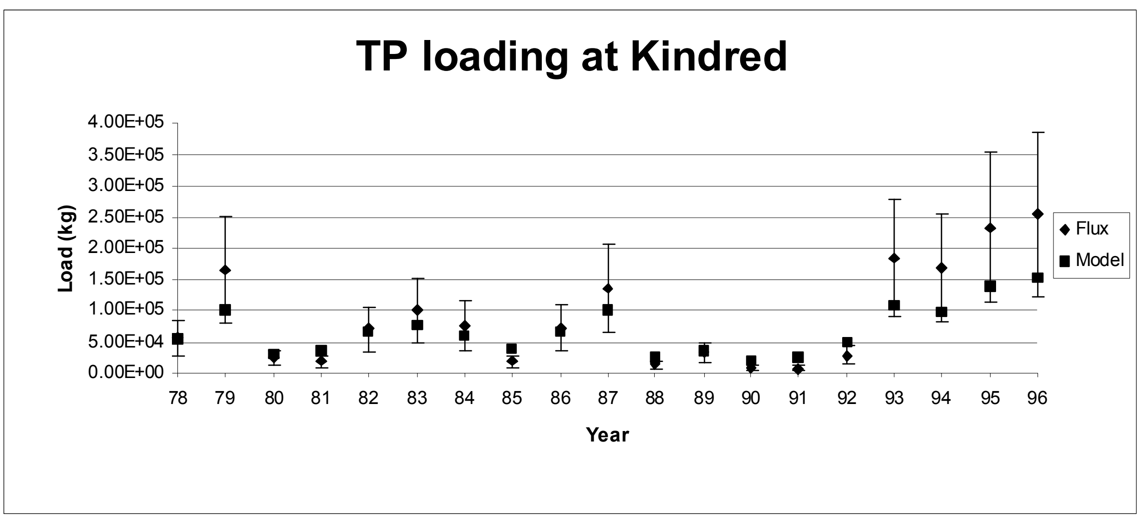


Figure A4-16

On the Red River, loading estimates were compared at Halstad and Emerson. At Halstad, model agreement was generally good for low and moderate flow years. During high flow years the HEC-5Q estimated loading was generally higher than predicted using FLUX. This is probably due to an overestimation of loading from the Red River during the high flow years by HEC-5Q due to the mean monthly loading assumption that does not reflect any flow or reservoir operation considerations. At Emerson, the critical location for load computations, the models had good agreement as seen in the **Figure A4-17** below.

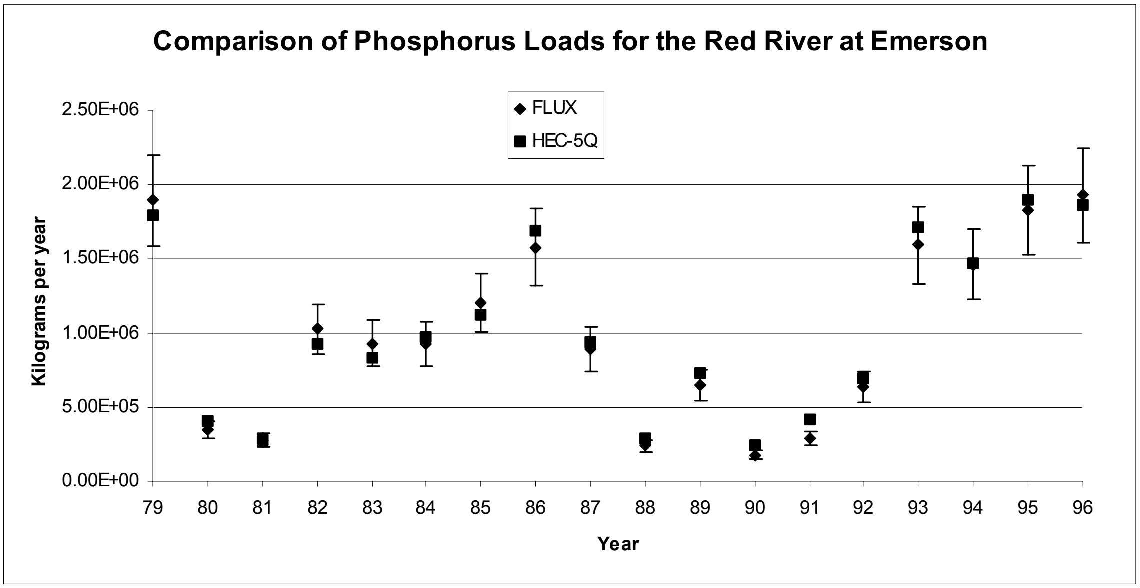


Figure A4-17

The nutrient model is not intended represent actual concentrations, but instead is designed to represent general characteristics of the modeled system. Model results should not be viewed in an absolute sense, but in a relative sense. The purpose of the model is to mimic general patterns that are present in the system and provide a relative benchmark for assessing eutrophication issues (relating to phosphorus) in Lake Ashtabula and phosphorus loading to the Sheyenne and Red Rivers resulting from a Devils Lake Outlet. The model, used as intended, is adequate for this and for addressing relative increases in phosphorus loading to the Sheyenne and Red Rivers. As stated previously, model will indicate relative changes and general conditions but not accurately model a specific event such as an algal bloom definitively.

Table A4-9 Tributary Water Quality Type Assignments			
Reach	# of Tributaries	Tributary WQ Type	% local flow assigned to tributary
Sheyenne River Headwaters Dummy Reservoir	1	1	100
Sheyenne River Headwaters to Insertion Point	1	1	100
Devils Lake Outlet Dummy Reservoir	1	2	100
Devils Lake Headwaters to Insertion Point	0	na	na
Insertion Point to Warwick	1	1	100
Warwick to Cooperstown	1	13	100
Cooperstown to Upper Ashtabula Reservoir	1	5	100
Lake Ashtabula Reservoir	1	5	100
Below Baldhill Dam to Valley City	1	5	100
Valley City to Lisbon	1*	5 15*	100
Lisbon to Kindred	3	5 5 5	27 47 26
Kindred to Junction with Red River of the North	2	7 7	84 16
Red River of the North Dummy Reservoir	1	3	100
Red River of the North Headwaters to Junction with Sheyenne River	1	11	100
Junction to Halstad	3	11 7 11	31 26 43
Halstad to Grand Forks	3	8 8 4	21 7 72
Grand Forks to Oslo	1	7	100
Oslo to Drayton	4	7 7 7 7	28 29 30 13
Drayton to Emerson	2*	7 7 14*	25 75

*Two reaches contain a constant distributed inflow quality and flow rate. This was provided to account for high concentrations experienced during low flow conditions.

Table A4-10 Comparison of Historical Record to Simulated Record										
Percentile	TDS		Sulfate		Chloride		Total Hardness		Non-Carbonate Hardness	
	Hist.	Sim.	Hist.	Sim.	Hist.	Sim.	Hist.	Sim.	Hist.	Sim.
Cooperstown										
minimum	169	271	37	49	4	7	79	181	0	0
10th	355	417	84	105	8	11	170	241	0	0
50th	597	604	140	149	16	17	310	302	0	0
90th	733	755	180	188	23	21	400	389	17	60
max	1070	944	360	224	39	29	510	483	88	151
count	192	10227	292	10227	192	10227	169	10227	133	10227
Baldhill Dam (Historic) vs Valley City (Simulated)										
minimum	196	288	48	81	5	9	96	182	0	5
10th	328	408	90	111	9	12	176	236	0	10
50th	476	490	130	132	14	14	220	270	0	22
90th	638	604	200	161	22	17	310	306	20	32
max	764	792	240	217	26	21	380	372	28	46
count	71	10227	71	10227	71	10227	49	10227	34	10227
Kindred										
minimum	200	227	56	73	6	7	120	155	0	9
10th	402	422	110	113	15	12	210	231	30	23
50th	539	554	150	148	27	16	310	285	59	37
90th	668	721	200	187	46	22	360	364	88	55
max	812	849	290	232	74	30	430	497	294	76
count	200	10227	200	10227	200	10227	129	10227	114	10227
Halstad										
minimum	176	304	37	58	5	9	130	199	11	23
10th	330	359	60	73	10	13	200	245	27	30
50th	428	411	110	88	17	18	270	265	59	43
90th	563	484	160	114	32	27	370	315	85	63
max	695	700	240	188	52	60	410	403	110	138
count	128	10227	128	10227	128	10227	60	10227	39	10227

Table A4-10 - Continued Comparison of Historical Record to Simulated Record										
Percentile	TDS		Sulfate		Chloride		Total Hardness		Non-Carbonate Hardness	
	Hist.	Sim.	Hist.	Sim.	Hist.	Sim.	Hist.	Sim.	Hist.	Sim.
Grand Forks										
minimum	158	264	18	40	3	7	120	177	5	14
10th	231	319	36	54	5	9	165	215	12	22
50th	322	355	69	72	10	12	230	239	40	33
90th	445	405	120	89	16	18	275	271	91	55
max	570	531	200	131	34	47	320	337	203	76
count	85	10227	85	10227	87	10227	56	10227	44	10227
Emerson										
minimum	251	294	6	44	10	8	170	177	31	18
10th	322	363	54	64	19	12	208	224	35	27
50th	433	427	92	87	37	20	260	251	65	45
90th	631	570	140	115	110	26	350	292	123	70
max	1100	805	230	173	240	82	500	385	150	131
count	122	10227	122	10227	122	10227	59	10227	38	10227

Exhibit A

Example HEC-5Q Input Data File (Conservative)

```
TI      Devils Lake Project Water Quality Impact
TI      Existing Baldhill Dam Configuration WITH 5 FT RAISE
TI      Sheyenne River and Red River WET7 SCENARIO PELICAN LAKE PUMP START MAY
2006
c       Filename = Q5PHP248.DAT          update DJR/jds 7/18/98
C       REVISED TO USE BHD OPERATION PLAN B 8/14/98
C ICE REMOVED ON SHEYENNE DUE TO LOW FLOWS DURING WINTER AND LOADING
ASSUMPTIONS
c. July 6 ... JA        000101  471231       C       2       0       0       0
c   set IP5 = 5 to reduce output size  |
c.. Y2K <<< JA        000101  471231       C       0       0       0       0
JA      20001001        20500930      24       C       0       0
c.          GUI output interval = 5  days      |
JF  gui=  GUPL248R                             5
JF  out=  Q5PL248R

c.   ID1      F1      ID2      F2      ID3      F3      min      max
JG     1      1.                                          0     36.Temperature, C
JG     2      1.                                          0   1000.Devils Lake
Trace
JG     3      1.                                          0   1000.TDS, mg/L
JG     4      1.                                          0   1000.SO4, mg/L
JG     5      1.                                          0    500.Total
Hardness, mg/L
JG     6      1.                                          0    500.Non-CO3
Hardness, ug/L
JG     7      1.                                          0    500.Chloride, mg/L
JG    28                                                  0   5000.Flow, cfs
JG    29                                               1500      1.Elevation,
feet

ZW   DLRQP248.DSS                      A=DL_5Q   F=WET  PL248PUMPRR

JZ  1464   464.0 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ   999  1465.2 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ -1463   462.5 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ -1408   407.5 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ -1317   317.0 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ  1271   292.6 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ  1271   287.0 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ  1271   277.3 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ  1271   271.0 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ -1253   253.0 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ -1162   162.1 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ -1068    67.9 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ  -428   426.0 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ  -375   375.2 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ  -296   295.0 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ  -271   271.2 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
JZ  -207   206.7 TEMP    DLTRC    TDS     SO4--    T-CO3    N-CO3    CL-
```

```
JZ   -99   155.0 TEMP    DLTRC   TDS      SO4--   T-CO3   N-CO3   CL-


c.... Excel specific output file (CDF: do not use "," in identification)
c.... This file provides the input for the "stand alone" mass accounting
routine.
EXCEL OUT       DLPL248R.xxx
c               |       |       |                         |
c. flag          element Parameter Identification
EXCEL ELEM            1       0FLOW @ HWY 30
EXCEL ELEM            1       2TRACER @ HWY 30
EXCEL ELEM            1       3TDS @ HWY 30
EXCEL ELEM            1       4SULFATE @ HWY 30
EXCEL ELEM            3       0FLOW DEVILS LAKE
EXCEL ELEM            3       2TRACER DEVILS LAKE
EXCEL ELEM            3       3TDS DEVILS LAKE
EXCEL ELEM            3       4SULFATE DEVILS LAKE
EXCEL ELEM            5       0FLOW AT INSERTION POINT
EXCEL ELEM            5       2TRACER AT INSERTION POINT
EXCEL ELEM            5       3TDS AT INSERTION POINT
EXCEL ELEM            5       4SULFATE AT INSERTION POINT
EXCEL ELEM           33       0FLOW AT WARWICK
EXCEL ELEM           33       2TRACER AT WARWICK
EXCEL ELEM           33       3TDS AT WARWICK
EXCEL ELEM           33       4SULFATE AT WARWICK
EXCEL ELEM           73       0FLOW @ COOPERSTOWN
EXCEL ELEM           73       1TEMP @ COOPERSTOWN
EXCEL ELEM           73       2TRACER AT COOP
EXCEL ELEM           73       3TDS @ COOPERSTOWN
EXCEL ELEM           73       4SULFATE @ COOPERSTOWN
EXCEL ELEM           73       5Total Hardness @ COOP
EXCEL ELEM           73       6Non-CO3 Hard. @ COOP
EXCEL ELEM           73       7Chloride @ COOP
EXCEL ELEM           80       0FLOW @ BALDHILL DAM
EXCEL ELEM           80       1TEMP @ BALDHILL DAM
EXCEL ELEM           80       2TRACER @ BALDHILL DAM
EXCEL ELEM           80       3TDS @ BALDHILL DAM
EXCEL ELEM           80       4SULFATE @ BALDHILL DAM
EXCEL ELEM           80       5Total Hardness @ BHD
EXCEL ELEM           80       6Non-CO3 Hard. @ BHD
EXCEL ELEM           80       7Chloride @ BHD
EXCEL ELEM          123       0FLOW @ LISBON
EXCEL ELEM          123       1TEMP @ LISBON
EXCEL ELEM          123       2TRACER @ LISBON
EXCEL ELEM          123       3TDS @ LISBON
EXCEL ELEM          123       4SULFATE @ LISBON
EXCEL ELEM          161       0FLOW @ KINDRED
EXCEL ELEM          161       1TEMP @ KINDRED
EXCEL ELEM          161       2TRACER @ KINDRED
EXCEL ELEM          161       3TDS @ KINDRED
EXCEL ELEM          161       4SULFATE @ KINDRED
EXCEL ELEM          161       5Total Hard @ KINDRED
EXCEL ELEM          161       6Non-CO3 Hard. @ KINDRED
EXCEL ELEM          161       7Chloride @ KINDRED
```

```
EXCEL ELEM          175       0FLOW @ HORACE
EXCEL ELEM          175       1TEMP @ HORACE
EXCEL ELEM          175       2TRACER @ HORACE
EXCEL ELEM          175       3TDS @ HORACE
EXCEL ELEM          175       4SULFATE @ HORACE
EXCEL ELEM          217       0FLOW @ HALSTAD
EXCEL ELEM          217       1TEMP @ HALSTAD
EXCEL ELEM          217       2TRACER @ HALSTAD
EXCEL ELEM          217       3TDS @ HALSTAD
EXCEL ELEM          217       4SULFATE @ HALSTAD
EXCEL ELEM          217       7Chloride @ HALSTAD
EXCEL ELEM          247       0FLOW @ GRAND FORKS
EXCEL ELEM          247       1TEMP @ GRAND FORKS
EXCEL ELEM          247       2TRACER @ GRAND FORKS
EXCEL ELEM          247       3TDS @ GRAND FORKS
EXCEL ELEM          247       4SULFATE @ GRAND FORKS
EXCEL ELEM          247       5Total Hardness @ GF
EXCEL ELEM          247       6Non-CO3 Hard. @ GF
EXCEL ELEM          247       7Chloride @ GF
EXCEL ELEM          302       0Flow @ Emerson
EXCEL ELEM          302       1Temperature @ Emerson
EXCEL ELEM          302       2TRACER @ EMERSON
EXCEL ELEM          302       3TDS @ Emerson
EXCEL ELEM          302       4Sulfate @ Emerson
EXCEL ELEM          302       5Total Hard @ Emerson
EXCEL ELEM          302       6Non-CO3 Hard. @ Emerson
EXCEL ELEM          302       7Chloride @ Emerson

nolist

C.  Fargo, ND Meteorological data

c. Y2K compatible Met file is created by "met_Y2K.exe"
c. Y2K <<< EZFILE= mett18s9.dat

EZFILE= METWET7.Y2K
EZEND
C

list

C.IPHYTO   CONID(1)
C.  TEMP DLTRACE     TDS SULFATE   THARD  NCHARD   CHLOR
QC     1       1       1       1       1       1       1

TQDLTRACER
TQTDS
TQSULFATE
TQTOTAL HARDNESS
TQNON CARBONATE HARDNESS
TQCHLORIDE

c. July 6 ... L1   182       1
c      |   printout interval = 1/2 year to reduce output size
```

```
L1   182       1

c. Dummy Reservoir, Sheyenne River Headwater

c.  IRCP    METL     IPL     SDZ   EDMAX   XQPCT   XQDEP    FK2R    FK2C
c. ice <<< L2  1464       1                     4.6     0.8     2.0       0
0

c.... Example seasonal ice thickness; see description of L2 and RX Records in
"exhibit_y2K.doc"
c.  IRCP    METL     IPL     SDZ   EDMAX   XQPCT   XQDEP      IZ   FICEL
L2  1464       1                     4.6     0.8     2.0       0       0
C RX             1      18      15      22      35      26      50      27
C RX            65      25      85      18     100       8     110       0
C RX           320       0     366      18

LA            20.
RS     5     10.     20.     32.     46.     62.
RA     5      9.     11.     13.     15.     17.
RE     5    1440    1441    1442    1443    1444

LS     0       0     1.0    1000       0      20      11    1442
R1     1      20      11     100     200       0
LI     I IN   F        1      1.                 HWY 30 INFLOW
R1     2      20      11     100     200       0

L9  TEMP     1.0       0
L9 CONS1       0       0
L9 CONS2     500       0
L9 CONS3      80       0
L9  NCON     100       0
L9  CBOD      20       0
L9  BODN      10       0

c.                                RO2CO2
KB                                   0.

C.UCONDK  BODCDK  BODNDK  CNH3DK   TCBDK  DOMDK1  DOMDK2  DOMDK3
DK  0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00

EL

c. Dummy Reservoir, Devils Lake Inflow

c.  IRCP    METL     IPL     SDZ   EDMAX   XQPCT   XQDEP    FK2R    FK2C
c.  ice <<< L2   999       1                     4.6     0.8     2.0       0
0

c.  IRCP    METL     IPL     SDZ   EDMAX   XQPCT   XQDEP      IZ   FICEL
L2   999       1                     4.6     0.8     2.0       0       0
c. No RX records are required since the ice zone (#1) characteristics were
defined above (CP 1464)

LA            20.
```

```
RS      5      10.      20.      32.      46.      62.
RA      5       9.      11.      13.      15.      17.
RE      5    1440     1441     1442     1443     1444

LS      0        0      1.0     1000        0       20       11     1442
R1      1       20       11      100      200        0
LI      I  IN   F         2       1.DL  INFLO
R1      2       20       11      100      200        0

L9   TEMP        1        0
L9  CONS1     1000        0
L9  CONS2      960        0
L9  CONS3      420        0
L9   NCON      360        0
L9   CBOD       80        0
L9   BODN       80        0

EL

C. Lake Ashtabula

c.ID IRCP    METL      IPL      SDZ    EDMAX    XQPCT    XQDEP       IZ    FICEL
L2   1271       1                        8.0      0.4      1.0        5        6

c. Lake Astabula ice thickness / 20 Nov 2000 10:36 e.mail

RX              0     17.0        4     18.8       14     21.5       24     24.0
RX             34     25.8       44     26.5       54     26.3       64     25.0
RX             74     22.3       84     18.5       94     13.0      104      5.5
RX            114      0.0      320      0.0      330      3.5      340      8.0
RX            350     11.8      360     15.2      366     17.0

RS     36       0       50      300     1000     2500     4400     6500    10500
14200
RS 25100   31000    32600    34200    37600    41300    45500    50000    54500
59500
RS 65000   70600    71740    76300    82100    88300    95000   101300   104550
107800
RS115000  122500   130000   137500   145500   153500   157500
RA     36       0       50      100      250      550      800     1100     1500
1800
RA   2600    3300     3400     3550     3750     4000     4250     4500     4700
5000
RA   5200    5400     5500     5700     5900     6150     6400     6600     6700
6800
RA   7150    7400     7600     7850     8100     8300     8450
RE     36    1223     1225     1230     1235     1240     1243     1245     1248
1250
RE   1255    1257   1257.5     1258     1259     1260     1261     1262     1263
1264
RE   1265    1266   1266.2     1267     1268     1269     1270     1271   1271.5
1272
RE   1273    1274     1275     1276     1277     1278   1278.5
```

```
c.ISROP2  ISROP3      A3     SRDX     DEQT     TOTV     TOTA    SRELC
LS            17     1.0     3520        0   157500     8450        0

lt    10   .2E-7   2.E-4   1.E-6      -1.      .75
LU           0.1     0.1     0.1      0.1      0.1      0.1      0.1      0.1
0.1
LU           0.1

C Lake Ashtabula Section 30, RM 1303
R2     1    7000  1257.6       10  1258.0       30  1259.3       60  1261.3
75
R31265.5     108  1267.5      130  1270.3      220  1271.0      320  1280.0
1080

LI    CP             1303      1.
LV US        0.1     0.1     0.1      0.1      0.1      0.1      0.1      0.1
0.1
LV           0.1

C Lake Ashtabula Section 23, RM 1301.5
R2     2   11400  1255.0       10  1257.6       57  1260.0       85  1263.4
116
R31264.0     130  1265.0      240  1268.0      280  1271.0      280  1280.0
1430

C Lake Ashtabula Section 20, RM 1299.4
R2     3   10400  1251.8       25  1258.0      127  1260.8      150  1262.6
230
R31262.7     282  1265.6      340  1266.4      420  1271.0     1170  1280.0
1680

LV  DS        -1      14     1.5

C Lake Ashtabula Section 19, RM 1298.2
R2     4    5100  1252.0       50  1256.0      220  1257.0      335  1263.0
420
R31265.0     500  1268.8     1020  1269.0     1040  1271.0     1200  1280.0
1650

C Lake Ashtabula Section 18, RM 1296.9
R2     5    5250  1249.0       10  1253.5       85  1256.0      185  1259.0
660
R31264.0     925  1271.0     1450  1280.0     1640

C Lake Ashtabula Section 17, RM 1295.3
R2     6    9300  1249.2       50  1259.0      165  1262.2      650  1263.8
950
R31265.0    1290  1269.5     1355  1271.0     1365  1280.0     1520

C Lake Ashtabula Section 16, RM 1292.6
R2     7   10900  1246.0       10  1249.4      120  1254.0      195  1259.5
495
R31260.0     880  1265.0     1500  1266.5     1560  1271.0     1720  1280.0
2080
```

```
C Lake Ashtabula Section 15, RM 1289.8
R2     8   10600  1246.0      10  1251.0     140  1253.8     380  1257.0
745
R31260.0    1400  1266.7    1870  1271.0    2040  1280.0    2360

C Lake Ashtabula Section 14, RM 1287.0
R2     9   12950  1241.6      10  1244.0     195  1250.0     435  1256.5
1360
R31263.5    1800  1266.0    1890  1271.0    1910  1280.0    2000

C Lake Ashtabula Section 13, RM 1284.0
R2    10    7900  1239.0      50  1244.0     295  1249.0     465  1254.5
950
R31260.0    1220  1265.5    1410  1271.0    1550  1280.0    1800

C Lake Ashtabula Section 8, RM 1283.0
R2    11    2175  1237.0      10  1240.0     100  1251.4     330  1253.0
1150
R31262.0    2320  1269.0    2550  1271.0    2630  1280.0    2800
LI      I IN F          5     1.0    BALDHILL CREEK

C Lake Ashtabula Section 6, RM 1282.0
R2    12    6175  1239.0      10  1241.4     120  1247.5     230  1253.5
290
R31260.0    2605  1266.5    2745  1271.0    2755  1280.0    2900

C Lake Ashtabula Section 5, RM 1279.5 removed 1240, 125.
R2    13   10550  1232.0      50  1244.0     320  1247.0    1250  1248.0
1265
R31254.0    1612  1260.0    1780  1266.0    1980  1271.0    1995  1280.0
2160

C Lake Ashtabula Section 4, RM 1277.3
R2    14    9900  1230.0      10  1238.0     305  1241.0     430  1243.0
530
R31245.0     920  1250.0    2080  1264.0    2420  1271.0    2585  1280.0
2760

LV  DS        -1      17     1.5

C Lake Ashtabula Section 3, RM 1274.7
R2    15    9700  1227.5      60  1238.0     175  1241.0     230  1242.5
1050
R31250.0    1300  1260.0    1600  1271.0    1850  1280.0    2000

C Lake Ashtabula Section 2, RM 1272.0
R2    16    8250  1225.0      10  1230.0     140  1235.0     320  1240.0
1180
R31250.0    1650  1260.0    1900  1271.0    2045  1280.0    2200

c Lake Ashtabula Section 1, RM 1271.0
R2    17    3200  1223.0      40  1226.0     115  1237.0     220  1240.0
1250
```

```
R31244.5    1300  1250.0    1500  1260.0    1640  1271.0    1770  1280.0
1880

c. This record specifies that flow diverts to the second weir/orifice
(spillway) as
c. flow increases beyond 440 cfs (QSET1).  As flow drops below 220 cfs
(QSET2), the
c. flow diverts back to weir/orifice #1 (low level outlet)
c.  Loc   NWEIR1  WELEV1  WIDTH1   QSET1  NWEIR2  WELEV2  WIDTH2   QSET2
QWMIN   LAYMQ
LW   DS        2   1252.    120.    440.       1   1239.     60.    220.
0

L9  TEMP       2       0
L9 CONS1       0       0
L9 CONS2     680       0
L9 CONS3     200       0
L9  NCON     300       0
L9  CBOD       5       0
L9  BODN      15       0

EL

c. Dummy Reservoir, Red River Headwater

c.  IRCP    METL     IPL     SDZ   EDMAX   XQPCT   XQDEP    FK2R    FK2C
c. ice <<< L2   453       1                    4.6     0.8     2.0       0
0

c.  IRCP    METL     IPL     SDZ   EDMAX   XQPCT   XQDEP      IZ   FICEL
L2   453       1                     4.6     0.8     2.0       0       0

C RX             1      18      15      22      35      26      50      27
C RX            65      25      85      18     100       8     110       0
C RX           320       0     366      18

LA           20.
RS      5    10.     20.     32.     46.     62.
RA      5     9.     11.     13.     15.     17.
RE      5    877     878     879     880     881

LS                   1.0    1000       0      20      11     879
R1      1      20     11     100     200       0
LI      I  IN   F      3      1. Red Riv
R1      2      20     11     100     200       0

L9  TEMP       1       0
L9 CONS1       0       0
L9 CONS2     345       0
L9 CONS3      50       0
L9  NCON     270       0
L9  CBOD      20       0
L9  BODN      15       0
```

```
EL

C. STREAM DATA

c. July 6 ... S1   182       1       0
c      |   printout interval = 1/2 year to reduce output size
S1   182       1       0

c. Sheyenne - Red River of the North
C  Head waters of Sheyenne River, Highway 30 south of Maddock, ND
C  to Devils Lake inflow.

S2  1464   464.0    1463   463.2   0.400
SI    I  IN  F     463.5       1      1.   Incr. Inflow Quality nr Warwick

c.... water quality coefficients (if any)
C.UCONDK  BODCDK  BODNDK  CNO3DK   TCBDK  DOMDK1  DOMDK2  DOMDK3
c.DK                 .05     .02      .5    .040    .015     .01
DK                   .00     .00     .00     .00     .00     .00

C. DL TO CONFLUENCE
S2   999  1465.2    1463 1463.20   1.000
C.SI    W             1464       20.003531

C. CONFLUENCE TO WARWICK
S2  1463   463.2    1408   407.5   1.989
SI    I  IN  F       435       1     1.0   LOCAL INFLOW  Warwick

C. WARWICK TO COOPERSTOWN
S2  1408   407.5    1317   317.0   2.262
SI    I  IN  F       362      13     1.0  COMPUTED LOCAL COOP QUALITY
C CHANGED TRIB TYPE FROM 13 TO 1 ON 3/19/01 TO TEST

C. COOPERSTOWN TO LAKE ASHTABULA
S2  1317   317.0    1303   303.0   2.000
SI    I  IN  F       310       5     1.0  BHC QUALITY
C CHANGED TRIB TYPE FROM 5 TO 1 ON 3/19/01 TO TEST

C. BALDHILL DAM TO VALLEY CITY
S2  1271   270.5    1253   253.0   2.500
SI    I  IN  F       260       5      1.  BHC QUALITY

C. VALLEY CITY TO LISBON
S2  1253   253.0    1162   162.1   2.525
SI    I  IN  F       240       5      1.  BHC QUALITY
SI    I  IN  NP    170.0      15    0.10  LOW FLOW INPUT
C.    I  IN  F       240       1      1.      T-240 Tributary

C. LISBON TO KINDRED
S2  1162   162.1    1068    67.9   2.479
SI    I  IN  F       158       5    0.27 Timber Coulee
SI    I  IN  F       150       5    0.47 Dead Colt Creek
C  SI    I  IN  NP      120      18    0.10 LOW FLOW GW CONTRIB.
SI    I  IN  F        94       5    0.26 Iron Springs
```

```
C.      BALDHILL CREEK WQ
C.      0.17 ADDED TO TC &DCC, 0.18 TO IRON SPRINGS FOR LQ DIST.

C === Sheyeene River, RM 67.9 Kindred  ND USGS Gage 05059000 ===
C === to Sheyeene River at Junction with Red River ===
S2  1068    67.9     428     0.0    2.611
SI    I  IN   F      19.8       7    0.84 Maple River (84% of Local Flow)
C  SI    I  IN   F      13.2       7    0.05 Lower Rush River (3.7% of Local
Flow)
SI    I  IN   F      11.4       7    0.16 Rush River (9.7% of Local Flow)+ RUSH
RIVER
C. ALL LOCAL FLOW MUST BE ACCOUNTED FOR WITH A QUALITY

C === Red River, RM 454.0 Fargo, ND USGS Gage 05054000
C === to Red River at Junction with Sheyeene River
S2   453   453.0     428   427.5    2.550
C  SI    I  IN   F       440      11      1.  MINN TRIB QUALITY
C === No Tributaries in this reach

C === Sheyenne River Junction at Red River, RM 427.2
C === to Red River, RM 375.2 at Halstad, MN ===
S2   428   427.5     375   375.2    2.615
SI    I  IN   F     417.2      11     .31  Buffalo  (31% of total local)
SI    I  IN   F     400.0       7     .26
SI    I  IN   F     380.3      11     .43  Wild Rice MN (43% of total local)
C. .26 ADDED TO MIDREACH TO REPRESENT ND LOCAL CONTRIBUTION

C === Red River, RM 375.2 at Halstad, MN ===
C === to Red River, RM 296.2 at Grand Forks ND ===
S2   375   375.2     296   296.2    2.633
SI    I  IN   F     357.9       8     .21  Goose (19% of total local)
C SI    I  IN   F     357.1       6     .05  Marsh (2% of total local)
SI    I  IN   F     336.3       8     .07  Sandhill (7% of total local)
SI    I  IN   F     298.0       4     .72  Red Lake (60% of total local)
C.  0.03 ADDED TO EACH TRIB TO ACCOUNT FOR LOCAL FLOW
C  Goose andMarsh Rivers entered the same element, Marsh was combined to
C  enter at the same location as Goose, both have similar wq types,
C  5% Marsh flow added to 22% Goose flow to toal 27%.  jds 6/18/97

C === Red River, RM 296.2 at Grand Forks ND ===
C === to RM 271.2: Oslo MN, USGS Gage 05083500 ===
S2   296   296.2     271   271.2    2.500
C  SI    I  IN   F       284       4     0.5  ASSUME RED LK QUALITY
SI    I  IN   F       280       7     1.0  ASSUME PARK

C === No Tributaries in this reach

C === RM 271.2 Oslo MN, USGS Gage 05083500 ===
C === To RM 206.7 Drayton, ND USGS Gage 05092000 ===
S2   271   271.2     207   206.7    2.481
SI    I  IN   F     243.3       7     .28  Forest
SI    I  IN   F     230.2       7     .29  Snake
SI    I  IN   F     222.3       7     .30  Park
SI    I  IN   F     219.5       7     .13  Tamarac
```

```
C. 0.02 ADDED TO ALL BUT TAMARAC WHICH GOT 0.03 ADDED   FOR LOCAL FLOW

C === RM 206.7 Drayton, ND USGS Gage 05092000 ===
C === to RM 155.0 International Boundary ===
S2   207   206.7      99   155.0   2.585
SI     I  IN  NP    204.0      14     0.25  LOW FLOW INPUT
SI     I  IN  F     175.1       7      .25  Two Rivers
SI     I  IN  F     158.0       7      .75  Pembina
C. 0.02 ADDED TO EACH TO ACCOUNT FOR LOCAL FLOW

C.  Sheyenne River
c. ice <<< SR  1464     428       1      1.       2
C. Red River
c. ice <<< SR  -453      99       1      1.       2

c. Two SR Records are now required to defin each reaeration, bottom
conductance and ice zone.
c.  US CP   DS CP    METZ   HEXF   K2OPP   RK2MI     RK2   K2min   K2max
C.                     DC  BEDDC  BEDDEP      IZ   FICEL
C.  Sheyenne River
c. Typical value for reaeration constraints and bottom thermal conductance are
included as an example.
SR  1464    1303       1      1.       2       0    -1.5     1.0    10.0
SR                  0.44    .010     1.0       1       6
SX             1       0      15       0      35       0      50       0
SX            65       0      85       0     100       0     110       0
SX           320       0     366       0

SR  1271     428       1      1.       2       0    -1.5     1.0    10.0
SR                  0.44    .010     1.0       2       6
SX             1       0      15       0      35       0      50       0
SX            65       0      85       0      95       0     320       0
SX           366       0
C  SX             1      22      15      26      35      29      50      31
C  SX            65      28      85      21     100      12     115       0
C  SX           320       0     366      18

c... Alternative ice zone definition by date are also allowed for the stream.
c. SX      20000101      15
c. SX      20000121      21
c. SX      20000218      22
c. SX      20000318      22
c. SX      20000325      16
c. SX      20000408       6
c. SX      20000415       0
c. SX      20001117       0
c. SX      20001203       5
c. SX      20001224      14
c. SX      20010114      22
c. SX      20010225      27
c. SX      20010318      17
c. SX      20010410       6
c. SX      20010415       0
c. SX      20011202       0
```

```
c. SX      20011217       8
c. SX      20011231      12
C. Red River
C  SR  -453      99       1      1.       2       0    -1.5     1.0    10.0
C  SR                   0.44    .010     1.0       3       6
SR   453     296       1      1.       2       0    -1.5     1.0    10.0
SR                  0.44    .010     1.0       3       6
SX             1      12      15      16      35      18      50      21
SX            65      18      85      10      95       0     320       0
SX           366      12
SR  -296      99       1      1.       2       0    -1.5     1.0    10.0
SR                  0.44    .010     1.0       4       6
SX             1      14      15      18      35      21      50      24
SX            65      21      85      12     105       0     320       0
SX           366      14

c.nolist

c.... Stream x-section data
C       s3_rjh.dat
S3FILE= S3REV.DAT
S3END
ES
list

C... TRIBUTARY INFLOW DATA
c. Y2K <<< I1     0  000101  471231       1
I1      20001001        20500930

c. BASINS input
c. DSS input <<< I2      TR16S9A.TRB                               ST_PAUL

c. The tributary data are similar to the input data to the program that was
used to create "TR16S9A.TRB"

I2FILE= TRWQP248.DAT

C.I2FILE= intribwq.dat
C.I2END

EI

c. July 6 ... Gate operatiuon data not required if all reservoirs are
longitudinally segmented
C.... TYPICAL GATE OPERATION DATA
c G1      20000101        20471231
c G2 1464 20000131       1
c G2  999 20000131       1
c G2 1271 20000131       1
c G2  453 20000131       1

ER
```

Example Tributary WQ File (Conservative)

```
c      1       2       3       4       5       6       7       8       9
10      11      12
c      |       |       |       |       |       |       |       |       |
|       |       |

I2     1      UQ           Sheyenne River Headwaters (HWY 30)
c.  flow    temp     # 1     # 2     # 3     # 4     # 5     # 6     # 7
IU     1       t       0      I3      I3      I3      I3      I3
I7     1             0.00    0.90     0.     32.     0.3
C  I3  ZR    A=DEVIL     B=HWY 30         C=TEMP-INC      F=COMPUTED
I3  ZR    A=DEVIL     B=HWY 30         C=TDS-INC        F=THS7
I3  ZR    A=DEVIL     B=HWY 30         C=SO4-INC        F=THS7
I3  ZR    A=DEVIL     B=HWY 30         C=HRD-INC        F=THS7
I3  ZR    A=DEVIL     B=HWY 30         C=NCHRD-INC      F=THS7
I3  ZR    A=DEVIL     B=HWY 30         C=CHL-INC        F=THS7

C. DEVILS LAKE INFLOW
I2     2      UQ           Devils Lake Inflow
c.  flow    temp     # 1     # 2     # 3     # 4     # 5     # 6     # 7
IU     1       T    1000      I3      I3      I3      I3      I3
I7     1             0.00    0.95     0.     32.     0.3
C  I3  ZR    A=DEVIL     B=DEVILS LAKE     C=TEMP-INC      F=COMPUTED
I3  ZR    A=DEVIL     B=DEVILS LAKE     C=TDS-INC        F=THS7 PL2480PUMP
I3  ZR    A=DEVIL     B=DEVILS LAKE     C=SO4-INC        F=THS7 PL2480PUMP
I3  ZR    A=DEVIL     B=DEVILS LAKE     C=HRD-INC        F=THS7 PL2480PUMP
I3  ZR    A=DEVIL     B=DEVILS LAKE     C=NCHRD-INC      F=THS7 PL2480PUMP
I3  ZR    A=DEVIL     B=DEVILS LAKE     C=CHL-INC        F=THS7 PL2480PUMP

C. RED RIVER HEADWATERS
I2     3      UQ             Red River Headwaters Tributary
c.  flow    temp     # 1     # 2     # 3     # 4     # 5     # 6     # 7
IU     1       t       0   12FMR   12FMR   12FMR   12FMR   12FMR
I7     1             0.00    0.95     0.     32.     0.3
I5   345     350     320     360     375     355     370     330     415
290     315     410
I5    49      52      68      88      92      73     105      63      98
44      54      86
I5   270     280     230     245     260     250     255     240     240
230     255     300
I5    21      24      53      70      63      39      77      45      45
26      29      36
I5    11      11      11      11      11      11      11      11      11
11      11      11

c. RED LAKE RIVER TRIBUTARY
I2     4      UQ             Red Lake River Tributary
c.  flow    temp     # 1     # 2     # 3     # 4     # 5     # 6     # 7
IU     1       t       0   12FMR   12FMR   12FMR   12FMR   12FMR
I7     1             0.00     1.0     0.     32.     0.3
I5   250     230     240     230     290     300     290     240     310
270     260     260
```

```
I5    14       11       19       44       59       47       40       23       61
40       31       20
I5   195      180      190      170      210      190      165      175      220
200      210      210
I5     7        4        4       42       65       38        3        2       59
13       25       12
I5     4        4        4        4        4        4        4        4        4
4        4        4

C. BALDHILL CREEK TRIBUTARY
I2     5      UQ            BALDHILL CREEK TRIBUTARY
IU     1        t        0   12FMR   12FMR   12FMR   12FMR   12FMR
I7     1               0.0    0.90      0.     32.     0.3
I5   860      860      250      210      505      600      650      645      560
625      625      795
I5   250      250       70       70      180      180      230      210      160
185      185      210
I5   540      540      140      150      275      350      330      290      310
350      350      420
I5    73       73       37       48       81       83       70       26       41
58       58       69
I5    37       17        7        7       14       17       25       22       18
21       25       25

C. GOOSE  MAPLE RUSH AND BEAVER COMBINED TRIBUTARIES
I2     6      UQ            GOOSE COMBINED TRIBS
IU     1        t        0   12FMR   12FMR   12FMR   12FMR   12FMR
I7     1               0.0    0.95      0.     32.     0.3
I5  1490     1530      355      500      910     1060     1070      915      925
1020     1080     1370
I5   580      570      110      180      410      440      470      360      390
430      430      520
I5   830      760      180      275      520      560      610      535      620
515      615      760
I5   400      370       60      110      255      275      320      240      300
230      300      370
I5   110       95       15       15       25       35       50       45       35
45       45       60

C. PARK RIVER TRIBUTARY
I2     7      UQ              PARK RIVER TRIBUTARY
IU     1        t        0   12FMR   12FMR   12FMR   12FMR   12FMR
I7     1               0.0    0.90      0.     32.     0.3
I5   865      865      550      355      585      795      795      825      790
735      920      920
I5   285      285      165      120      190      240      240      250      240
200      270      270
I5   455      455      465      175      305      360      360      360      360
310      420      420
I5   155      155      190       70      140      140      140      140      140
100      150      150
I5    85       85       45       22       70       65      130      120       95
145      125      125
```

```
C. TONGUE RIVER TRIBUTARY
I2      8      UQ              TONGUE RIVER TRIBUTARY
IU      1       t        0   12FMR   12FMR   12FMR   12FMR   12FMR
I7      1              0.0   0.90      0.     32.     0.3
I5    435     435      360     305     340     365     345     370     390
350     370     370
I5     90      90       85      75      90     105      85      95     100
80      85      85
I5    310     310      310     145     225     230     230     230     240
240     270     270
I5     41      41       37      21      48      52      52      52      31
31      41      41
I5     10      10       10      10      10      10      10      10      10
10      10      10

C. PEMBINA RIVER TRIBUTARY
I2      9      UQ              PEMBINA RIVER TRIBUTARY
IU      1       t        0   12FMR   12FMR   12FMR   12FMR   12FMR
I7      1              0.0    0.90      0.     32.     0.3
I5    650     565      360     305     495     570     565     510     560
580     600     705
I5    210     175      110     100     170     190     190     160     190
195     210     230
I5    430     395      195     175     270     325     325     290     330
355     370     450
I5    110     105       70      50      80      85      85      85     100
95     110     100
I5     12      12       12      12      12      12      12      12      12
12      12      12

C. FOREST RIVER TRIBUTARY
I2     10      UQ              FOREST RIVER TRIBUTARY
IU      1       t        0   12FMR   12FMR   12FMR   12FMR   12FMR
I7      1              0.0    0.90      0.     32.     0.3
I5    630     630      555     380     505     460     555     530     535
460     510     690
I5    140     140      135     120     145     125     140     140     145
120     135     170
I5    500     500      430     210     350     330     340     320     310
320     370     480
I5    140     140      130      70      95      85      85      80      80
85     100     140
I5     45      45       45      20      20      20      35      30      30
25      30      35

C. MINNESOTA OTHER TRIBUTARIES BASED ON WILD RICE RIVER
I2     11      UQ             OTHER MINNESOTA TRIBS
IU      1       t        0   12FMR   12FMR   12FMR   12FMR   12FMR
I7      1              0.0    0.90      0.     32.     0.3
I5    450     450      390     265     285     285     315     295     355
320     350     350
I5     23      23       37      42      38      23      35      20      54
35      26      26
```

```
I5   400      400      335      200      240      240      240      240      295
280      300      300
I5    10       10        5       30       25        5       20        5       15
15       10       10
I5     4        4        4        4        4        4        4        4        4
4        4        4

C. WARWICK LOCAL FLOW CONCENTRATIONS - MONTHLY MEDIANS
C. Warwick local flow conc. assumed to be the same as mean monthly conc.
I2    12       UQ            WARWICK LOCAL FLOW QUALITY
IU     1        t        0   12FMR   12FMR   12FMR   12FMR   12FMR
I7     1               0.0    0.90      0.     32.     0.3
I5   500      525      380      370      600      700      535      520      510
400      520      450
I5    90       85       70       80      140      160      110      125      115
75       100      80
I5   300      335      350      150      270      300      260      245      230
220      220      270
I5     0        0        0        0        0        0        0        0        0
0        0        0
I5    13       13       13       13       13       13       13       13       13
13       13       13

C. LOCAL INFLOW QUALITY NEAR COOPERSTOWN
c. Coop local flow conc. computed from long term records btwn coop & warwick
I2    13       UQ            COOP LOCAL FLOW QUALITY
IU     1        t        0   12FMR   12FMR   12FMR   12FMR   12FMR
I7     1               0.0    0.90      0.     32.     0.3
I5   980      980      535      385      510      575      620      630      625
825      635      820
I5   220      220      180      120      140      140      170      155      160
230      175      220
I5   500      500      350      240      310      320      330      310      315
365      375      445
I5     0        0        0        0        0        0        0        0        0
0        0        0
I5    30       30       20       10       10       15       20       17       20
20       18       26

C. LOCAL GW INFLOW QUALITY BETWEEN DRAYTON AND EMERSON
c. Coop local flow conc. computed from long term records btwn coop & warwick
I2    14       UQ        0   #14 GW BETWEEN DRAYTON AND EMERSON
IU     1        H        0   6000.     200      400      140      80
I6    61       16        2      -2
C I7     1               0.0    0.90      0.     32.     0.3
C I5   980      980      535      385      510      575      620      630      625
825      635      820
C I5   220      220      180      120      140      140      170      155      160
230      175      220
C I5   500      500      350      240      310      320      330      310      315
365      375      445
C I5     0        0        0        0        0        0        0        0        0
0        0        0
```

```
C I5    30      30      20      10      10      15      20      17      20
20      18      26

C. LOCAL GW INFLOW QUALITY BETWEEN DRAYTON AND EMERSON
c. Coop local flow conc. computed from long term records btwn coop & warwick
I2    15      UQ       0   #14 GW BETWEEN valley city and lisbon
IU     1       H       0   1000.     150     310      60      30
I6    61      16       2      -2
C I7     1             0.0    0.90      0.     32.     0.3
C I5   980     980     535     385     510     575     620     630     625
825     635     820
C I5   220     220     180     120     140     140     170     155     160
230     175     220
C I5   500     500     350     240     310     320     330     310     315
365     375     445
C I5     0       0       0       0       0       0       0       0       0
0       0       0
C I5    30      30      20      10      10      15      20      17      20
20      18      26
```

Example HEC-5Q Input File (Nutrient Phase 2)

```
TI      Devils Lake Project Water Quality Impact
TI      Existing Baldhill Dam Configuration
TI      Nutrients, algae, pH, ice, etc.
c       Original Filename = dl5q2848.dat      update DJR/jds 7/09/98

c   set IP5 = 0 to reduce output size  |
JA      20001001        20500930      24       C       0       0

c.          GUI output interval = 5  days      |
JF  gui=  GAPWP30                              5
JF  out=  QALGPWP3.out


c. "benthic algae" triggers the benthic algae option.  All related data reside
in "balgae.dat"
benthic algae = balgae.dat

c.... Excel specific output file (CDF: do not use "," in identification)
EXCEL OUT       QALGPWP3.XXX
c               |       |       |                        |
c. flag          element Parameter Identification
C. EXCEL ELEM           4       0FLOW OUT OF DEVILS LAKE
C. EXCEL ELEM           4       4PO4-4 OUT OF DEVILS LAKE
EXCEL ELEM           72       0Flow @ COOPERSTOWN
EXCEL ELEM           72       1Temperature @ COOPERSTOWN
C. EXCEL ELEM           72       2TDS, mg/L @ COOPERSTOWN
EXCEL ELEM           72       3NO3-N, mg/L @ COOPERSTOWN
EXCEL ELEM           72       4PO4-P, mg/L @ COOPERSTOWN
EXCEL ELEM           72       5Phytoplankton @ COOPERSTOWN
EXCEL ELEM           72       7NH3-N, mg/L @ COOPERSTOWN
EXCEL ELEM           72       8Oxygen, mg/L @ COOPERSTOWN
EXCEL ELEM           72       9Labile DOM, mg/L @ COOPERSTOWN
EXCEL ELEM           72      10Refractory DOM, mg/L @ COOPERSTOWN
EXCEL ELEM           72      11Devils Lake Tracer @ COOPERSTOWN
EXCEL ELEM           72      12Alkalinity, CaCO3 @ COOPERSTOWN
EXCEL ELEM           72      13pH @ COOPERSTOWN
C. EXCEL ELEM           72      22Particulate #1 @ COOPERSTOWN
C. EXCEL ELEM           72      23Particulate #2 @ COOPERSTOWN
C. EXCEL ELEM           79       4PO4-P, mg/L INTO ASHTABULA
EXCEL ELEM           80       0Flow @ BELOW BALDHILL DAM
EXCEL ELEM           80       1Temperature @ BELOW BALDHILL DAM
C. EXCEL ELEM           80       2TDS, mg/L @ BELOW BALDHILL DAM
EXCEL ELEM           80       3NO3-N, mg/L @ BELOW BALDHILL DAM
EXCEL ELEM           80       4PO4-P, mg/L @ BELOW BALDHILL DAM
EXCEL ELEM           80       5Phytoplankton @ BELOW BALDHILL DAM
EXCEL ELEM           80       7NH3-N, mg/L @ BELOW BALDHILL DAM
EXCEL ELEM           80       8Oxygen, mg/L @ BELOW BALDHILL DAM
EXCEL ELEM           80       9Labile DOM, mg/L @ BELOW BALDHILL DAM
EXCEL ELEM           80      10Refractory DOM, mg/L @ BELOW BALDHILL DAM
EXCEL ELEM           80      11Devils Lake Tracer @ BELOW BALDHILL DAM
EXCEL ELEM           80      12Alkalinity, CaCO3 @ BELOW BALDHILL DAM
EXCEL ELEM           80      13pH @ BELOW BALDHILL DAM
```

C. EXCEL ELEM	80	22Particulate #1 @ BELOW BALDHILL DAM
C. EXCEL ELEM	80	23Particulate #2 @ BELOW BALDHILL DAM
C. EXCEL ELEM	122	0Flow @ LISBON
C. EXCEL ELEM	122	1Temperature @ LISBON
C. EXCEL ELEM	122	2TDS, mg/L @ LISBON
C. EXCEL ELEM	122	3NO3-N, mg/L @ LISBON
C. EXCEL ELEM	122	4PO4-P, mg/L @ LISBON
C. EXCEL ELEM	122	5Phytoplankton @ LISBON
C. EXCEL ELEM	122	7NH3-N, mg/L @ LISBON
C. EXCEL ELEM	122	8Oxygen, mg/L @ LISBON
C. EXCEL ELEM	122	9Labile DOM, mg/L @ LISBON
C. EXCEL ELEM	122	10Refractory DOM, mg/L @ LISBON
C. EXCEL ELEM	122	11Devils Lake Tracer @ LISBON
C. EXCEL ELEM	122	12Alkalinity, CaCO3 @ LISBON
C. EXCEL ELEM	122	13pH @ LISBON
c. EXCEL ELEM	122	22Particulate #1 @ LISBON
C. EXCEL ELEM	122	23Particulate #2 @ LISBON
EXCEL ELEM	160	0Flow @ KINDRED
EXCEL ELEM	160	1Temperature @ KINDRED
C. EXCEL ELEM	160	2TDS, mg/L @ KINDRED
EXCEL ELEM	160	3NO3-N, mg/L @ KINDRED
EXCEL ELEM	160	4PO4-P, mg/L @ KINDRED
EXCEL ELEM	160	5Phytoplankton @ KINDRED
EXCEL ELEM	160	7NH3-N, mg/L @ KINDRED
EXCEL ELEM	160	8Oxygen, mg/L @ KINDRED
EXCEL ELEM	160	9Labile DOM, mg/L @ KINDRED
EXCEL ELEM	160	10Refractory DOM, mg/L @ KINDRED
EXCEL ELEM	160	11Devils Lake Tracer @ KINDRED
EXCEL ELEM	160	12Alkalinity, CaCO3 @ KINDRED
EXCEL ELEM	160	13pH @ KINDRED
C. EXCEL ELEM	160	22Particulate #1 @ KINDRED
C. EXCEL ELEM	160	23Particulate #2 @ KINDRED
c. EXCEL ELEM	170	1Temperature @ HORACE
EXCEL ELEM	216	0Flow @ HALSTAD
EXCEL ELEM	216	1Temperature @ HALSTAD
C. EXCEL ELEM	216	2TDS, mg/L @ HALSTAD
EXCEL ELEM	216	3NO3-N, mg/L @ HALSTAD
EXCEL ELEM	216	4PO4-P, mg/L @ HALSTAD
EXCEL ELEM	216	5Phytoplankton @ HALSTAD
EXCEL ELEM	216	7NH3-N, mg/L @ HALSTAD
EXCEL ELEM	216	8Oxygen, mg/L @ HALSTAD
EXCEL ELEM	216	9Labile DOM, mg/L @ HALSTAD
EXCEL ELEM	216	10Refractory DOM, mg/L @ HALSTAD
EXCEL ELEM	216	11Devils Lake Tracer @ HALSTAD
EXCEL ELEM	216	12Alkalinity, CaCO3 @ HALSTAD
EXCEL ELEM	216	13pH @ HALSTAD
c EXCEL ELEM	216	22Particulate #1 @ HALSTAD
C. EXCEL ELEM	216	23Particulate #2 @ HALSTAD
EXCEL ELEM	246	0Flow @ GRAND FORKS
EXCEL ELEM	246	1Temperature @ GRAND FORKS
C. EXCEL ELEM	246	2TDS, mg/L @ GRAND FORKS
EXCEL ELEM	246	3NO3-N, mg/L @ GRAND FORKS
EXCEL ELEM	246	4PO4-P, mg/L @ GRAND FORKS
EXCEL ELEM	246	5Phytoplankton @ GRAND FORKS

```
EXCEL ELEM          246       7NH3-N, mg/L @ GRAND FORKS
EXCEL ELEM          246       8Oxygen, mg/L @ GRAND FORKS
EXCEL ELEM          246       9Labile DOM, mg/L @ GRAND FORKS
EXCEL ELEM          246      10Refractory DOM, mg/L @ GRAND FORKS
EXCEL ELEM          246      11Devils Lake Tracer @ GRAND FORKS
EXCEL ELEM          246      12Alkalinity, CaCO3 @ GRAND FORKS
EXCEL ELEM          246      13pH @ GRAND FORKS
C. EXCEL ELEM          246      22Particulate #1 @ GRAND FORKS
C. EXCEL ELEM          246      23Particulate #2 @ GRAND FORKS
EXCEL ELEM          302       0Flow @ CanUSA
EXCEL ELEM          302       1Temperature @ CanUSA
C. EXCEL ELEM          302       2TDS, mg/L @ CanUSA
EXCEL ELEM          302       3NO3-N, mg/L @ CanUSA
EXCEL ELEM          302       4PO4-P, mg/L @ CanUSA
EXCEL ELEM          302       5Phytoplankton @ CanUSA
EXCEL ELEM          302       7NH3-N, mg/L @ CanUSA
EXCEL ELEM          302       8Oxygen, mg/L @ CanUSA
EXCEL ELEM          302       9Labile DOM, mg/L @ CanUSA
EXCEL ELEM          302      10Refractory DOM, mg/L @ CanUSA
EXCEL ELEM          302      11Devils Lake Tracer @ CanUSA
EXCEL ELEM          302      12Alkalinity, CaCO3 @ CanUSA
EXCEL ELEM          302      13pH @ CanUSA
C. EXCEL ELEM          302      22Particulate #1 @ CanUSA
C. EXCEL ELEM          302      23Particulate #2 @ CanUSA

c.   ID1      F1     ID2      F2     ID3      F3     min     max
JG     1      1.                                       0     36.Temperature, C
JG     2      1.                                       0   1000.TDS
JG     7      1.                                       0     0.5NH3-N, mg/L
JG     3      1.                                       0     1.0NO3-N, mg/L
JG     4      1.                                       0     1.0PO4-P, mg/L
c. Algae in mg/L ===> 10 ug/L (1:100)
JG     5     10.                                       0    100.Chlorophyll a,
ug/L
c. 5-Day BOD:  DOM 1 @ 0.06/day + DOM 2 @ 0.02/day + phytoplankton @ 0.2/day
c. resp = 0.2/day; (i-exp(-R*t))*1.4 = 0.9; 0.06 ==> 0.36; 0.02 ==> 0.13
JG     5     0.9      9     .36      10     .13        0     10.BOD5, mg/L
c. dissolved organic carbon (DOC): DOM1 + DOM2
JG     9     .40     10     .40                        0
10.algae+DOM==>DOC, mg/L
JG    22     .40      5     .40                        0     10.Algae+TSS1-C,
mg/L
JG    22      1.     23      1.                        0     50.TSS1+TSS2
JG     8      1.                                       0     18.Oxygen, mg/L
JG    11      1.                                       0   1000.Devils Lake
Tracer
JG    12      1.                                       0    400.Alkalinity,
CaCO3
JG    13      1.                                       6     10.pH
JG   BA1    .001                                       0     25.Benthic Algae,
g/M2
JG   BA2    .001                                       0   1000.Benthic Algae,
g/M
```

```
JG   BA3      1.                                       0    100.Benthic Algae,
mg/L
JG    28                                               0    500.Flow, cfs
JG    29                                            1500      1.Elevation,
feet

nolist


C.  Fargo, ND Meteorological data
EZFILE= METWET7.Y2K
EZEND

c. DSS input
c. Tag   A Part  B Part         C Part        F Part    E Part  D Part
c. T574  DEVIL   FARGO          EQTEMP        AVERAGE   1DAY    01JAN1971 -
01JAN2000
c. T604  - - -   - - - - - - -  EXRATE        AVERAGE   1DAY    01JAN1971 -
01JAN2000
c. T634  - - -   - - - - - - -  SWRAD         AVERAGE   1DAY    01JAN1971 -
01JAN2000
c. T664  - - -   - - - - - - -  WIND          AVERAGE   1DAY    01JAN1971 -
01JAN2000
c. Note that the "C" part may be omitted if these identifications are used
c. i.e., A single record >>> "ET  A=Devil  B=Fargo  E=1day  F=Average"
c. If the "C" part is included, the input sequence must be for ET, KE, solar
rad and wind
C EZ            24      PR ZR      FARGO HOURLY DATA
C ET  A=Devil  B=Fargo  C=EQTEMP0   E=1day  F=Average
C ET  A=Devil  B=Fargo  C=EXRATE0   E=1day  F=Average
C ET  A=Devil  B=Fargo  C=SWRAD0    E=1day  F=Average
C ET  A=Devil  B=Fargo  C=WIND0     E=1day  F=Average
C EZ            24      PR ZR      Dazey HOURLY DATA
C ET  A=Devil  B=dazey  C=EQTEMP   E=1day  F=Average
C ET  A=Devil  B=dazey  C=EXRATE   E=1day  F=Average
C ET  A=Devil  B=dazey  C=SWRAD    E=1day  F=Average
C ET  A=Devil  B=dazey  C=WIND     E=1day  F=Average
C EZEND

C

list

c IPHYTO   CONID(1)
C.    WQ DLTRACE     pH/Alk                          TSS
QC     6       1       1       0       0       0       2       0

c      |   printout interval = 1/2 year to reduce output size
L1   182       1

c. Dummy Reservoir, Sheyenne River Headwater

c.  IRCP    METL     IPL     SDZ    EDMAX   XQPCT   XQDEP      IZ   FICEL
L2  1464       1                       8.     0.4      1.       0       0
```

```
LA           20.
RS      5     10.      20.      32.      46.      62.
RA      5      9.      11.      13.      15.      17.
RE      5    1440     1441     1442     1443     1444

LS      0       0      1.0     1000        0       20       11     1442
R1      1      20       11      100      200        0
LI      I  IN   F        1       1.                  HWY 30 INFLOW
R1      2      20       11      100      200        0

L9  TEMP     1.0        0
L9 TDS       500        0
L9 NO3-N     .20        0
L9 PO4-P     .15        0
L9 algae     .20        0
L9 NH3-N     .20        0
L9 LDOM       2.        0
L9 RDOM       8.        0
L9 oxy      12.5        0
L9 Soxy     250.        0
L9 SNH3       8.        0
L9 SPO4       2.        0
L9 CL-       0.0        0
L9 ALKA     220.        0
L9 PH        8.0        0
L9 SSOL1      5.        0
L9 SSOL2      5.        0


c. The following records contain values of coefficients and rate constants
c. used in the equations for various water quality parameters.  The
c. coefficients specified on records KA through KF are global and pertain to
c. all reservoirs and stream reaches.  These coefficients can only be set with
c. the first reservoirs data.  If these data are not entered at that time,
c. the default values would apply.

C. QUNCON  QCBOD   QNBOD  QREAIR    QCSS    QCCB   QCDOM    QMN2    QFE2   QS2
KA          1.06    1.06      -1    1.06            1.06
KA  1.07

C.O2CBOD  O2NBOD  O2RESP  O2PHOT  RO2CO2  CO2BOD   O2DOM   O2MN2   O2FE2  O2S2
c.KB      0      -1      1.2     1.6     1.0     .20     1.2      -1      -1
-1
KB      0      -1      1.2     1.6     1.0     .20     1.2      -1      -1    -1

C.  BIOP    BION    BIOC  ALG_RN  ALG_MN  ALG_RD  ALG_MD  ALG_RS  ALG_MS
c.KC  .008     .05     .40     .60     .20     .25     .30     .15     .50
KC  .008     .05     .40     .50     .10     .40     .30     .10     .60

C. DOMP1   DOMN1   DOMC1   DOMP2   DOMN2   DOMC2
KD  .005    .035     .40    .005    .035     .40

C. SSOLP   SSOLN   SSOLC  SSOLO2
```

```
KE  .005    .035     .40     1.4

C. OXLIM   FN0O2   FP0O2  FD10O2  FD20O2  FD30O2  FSS0O2
KF   1.5     1.0      3.       .5      .5      .5      .5

C.  PMAX   PRESP   PSETL   TPS2L    PS2N    PS2P    PS2C  EXTINP    XLAT
EDMAX
K1   2.0     .20    0.33  0.0050    .050    .025      -1      -1    47.1
8.0

C. PMORT(1-10)        Mar     Apr     May     Jun     Jul     Aug     Sep
Oct
C.K2  .005    .005    .010    .025    .040    .045    .040    .035    .025
.015
C.K2  .010    .005

C. ALGT1   ALGT2   ALGT3   ALGT4
K3    2.     18.     26.     32.

C.UCONDK  BODCDK   NH3DK   NO3DK   TCBDK  DOMDK1  DOMDK2  DOMDK3
c.DK                  .060    .080      -1    .040   0.005    0.02
DK                   .050    .050      -1    .020   0.002    0.02

C.   ISU   TEMP1    VEL1   TEMP2    VEL2   TEMP3    VEL3     EXT    SSDK
TAUCD
DS    -1      1.     0.7     18.     0.8     28.     0.9     .15    .004
.10
DS    -2      1.     1.9     18.     2.0     28.     2.1     .05    .000
.10

c    ISU  PPART1  PPART2  PO4SET   TAUCD  NO3UPTK
c.PS     1      0.      0.     .20     .10     .10

EL


c. Dummy Reservoir, Devils Lake Inflow

c.  IRCP    METL     IPL     SDZ   EDMAX   XQPCT   XQDEP      IZ   FICEL
L2   999       1                      8.     0.4      1.       0       0
LA            20.
RS     5     10.     20.     32.     46.     62.
RA     5      9.     11.     13.     15.     17.
RE     5    1440    1441    1442    1443    1444

LS     0       0     1.0    1000       0      20      11    1442
R1     1      20      11     100     200       0
LI     I IN   F        2      1.DL INFLO
R1     2      20      11     100     200       0


EL

C. Lake Ashtabula
```

```
c.ID IRCP   METL     IPL     SDZ   EDMAX   XQPCT   XQDEP      IZ   FICEL
L2  1271       1                     -8.     0.4     1.0       3       6

c second L2 Record (optional continuation)
c  FK2R:   Fractional reduction in the dissolved oxygen deficit/excess in
c          the reservoir release due to tailwater reaeration.c
c  FK2C:   Fractional reduction in the carbon dioxide deficit/excess in
c          the reservoir release due to tailwater reaeration.
c  FK2S:   Fractional reduction in the sulfide concentration in the
c          reservoir release due to tailwater reaeration.
c  SFMET1: Scaling factor for the equilibrium temperature.
c  SFMET2: Scaling factor for the surface heat exchange rate.
c          SFMET 1 & 2 may be used to adjust meteorological conditions to the
site.
c   FK2R    FK2C    FK2S  SFMET1  SFMET2
L2    1.      1.             1.0     1.3

c. Seasonal Ice Cover
c. Lake Astabula ice thickness / 20 Nov 2000 10:36 e.mail
c.Date          day    ice
c.15-Nov  320  320  0
c.25-Nov  330  330  3.5
c.5-Dec   340  340  8
c.15-Dec  350  350 11.8
c.25-Dec  360  360 15.2
c.4-Jan   370    4 18.8
c.14-Jan  380   14 21.5
c.24-Jan  390   24 24
c.3-Feb   400   34 25.8
c.13-Feb  410   44 26.5
c.23-Feb  420   54 26.3
c.5-Mar   430   64 25
c.15-Mar  440   74 22.3
c.25-Mar  450   84 18.5
c.4-Apr   460   94 13
c.14-Apr  470  104  5.5
c.24-Apr  475  114  0

RX            0    17.0       4    18.8      14    21.5      24    24.0
RX           34    25.8      44    26.5      54    26.3      64    25.0
RX           74    22.3      84    18.5      94    13.0     104     5.5
RX          114     0.0     320     0.0     330     3.5     340     8.0
RX          350    11.8     360    15.2     366    17.0

C. Seasonal Secchi Disk (with ice thickness effects)
LE            1       2      90       8     150       5     210       6
LE          300       8     366       2

RS    30      0      50     300    1000    2500    4400    6500   10500
14200
RS 25100  31000   32600   34200   37600   41300   45500   50000   54500
59500
```

```
RS 65000   70600   71740   76300   82100   88300   95000  101300  107800
115000
RS116500
RA    30       0      50     100     250     550     800    1100    1500
1800
RA  2600    3300    3400    3550    3750    4000    4250    4500    4700
5000
RA  5200    5400    5500    5700    5900    6150    6400    6600    6800
7150
RA  7200
RE    30    1223    1225    1230    1235    1240    1243    1245    1248
1250
RE  1255    1257  1257.5    1258    1259    1260    1261    1262    1263
1264
RE  1265    1266  1266.2    1267    1268    1269    1270    1271    1272
1273
RE1273.2

c.ISROP2  ISROP3      A3    SRDX    DEQT    TOTV    TOTA   SRELC
LS            17    100.    3520       0  116500    7200       0

c.lt  10  .01E-4   2.E-4   1.E-6     -1.     .75
c.lt    10  .01E-4   2.E-4  2.0E-6    -7.5     .75
lt    10  .01E-4   5.E-4  0.4E-6    -25.    1.33
LU           0.1     0.1     0.1     0.1     0.1     0.1     0.1     0.1
0.1
LU           0.1

C Lake Ashtabula Section 30, RM 1303
R2     1    7000  1257.6      10  1258.0      30  1259.3      60  1261.3
75
R31265.5     108  1267.5     130  1270.3     220  1271.0     320

LI    CP            1303      1.
LV US        0.1     0.1     0.1     0.1     0.1     0.1     0.1     0.1
0.1
LV           0.1

C Lake Ashtabula Section 23, RM 1301.5
R2     2   11400  1255.0      10  1257.6      57  1260.0      85  1263.4
116
R31264.0     130  1265.0     240  1268.0     280  1271.0     280

C Lake Ashtabula Section 20, RM 1299.4
R2     3   10400  1251.8      25  1256.0      90  1258.0     127  1260.8
150
R31262.6     230  1262.7     282  1265.6     340  1266.4     420  1271.0
1170

LV US        0.1     0.1     0.1     0.1     0.1     0.1     0.1     0.1
0.1
LV           0.1

C Lake Ashtabula Section 19, RM 1298.2
```

```
R2      4    5100  1252.0      50  1256.0     220  1257.0     335  1263.0
420
R31265.0     500  1268.8     800  1269.0     940  1271.0    1200

C Lake Ashtabula Section 18, RM 1296.9
R2      5    5250  1249.0      10  1253.5      85  1256.0     185  1259.0
660
R31264.0     925  1271.0    1450

C Lake Ashtabula Section 17, RM 1295.3
R2      6    9300  1249.2      50  1259.0     165  1262.2     650  1263.8
950
R31265.0    1290  1269.5    1355  1271.0    1365

C Lake Ashtabula Section 16, RM 1292.6
R2      7   10900  1246.0      10  1249.4     120  1254.0     195  1259.5
495
R31260.0     880  1265.0    1500  1266.5    1560  1271.0    1720

c.LV  DS         -1      14    1.33
c.LV  DS         -1      14    2.0

C Lake Ashtabula Section 15, RM 1289.8
R2      8   10600  1246.0      10  1251.0     140  1253.8     380  1257.0
745
R31260.0    1400  1266.7    1870  1271.0    2040

C Lake Ashtabula Section 14, RM 1287.0
R2      9   12950  1241.6      10  1244.0     195  1250.0     435  1256.5
1360
R31263.5    1800  1266.0    1890  1271.0    1910

C Lake Ashtabula Section 13, RM 1284.0
R2     10    7900  1239.0      50  1244.0     295  1249.0     465  1254.5
950
R31260.0    1220  1265.5    1410  1271.0    1550

C Lake Ashtabula Section 8, RM 1283.0
R2     11    2175  1237.0      10  1240.0     100  1251.4     330  1253.0
1150
R31262.0    2320  1269.0    2550  1271.0    2630
LI      I IN F           5     1.0    BALDHILL CREEK

C Lake Ashtabula Section 6, RM 1282.0
R2     12    6175  1239.0      10  1241.4     120  1247.5     230  1253.5
290
R31260.0    2605  1266.5    2745  1271.0    2755

C Lake Ashtabula Section 5, RM 1279.5
R2     13   10550  1232.0      50  1240.0     125  1244.0     320  1247.0
1250
R31248.0    1265  1254.0    1612  1260.0    1780  1266.0    1980  1271.0
1995
```

```
C Lake Ashtabula Section 4, RM 1277.3
R2    14    9900  1230.0      10  1238.0     305  1241.0     430  1243.0
530
R31245.0     920  1250.0    2080  1264.0    2420  1271.0    2585

c.LV  DS        -1      17    1.33

C Lake Ashtabula Section 3, RM 1274.7
R2    15    9700  1227.5      60  1238.0     175  1241.0     230  1242.5
1050
R31250.0    1300  1260.0    1600  1271.0    1850

LV  DS        -1       4    1.25

C Lake Ashtabula Section 2, RM 1272.0
R2    16    8250  1225.0      10  1230.0     140  1235.0     320  1240.0
1180
R31250.0    1650  1260.0    1900  1271.0    2045

c Lake Ashtabula Section 1, RM 1271.0
R2    17    3200  1223.0      40  1226.0     115  1237.0     220  1240.0
1250
R31244.5    1300  1250.0    1500  1260.0    1640  1271.0    1770

c. This record specifies that flow diverts to the second weir/orifice
(spillway) as
c. flow increases beyond 440 cfs (QSET1).  As flow drops below 220 cfs
(QSET2), the
c. flow diverts back to weir/orifice #1 (low level outlet)
c.    Loc   NWEIR1  WELEV1  WIDTH1   QSET1  NWEIR2  WELEV2  WIDTH2   QSET2
QWMIN   LAYMQ
c.LW   DS        2   1252.    120.    440.       1   1239.     60.    220.
0
LW   DS        2   1252.    120.    440.       1   1242.     60.    400.
12.       8

L9 TEMP      4.0       0
L9 TDS       500       0
L9 NO3-N     .20       0
L9 PO4-P     .15       0
L9 algae     .20       0
L9 NH3-N     .20       0
L9 LDOM       2.       0
L9 RDOM       8.       0
L9 oxy      12.5       0
L9 Soxy     500.       0
L9 SNH3       4.       0
c.... use 1/2 measured ( 8 mgm2day results in too much PO4 )
L9 SPO4       2.       0
L9 CL-         0       0
L9 ALKA     220.       0
L9 PH        8.0       0
L9 SSOL1      5.       0
L9 SSOL2      5.       0
```

```
EL

c. Dummy Reservoir, Red River Headwater

c.  IRCP    METL     IPL     SDZ   EDMAX   XQPCT   XQDEP      IZ   FICEL
L2   453       1                      8.     0.4      1.       0       0
LA           20.
RS     5     10.     20.     32.     46.     62.
RA     5      9.     11.     13.     15.     17.
RE     5     877     878     879     880     881

LS                   1.0    1000       0      20      11     879
R1     1      20      11     100     200       0
LI     I IN   F        3      1. Red Riv
R1     2      20      11     100     200       0

L9  TEMP       1       0
L9 TDS       500       0
L9 NO3-N     .15       0
L9 PO4-P     .15       0
L9 algae     .20       0
L9 NH3-N     .15       0
L9 LDOM       2.       0
L9 RDOM       8.       0
L9 oxy      12.5       0
L9 Soxy     250.       0
L9 SNH3       8.       0
L9 SPO4       2.       0
L9 CL-         0       0
L9 ALKA     220.       0
L9 PH        7.9       0
L9 SSOL1      5.       0
L9 SSOL2      5.       0

EL

C. STREAM DATA

c      |   printout interval = 1/2 year to reduce output size
S1   182       1       0

c. Sheyenne - Red River of the North
C  Head waters of Sheyenne River, Highway 30 south of Maddock, ND
C  to Devils Lake inflow.

S2  1464   464.0    1463   463.2   0.4
SI    I  IN   F     463.5      12      1.   Incr. Inflow Quality nr Warwick

c. stream benthic sink / source rates
SB   250      8.      2.

C.  Use elevated algal respairation to represent the conversion of settled
algae to nutrients / DOM
```

```
C.  PMAX   PRESP   PSETL   TPS2L    PS2N    PS2P    PS2C  EXTINP    XLAT
EDMAX
K1   0.2     2.0     0.0   0.050    .120    .025      -1      -1    47.1
8.0

C.UCONDK  BODCDK   NH3DK   NO3DK   TCBDK  DOMDK1  DOMDK2  DOMDK3
c.DK                  0.60    .080      -1    .060   0.008    0.03
DK                  0.20    .080      -1    .030   0.003    0.03

C.   ISU   TEMP1    VEL1   TEMP2    VEL2   TEMP3    VEL3     EXT    SSDK
TAUCD
DS    -1      1.    .001     18.    .002     28.    .003     .20    .010
.10

C. DL TO CONFLUENCE
S2   999  1465.2    1463 1463.2    1.000

C. CONFLUENCE TO WARWICK
S2  1463   463.2    1408   407.5   1.989
SI     I  IN  F      435      12     1.0   LOCAL INFLOW  Warwick

C. WARWICK TO COOPERSTOWN
S2  1408   407.5    1317   317.0   2.262
SI     I  IN  F      362      13     1.0  COMPUTED LOCAL COOP QUALITY

C. COOPERSTOWN TO LAKE ASHTABULA
S2  1317   317.0    1303   303.0   2.000
SI     I  IN  F      310       5     1.0  BHC QUALITY

C. BALDHILL DAM TO VALLEY CITY
S2  1271   270.5    1253   253.0   2.500
SI     I  IN  F      260       5      1.  BHC QUALITY

C. VALLEY CITY TO LISBON
S2  1253   253.0    1162   162.1   2.525
SI     I  IN         250      17     .41  Valley City
SI     I  IN  F      240       5      1.  BHC QUALITY
SI     I  IN  NP   170.0      15    0.10  LOW FLOW INPUT

C. LISBON TO KINDRED
S2  1162   162.1    1068    67.9   2.479
SI     I  IN         161      17     .06  Lisbon
SI     I  IN  F      158       5    0.27 Timber Coulee
SI     I  IN  F      150       5    0.47 Dead Colt Creek
SI     I  IN  F       94       5    0.26 Iron Springs
C.      BALDHILL CREEK WQ
C.      0.17 ADDED TO TC &DCC, 0.18 TO IRON SPRINGS FOR LQ DIST.

C === Sheyeene River, RM 67.9 Kindred  ND USGS Gage 05059000 ===
C === to Sheyeene River at Junction with Red River ===
S2  1068    67.9     428     0.0   2.611
SI     I  IN         65.      17    .004  Kindred
SI     I  IN  F     19.8       6    0.84 Maple River (84% of Local Flow)
SI     I  IN         15.      17     .35  Fargo to Sheyenne
```

```
SI    I  IN  F      11.4       6    0.16 Rush River (9.7% of Local Flow)
C. ALL LOCAL FLOW MUST BE ACCOUNTED FOR WITH A QUALITY

C === Red River, RM 454.0 Fargo, ND USGS Gage 05054000
C === to Red River at Junction with Sheyeene River
S2   453   453.0     428   427.5   2.550
SI    I  IN           450      17     3.3  Fargo / Moorhead
SI    I  IN  F        440      11      1.  MINN TRIB QUALITY
C === No Tributaries in this reach

C === Sheyenne River Junction at Red River, RM 427.2
C === to Red River, RM 375.2 at Halstad, MN ===
S2   428   427.5     375   375.2   2.615
SI    I  IN  F     417.2      11     .44  Buffalo  (31% of total local)
SI    I  IN  F     380.3      11     .56  Wild Rice MN (43% of total local)
C. .13 ADDED TO EACH TRIB TO ACCOUNT FOR LOCAL INFLOW

C === Red River, RM 375.2 at Halstad, MN ===
C === to Red River, RM 296.2 at Grand Forks ND ===
S2   375   375.2     296   296.2   2.633
SI    I  IN  NP       372      16    0.01  Nutrient source
SI    I  IN  F     357.9       6     .27  Goose (19% of total local)
C SI    I  IN  F     357.1       6     .05  Marsh (2% of total local)
SI    I  IN  F     336.3       6     .10  Sandhill (7% of total local)
SI    I  IN  F     298.0       4     .63  Red Lake (60% of total local)
C.  0.03 ADDED TO EACH TRIB TO ACCOUNT FOR LOCAL FLOW
C  Goose andMarsh Rivers entered the same element, Marsh was combined to
C  enter at the same location as Goose, both have similar wq types,
C  5% Marsh flow added to 22% Goose flow to toal 27%.  jds 6/18/97

C === Red River, RM 296.2 at Grand Forks ND ===
C === to RM 271.2: Oslo MN, USGS Gage 05083500 ===
S2   296   296.2     271   271.2   2.500
SI    I  IN           295      17     3.7  Grand Forks
SI    I  IN  NP       290      16    0.01  Nutrient source
SI    I  IN  F        284       4     0.5  ASSUME RED LK QUALITY
SI    I  IN  F        280       7     0.5  ASSUME PARK

C === No Tributaries in this reach

C === RM 271.2 Oslo MN, USGS Gage 05083500 ===
C === To RM 206.7 Drayton, ND USGS Gage 05092000 ===
S2   271   271.2     207   206.7   2.481
SI    I  IN  NP    260.0      16    0.01  Nutrient source
SI    I  IN  F     243.3      10     .28  Forest
SI    I  IN  F     230.2      11     .29  Snake
SI    I  IN  F     222.3       7     .30  Park
SI    I  IN  F     219.5      11     .13  Tamarac
C. 0.02 ADDED TO ALL BUT TAMARAC WHICH GOT 0.03 ADDED   FOR LOCAL FLOW

C === RM 206.7 Drayton, ND USGS Gage 05092000 ===
C === to RM 155.0 International Boundary ===
S2   207   206.7      99   155.0   2.585
SI    I  IN  NP    204.0      14    0.25  LOW FLOW INPUT
```

```
SI     I  IN  F     175.1      11      .25  Two Rivers
SI     I  IN  F     158.0       9      .75  Pembina
C. 0.02 ADDED TO EACH TO ACCOUNT FOR LOCAL FLOW

C.  Sheyenne River
c.  US CP   DS CP    METZ   HEXF   K2OPP   RK2MI     RK2   K2min   K2max
C.                     DC  BEDDC  BEDDEP      IZ   FICEL
SR  1464    1303        1    .90       2       0    -1.5     1.0    10.0
SR                   0.44   .010     1.0       1       6
SX                1    12     15      15      35      18      50      18
SX               65    17     85      15     100       5     110       0
SX              320     0    366      12
SR  1271     428        1   0.95       2       0    -1.5     1.0    10.0
SR                   0.44   .010     1.0       1       6

C. Red River
SR  -453      99        1     1.       2       0    -1.5     1.0    10.0
SR                   0.44   .010     1.0       2       6
SX                1    12     15      15      35      18      50      18
SX               65    17     85      15     100       5     110       0
SX              320     0    366      12

nolist

c.... Stream x-section data
S3FILE= S3rev.DAT
S3END

ES

list

C... TRIBUTARY INFLOW DATA........... 1996 - 1999
I1      20001001        20500930

c.  All inflow data for this application are input via file
c. "Trib_alg.dat" as specified by the "I2FILE=" Record.
c.  The file contains comments regarding the data.

I2FILE= TRWQPWP3.dat

I2END

EI

c.... Gate operatiuon data not required if all reservoirs are longitudinally
segmented
C.... TYPICAL GATE OPERATION DATA
c G1      20000101        20471231
c G2 1464 20000131       1
c G2  999 20000131       1
c G2 1271 20000131       1
c G2  453 20000131       1
ER
```

Example Tributary WQ File (Nutrient)

```
c  1 Flow                         Parameter #
c  2 Temperature                        1
c  3 TDS                                2
c  4 NO3-N                              3
c  5 PO4-P                              4
c  6 Phytoplankton                      5
c  7 NH3-N                              7
c  8 Dissolved Oxygen                   8
c  9 Labile DOM (C-BOD)                 9
c 10 Refractory DOM                    10
c 11 Devils Lake Tracer                11
c 12 Alkalinity as CaCO3               12
c 13 pH                                13
c 13 Volatile Suspended Solids         22
c 14 Colloidal Suspended Solids        23

c      1       2       3       4       5       6       7       8       9
10      11      12
c      |       |       |       |       |       |       |       |       |
|       |       |

c. Global scaling factors for tributaries.
c.... scale Ch_a to phytoplankton : 10 ug/L = 1 mg/L
c.   flow    temp     tds      NO3      PO4   algae     NH3      DO    DOM 1   DOM
2
IG    1.      1.      1.       1.       1.     .10      1.       1.      2.0
10.0
c.    DL      Alka     pH     SS#1     SS#2
IG   1.0      1.0      1.      1.       1.

I2      1      UQ          Sheyenne River Headwaters (HWY 30)
c.   flow    temp     tds      NO3      PO4   algae     NH3      DO    DOM 1   DOM
2
c.    DL     Alka      pH     SS#1     SS#2
IU      1       t      I3      .25    12FMR     H       .15      H       1.0
1.5
IU      0     200     7.7       F1      F1
I7      1            0.00     0.90      0.     32.      0.3
I3   ZR    a=DEVIL     b=HWY 30          c=TDS-INC        f=THS7
I5   .10    .260     .26      .25      .22     .25     .29     .27      .22
.23     .10     .10
I6     14      5.     -4.       .0
I6     15     10.      .3      3.0
I7   1464            -1.     0.01      0.5     99.
I7   1464           -12.     0.10      1.0    999.


C. DEVILS LAKE INFLOW
I2      2      UQ          Devils Lake Inflow
IU      1       t      I3     .045      .29     S 2     .04      H       1.0
1.
```

```
IU  1000     290     8.4     S 2      1.
I7     1             0.00    0.90     0.     32.     0.3
I3  ZR    a=devil     b=devils lake      c=TDS-INC       f=THS7 PL300PUMP
I8    21      0.     .30     75.     .35    135.     .20    165.     .15
I8           270.     .15    330.     .20    366.     .30
I6    23     .06    .035    .010
c. I6    24      5.     -4.      .0
c. I6    25     10.      .3     3.0
c... Phytoplankton to VSS (wag)
I8    22      0.     .10     75.     .15    135.     2.0    165.    5.0
I8           270.     5.0    330.     .20    366.     .10

C. RED RIVER HEADWATERS; Red RM 453
I2     3     UQ              Red River Headwaters Tributary
IU     1        t   12FMR     .20   12FMR     H       .10     H       1.0
1.
IU     0     200     7.8      F1      F1
I7     1             0.00    0.95     0.     32.     0.3
I5   345     350     320     360     375     355     370     330     415
290     315     410
I5   .63     .42     .52     .31     .47     .47     .66     .36     1.0
.30     .34     .39
I6    34      5.     -4.      .0
I6    35     10.      .3     3.0
I7   453             -1.   0.002     0.5     99.
I7   453            -12.    0.02     1.0    999.


c. RED LAKE RIVER TRIBUTARY; Red RM 298
I2     4     UQ              Red Lake River Tributary
c.  flow    temp     tds     NO3     PO4   algae     NH3      DO   DOM 1   DOM
2
c.    DL    Alka      pH    SS#1    SS#2
IU     1        t   12FMR     .30   12FMR     H       .10     H       1.0
1.6
IU     0     170     8.0      F1      F1
I7     1             0.00    0.99     0.     32.     0.3
I5   250     230     240     230     290     300     290     240     310
270     260     260
I5   .04     .03     .16     .14     .06     .08     .15     .06     .11
.06     .06     .03
I6    44      5.     -4.      .0
I6    45     10.      .3     3.0
I7   296             -1.   0.001     0.5     99.
I7   296            -12.    0.01     1.0    999.

C. BALDHILL CREEK TRIBUTARY; Sheyenne RM 280
I2     5      UQ             BALDHILL CREEK TRIBUTARY
c.  flow    temp     tds     NO3     PO4   algae     NH3      DO   DOM 1   DOM
2
c.    DL    Alka      pH    SS#1    SS#2
IU     1        t   12FMR     .25   12FMR     H       .15     H       1.0
1.2
IU     0     170     7.8      F1      F1
```

```
I7     1             0.00    0.90      0.      32.     0.3
I5   860     860     250     210     505     600     650     645     560
625     625     795
I5    .1    .130     .30     .20     .17     .15     .17     .17     .10
.10     .10     .10
I6    54      5.      -4.      .0
I6    55     10.       .3     3.0
I7   296              -1.   0.001     0.5     99.
I7   296             -12.    0.01     1.0    999.

C. GOOSE, MAPLE, RUSH AND BEAVER COMBINED TRIBUTARIES; Sheyenne RM 10 to 20
I2      6      UQ              GOOSE COMBINED TRIBS
IU      1       t   12FMR     .35   12FMR     H       .20     H       1.0
1.
IU      0     300     8.0      F1      F1
I7      1            0.00    0.95      0.      32.     0.3
I5  1490    1530     355     500     910    1060    1070     915     925
1020    1080    1370
I5   .10    .200     .36     .18     .11     .21     .27     .28     .22
.10     .10     .10
I6    64      5.      -4.      .0
I6    65     10.       .3     3.0
I7   428              -1.   0.004     0.5     99.
I7   428             -12.    0.04     1.0    999.

C. PARK RIVER TRIBUTARY; Red RM 222
I2      7      UQ                PARK RIVER TRIBUTARY
IU      1       t   12FMR     .30   12FMR     H       .10     H       1.0
1.
IU      0     200     8.0      F1      F1
I7      1            0.00    0.90      0.      32.     0.3
I5   865     865     550     355     585     795     795     825     790
735     920     920
I5   .09     .49     .42     .38     .21     .20     .33     .36     .23
.14     .14     .14
I6    74      5.      -4.      .0
I6    75     10.       .3     3.0
I7   271              -1.   0.006     0.5     99.
I7   271             -12.    0.06     1.0    999.

C. TONGUE RIVER TRIBUTARY; Red RM ??? (not used)
I2      8      UQ                TONGUE RIVER TRIBUTARY
IU      1       t   12FMR     .30   12FMR     H       .10     H       1.0
1.
IU      0     200     8.0      F1      F1
I7      1            0.00    0.90      0.      32.     0.3
I5   435     435     360     305     340     365     345     370     390
350     370     370
I5   .09     .49     .42     .38     .21     .20     .33     .36     .23
.14     .14     .14
I6    84      5.      -4.      .0
I6    85     10.       .3     3.0
I7    99             -1.2   0.002     0.5     99.
I7    99             -12.    0.02     1.0    999.
```

```
C. PEMBINA RIVER TRIBUTARY; Red RM 158
I2     9      UQ             PEMBINA RIVER TRIBUTARY
IU     1       t   12FMR     .30   12FMR     H        .10     H       1.0
1.
IU     0     200     8.0     F1      F1
I7     1             0.00    0.90     0.      32.     0.3
I5   650     565     360     305     495     570     565     510     560
580     600     705
I5   .09     .49     .42     .38     .21     .20     .33     .36     .23
.14     .14     .14
I6    94      5.     -4.      .0
I6    95     10.      .3     3.0
I7    99             -1.2   0.002     0.5     99.
I7    99             -12.    0.02     1.0    999.

C. FOREST RIVER TRIBUTARY; Red RM 243
I2    10      UQ             FOREST RIVER TRIBUTARY
IU     1       t   12FMR     .30   12FMR     H        .10     H       1.0
1.
IU     0     200     8.0     F1      F1
I7     1             0.00    0.90     0.      32.     0.3
I5   630     630     555     380     505     460     555     530     535
460     510     690
I5   .09     .49     .42     .38     .21     .20     .33     .36     .23
.14     .14     .14
I6   104      5.     -4.      .0
I6   105     10.      .3     3.0
I7   207             -1.    0.002     0.5     99.
I7   207             -12.    0.02     1.0    999.

C. MINNESOTA OTHER TRIBUTARIES BASED ON WILD RICE RIVER; Red RM 380 to 430
I2    11      UQ            OTHER MINNESOTA TRIBS
IU     1       t   12FMR     .30   12FMR     H        .10     H       1.0
1.
IU     0     300     7.9     F1      F1
I7     1             0.00    0.90     0.      32.     0.3
I5   450     450     390     265     285     285     315     295     355
320     350     350
I5   .10     .15     .30     .30     .17     .15     .17     .17     .15
.10     .10     .10
I6   114      5.     -4.      .0
I6   115     10.      .3     3.0
I7   428             -1.    0.005     0.5     99.
I7   428             -12.    0.05     1.0    999.

C. Warwick local flow conc. assumed to be the same as mean monthly conc.;
Sheyenne RM 435
I2    12      UQ           WARWICK LOCAL FLOW QUALITY
IU     1       t   12FMR     .25   12FMR     H        .15     H       1.0
1.
IU     0     260     7.9     F1      F1
I7     1             0.00    0.90     0.      32.     0.3
```

```
I5   500     525     380     370     600     700     535     520     510
400     520     450
I5   .20    .260     .26     .25     .22     .25     .29     .27     .22
.23     .20     .20
I6   124      5.     -4.      .0
I6   125     10.      .3     3.0
I7  1408             -1.    0.05     0.5     99.
I7  1408            -12.    0.50     1.0    999.

c. Coop local flow conc. computed from long term records btwn coop & warwick;
Sheyenne RM 362
I2    13      UQ           COOP LOCAL FLOW QUALITY
IU     1       t   12FMR     .25   12FMR     H       .15     H       1.0
1.
IU     0     280     7.8      F1      F1
I7     1            0.00    0.90      0.     32.     0.3
I5   980     980     535     385     510     575     620     630     625
825     635     820
I5   .20    .260     .26     .25     .22     .25     .29     .27     .22
.23     .20     .20
I6   134      5.     -4.      .0
I6   135     10.      .3     3.0
I7  1317             -1.    0.01     0.5     99.
I7  1317            -12.    0.10     1.0    999.

C. LOCAL GW INFLOW QUALITY BETWEEN DRAYTON AND EMERSON
c. Coop local flow conc. computed from long term records btwn coop & warwick
I2    14      UQ       0   #14 GW BETWEEN DRAYTON AND EMERSON
c.  flow    temp     tds     NO3     PO4   algae     NH3      DO   DOM 1   DOM
2
c.    DL    Alka      pH    SS#1    SS#2
IU     1       H   6000.      1.      .1      0.     .01      2.       0
5
IU     0     500     7.0      0.      0.
I6    61      16       2      -2

C. LOCAL GW INFLOW QUALITY BETWEEN DRAYTON AND EMERSON
c. Coop local flow conc. computed from long term records btwn coop & warwick
I2    15      UQ       0   #14 GW BETWEEN valley city and lisbon
IU     1       H   1000.      2.      .1      0.     .01      2.       0
.2
IU     0     500     7.0      0.      0.
I6    61      16       2      -2

C. GW INFLOW to the Red River
I2    16      UQ       0   #14 GW BETWEEN valley city and lisbon
c.  flow    temp     tds     NO3     PO4   algae     NH3      DO   DOM 1   DOM
2
c.    DL    Alka      pH    SS#1    SS#2
IU     1       H   1000.      5.      .1      0.      .1      2.       0
.2
IU     0     500     7.0      0.      0.
I6    61      16       2      -2
```

```
c.  flow    temp     tds     NO3     PO4   algae    NH3      DO   DOM 1   DOM
2
IG   1.      1.      1.      .1      .1     .10      .1      1.      .2
.2
c.   DL     Alka      pH    SS#1    SS#2
IG  1.0     1.0      1.      1.      1.
C. Concentration Secondary
I2   17     UQ              Concentration Secondary
c.  flow    temp     tds     NO3     PO4   algae    NH3      DO   DOM 1   DOM
2
c.   DL    Alka       pH    SS#1    SS#2
IU    1       t    1000.     20.      8.      0.    100      5.     100
100
IU    0     200      7.5     50.     50.
I7    1             0.00    0.95      0.     32.    0.3
```

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8. Minnesota Pollution Control Agency, Red River Basin Information Document, 1997, pp. 37-44.

9. Cowdery, 1998, Ground-Water Quality in the Red River of the North Basin, Minnesota and North Dakota, 1991-1995, USGS Water-Resources Investigations Report 98-4175.

10. Smith, 2001, **Revision to Exhibit 3. Description of Program Input, from HEC-5 Simulation of Flood Control and Conservation Systems, Appendix on Water Quality Analysis.**

Section 5 – Hydrologic Effectiveness

To evaluate the hydrologic effectiveness of the proposed outlet plans, three sets of statistics or appraisals were developed. The first sets are elevation-frequency relationships for with- and without-project conditions. Elevation-frequency conveys the probability that a specified elevation will be equaled or exceeded in any given year. It is commonly used in floodplain management to establish the 100-yr floodplain. The second set of statistics conveys the frequency of traces whose maximum elevations would equal or exceed specified lake levels over their 50-yr period. It is a measure of risk. It is similar to elevation-frequency mentioned before; however, probability is expressed in terms of a 50-yr period rather than in any given year. These two sets are presented with respect to the stochastic analysis.

The third set describes the reduction in peak and long-term lake levels. They indicate how well the outlet plans performed by drawing the lake down. This analysis is probably of most direct interest because it defines the maximum extent of flooding with and without the outlet. This set is addressed with respect to the scenarios. In describing the effectiveness of each plan, **Table A5-1** describes the nomenclature that is used to identify each plan in the figures and tables in this report

Elevation Frequency (Stochastically Based)

To evaluate the hydrologic effectiveness of proposed Devils Lake management measures, comparison with the existing, without-project condition is necessary. A variety of analyses can be done, but the most pertinent and most applicable characterization for a terminal lake is the lake's elevation-frequency. By comparing this relationship for with- and without-project, a quantitative measure of the outlet's hydrologic effectiveness can be made.

Figure A5-1 shows possible future levels of Devils Lake along with the probability of exceeding those levels, given initial conditions existing in October 2000. Probabilities are computed based on 10,000 traces from a statistical water mass-balance model. This is for the without-project condition. The model simulations began 01 Oct 2000 with an initial lake level of 1446.0 feet above sea level. The lake level that is exceeded with a given probability may change depending on antecedent precipitation, lake levels, and inflows at the beginning of the simulation period. The magnitude of the change is greater during periods of extreme wet or dry conditions. Information in this figure should not be used to forecast future lake behavior, because the limited temporal resolution of the model is not sufficient for short-term prediction. It is not used to forecast actual lake levels in the near term. However, assuming stationary climatic conditions, the figure can be used by water resource managers to determine the likelihood of future lake levels.

The Devils Lake elevation at the 1-percent exceedence frequency can be estimated for any given year in the next 50 years. As seen in **Figure A5-1** it does vary from year to year but eventually reaches an equilibrium elevation value of approximately 1457.

TABLE A5-1
PLAN NOMENCLATURE WITH DESCRIPTION

ALTERNATIVE	DESCRIPTION
W/O project	Without-project.
WB300/450	West Bay, 300 cfs, constrained outlet for 450 mg/l SO4 and 600 cfs Sheyenne River channel capacity.
WB480	West Bay,480 cfs, unconstrained outlet.
PL300/450	Pelican Lake 300 cfs, constrained outlet for 450 mg/l SO4 and 600 cfs Sheyenne River channel capacity.
PL480	Pelican Lake, 480 cfs, unconstrained outlet.
UBS	50 % Upper Basin Storage
UBS/300/450	50 % Upper Basin Storage, West Bay 300 cfs, constrained outlet for 450 mg/l SO4 and 600 cfs Sheyenne River channel capacity.
EDL480	East Devils Lake, 480 cfs, unconstrained outlet.
PL2/480/250	Pelican Lake, 480 cfs, constrained outlet for 250 mg/l SO4 and 600 cfs Sheyenne River channel capacity. "PL2" refers to Pelican plan 2 whereby Big Coulee and rerouted Channel A flow is sequestered behind HWY 19. No West Bay backflow into Pelican Lake. Pelican Lake may drawdown below West Bay, but is not allowed to exceed West Bay elevation. Excess runoff is allowed to flow into West Bay.
PL3/480/250	Pelican Lake, 480 cfs, constrained outlet for 250 mg/l SO4 and 600 cfs Sheyenne Rive channel capacity. "PL3" refers to same plan as "PL2" except Pelican Lake is allowed to exceed West Bay's elevation up to 1454.
PLUGTC	Toulna Coulee outlet is plugged to elevation 1463. No outlet.
WB480/350/ZIEB	West Bay, 480 cfs, constrained outlet for 350 mg/l SO4. A barrier is installed at Zieback Pass to prevent higher concentrated flow east of the Pass from back-fluxing into West Bay.
WB480/450	West Bay, 480 cfs, constrained outlet for 450 mg/l SO4 and 600 cfs Sheyenne River channel capacity.
WB480/350/HWY57	West Bay, 480 cfs, constrained outlet for 350 mg/l SO4 and 600 cfs Sheyenne River channel capacity. A barrier is installed at HWY 57 to prevent higher concentrated flow east of HWY 57 from back-fluxing into West Bay.
PL480/300/HWY57	Pelican Lake, 480 cfs, constrained outlet for 300 mg/l SO4 and 600 cfs Sheyenne River channel capacity. A barrier is installed at HWY 57 to prevent higher concentrated flow east of HWY 57 from back-fluxing into Pelican Lake.
SWC100/300/375	NDSWC plan 100 cfs yr 2004, 300 cfs total in yr. 2006, constrained for 375 mg/l SO4 and 600 cfs Sheyenne River channel capacity. Drawdown to elev. 1441.4 ft.
SWC100/300/300	NDSWC plan 100 cfs yr 2004, 300 cfs total in yr. 2006, constrained for 300 mg/l SO4 and 600 cfs Sheyenne River channel capacity. Includes Dry Lake Diversion. Drawdown to elev. 1443.0 ft.
SWC100/250/PL300/450	NDSWC plan 100 cfs constrained for 250 mg/l SO4, yr 2003 to yr 2005 then Pelican Lake 300 cfs constrained for 450 mg/l SO4 and 600 cfs channel capacity. No concurrent pumping. Drawdown to elev. 1441.4 ft.
SWC100/PL300/375	NDSWC plan 100 cfs yr 2004 plus Pelican Lake 300 cfs both constrained for 375 mg/l SO4 and 600 cfs channel capacity. Concurrent pumping. Drawdown to elev. 1441.4 ft.
PL300/250	Pelican Lake, 300 cfs, outlet, constrained for 250 mg/l SO4 and 600 cfs Sheyenne River channel capacity. Drawdown to elev. 1441.4 ft.
PL300/375	Pelican Lake, 300 cfs, constrained for 375 mg/l SO4 and 600 cfs Sheyenne River channel capacity. Drawdown to elev. 1441.4 ft.
PL300/300	Pelican Lake 300 cfs, outlet, constrained for 300 mg/l SO4 and 600 cfs Sheyenne River channel capacity. Drawdown to elev. 1443.0 ft.
PL300/300/ND	Pelican Lake 300 cfs, outlet, constrained for 300 mg/l SO4 and 600 cfs Sheyenne River channel capacity. Drawdown to elev. 1443.0. No Dry L. diversion.
PL300/300/NAP	Pelican Lake 300 cfs, outlet, constrained for 300 mg/l SO4 and 600 cfs Sheyenne River channel capacity. Drawdown to elev. 1443.0. No August pumping.
PL300/300/ramp	Pelican Lake 300 cfs, outlet, constrained for 300 mg/l SO4 and 600 cfs Sheyenne River channel capacity. Drawdown to elev. 1443.0. Ramp up during period in 50 cfs increments. Ramp down only at end of 50-yr period.
PL300/300/fcst	Pelican Lake 300 cfs, outlet, constrained for 300 mg/l SO4 and 600 cfs Sheyenne River channel capacity. Drawdown to elev. 1443.0. If inflows up to June 1 are greater than 60,000 ac.-ft., then 300 cfs pump capacity. If less than 60,000 ac.-ft., then 200 cfs pumping capacity.

Figures A5-2 to A5-10 also present the with-project elevation-frequency relationships for each alternative simulated in the stochastic analysis. The East Devils Lake 480 cfs alternative results are the same as the West Bay and Pelican Lake 480 cfs plans. These figures show reductions for each percentile. For example, the peak elevation for the 1-percent elevation-frequency in any given year is lowered for the Pelican Lake 300 cfs plan (constrained for 450 mg/l), by 1.2 ft. during the 50-yr simulation and by 4.6 ft. at the end of 50 years. **Figure A5-11** shows the same information as **Figure A5-1** only in terms of the full range of elevations.

Risk of High Lake Levels (stochastically based)

The other evaluation tool for plan effectiveness included the tallying of the number of traces with peak elevations that equaled or exceeded a given elevation within a specified time period. **Table A5-2** summarizes this information by listing the number of traces in percent for specified key elevations for each alternative. Examination of this table indicates, as expected, that the frequency of all lake levels are reduced for all plans.

Figure A5-12 shows the frequency plots for durations from 10- to 50-yrs. **Figure A5-13** and **A5-14** show the alternatives studied with the stochastic analysis for the 50-yr duration.

TABLE A5-2
Percent of Traces That Equal
Or Exceed Specified Elevation
In 50-years

	ELEVATION (ft. asl)				
PLAN	**1448**	**1450**	**1453**	**1455**	**1459**
W/O PROJECT	84.8	50.6	29.3	20.4	9.4
WB300/450	83.1	45.2	22.2	14.2	5.2
WB480	73.9	29	11.1	6.9	2.5
PL300/450	78.4	36.1	16.2	10.6	4.1
PL480	73.9	29.1	11.1	6.9	2.5
UBS[1]	82.9	45.6	25.4	17.3	7.7
UBS/300/450[2]	81.1	41.3	19.8	12.9	4.6
EDL480	73.9	29	11.1	6.9	2.5
PL2/480/250	78.9	37.4	16.8	10.6	4.21
PL3/480/250	74.1	31.3	16.2	10.2	4.1
PL300/350/wd	79.6	38.5	17.3	11.1	4.3
PL300/350/nd	82.0	43.3	20.9	13.5	5.2
PL300/300	80.6	40.2	18.3	12.0	4.6

[1] Upper Basin Storage, 50% Restoration
[2] West Bay 300cfs pump, 50% Upper Basin Storage & Expanded Infrastructure

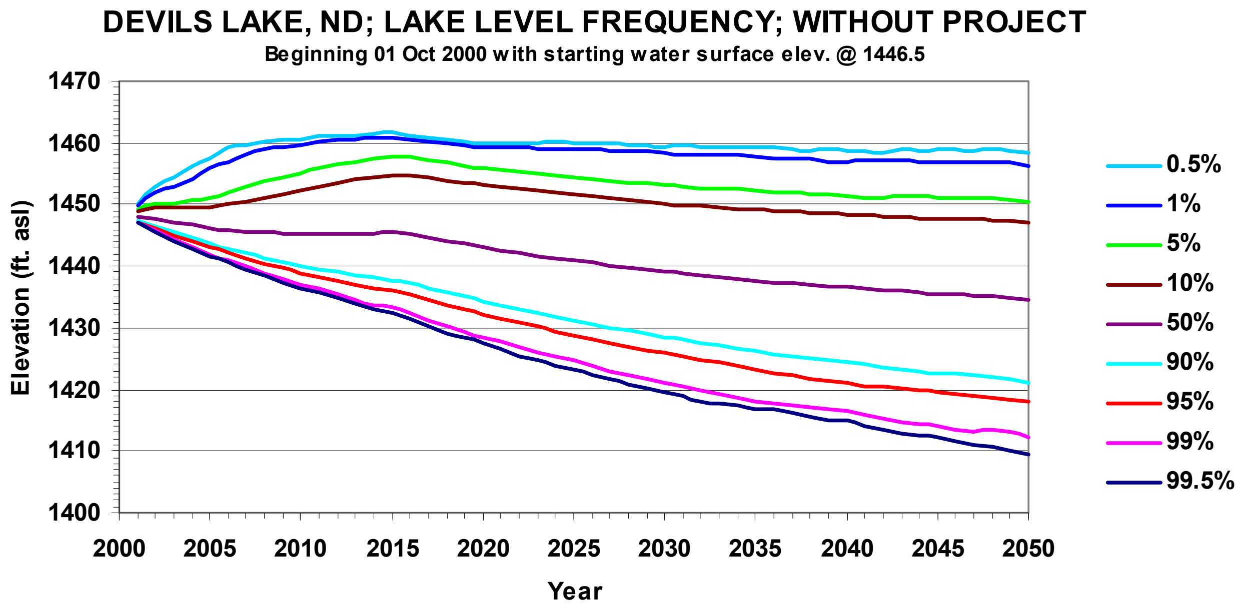


FIGURE A5-1

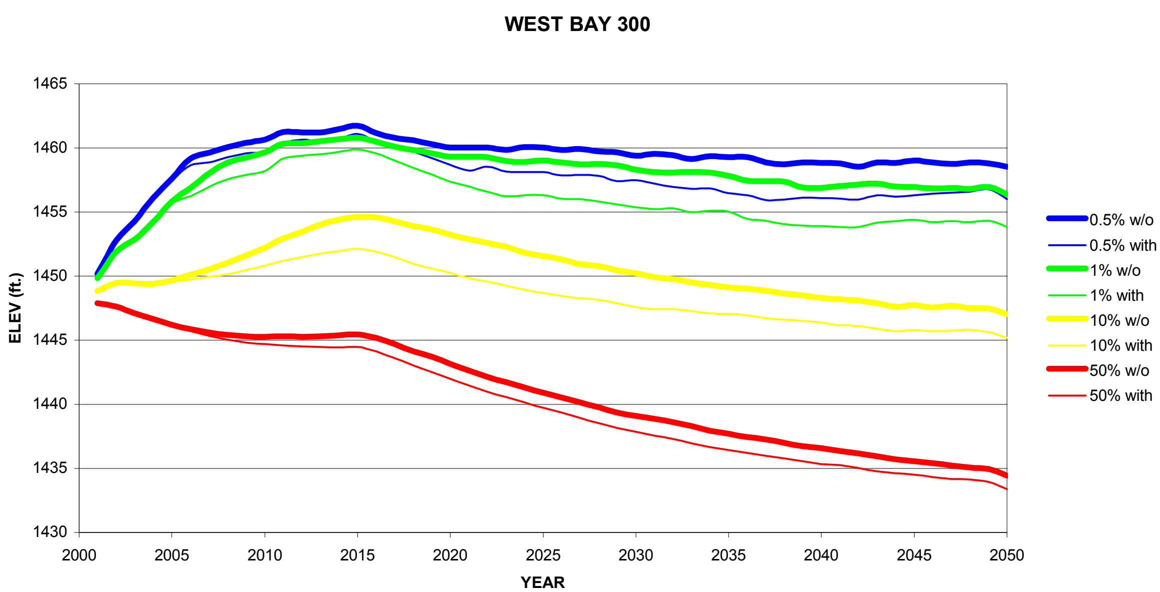


FIGURE A5-2

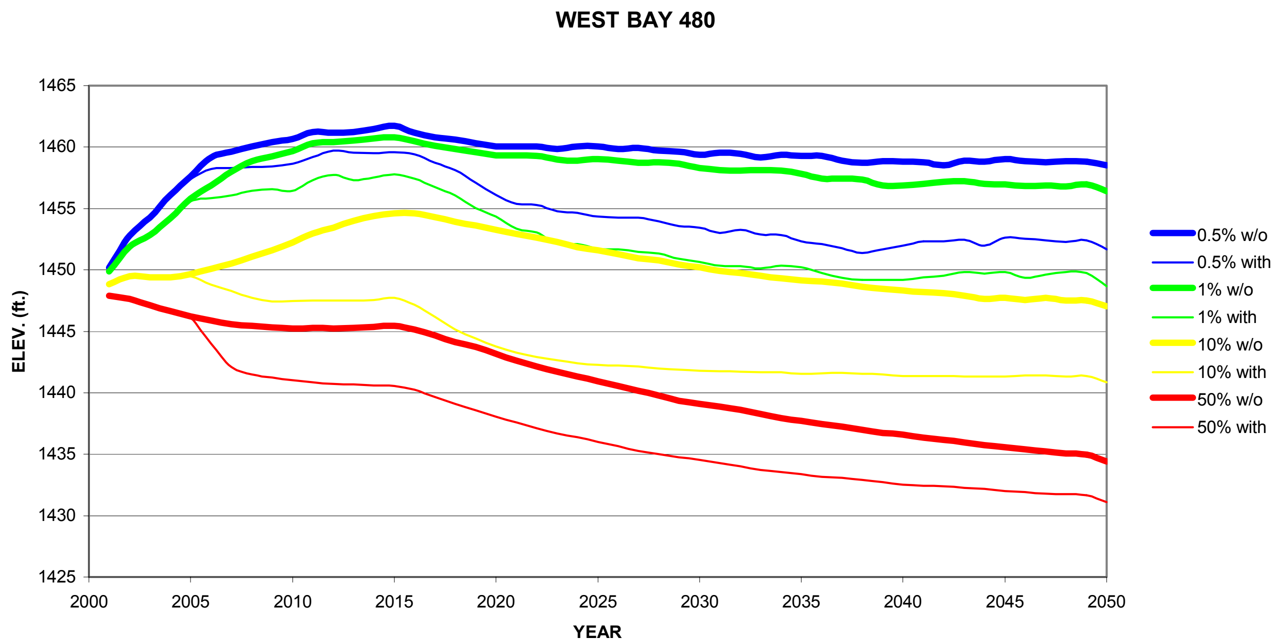


FIGURE A5-3

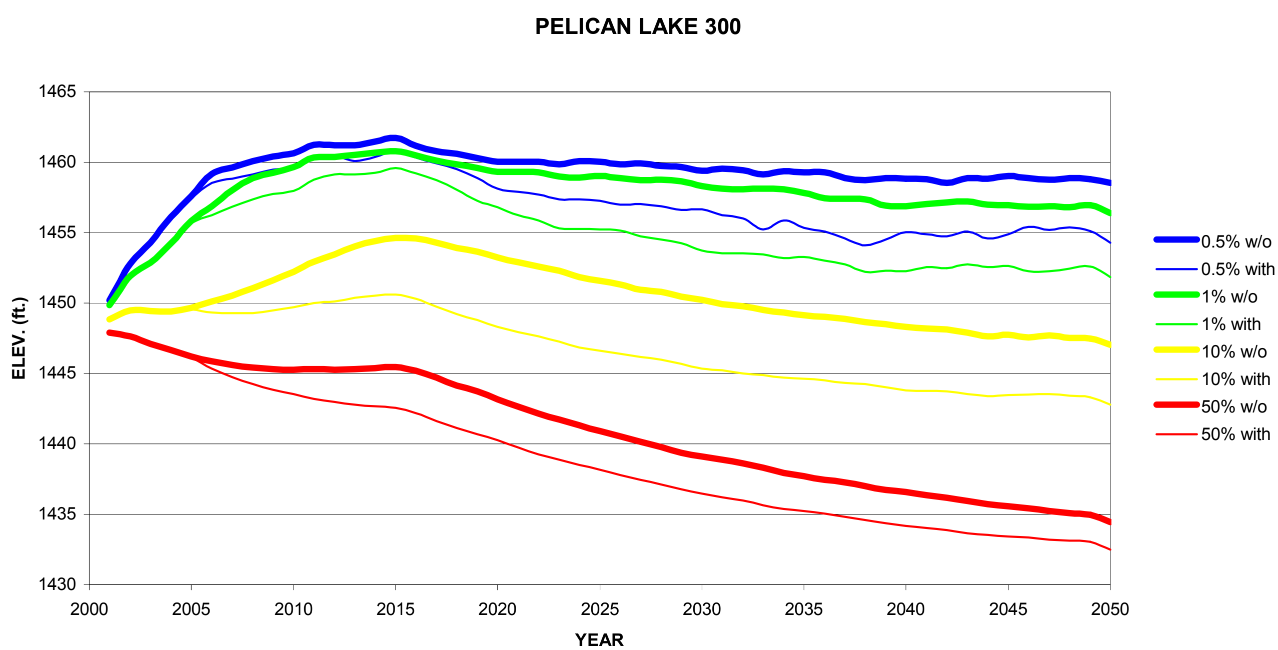


FIGURE A5-4

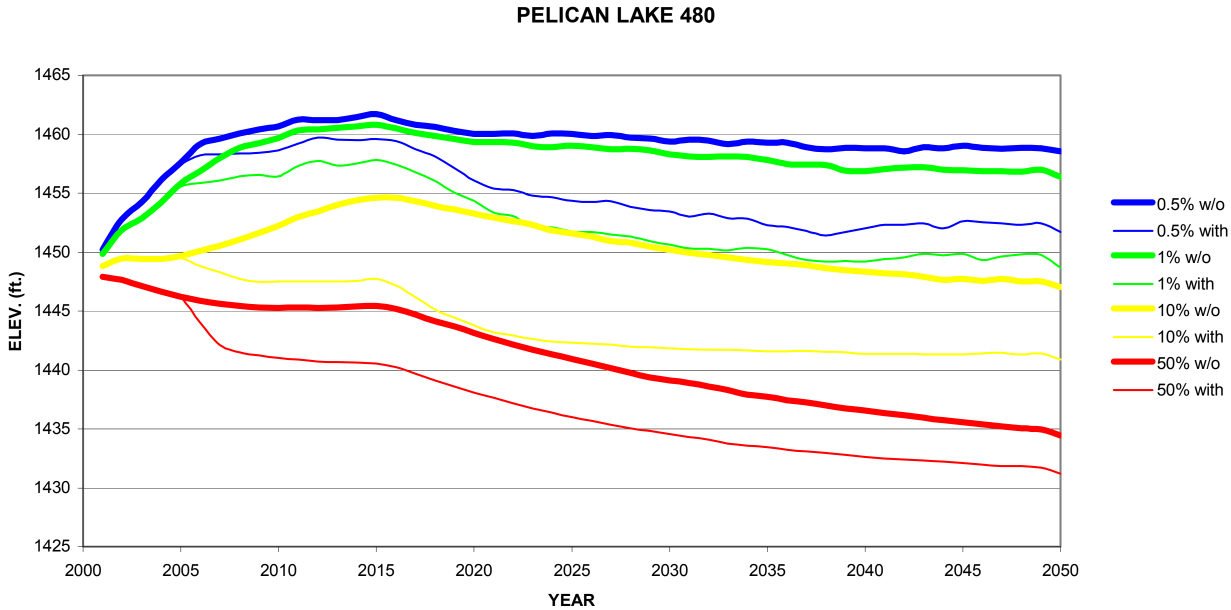


FIGURE A5-5

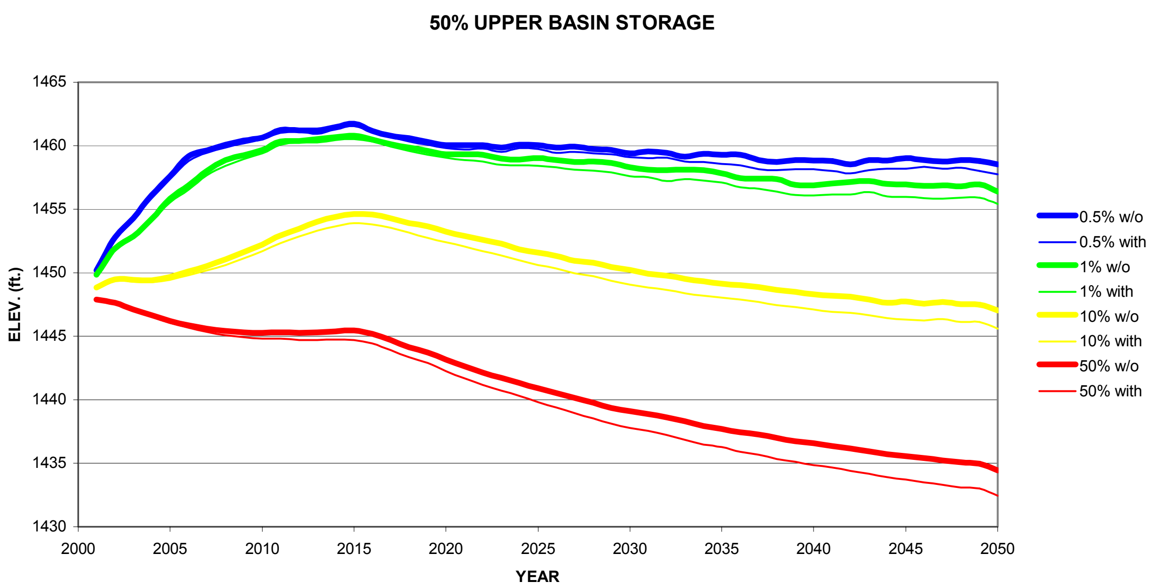


FIGURE A5-6

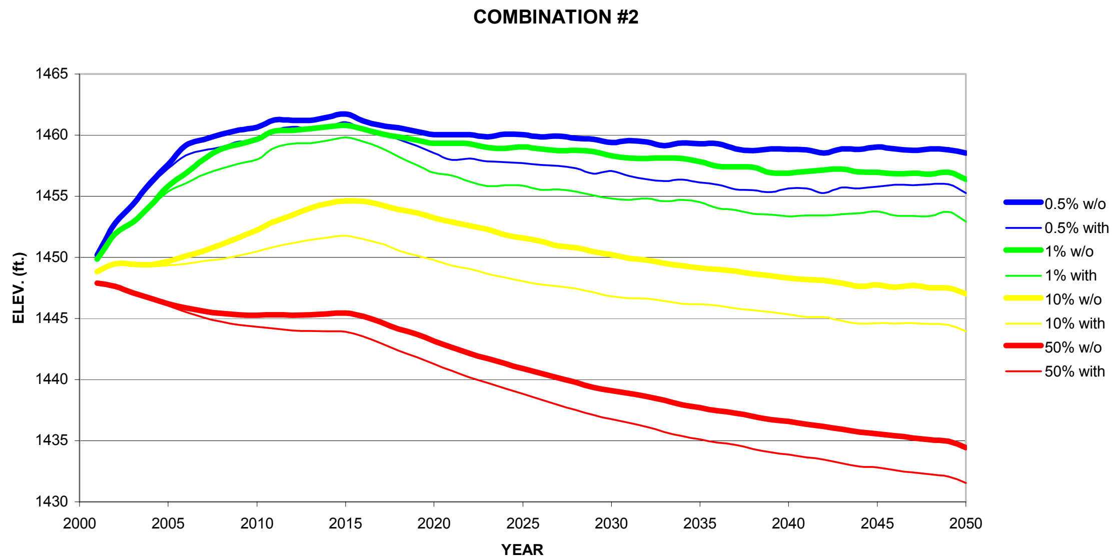


FIGURE A5-7

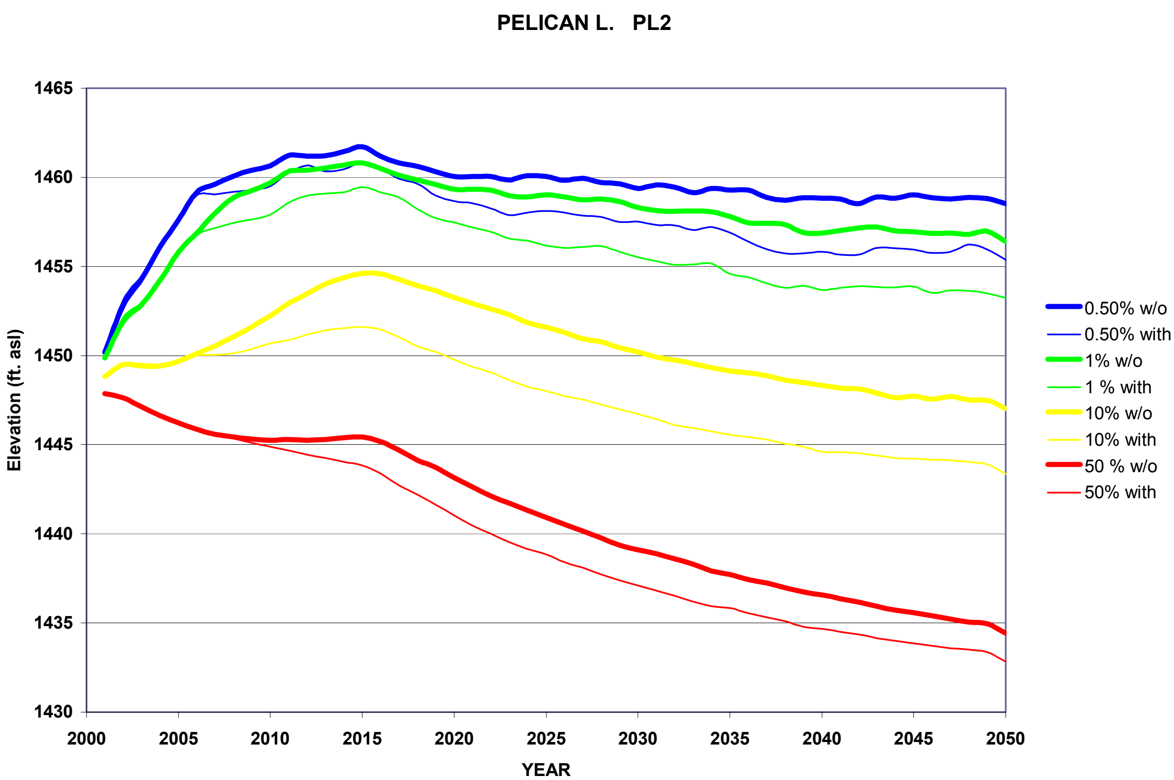


FIGURE A5-8

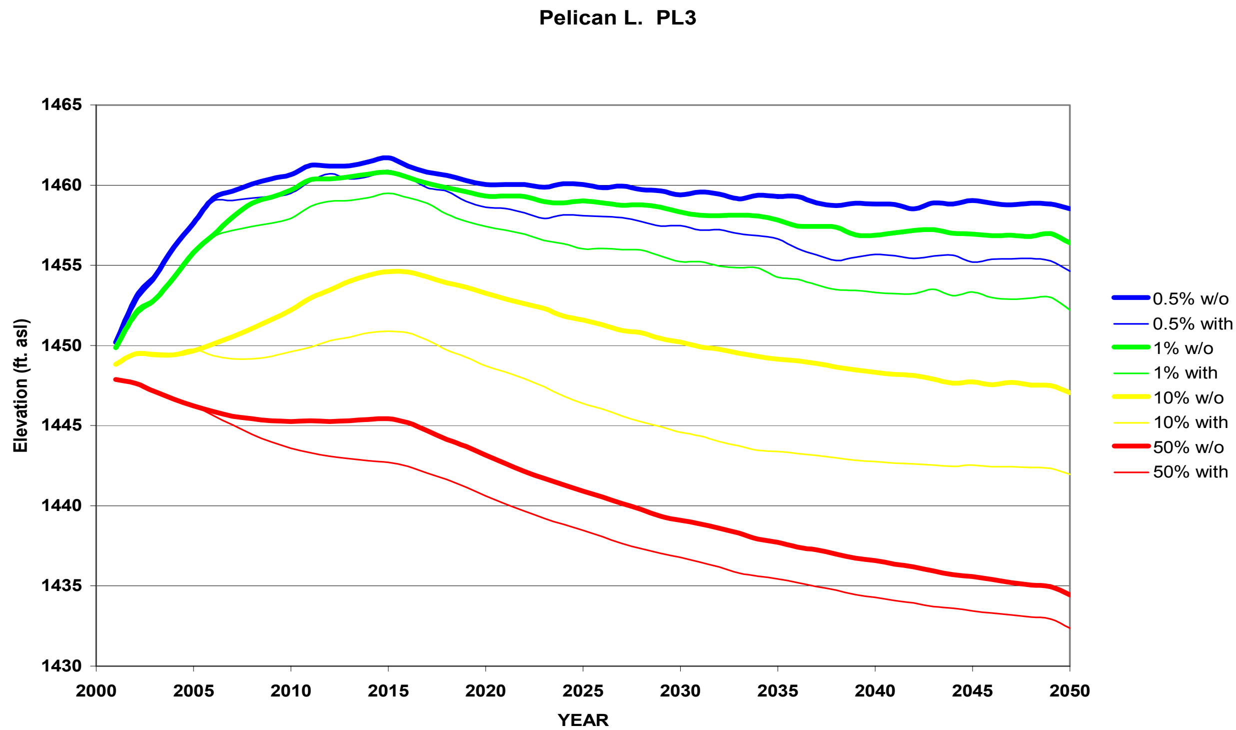


FIGURE H-9

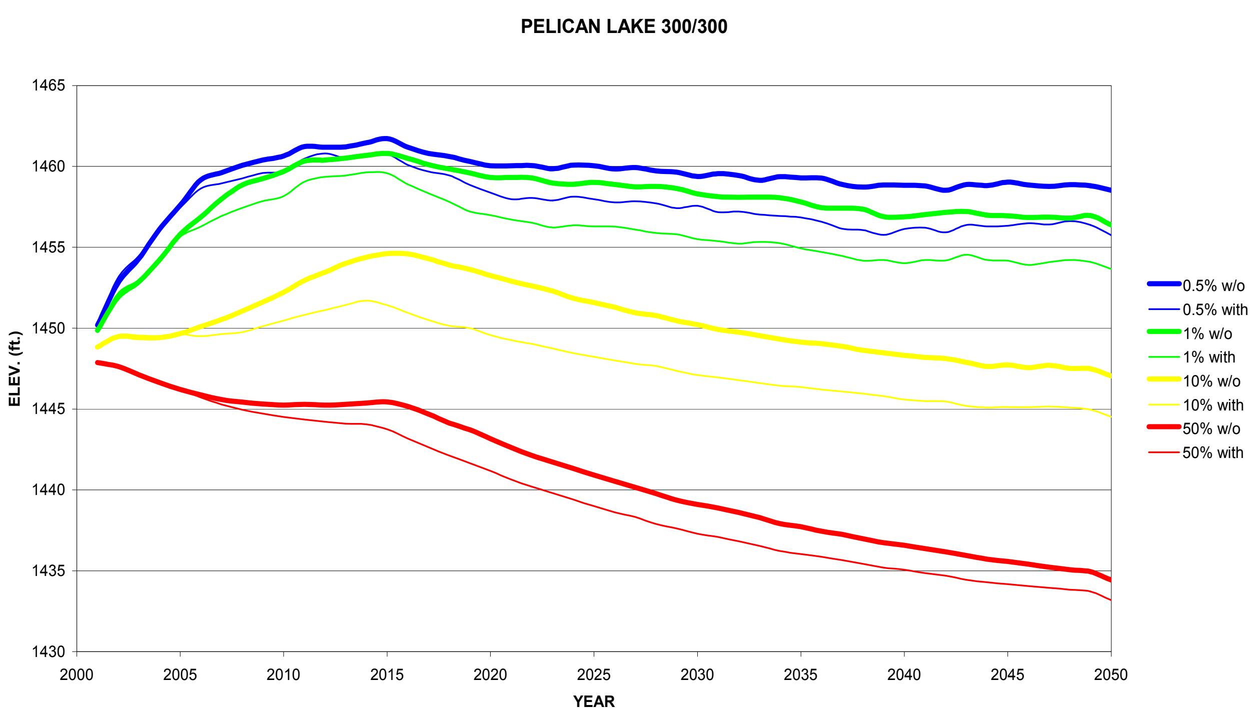


FIGURE A5-10

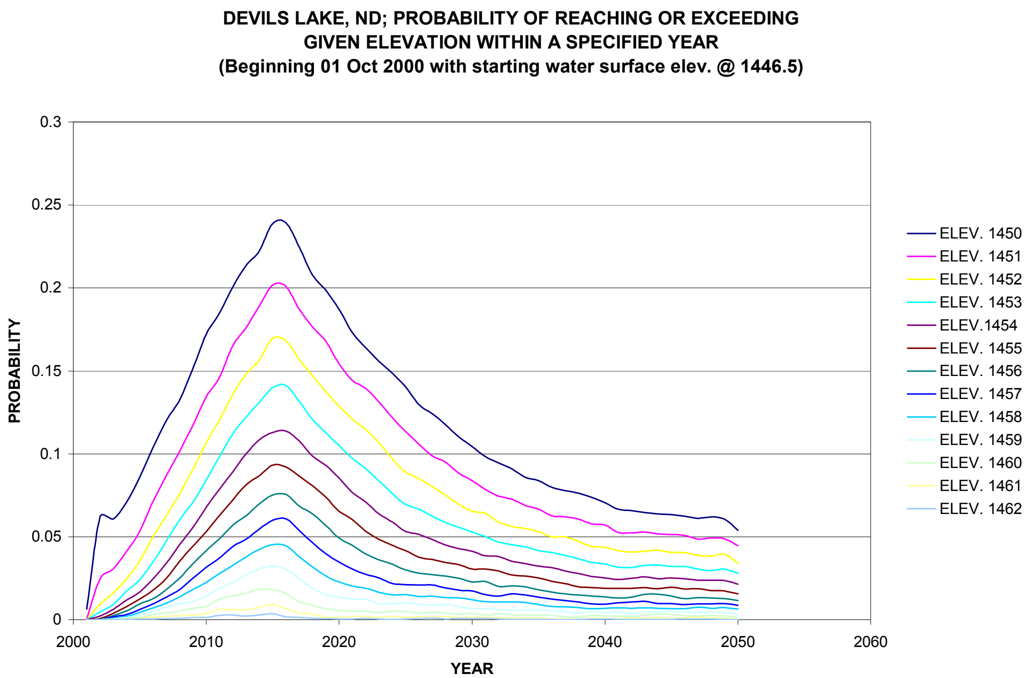


FIGURE A5-11

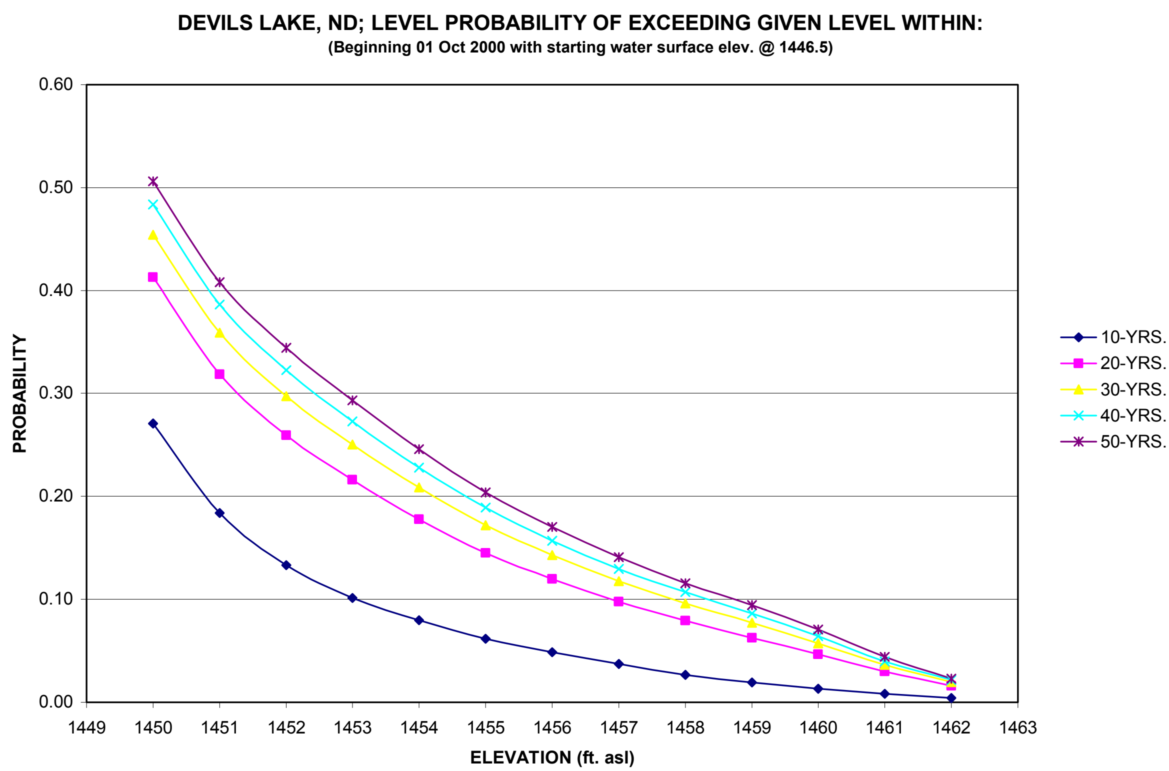


FIGURE A5-12

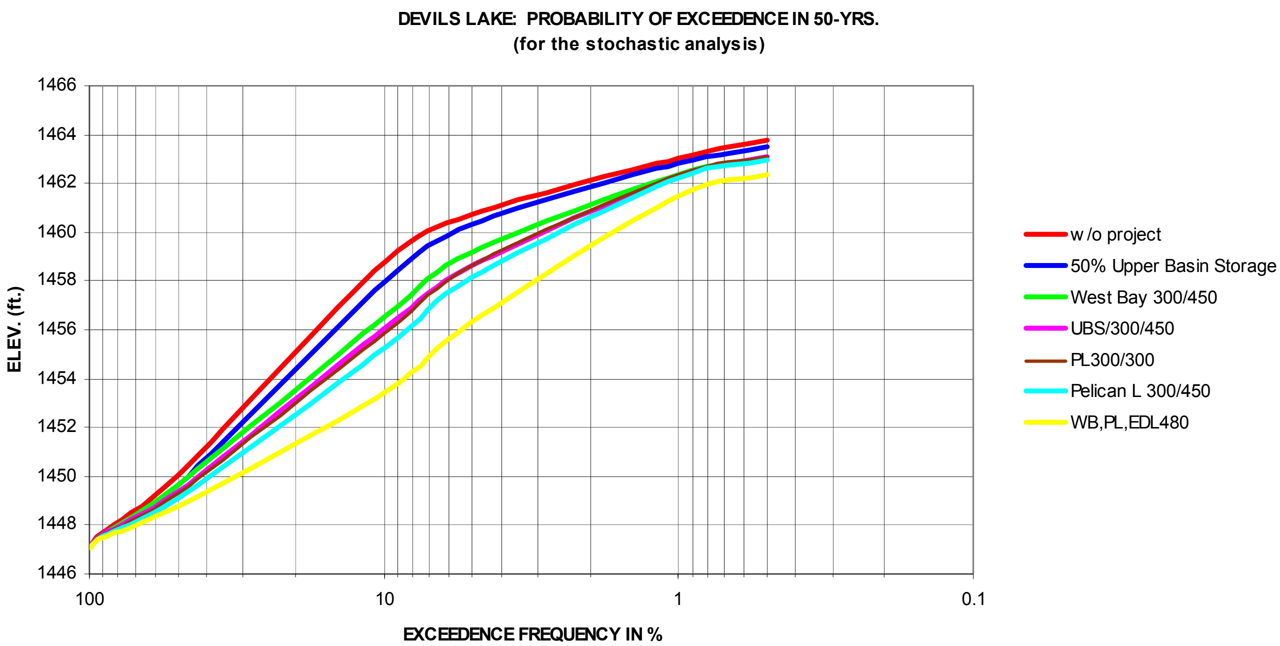


FIGURE A5-13

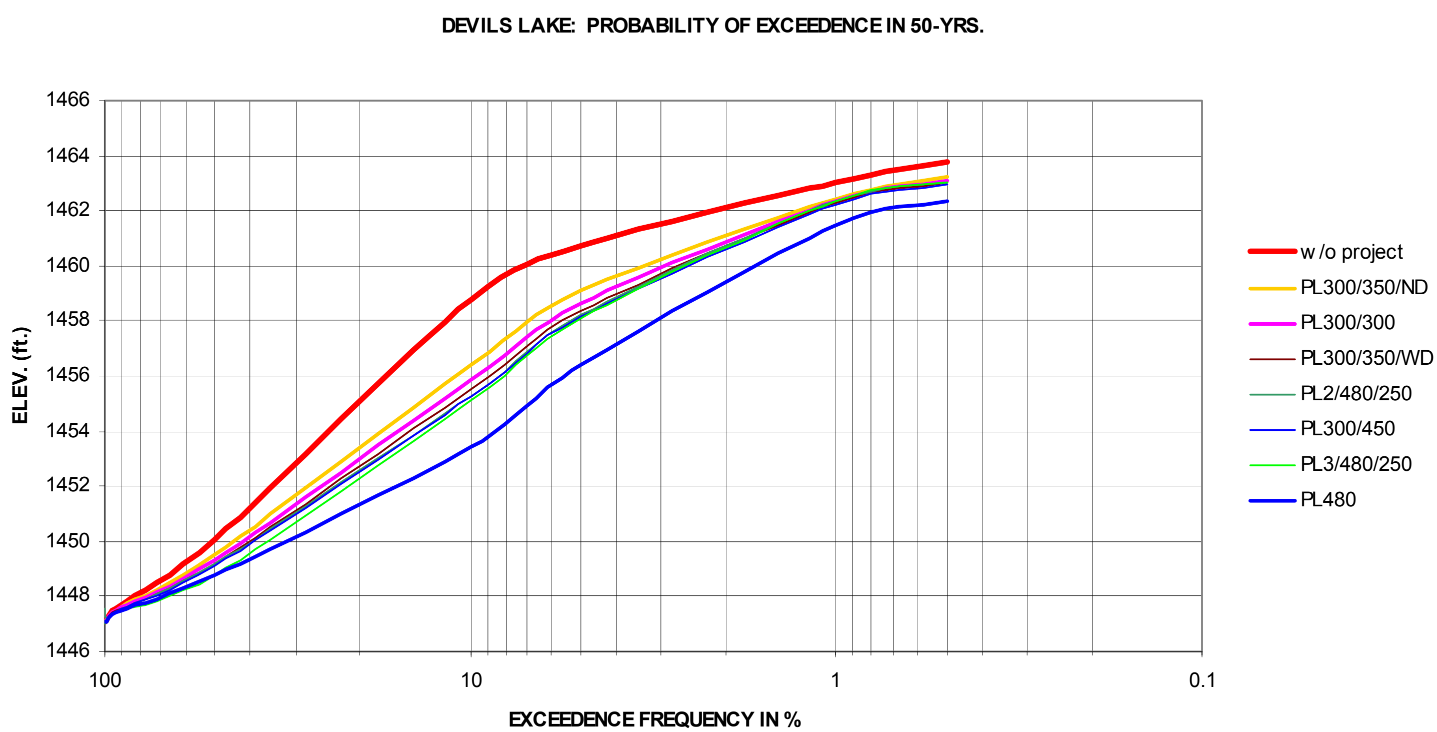


FIGURE A5-14

Degree of Protection

As stated in the Emergency Flood Plan section of this Appendix, there are two emergencies – downstream and within-lake basin. Degree of protection for a terminal lake can be relative to two types of events – hydrometeorological and hydro-climatological. For the downstream emergency, the adopted hydrometeorological degree of protection is initially the SPF. The zero-damage elevation is assumed to be elevation 1459. Above this elevation damage would begin to occur downstream. The hydroclimatological degree of protection can be estimated from the USGS stochastic model. The risk of reaching or exceeding the natural overflow elevation within 50 years for without project conditions is 9.4%. **Table A5-3** shows the estimated degree of protection for the various alternatives. For example, the Pelican Lake cfs outlet alternative would have an estimated degree of protection of approximately 4.1%. The risk of reaching or exceeding the zero-damage elevation (relative to the downstream emergency) of 1459 during 50 years of project life is 4.1%. The chance of overflow in 50 years is reduced by 5.3% for this alternative.

For the within-lake basin emergency, the adopted hydrometeorlogical degree of protection is the 1% event. Zero-damage elevation for this emergency is assumed to be at elevation 1448. The risk of reaching or exceeding elevation 1448 in the next 50 years would be 84.8%. The degree of protection for within-lake for the Pelican Lake 300 cfs alternative would be 78.49 %. There is a 78.4 % chance that the lake would reach or exceed elevation 1448 in the next 50 years, a reduction of 6.4%. **Table A5-3** shows the risk or degree of protection for the various alternatives. It should be noted that the primary within-lake basin benefit of a project is the reduction in the long-term lake level and not so much the potential for the project to prevent the lake from rising above the zero-damage elevation.

TABLE A5-3
Risk of reaching critical Elevations
(Degree of Protection)

Emergency Plan	WITHIN LAKE % chance of reaching or exceeding elev. 1448.0 in 50-yrs.	DOWNSTREAM % chance of reaching or exceeding natural overflow elev. 1459.0 in 50-yrs.
w/o project	84.8	9.4
WB 300	83.1	5.2
WB 480	73.9	2.5
PL 300	78.4	4.1
PL480	73.9	2.5
UBS[1]	82.9	7.7
UBS/300/450[2]	81.1	4.6
EDL 480	73.9	2.5
PL2/480/250	78.9	4.2
PL3/480/250	74.1	4.1
PL300/350/WD	79.6	4.3
PL300/350/ND	82.0	5.2
PL300/300	80.6	4.6

1 50% upper basin storage

2 Combination includes: 50% upper basin storage, West Bay 300 cfs pump, & infrastructure

It is important that the outlet does not hasten extreme lake-level declines or worsen in-lake water quality in the event that drought conditions should occur in the future. Low lake levels and poor water quality would threaten the thriving fish population and result in adverse effects on the local economy. The effect of the outlet on low lake levels is shown in **reference 1.** There is a 50-percent chance the minimum lake level from year 2001to 2050 will be less than 1430 ft., msl and a 10-percent chance the minimum lake level for 2001-50 will be less than 1420 ft., msl. Although there is a moderate chance (10 percent) the lake will return to low levels comparable to much of 1900's (less than 1420 ft. msl) by 2050, the lake is not likely to fall to those levels until well beyond 2050. The Pelican Lake outlet has negligible effect on the probabilities of attaining low lake levels. The outlet ceases operation when lake levels fall below 1441.4 ft., msl and the outlet discharge becomes severely limited by the sulfate constraint well before the lake falls to that level. (See **reference 1)**

The outlet also has negligible effect on the probabilities of obtaining high sulfate concentrations in Main Bay. Similar results were obtained for each of the other lake boxes as well. Although sulfate concentrations may well exceed the high levels obtained in the early 1990's within the next 50 years, the outlet does not increase the potential for poor in-lake water quality conditions in the future.

Hydrologic Effectiveness (Scenario Based)

<u>Reduction in Peak and Long-term Lake Levels</u>

Table A5-4 shows how each proposed alternative performed based on two measures. First is the measure of reduced peak lake level within the 50-yr length of each trace. Reduction in peak level is the difference in maximum levels between the with- and without-outlet scenario in feet. This measurement indicates the extent that damages occur as the lake rises. Second is the measure of maximum drawdown in lake level throughout the entire 50-yr length of the trace. It is the maximum difference in feet between with- and without-outlet plan. **Figures A5-15 to A5-28** show the elevation reduction for each alternative compared with existing conditions for the WET future and the two more moderate futures identified as 1455 and 1450.

TABLE A5-4
Peak and 50-yr Elevation Reduction
For Each Plan And Hydrologic Scenario

HYDROLOGIC FUTURE	ALTERNATIVE	PEAK ELEV. 1400+(ft.)	PEAK REDUCTION (ft.)	ELEV. AFTER 50-yrs 1400+(ft.)	REDUCTION AFTER 50-yrs (ft.)
WET	w/o project	60.59		50.59	
	WB300/450	57.68	2.91	46.37	4.22
	WB480	52.93	7.66	36.54	14.05
	PL300/450	57.35	3.24	44.03	6.56
	PL480	52.94	7.65	36.62	13.97
	UBS1	60.41	0.18	49.75	0.84
	COMBINATION2	56.51	4.08	45.22	5.37
	EDL480	52.93	7.66	36.54	14.05
	PL2/480/250	55.00	5.59	46.90	3.69
	PL3/480/250	54.10	6.49	40.30	10.29
	PLUGTC	62.76	-2.17	52.09	-1.50
	WB480/350/ZIEB	53.50	7.09	42.10	8.49
	WB480/450	54.00	6.59	42.10	8.49
	WB450/350/HWY57	54.50	6.09	44.50	6.09
	PL480/300/HWY57	54.30	6.29	43.40	7.19
	PL300/250	n/a	n/a	n/a	n/a
	SWC100/300/375	60.00	0.59	48.90	1.69
	PL300/375	57.30	3.29	45.20	5.39
	PL300/300	57.50	3.09	47.10	3.49
	SWC100/PL300/375	55.20	5.39	42.20	8.39
	SWC100/300/300	60.40	0.19	49.80	0.79
	SWC100/250/PL300/450	57.30	3.29	43.98	6.61
	PL300/300ND	60.10	0.49	50.10	0.49
	PL300/300NAP	58.20	2.39	47.90	2.69
	PL300/300/ramp	57.70	2.89	47.30	3.29
	PL300/300/fcst	57.70	2.89	47.50	3.09

TABLE A5-4 (continued)
Peak and 50-yr Elevation Reduction
For Each Plan And Hydrologic Scenario

HYDROLOGIC FUTURE	ALTERNATIVE	PEAK ELEV. 1400+(ft.)	PEAK REDUCTION (ft.)	ELEV. AFTER 50-yrs 1400+(ft.)	REDUCTION AFTER 50-yrs (ft.)
MODERATE 1455	w/o project	54.89		35.08	
	WB300/450	53.70	1.19	33.95	1.13
	WB480	48.76	6.13	30.98	4.10
	PL300/450	50.55	4.34	32.33	2.75
	PL480	48.76	6.13	31.08	4.00
	UBS1	n/a	n/a	n/a	n/a
	COMBINATION2	52.89	2.00	31.97	3.11
	EDL480	n/a	n/a	n/a	n/a
	PL2/480/250	50.55	4.34	32.33	2.75
	PL3/480/250	50.10	4.79	32.30	2.78
	PL300/250	48.90	5.99	32.20	2.88
	SWC100/300/375	54.20	0.69	34.40	0.68
	PL300/375	51.00	3.89	32.60	2.48
	PL300/300	52.10	2.79	33.50	1.58
	SWC100/pl300/375	50.70	4.19	32.20	2.88
	SWC100/300/300	54.50	0.39	34.70	0.38
	PL300/300/ND	53.90	0.99	34.40	0.68
	PL300/300/NAP	52.40	2.49	33.60	1.48
	PL300/300/ramp	52.20	2.69	33.50	1.58
	PL300/300/fcst	52.20	2.69	33.50	1.58
MODERATE 1450	w/o project	50.05		37.62	
	WB300/450	49.49	0.56	37.30	0.32
	WB480	47.74	2.31	35.93	1.69
	PL300/450	47.74	2.31	36.53	1.09
	PL480	47.74	2.31	35.94	1.68
	UBS1	n/a	n/a	n/a	n/a
	COMBINATION2	48.83	1.22	35.12	2.50
	EDL480	n/a	n/a	n/a	n/a
	PL2/480/250	47.74	2.31	36.53	1.09
	PL3/480/250	48.90	1.15	37.30	0.32
	PL300/250	47.70	2.35	36.70	0.92
	PL300/300	48.90	1.15	37.00	0.62
	SWC100/300	49.90	0.15	37.50	0.12
	SWC100/300/300	49.90	0.15	37.50	0.12
	PL300/300/ND	49.60	0.45	37.40	0.22
	PL300/300/ramp	48.90	1.15	37.10	0.52
	PL300/300/fcst	48.90	1.15	37.10	0.52
DRY	w/o project	48.56		23.36	
	WB300/250	48.56	0.00	22.84	0.52
	WB480	48.56	0.00	21.39	1.97
	PL300/450	48.56	0.00	21.65	1.71
	PL480	48.56	0.00	21.53	1.83
	UBS[1]	n/a	n/a	n/a	n/a
	COMBINATION[2]	48.56	0.00	20.24	3.12
	EDL480	n/a	n/a	n/a	n/a

1 Upper Basin Storage, 50% restoration

2 Combination includes: 50% Upper Basin Storage, West Bay 300 cfs pump, & infrastructure

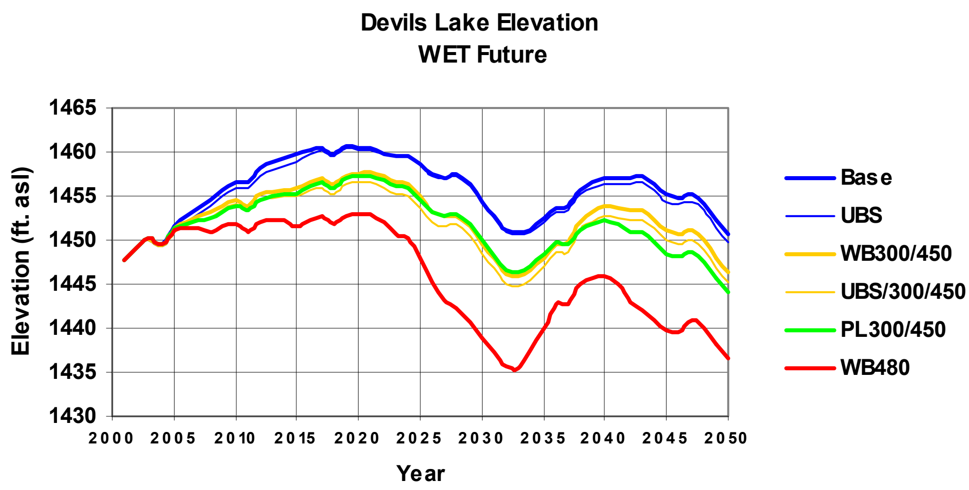


FIGURE A5-15

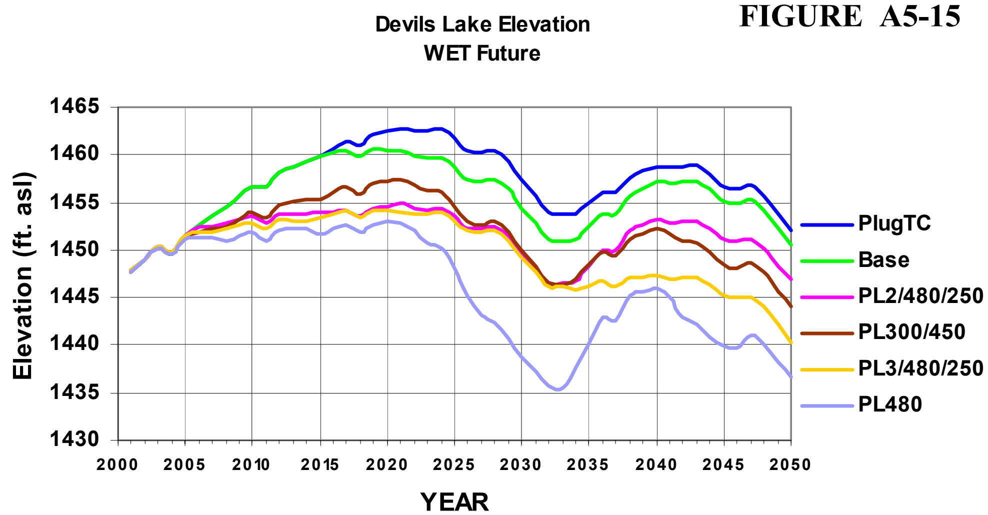


FIGURE A5-16

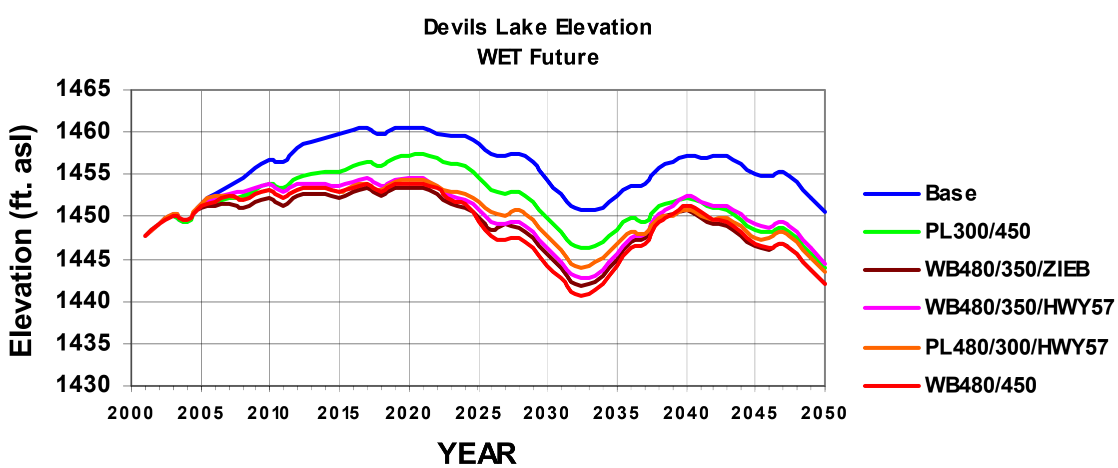


FIGURE A5-17

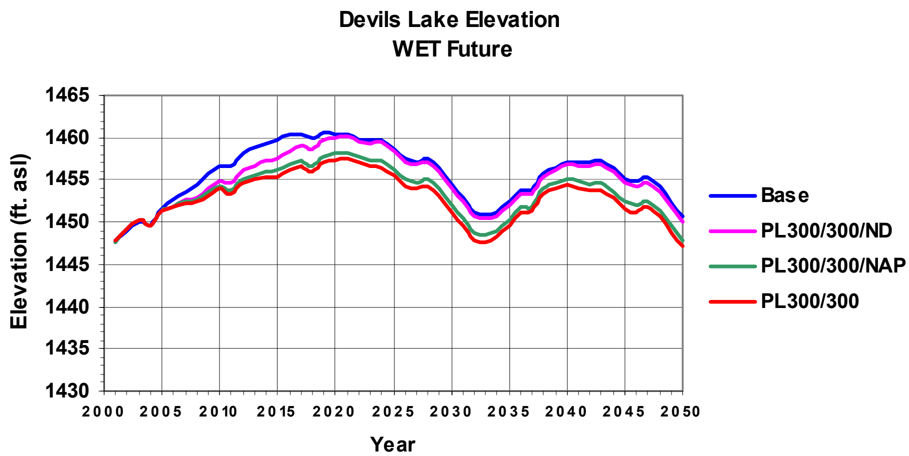


FIGURE A5-18

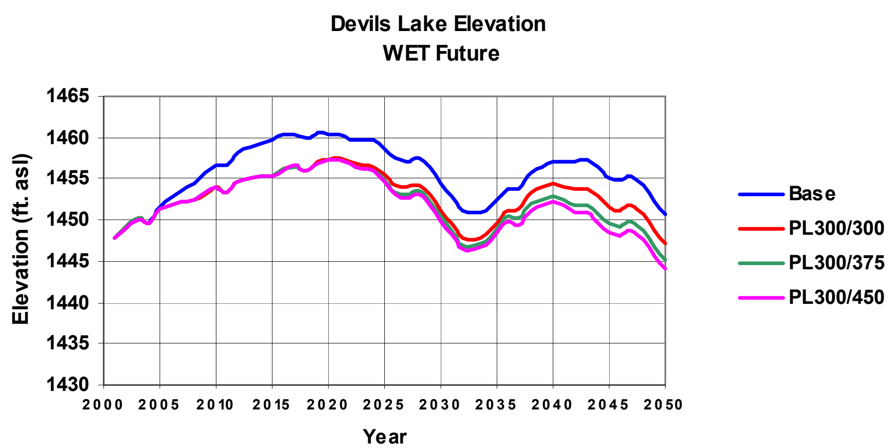


FIGURE A5-19

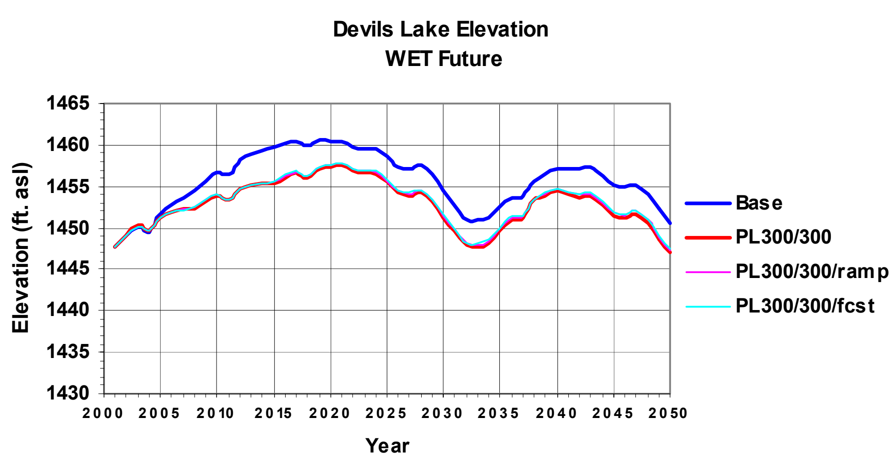


FIGURE A5-20

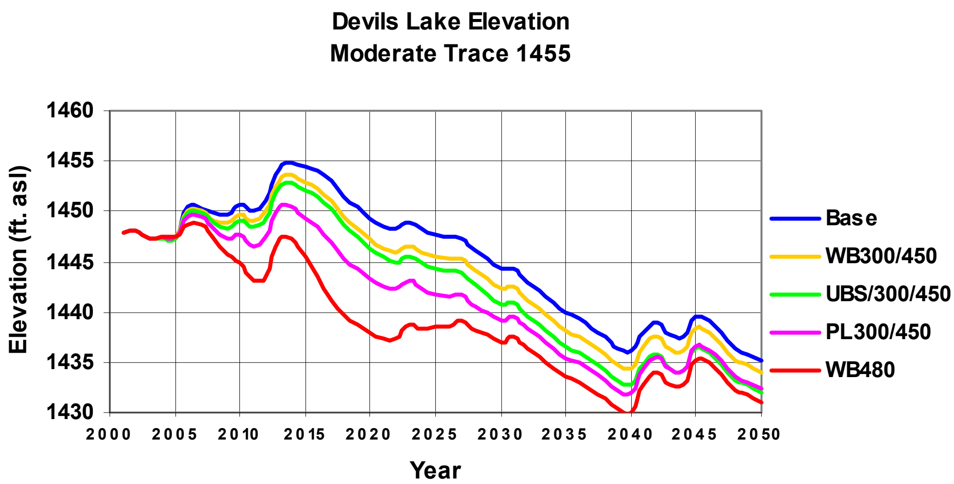


FIGURE A5-21

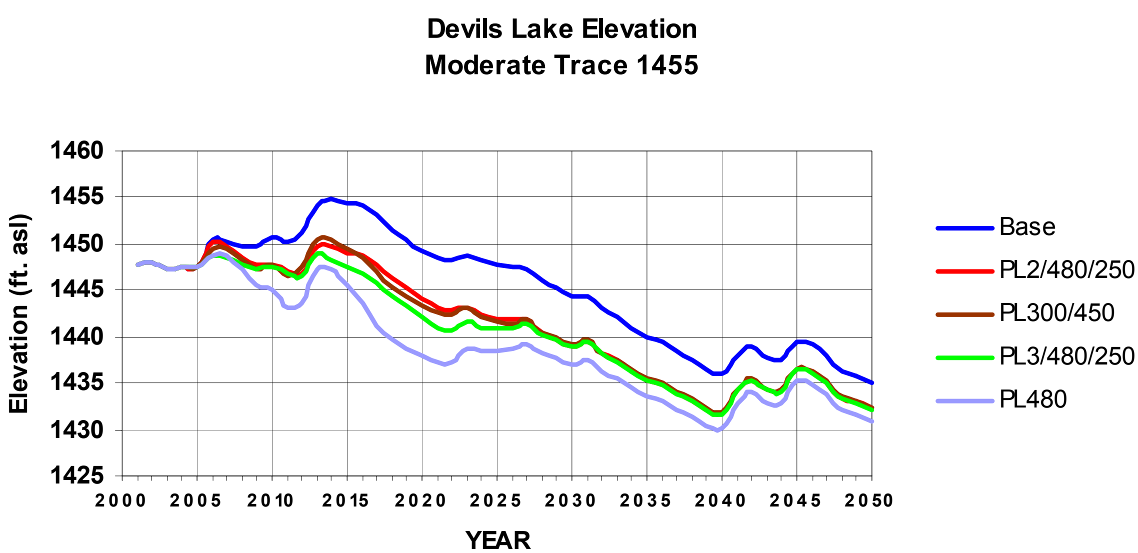


FIGURE A5-22

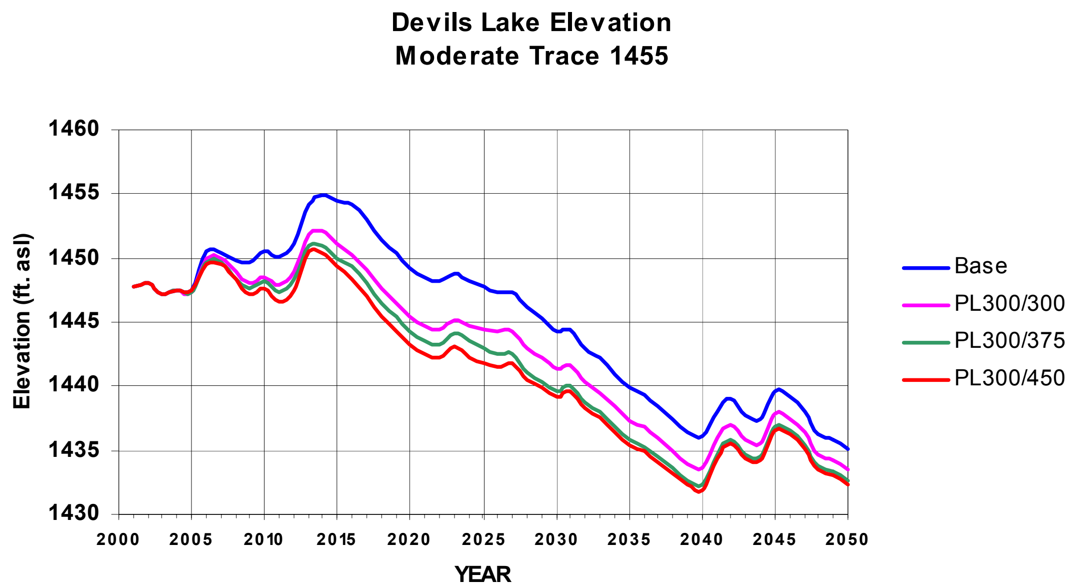


FIGURE A5-23

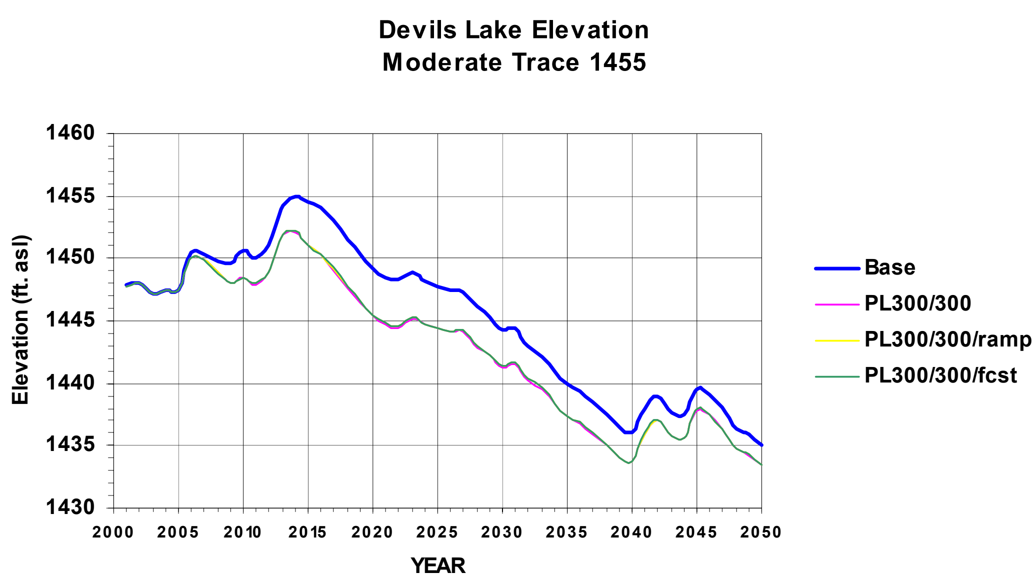


FIGURE A5-24

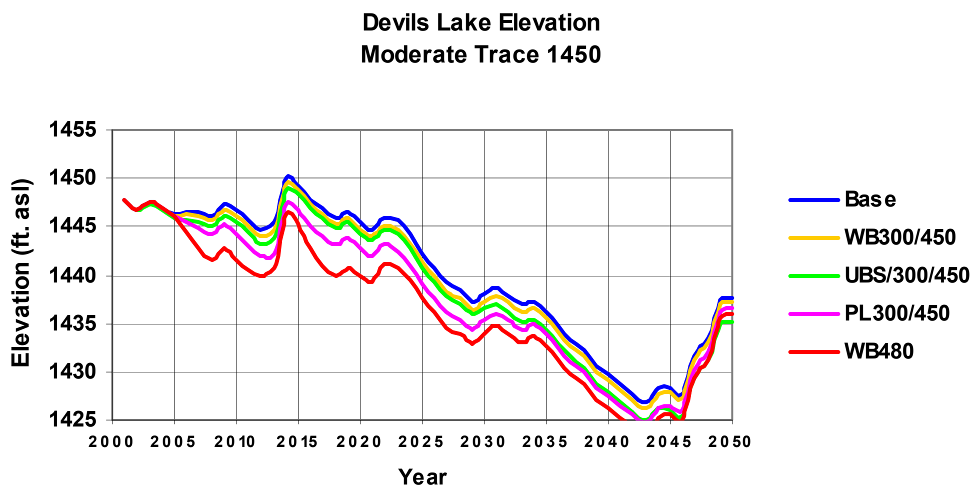


FIGURE A5-25

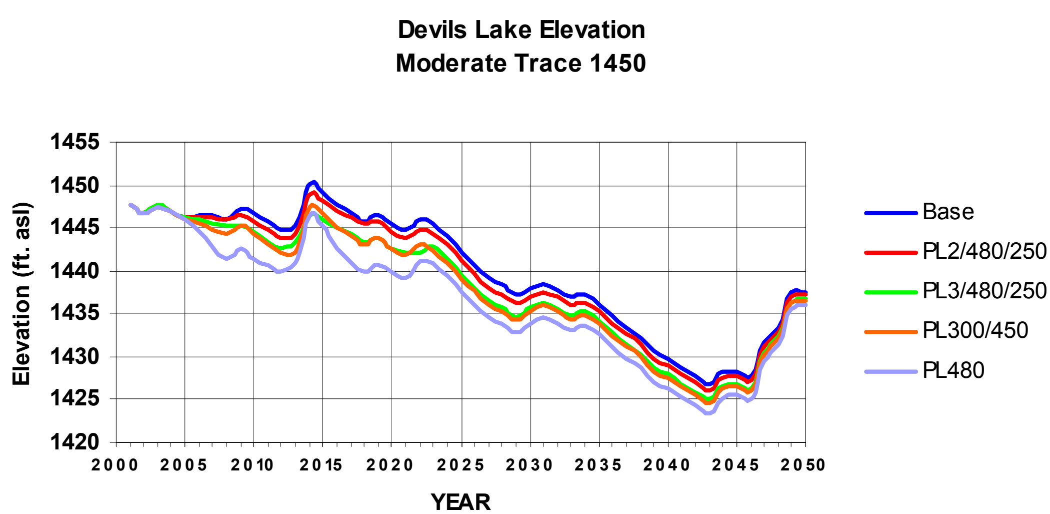


FIGURE A5-26

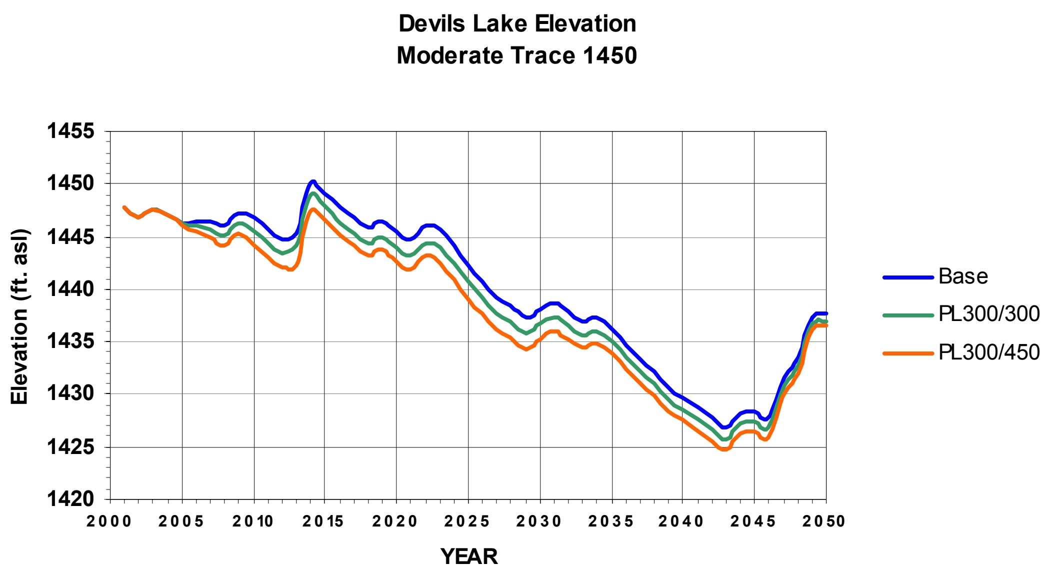


FIGURE A5-27

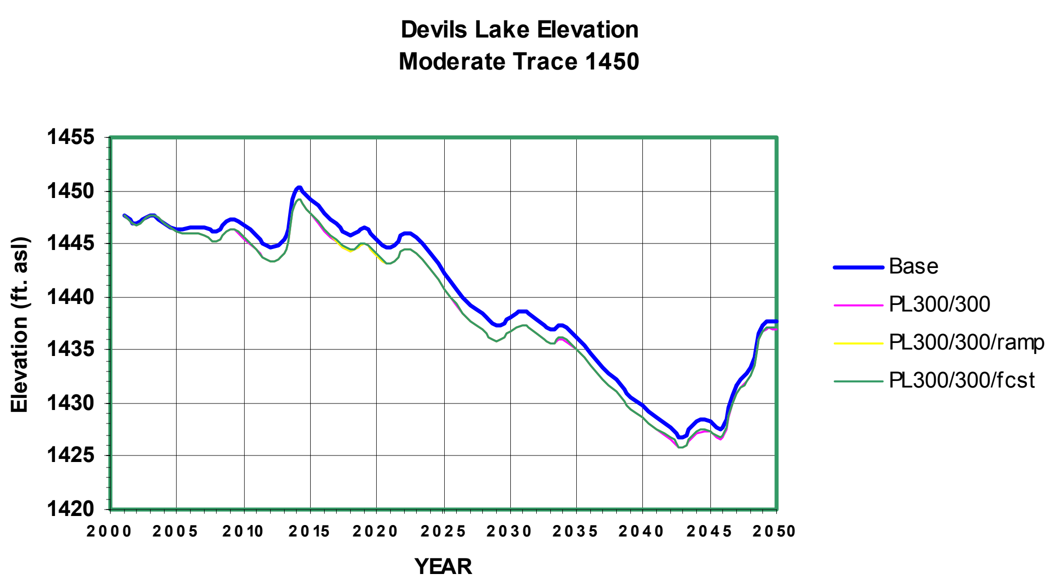


FIGURE A5-28

Downstream Flow Effects

Simulations were made for each of the four future scenarios for downstream impacts of flow and water quality. This section of the report addresses the flow impacts for the WET future and the moderate future 1455 only. Selected plots are provided because of the voluminous number that could be generated. The plots shown should give a good indication of the overall impacts of the alternatives. More plots can be provided upon request through the Project Manager at the St. Paul District. Plots are shown for the natural overflow during the WET future along with various alternative effects. For the Sheyenne River, Valley City was chosen as the key index location. No plots are shown for the Red River. At Grand Forks, the differences were not discernable for the various alternatives as well as the impact of a natural spill during the WET future.

To interpret the following graphs, nomenclature is provided in **Table A5-5. Figure A5-29** shows the natural outflow hydrograph at Tolna Coulee to the Sheyenne River for the WET future. Outflow begins in the year 2014 and reaches a peak discharge of 550 cfs in the year 2019. Outflow occurs each year after until year 2024.

Figure A5-30 shows the outflow hydrographs at Tola Coulee for the WET future for the natural condition and the Upper Basin Storage (UBS) alternative. The outflow hydrographs are similar; however, the UBS alternative would reduce the peak outflow by 100 cfs to approximately 425 cfs.

Figure A5-31 shows the outlflow hydrographs for the natural condition superimposed with the base condition that assumes erosion of the Tolna Coulee outlet. Peak outflow discharge would then be estimated at approximately 6,000 cfs. **Figure A5-32** shows the natural outflow hydrograph plotted with the West Bay 480 cfs unconstrained and the Pelican Lake 300 cfs constrained for 300 mg/l alternatives. These plots show that although the peak discharge to the Sheyenne River is not as high as the natural overflow condition (550 vs. 480 & 300 cfs), the volume would be considerably greater.

Figures A5-33 to **A5-36** show the West Bay 300 cfs, constrained alternatives. The BASE flow condition represents only flow in the Sheyenne River whereas the NOPUMP flow reflects natural Sheyenne River flow and any overflow from Devils Lake. Therefore, NOPUMP compared to BASE would indicate the relative impact of a natural overflow on the Sheyenne River.

Figures A5-37 to A5-40 show the Pelican Lake 300 cfs, constrained alternative. This is the adopted alternative to proceed to Plans and Specifications. **Figures A5-41 to A5-44** show the effect of an overflow from Tolna Coulee if the outlet is allowed to erode. It also shows the effect if the outlet is not allowed to overflow by comparing the NOPUMP condition with the BASE condition. **Figures A5-45 to A5-46** show the effectiveness of a 50 % Upper Basin Storage alternative. **Figures A5-47 to A5-58** show similar hydrographs as the above; however, instead of for the Wet future the more moderate future 1455 is presented.

TABLE A5-5
GRAPH NOMENCLATURE WITH
FIGURE LOCATION AND DESCRIPTION

LABEL	FIGURE #	DESCRIPTION
WET FUTURE (outflow Devils L.)		
THS7 NOPUMP	A5-29	Includes natural overflow with no pumped outlet flow.
THS7 STORAGE	A5-30	Upper basin storage effects (50 %).
THS7 ERODET	A5-31	Erosion effects of Tolna Coulee during overflow.
THS7 PL480PUMP	A5-32	Outlet from West Bary at 480 cfs unconstrained.
THS7 PL300PUMP	A5-33	Outlet from Pelican Lake at 300 cfs constrained for 300 mg/l
WET FUTURE (@Valley City)		
WET BASE	A5-33-36	No natural overflow, no pumped outlet flow, just Sheyenne flow.
WET NOPUMP	A5-33-36	Includes natural overflow & Sheyenne flow but no outlet flow.
WET WB300PUMP	A5-33-36	Outlet from West Bay at 300 cfs constrained & Sheyenne flow.
WET PL300PUMP	A5-37-40	Outlet from Pelican L. at 300 cfs constrained & Sheyenne flow.
WET ERODET	A5-41-44	Natural overflow assuming erosion effects & Sheyenne flow.
WET STORAGE	A5-45,46	Natural overflow with storage (50%) effects & Sheyenne flow
MODERATE FUTURE 1455 (@Valley City)		
MT2 WB300PUMP	A5-47-50	Outlet from West Bay at 300 cfs constrained & Sheyenne flow.
MT2 PL300PUMP	A5-51-54	Outlet from Pelican L. at 300 cfs constrained & Sheyenne flow.
MT2 WBSIO300PUMP	A5-55-58	Outlet from West Bay at 300 cfs constrained, storage effects (50%), infrastructure, & Sheyenne flow.

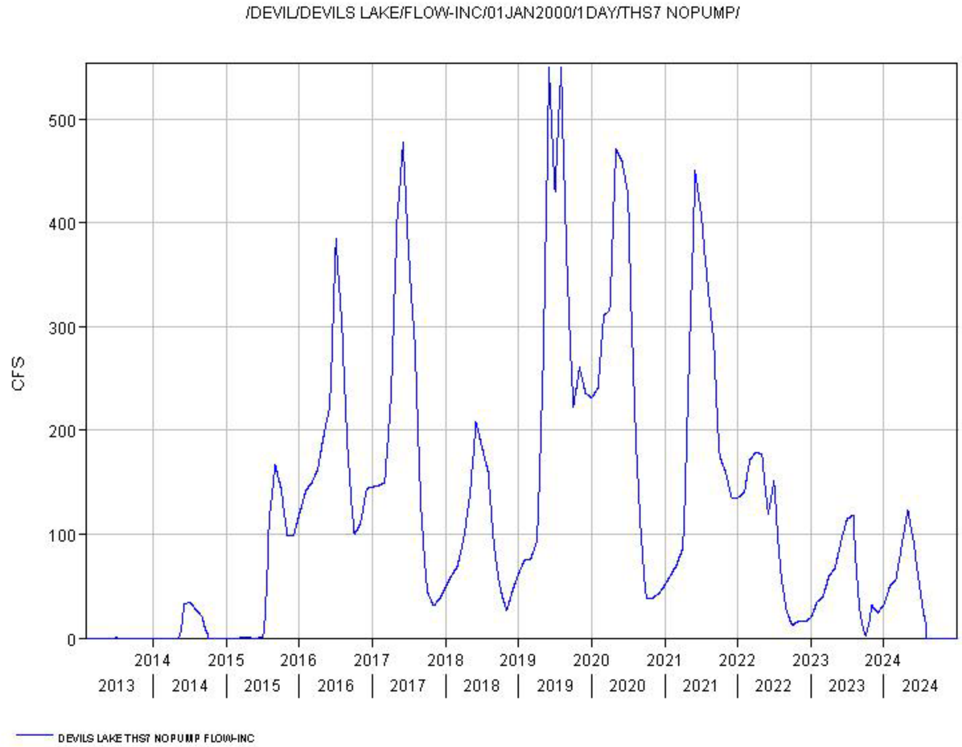


FIGURE A5-29

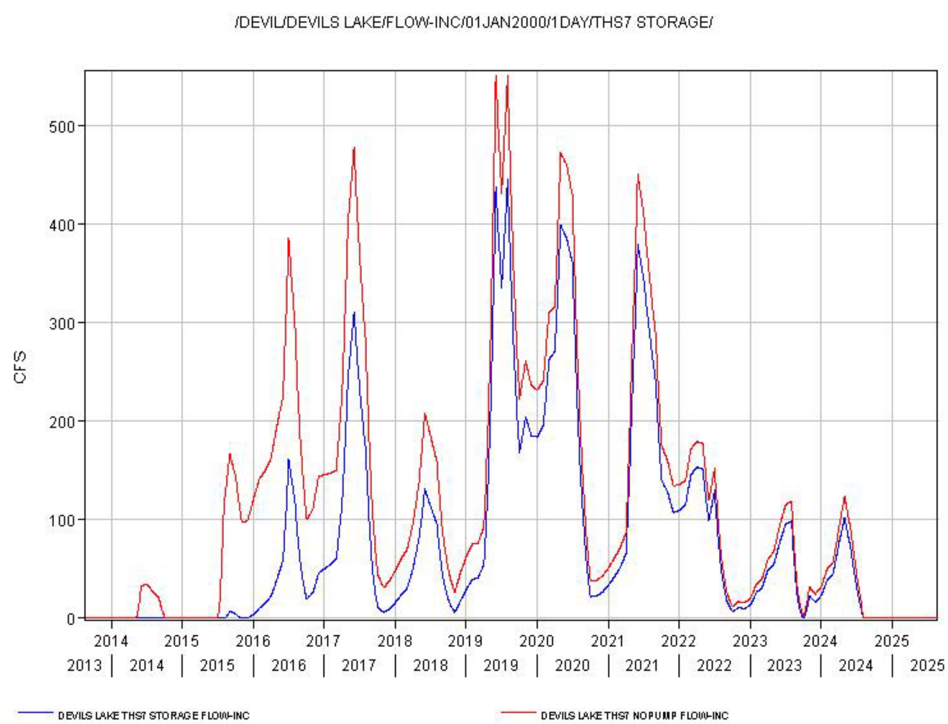


FIGURE A5-30

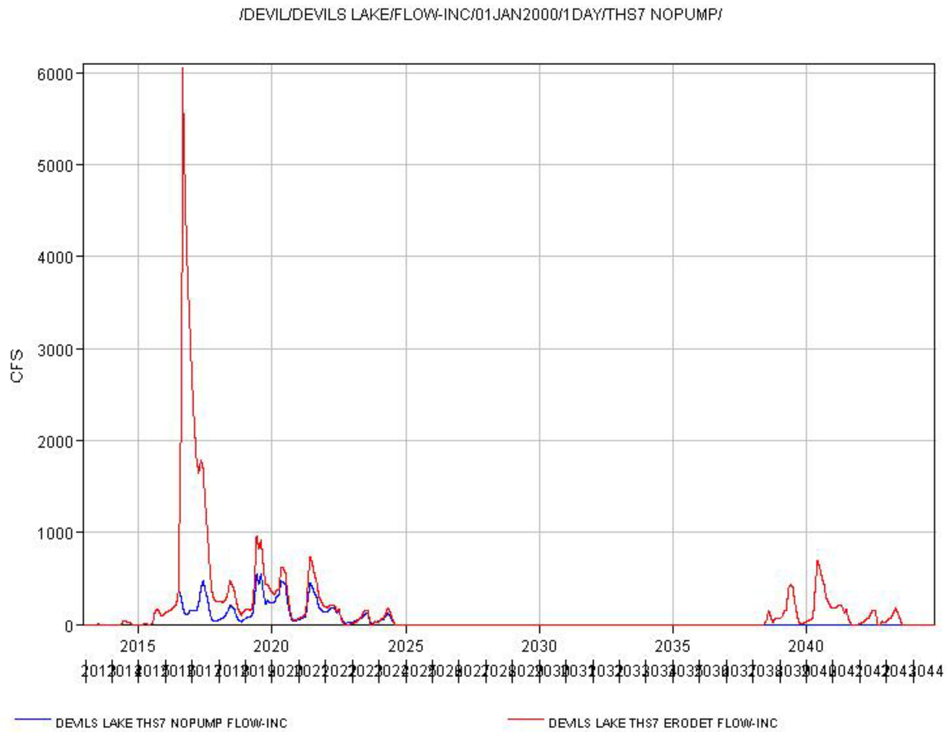
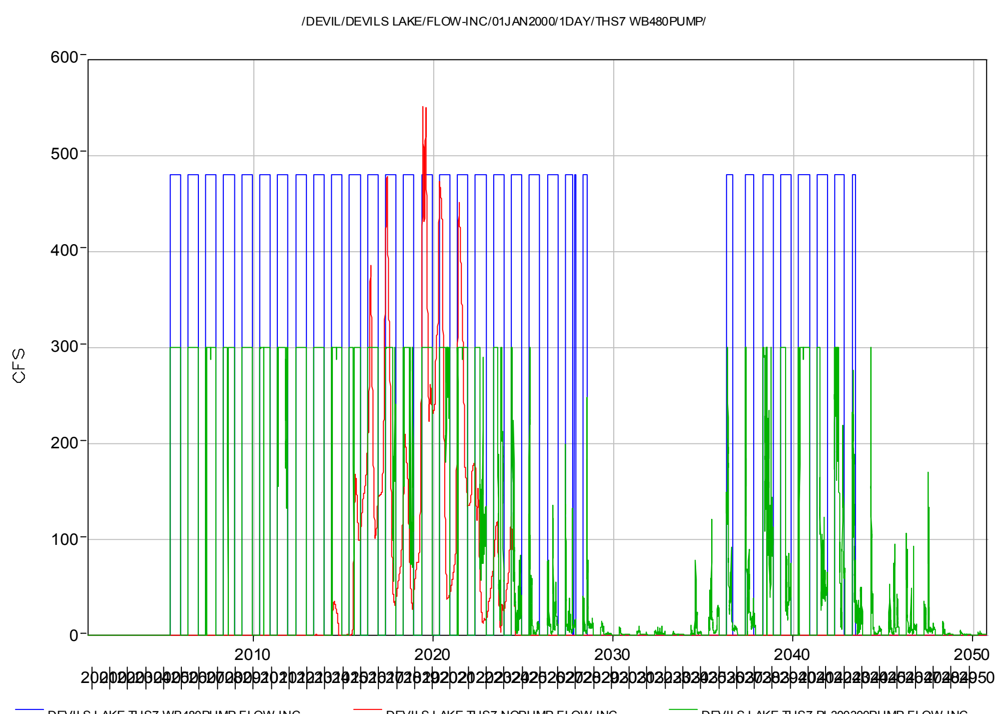


FIGURE A5-31



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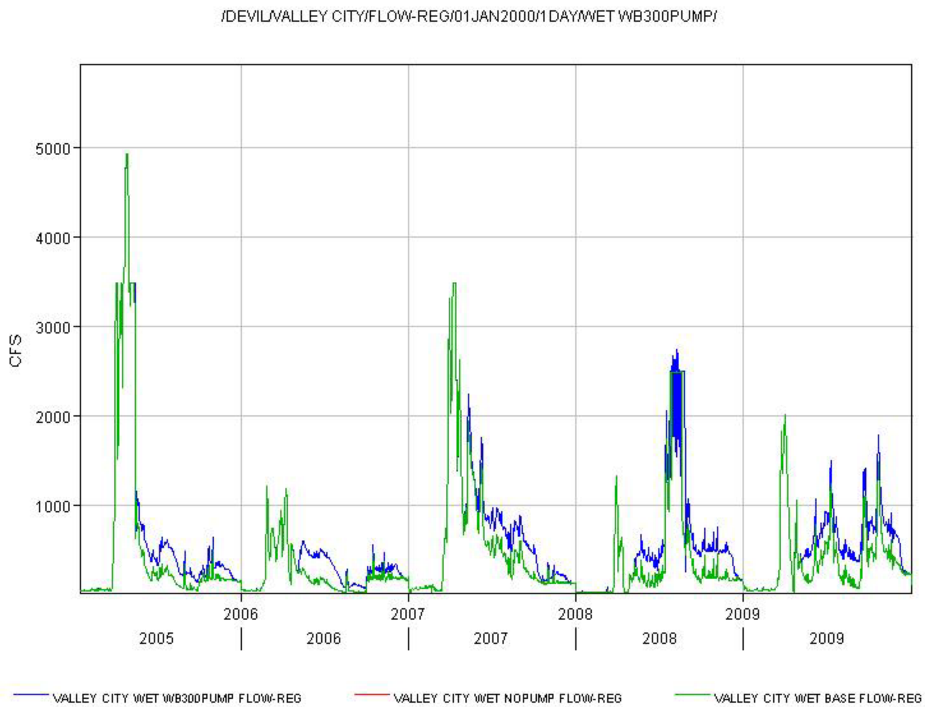


FIGURE A-33

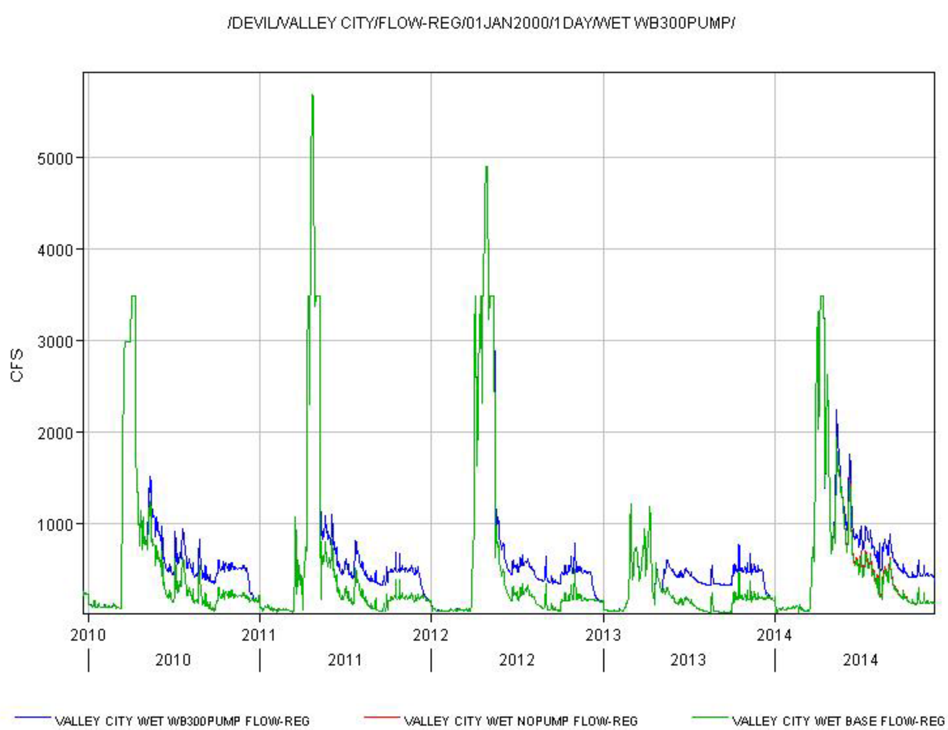


FIGURE A-34

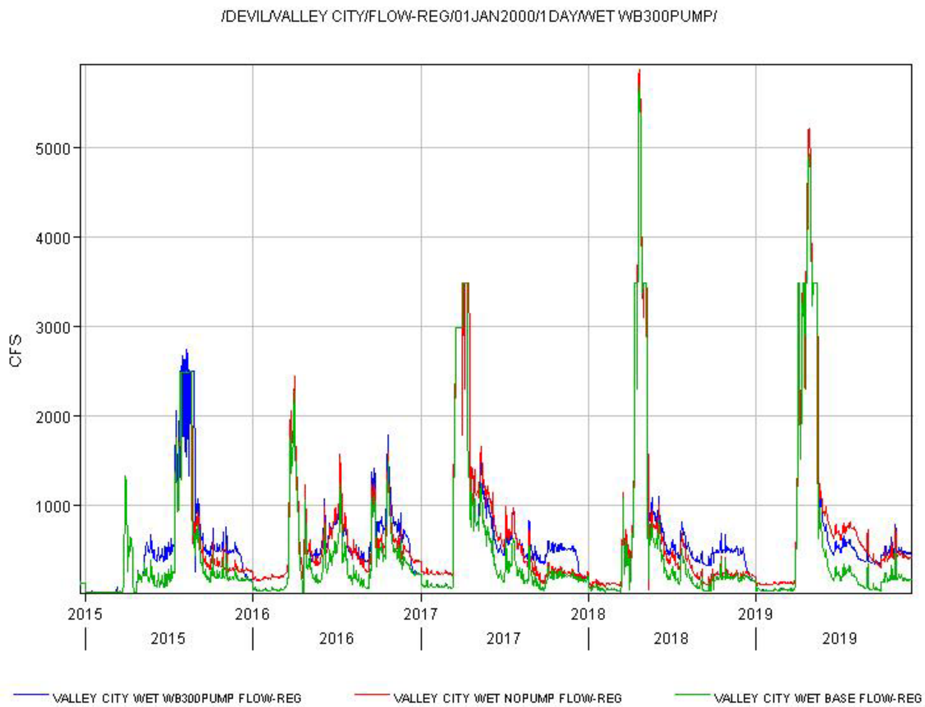


FIGURE A-35

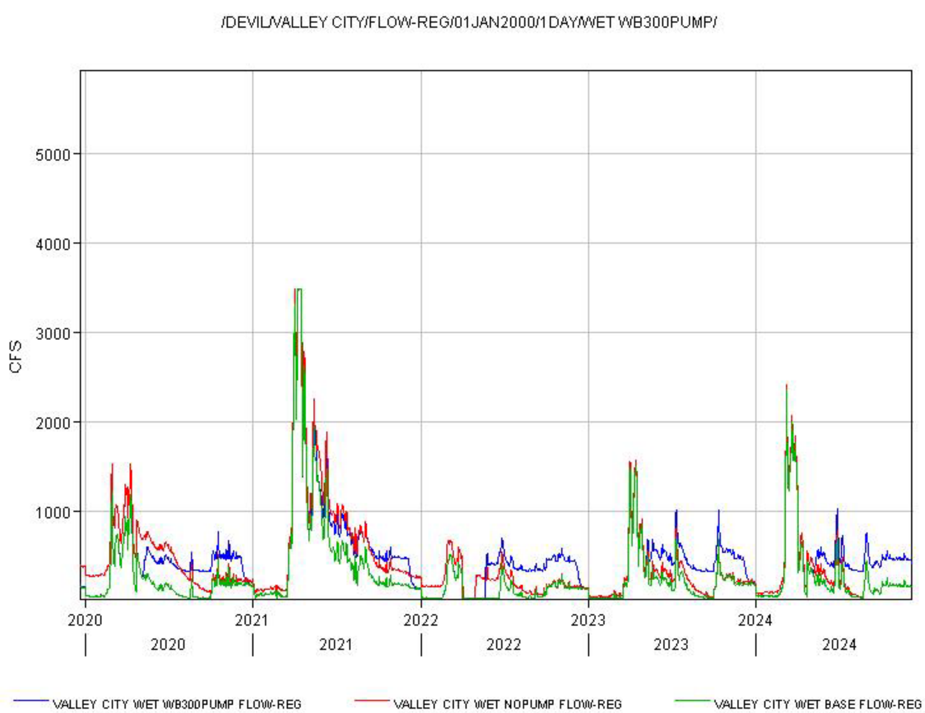


FIGURE A5-36

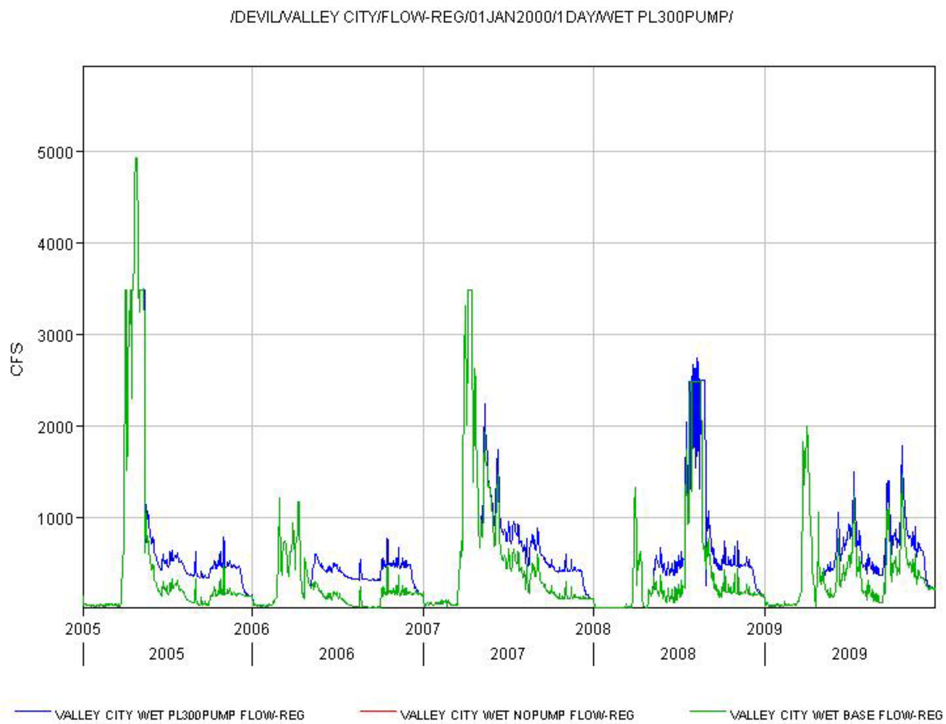


FIGURE A5-37

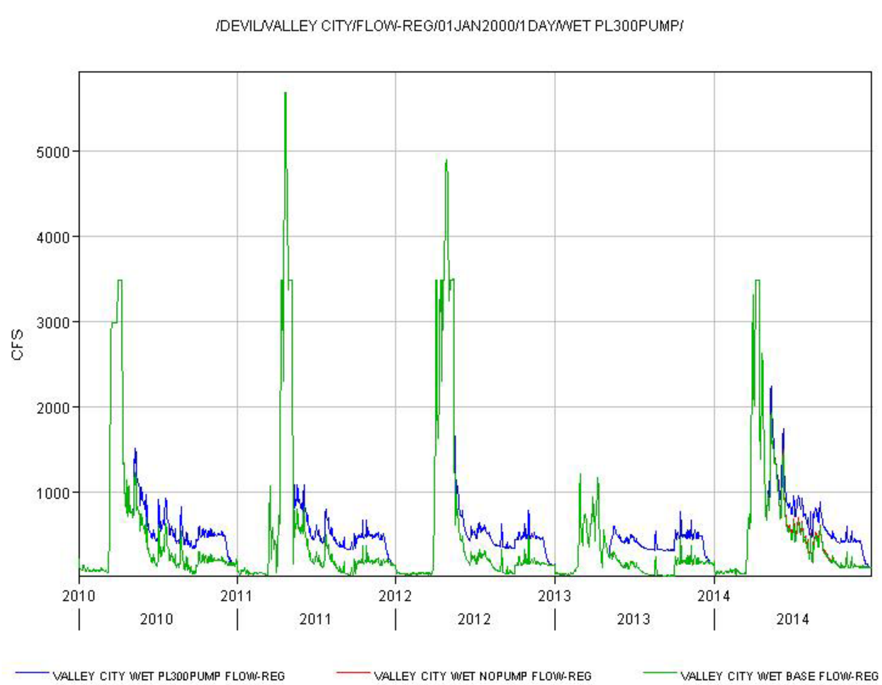


FIGURE A5-38

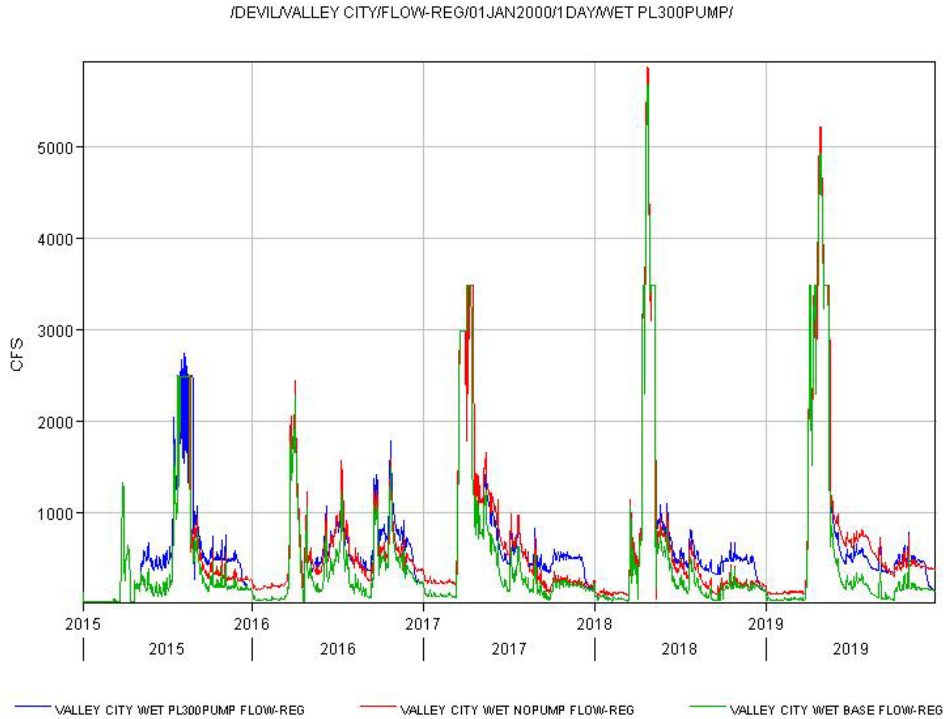


FIGURE A5-39

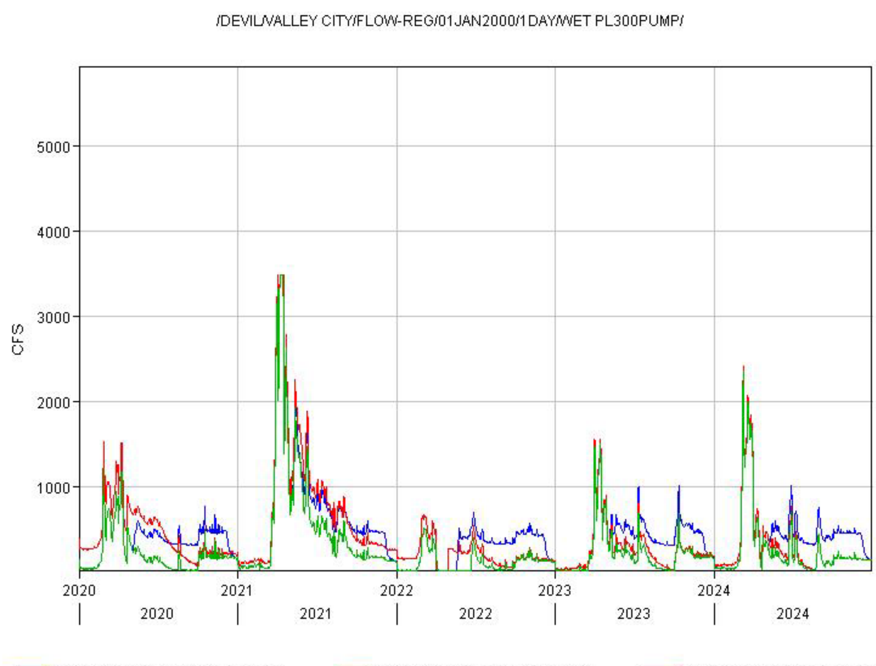


FIGURE A5-40

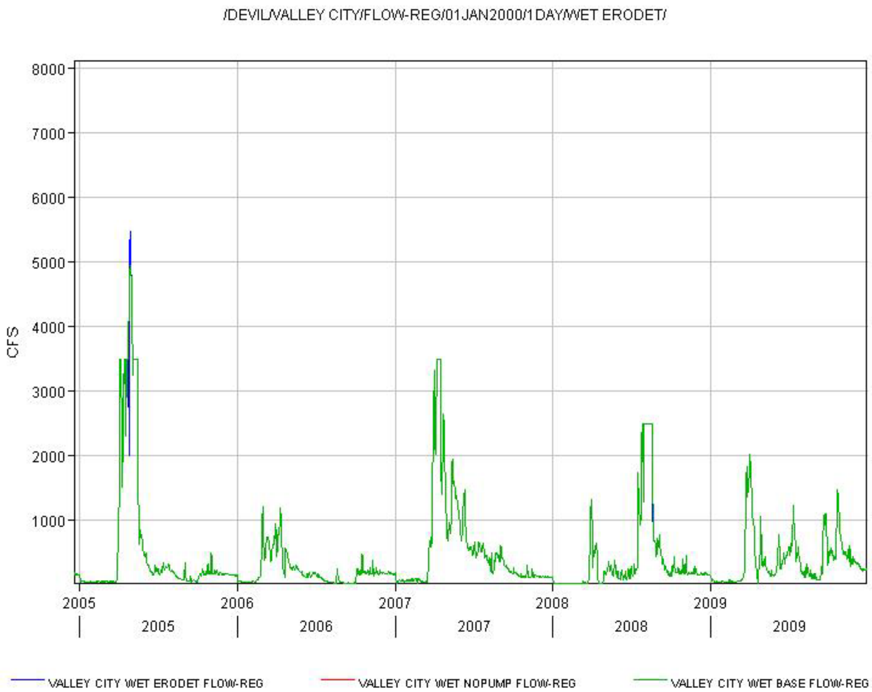


FIGURE A5-41

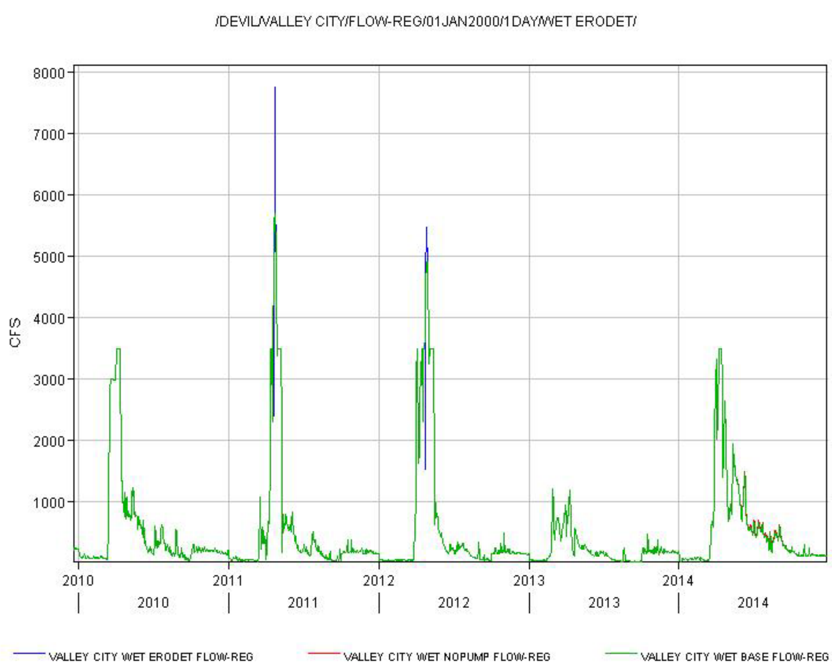


FIGURE A5-42

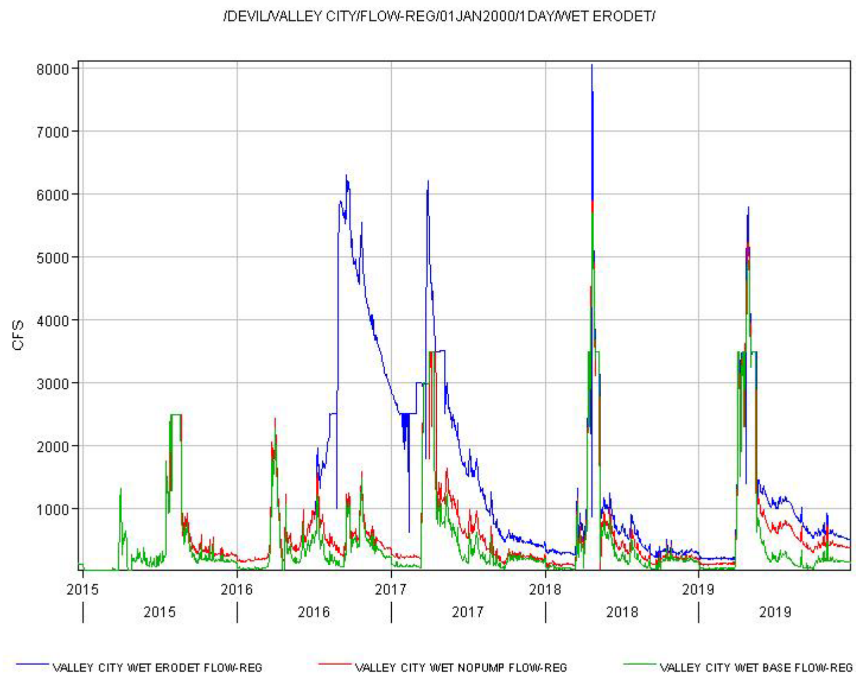


FIGURE A5-43

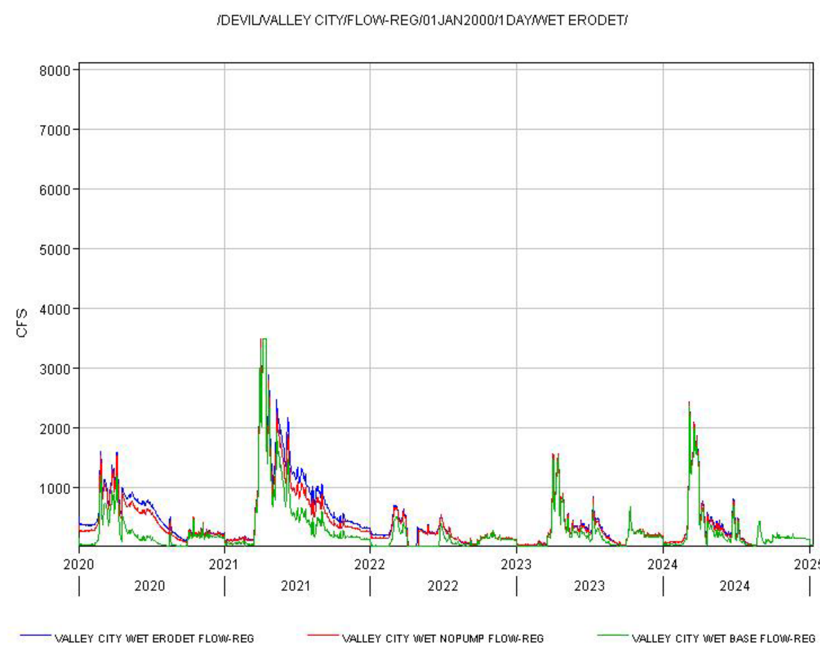


FIGURE A5-44

/DEVIL/VALLEY CITY/FLOW-REG/01JAN2000/1DAY/WET STORAGE/

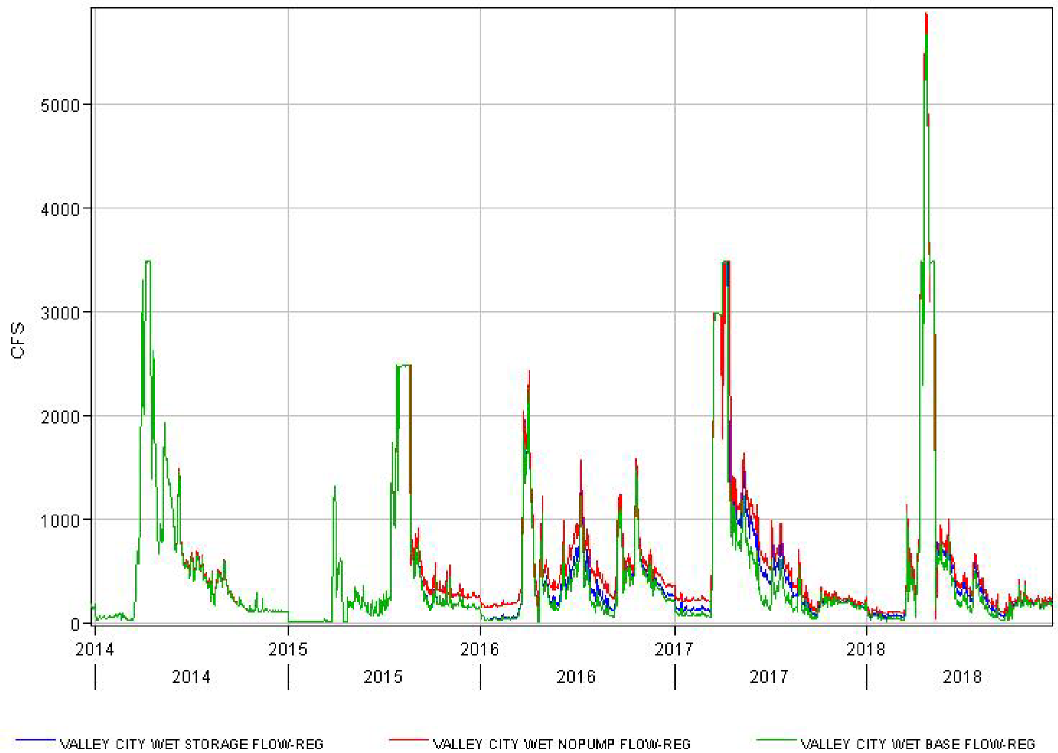


FIGURE A5-45

/DEVIL/VALLEY CITY/FLOW-REG/01JAN2000/1DAY/WET STORAGE/

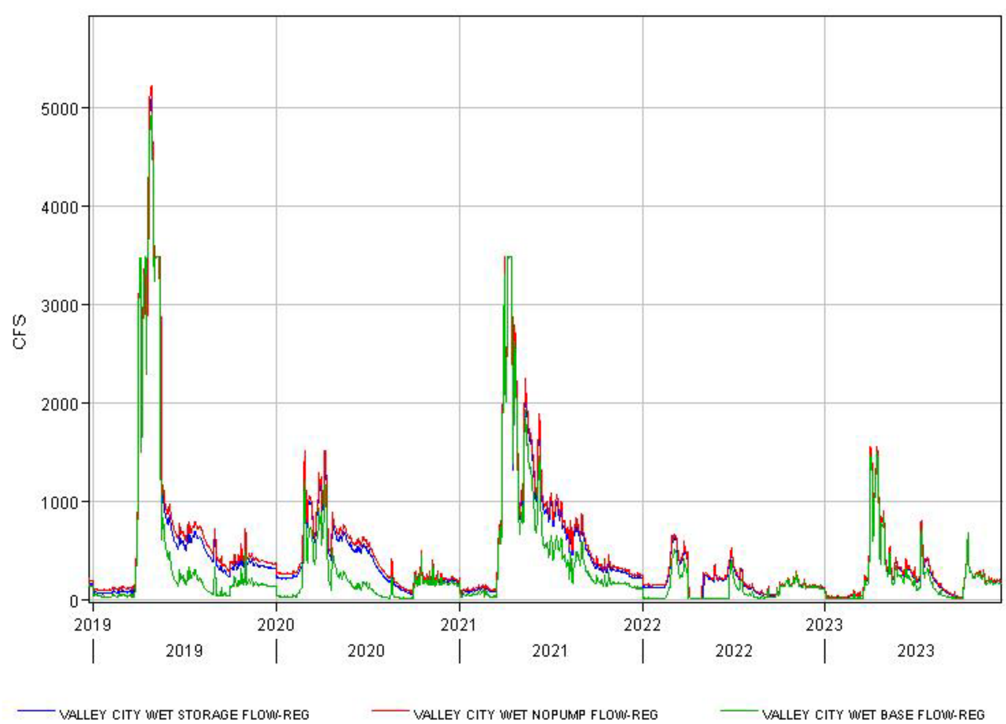
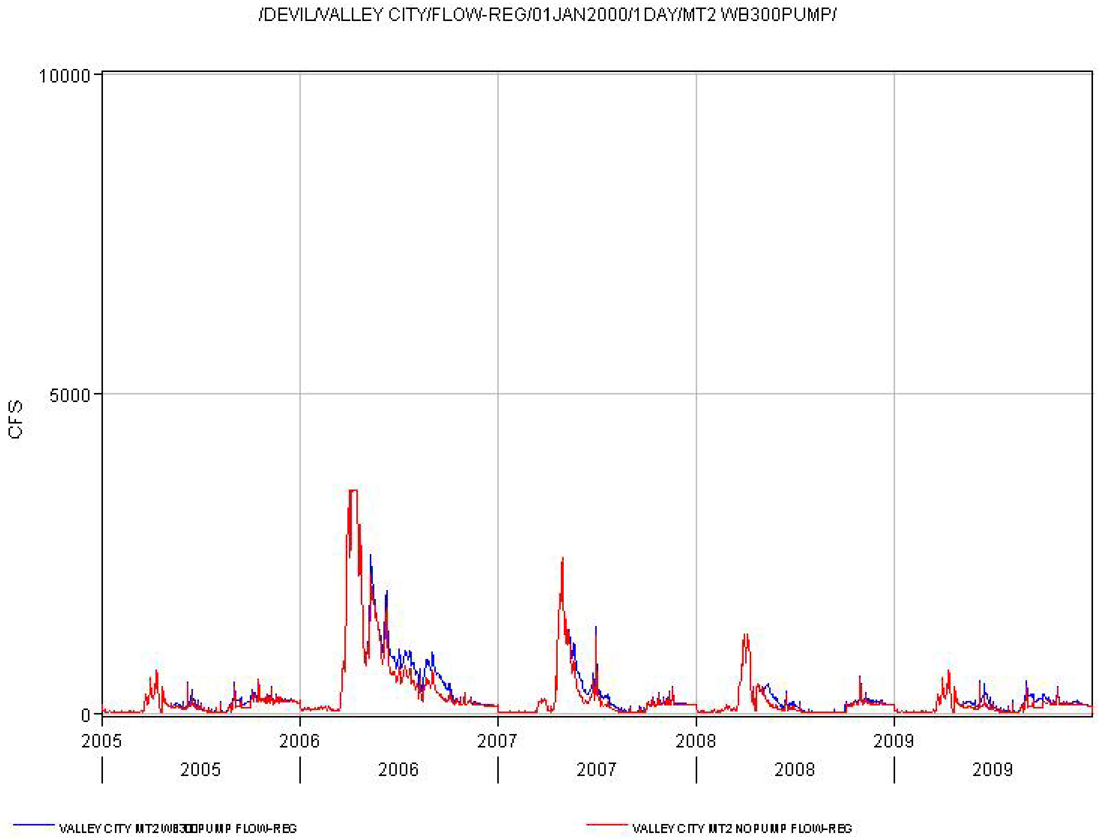


FIGURE A5-46



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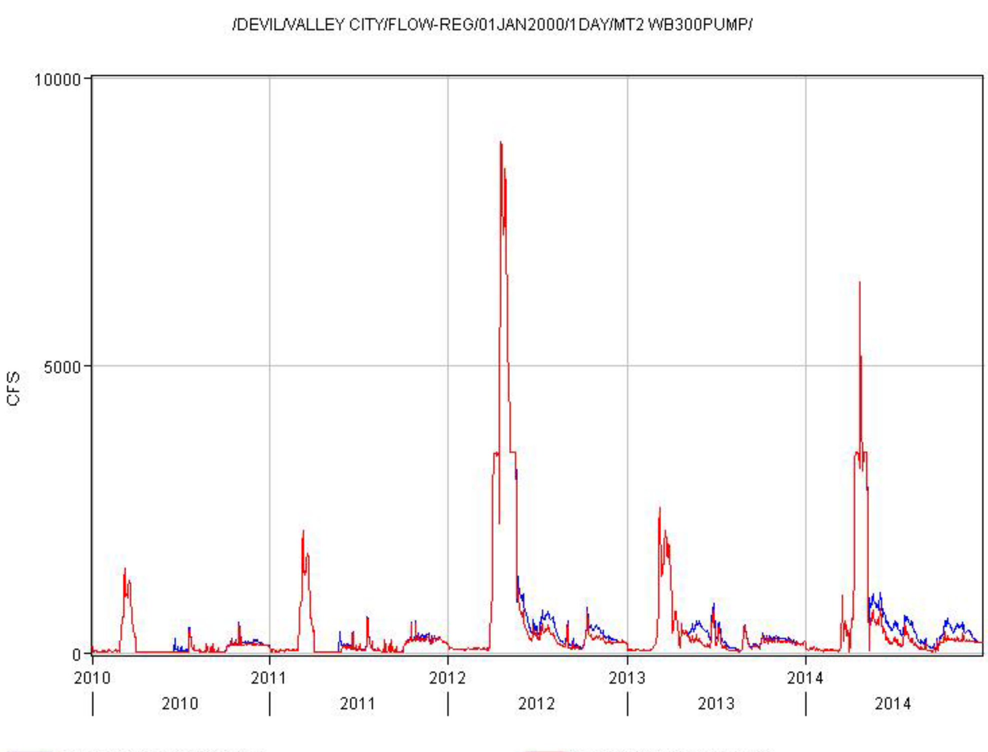


FIGURE A5-48

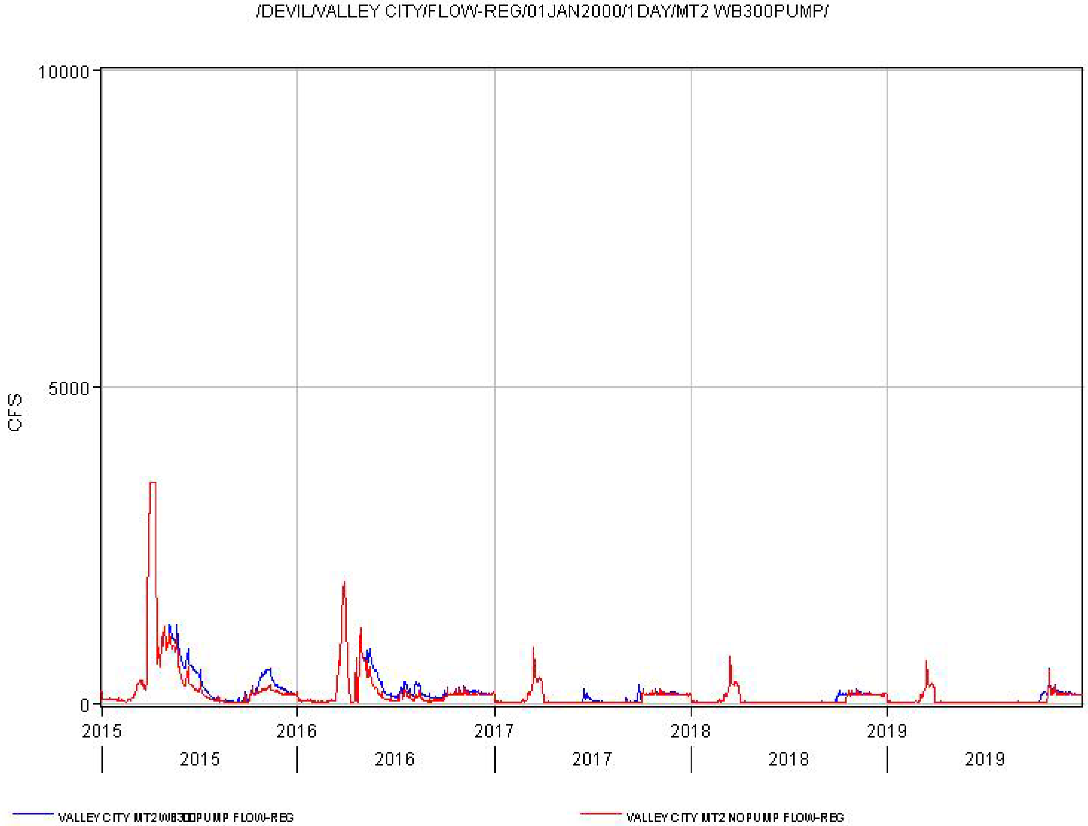


FIGURE A5-49

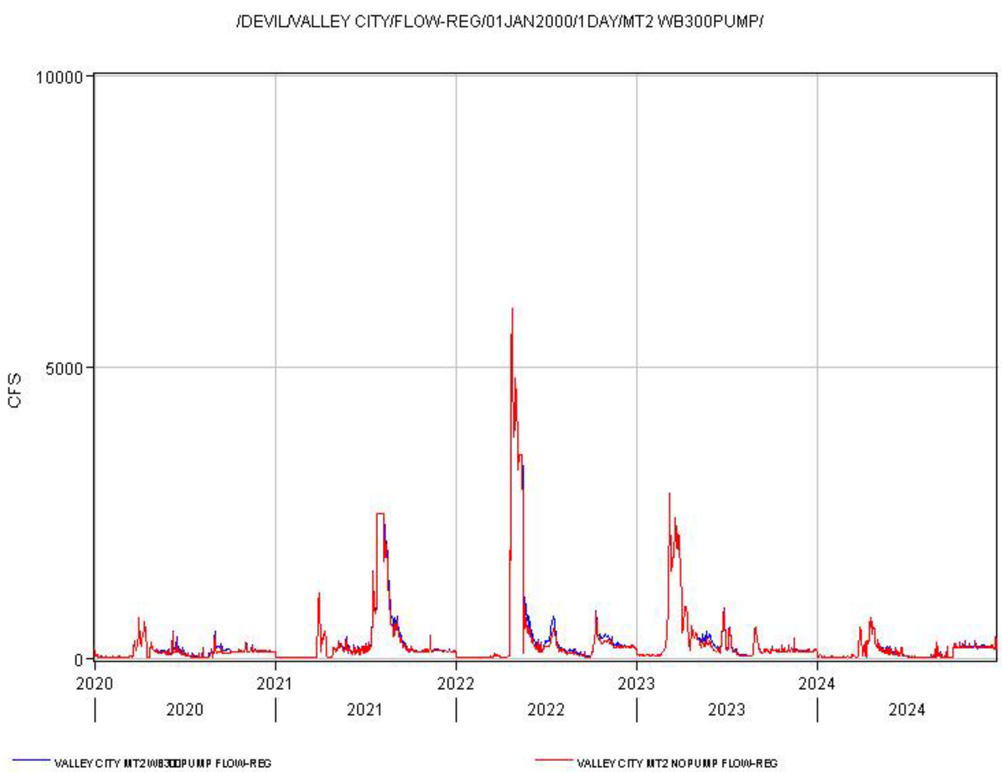
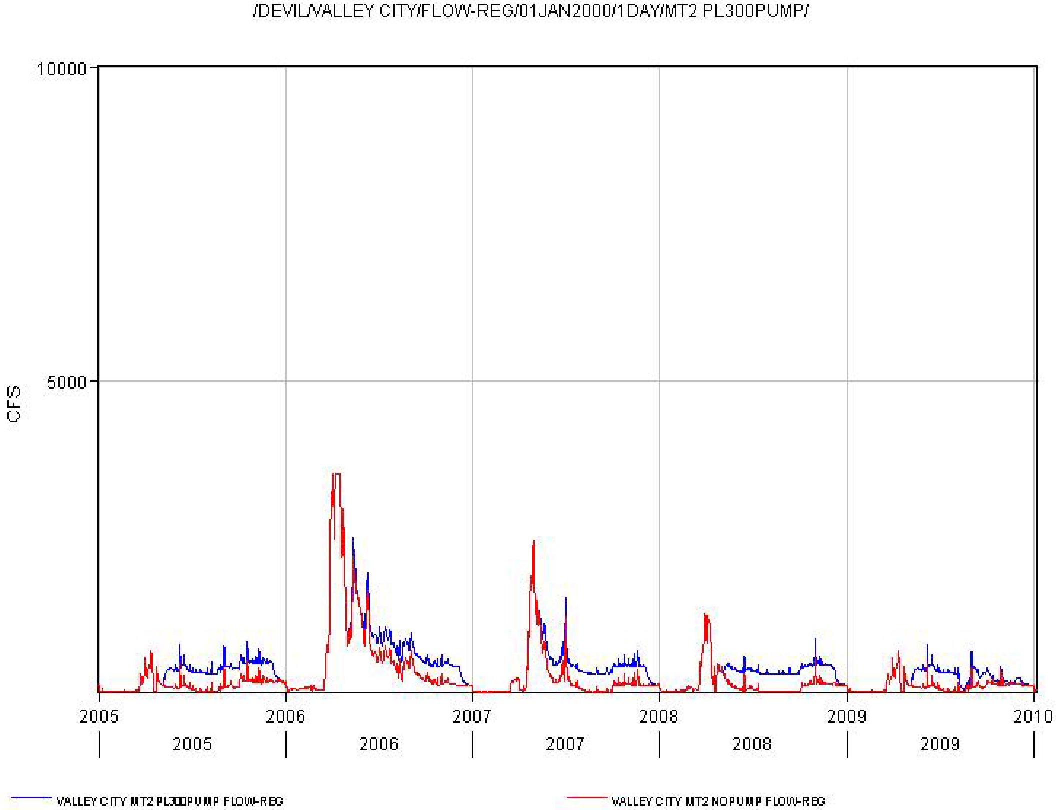


FIGURE A5-50



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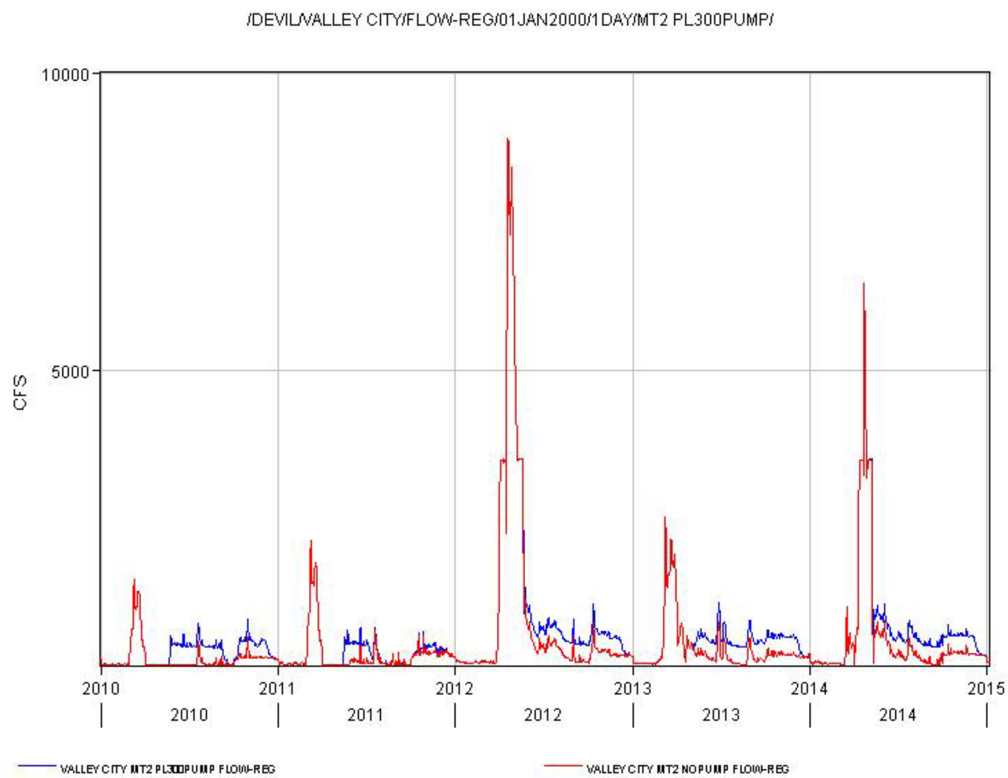


FIGURE A5-52

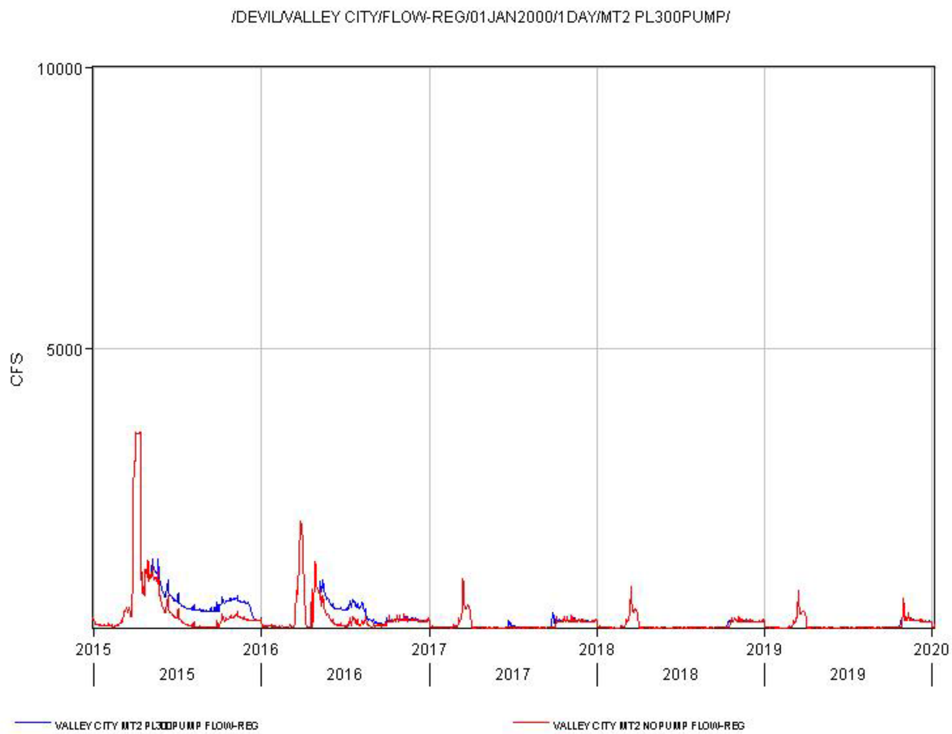


FIGURE A5-53

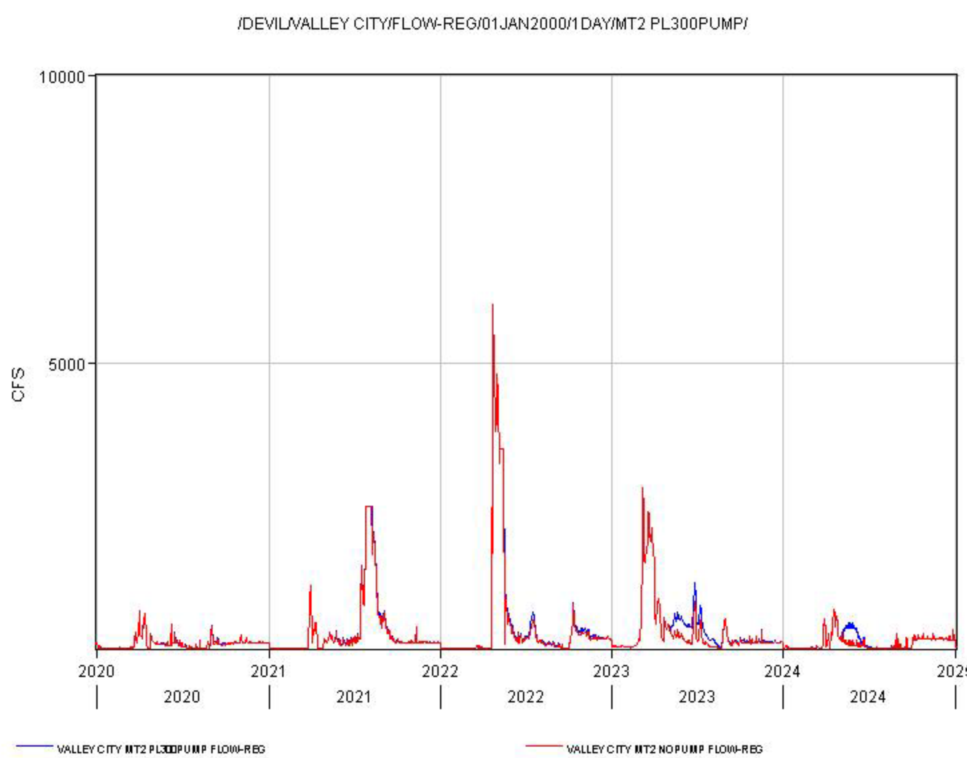


FIGURE A5-54

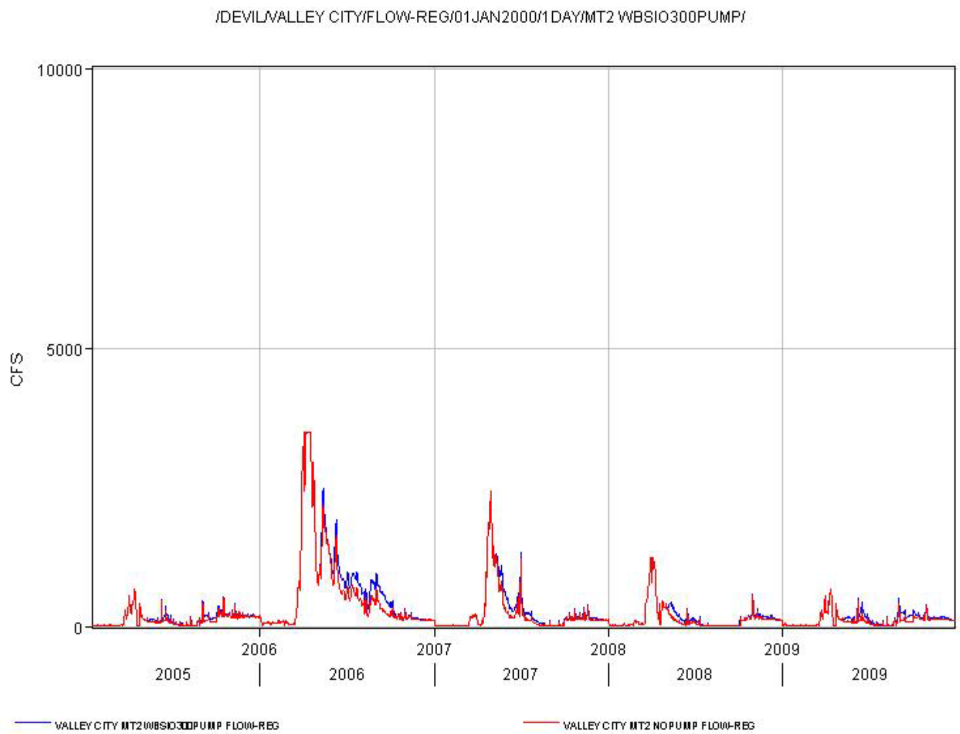


FIGURE A5-55

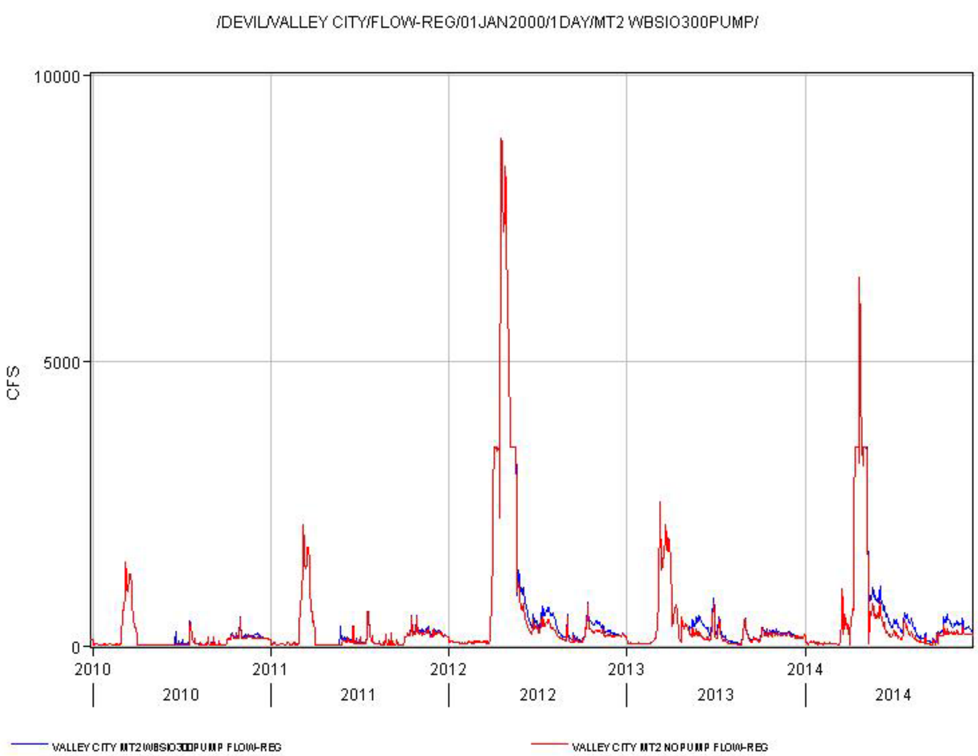


FIGURE A5-56

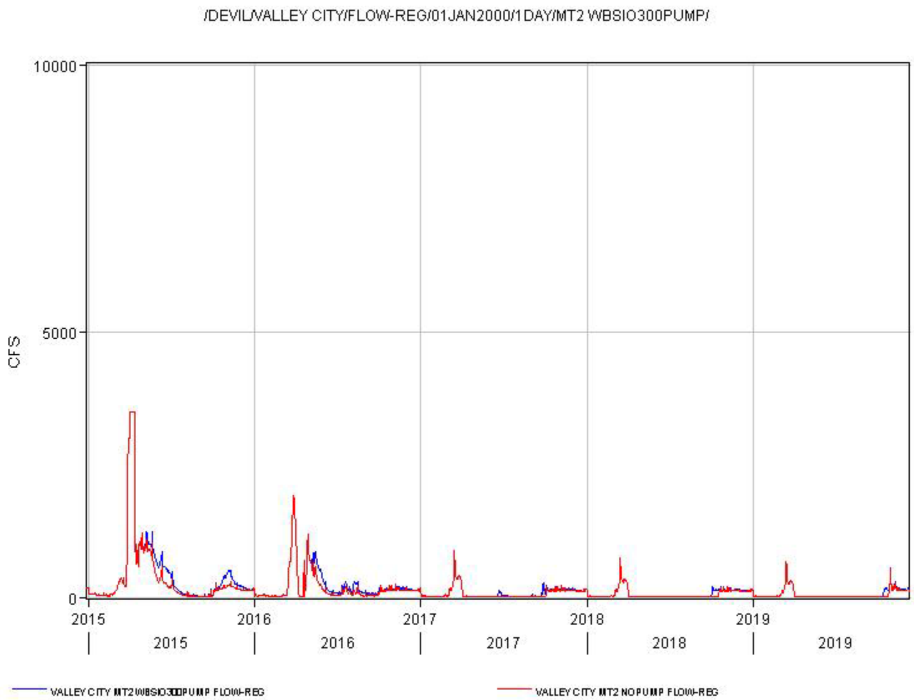


FIGURE A5-57

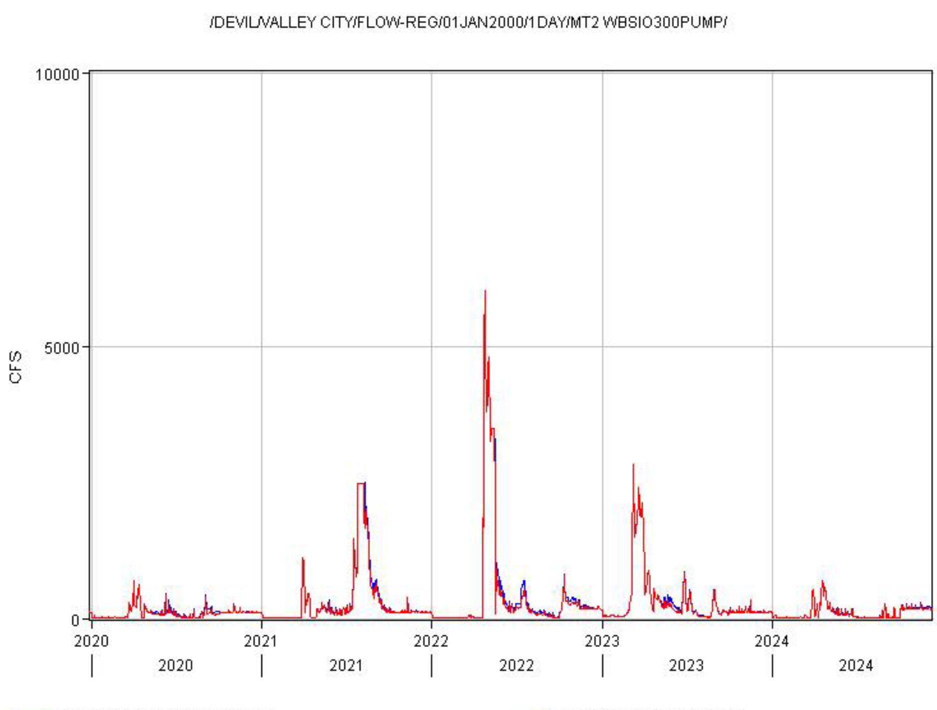


FIGURE A5-58

REFERENCES

1. Vecchia, A. V., 2002, Simulation of a Proposed Emergency Outlet From Devils Lake, North Dakota: U.S. Geological Survey Water Resources Investigations Report, in preparation.

Section 6 - Water Quality Effects

Devils Lake Outlets Water Quality Considerations

Devils Lake is a terminal lake occupying the lower portion of a subbasin that has been hydraulically isolated from the Red River of the North basin for several hundred years. As a result of this isolation it has been accumulating salt. The geomorphology of the Devils Lake basin has produced a chain of lakes, oriented from west to east, each with a higher salinity concentration than its upstream component. The complex geochemistry of Devils Lake over the long term has favored sulfate, which comprises about 50% of the total dissolved solids (TDS). The recent lake level rise has substantially reduced the TDS concentrations throughout the lake chain, but the TDS and especially sulfate remain at concentrations so much higher than in the Sheyenne River and Red River of the North that every effective outlet configuration and operating plan presents regulatory challenges, risk of environmental impairment, and degradation of source water for municiple and industrial and other downstream water users. The potentially effected downstream waters include about 460 miles of the Sheyenne River from various points of insertion and the confluence with the Red River of the North, and about 550 miles of the Red River of the North between Fargo, ND and Lake Winnepeg in Manitoba, Canada. The future water quality of Devils Lake itself would also be effected, especially depending on the location of the outlet and whether the lake would be allowed to overflow from the east end in a controlled or uncontrolled manner if the wet weather trend continues.

Hydrologic and water quality mass balance models were needed to evaluate the in-lake (USGS 5-Box Model) and downstream effects (HEC-5Q Model) of numerous outlet configurations and operating assumptions using several future scenarios. The models were designed initially to address those parameters associated with salinity that appeared to be most restrictive in terms of meeting water quality standards and other regulatory objectives downstream. On the Sheyenne River the most restrictive numerical criterion is the State of North Dakota's sulfate standard of 450 mg/l. On the Red River of the North it is the State of Minnesota's TDS standard of 500 mg/l. North of the border it is also a 500 mg/l TDS criterion. International water quality criteria, termed "objectives" were specified and adopted in May 1969 by the United States and Canada as recommended by the International Joint Commission (IJC). The objectives pertain to Article VI of the 1909 Boundary Treaty (between the United States and Great Britain) which provides that "the [international waters] shall not be polluted on either side to the injury of health or property of the other."

TDS and sulfate are relatively easy to model because they are highly soluble over a wide range of environmental conditions and can be reasonably assumed to be always in solution. The downstream model was later modified to track some of the non-conservative constituents including different forms of phosphorus and nitrogen and to represent algae and periphyton interactions with nutrients. Lake Ashtabula reservoir is now represented as a two dimensional basin so that both vertical and longitudinal gradients can be observed and constituent routing affected by thermal stratification is calculated. Both of the models now represent ice concentration effects. Some constituents such as calcium, magnesium, and sodium could not be directly modeled because the 5-Box model only tracks sulfate and TDS. Those substances were calculated with a spreadsheet program that keys on TDS and virtual dye tracer output from the HEC5-Q model and monitoring information about ionic proportions of major ions in the different basins of Devils Lake and the major downstream tributaries. Another spreadsheet program was used to calculate concentration-duration data.

Note: The next several pages address water quality only in terms of TDS and sulfate concentrations. The nutrients and algae capability of the model was not yet functional during the early screening of alternatives and so was not applied to the West Bay and East Devils Lake outlet alternatives and was not applied in any of the 480 cfs unconstrained scenarios. The part of this section entitled "Effects of Nutrient Loading From Pelican Lake Outlet Operations, 300 Constrained, Wet Scenario," beginning on page A-12_, begins the discussion of nutrient effects.

Downstream Water Quality Effects

Model Description

The USGS 5-Box model was designed to evaluate the probability of future lake level changes, to compute the hydrology and inter-basin sulfate mass balance for each future, and to generate flow and quality data for input to the downstream (HEC-5Q) model. The model was used to simulate the in-lake effects and discharge loading of various scenarios including constrained or unconstrained operations from West Bay, Pelican Lake, East Devils Lake, and uncontrolled overflow through the West Stump Lake natural outlet.

The HEC-5Q model was designed to compute the downstream routing of Devils Lake outlet water affecting water quality and flow in the Sheyennne River, Lake Ashtabula reservoir, and the Red River of the North. The model generated daily flow and concentration data for numerous 50-year long operating scenarios including a "wet" future in which the lake rises above the natural discharge elevation, a moderately wet future in which the lake rises to a maximum elevation of 1455 ft., another moderately wet future in which the lake rises to a maximum elevation of 1450 ft., and a dry future in which the lake doesn't rise but declines in the near future. The lake hydrographs in Plate 1 compare the three wet futures for the following outlet configurations and operating criteria;

West Bay outlet, 300 cfs capacity constrained (See hydrographs in Plate 1) so that effects at any of several hundred downstream locations could be compared with the no-outlet base condition. The data was used to evaluate the impact of outlet operations with respect to regulatory compliance parameters. Data from the model was also used to evaluate mitigation costs in the downstream water users study. A summary of the downstream water users study is provided in Section 7 of this appendix with reference to unattached documents. Data from the model was also used to evaluate potential effects on aquatic life, and potential effects on soil salinity (ref. Appendix C).

The USGS 5-Box model was designed to evaluate the probability of future lake level changes, to compute the hydrology and interbasin sulfate mass balance for each future, and to generate flow and quality data for input to the downstream (HEC-5Q) model. The model was used to simulate the in-lake effects and discharge loading of various scenarios including constrained or unconstrained operations from West Bay, Pelican Lake, East Devils Lake, and uncontrolled overflow through the West Stump Lake natural outlet.

The HEC-5Q model was designed to compute the downstream routing of Devils Lake outlet water affecting water quality and flow in the Sheyennne River, Lake Ashtabula reservoir, and the Red River of the North. The model generated daily flow and concentration data for 50-year long operating scenarios so that effects at any of several hundred downstream locations could be compared with the no-outlet base condition. The data was used to evaluate the impact of outlet operations with respect to regulatory compliance parameters. Data from the model was also used to evaluate mitigation costs in the downstream water users study, potential effects on aquatic life, and potential effects on soil salinity (see other documents). The model was also used to evaluate effects specific to Lake Ashtabula including algae response to nutrient loading but only for the Pelican Lake outlet alternatives.

Effects of Uncontrolled Overflow

The following describes some of the in-lake and downstream water quality effects of an uncontrolled overflow of Devils Lake through the Stump Lakes,Tolna Coulee, and into the Sheyenne River under the Wet Future Scenario. Two conditions were simulated; one assumes that the outlet course would not erode and the other assumes that the outlet elevation would erode to elevation 1450.5 ft over a period of nine months, producing an accelerating discharge with a peak of 6,060 cfs in the year 2019. Under the eroded version of the scenario, a second episode of overflow would begin in year 2038 because the lake would rise to the new lower spill elevation. The lake would reach a lake level of 1452.19 ft. msl with a peak outflow of 690 cfs. However, by this time, the outlet erosion would have stabilized and there would be no further erosion with the corresponding 1.4 ft. of head.

In-Lake Effects of Uncontrolled Overflow

In the wet scenario the Devils Lake chain would freshen considerably (**Plate 2**) during the first five years as a large mass of dissolved solids (salt) would move eastward into Stump Lake and East Devils Lake water would be displaced by East Bay water etc. East Devils Lake and Stump Lake would experience the greatest rate of change until their respective levels equalized. After five years the East Devils Lake water would be similar in quality to present day East Bay water and the TDS in Stump Lake would be less than 5000 mg/l, similar to present day East Devils Lake. During the next nine years the basins would gradually freshen without any large mass transfers of salt until the year 2014 when

Stump Lake would begin to overflow and the rate of freshening would again accelerate. After the overflow period the entire Devils Lake chain (excluding Stump Lake) would have water quality similar to the present day west end. If the overflow watercourse were allowed to erode to elevation 1450.5 ft., the freshening would happen sooner and Stump Lake water quality would be similar to the rest of the Devils Lake chain (data not shown in plate).

Downstream Effects of Uncontrolled Overflow

On Sheyenne River near Cooperstown, (Plate 2.5) the median TDS concentration under the base condition is about 600 mg/l. The overflow event would produce a peak concentration close to 3500 mg/l and a sustained condition of more than 1500 mg/l during most of the 11-year event. Under the eroded assumption the peak concentration would be about the same but would drop to a much lower level after the fifth year. The sulfate concentrations would peak above 1500 mg/l under both conditions. Under the uneroded condition sulfate would remain above 700 mg/l during much of the 11-year period. Under the eroded condition the sulfate concentration would drop to a range of 300 to 400 mg/l after the first few years. Under the uneroded condition the chloride concentration would exceed 200 mg/l during much of the time. North Dakota's chloride criterion for protection of aquatic life is 175 mg/l. Under the eroded condition during the second episode of overflow the TDS and sulfate peaks would approach 1100 mg/l and 500 mg/l respectively.

On the Sheyenne River at Valley City, (Plate 3) the median TDS concentration under the base condition is about 500 mg/l. The overflow event would produce a peak concentration close to 2600 mg/l and a sustained condition of more than 1200 mg/l during most of the 11-year event. Under the eroded assumption the peak TDS concentration would approach 3500 mg/l but would drop to a much lower level after the fifth year. The sulfate concentrations would peak above 1200 mg/l under both conditions. Under the uneroded condition sulfate would remain above 700 mg/l during much of the 11-year period. Under the eroded condition the sulfate concentration would drop to a range of 300 to 400 mg/l after the first few years. Under the uneroded condition the chloride concentration would exceed 175 mg/l during much of the time. North Dakota's chloride criterion for protection of aquatic life is 175 mg/l. Under the eroded condition during the second episode of overflow the TDS and sulfate peaks would approach 1000 mg/l and 400 mg/l respectively.

In Lake Ashtabula the aquatic communities would experience the same exposure to high and variable dissolved solids concentrations described for Cooperstown and Valley City above. In the uneroded scenario the discharge from Stump Lake would discontinue during the summer and resume in the spring of each year, causing an annual freshening in the upper reach of Lake Ashtabula during the late summer and winter (similar to Cooperstown plots). In the lower end of the reservoir pool near the dam, however, the high concentration condition would persist throughout the winter months and freshen only briefly in the spring (similar to Valley City plots).

On the Red River of the North near Halstad, MN, (Plate 4) the median TDS concentration under the base condition is about 400 mg/l. The overflow event (uneroded condtion) would produce a peak concentration close to 1200 mg/l and would remain in the range of 500 to 1000 mg/l during most of the 11-year event. Under the eroded assumption the peak TDS concentration would approach 3000 mg/l but would remain in the range of 400 – 800 mg/l after the fifth year. The sulfate concentrations would peak at about 450 mg/l under the uneroded condition and close to 1400 mg/l under the eroded condition. Under the uneroded condition sulfate would remain above 175 mg/l during much of the 11-year period. Under the eroded condition the sulfate concentration would drop to a range of 100 to 200 mg/l after the first few years. Under the uneroded condition the chloride concentration would peak at 100 mg/l and frequently approach 60 mg/l during much of the time. Minnesota's chloride criterion for protection of aquatic life is 100 mg/l. Under the eroded condition during the second episode of overflow the TDS and sulfate peaks would approach 700 mg/l and 300 mg/l respectively.

On the Red River of the North near Emerson Manitoba, (Plate 5) the median TDS concentration under the base condition is about 450 mg/l. The overflow event (uneroded condtion) would produce a peak concentration close to 1000 mg/l and would remain in the range of 400 to 700 mg/l during most of the 11-year event. Under the eroded assumption the peak TDS concentration would approach 2300 mg/l but would remain within the range of the base condition after the fifth year. The sulfate concentrations would peak at about 350 mg/l under the uneroded condition and close to 1100 mg/l under the eroded condition. Under the uneroded condition sulfate would remain under 200 mg/l during most of the time. Under the eroded condition the sulfate concentration would remain within the range of the baseline condition after the first few years. Under the uneroded condition the chloride concentration would peak at 130 mg/l and frequently approach 80. The baseline median for chloride is about 50 mg/l. Under the eroded condition during the second episode of overflow the TDS and sulfate peaks would approach 800 mg/l and 250 mg/l respectively.

Effects of Outlet Operations for the Wet Scenario

The following describes some of the in-lake and downstream water quality effects of different outlet configurations and operating strategies for the continued wet cycle scenario. The modeled data presented in the plates include 50-year time series plots for TDS and sulfate and concentration duration statistics based on data based on the first 10 years of operations. The 10-year time frame was chosen because it is the period common to all of the scenarios in which a lot of outlet pumping is needed to meet the lake drawdown objective. It is likely that the people and government agencies who have to decide to permit or accept water quality and other environmental changes downstream would be most interested in effects that would happen during the first few years of operation rather than averaged over a 50-year period. The modeled scenarios include the following;

West Bay outlet, 300 cfs and 480 cfs, unconstrained
Pelican Lake outlet, 300 cfs and 480 cfs, unconstrained
East Devils Lake outlet, 480 cfs unconstrained
Pelican Lake diversions options

Selected Plan, Pelican Lake Outlet, 300 cfs, 300 mg/l SO4 Constraint, 600 cfs Channel Capacity, Wet Scenario

Editor's Note: The present discussion of the "300 cfs – 300 mg/l" operating plan as described under the above heading "Selected Plan …" was not a part of the July 2002 version of this document (Appendix A) because the plan was not yet formulated. It is inserted here in the present version of the document without benefit of resequencing plate numbers or changing legend titles on plots and tables. The cost and time constraints of such editing was prohibitive. The reader should note that legends and other references using the notation "PL300" refer to the "300 cfs / 450 mg/l (SO4) constraint" operating plan and that legends using the notation "Outlet" in Plates 6A – 6M) refer to the Selected Plan operating constraints.

The selected plan provides for operating an outlet from Pelican Lake with constraints including; 300 cfs maximum pumping capacity, 7-month operation (May – November), regulate pumping to not exceed the 600 cfs channel capacity of the Sheyenne River, regulate pumping to not exceed 300 mg/l SO4 (sulfate) in the Sheyenne River, operate until a Devils Lake water surface elevation of 1443 ft. is achieved. The selected plan also calls for passing the entire outlet discharge through a sand filter to remove particulate solids.

Effect of Sand Filter

The sand filter is expected to affect water quality downstream by preventing particulate forms of nutrients from reaching the Sheyenne River. Monitoring data from Devils Lake (Table A6-1) indicate that about 96% of the nitrogen and approximately 19% of the phosphorus is associated with particulate substances (biota) during the open water season and so would be intercepted and retained by the sand filter. It is assumed that only dissolved forms would pass through. Discussion of downstream nutrient effects presented elsewhere in this document (p. A-190) and in the main report points out that outlet operations at 300 cfs from Pelican Lake would introduce about 40 tons of phosphorus per year into the Sheyenne River and that nitrogen concentrations would not significantly change. Action of the sand filter would effectively reduce the phosphorus load to about 32 tons per year and would likely cause reduced nitrogen concentrations in the downstream reaches. Note: HEC-5Q modeling for the "Selected Plan" (Pelican Lake outlet with 300 mg/l sulfate constraint) was not performed.

TABLE A6-1
DEVILS LAKE NUTREINTS DATA

DATE	Total Nitrogen (TKN mg/l as N)			Dissolved Nitrogen (NO2+NO3 mg/l as N)			Total Phosphorus (TPO4 mg/l as P)			Dissolved Phosphorus (DPO4 mg/l as P)		
	W.BAY	MAIN B	PELICAN	W.BAY	MAIN B	PELICAN	W.BAY	MAIN B	PELICAN	W.BAY	MAIN B	PELICAN
May-95	1.74	0.772		0.051	0.418		0.101	0.178				
Jul-95	1.26	1.37		0.008	0.019		0.215	0.232			0.222	
Oct-95	1.5	1.68		0.0025	0.0025		0.169	0.226		0.139	0.202	
Mar-96	1.87	1.71		0.27	0.1		0.269	0.31		0.253	0.344	
May-96	1.39	1.43		0.01	0.01		0.176	0.195		0.139	0.166	
Jul-96	1.51	1.73		0.02	0.01		0.239	0.217		0.206	0.193	
Aug-96	1.26	1.49		0.01	0.01		0.27	0.257		0.271	0.25	
Sep-96	1.7	1.62		0.01	0.01		0.281	0.262		0.238	0.241	
Oct-96	1.47	1.48		0.01	0.08		0.164	0.268		0.124	0.258	
Mar-97	2.14	2.02		0.09	0.24		0.158	0.244		0.143	0.243	
May-97	1.55	1.74		0.001	0.11		0.228	0.281		0.249	0.304	
Jul-97	1.61	1.46		0.05	0.04		0.253	0.303		0.233	0.242	
Aug-97	1.75	1.63		0.01	0.01		0.381	0.223		0.295	0.229	
Sep-97	1.67	1.56		0.05	0.03		0.314	0.332		0.3	0.306	
Oct-97	1.36	1.34		0.13	0.15		0.248	0.312		0.218	0.248	
May-98		1.87			0.08			0.948		0.218	0.23	
Jul-98	1.07	1.08		0.04	0.01		0.449	0.359		0.186	0.193	
Aug-98	1.56	1.31		0.03	0.01		0.77	0.717		0.352	0.276	
Sep-98	1.4	1.52		0.04	0.01		0.482	0.352		0.352	0.296	
Oct-98	1.15	1.46		0.06	0.07		0.39	0.368		0.229	0.262	
Feb-99	1.38	1.39	1.95	0.05	0.2	0.07	0.316	0.488	0.419	0.431	0.486	0.458
May-99		1.47	1.28		0.13	0.22		0.475	0.261		0.296	0.25
Aug-99		1.16	1.03		0.01	0.01		0.296	0.374		0.258	0.334
Oct-99		1.16	1.14		0.01	0.26		0.212	0.189		0.244	0.153
Feb-00		1.35	2.28		0.01	0.01		0.182	0.195		0.177	0.106
May-00		1.28	1.61		0.01	0.03		0.2	0.242		0.181	0.205
Aug-00		1.5	2.33		0.01	0.01		0.277	0.54		0.249	0.38
Oct-00	1.49	1.38	1.62	0.09	0.04	0.02	0.255	0.241	0.29	0.208	0.205	0.233
Mar-01	1.62	1.46	1.88	0.07	0.05	0.66	0.205	0.176	0.397	0.181	0.155	0.315
May-01	1.43	1.43	1.5	0.04	0.01	0.06	0.253	0.21	0.282	0.208	0.162	0.194
Aug-01	1.78	1.95	2.53	0.01	0.01	0.02	0.36	0.323	0.45	0.32	0.262	0.337
Oct-01	1.51	1.44	1.44	0.03	0.08	0.09	0.336	0.311	0.07	0.302	0.299	0.058
		Avg Tot Ni	**1.54**		**Avg Dis Ni**	**0.07**		**Avg Tot Pl**	**0.30**		**Avg Dis Pl**	**0.25**
		Sdev	0.31		Sdev	0.11		Sdev	0.14		Sdev	0.08
		Avg Particulate N as % of Total N				**96**		**Avg Particulate P as % of Total P**				**19**

Data From North Dakota Department of Health

In Lake Effects

Outlet operations from Pelican Lake In the Wet Future Scenario (Plate 6A) would affect water quality in Devils Lake by diverting some of the freshening inflow before it has occasion to blend with West Bay water. In the Wet Scenario it would also prevent the large eastward mass movement of salt associated with overflow from Stump Lake. Without an outlet the TDS concentration in Main bay would gradually decrease to a low of about 1000 mg/l. Outlet operations would hold the TDS at or above 1500 mg/l during the same period. Similarly, in East Bay, outlet operations would cause and increase in TDS of about 500 mg/l. In East Devils Lake outlet operations would result in a TDS increase of about 1000 mg/l by the 20th year.

Downstream Effects

On the upper Sheyenne River near Cooperstown, ND (Plate 6E), (Plate 6I) the median TDS concentration under the base condition, excluding the overflow, period is about 650 mg/l. With outlet operations from Pelican Lake constrained to 300 cfs and 300 mg/l sulfate the TDS median would increase slightly with annual peaks not exceeding the base condition. TDS concentrations would sometimes be lower that the base condition because Pelican Lake water is sometimes "fresher" than the Sheyenne River during base flow periods. During the first ten years of operation the TDS concentration would exceed 500 mg/l 86% of the time (base condition is 82%). The sulfate median would increase from about 160 mg/l (excluding the overflow period) to about 200 mg/l. During the first ten years of operation the sulfate concentration would exceed 250 mg/l 12% of the time (base condition 0%). The chloride concentrations would range between 8 and 55 mg/l seasonally. Under base conditions the chloride ranges between 8 and 25 mg/l.

In Lake Ashtabula above Valley City - Plates 6E and 6F describe the waters entering and discharging from Lake Ashtabula during the 50-year simulations (Cooperstown and Valley City plots respectively). The plots in Plate 6C zoom in on the first three years of operation and illustrate the dilution and storage effects of the reservoir. At the upper end of the lake the concentrations of TDS, sulfate, chloride, and other substances associated with Pelican Lake outlet operations would increase and decrease rapidly with the onset and cessation of outlet operations so that the winter and spring conditions would be the same as the base condition. Within the reservoir pool and in the discharge from the dam the concentrations would increase and decrease more gradually and the elevated concentrations would be sustained through the winter until the spring snowmelt season. Each winter during the time of reservoir draw-down for flood control storage there would be a majority component of Devils Lake water in the reservoir pool and in the discharge.

On the upper Sheyenne River near Valley City, ND (Plate 6F), (Plate 6I) the median TDS concentration under the base condition, excluding the overflow period, is about 500 mg/l. With outlet operations from Pelican Lake constrained to 300 cfs and 300 mg/l sulfate the TDS median would increase slightly. Annual peaks would sometimes exceed the base condition by as much as 150 mg/l. During the first ten years of operation the TDS concentration would exceed 500 mg/l 77% of the time (base condition is 52%). The sulfate median would increase from about 140 mg/l (excluding the overflow period) to about 180 mg/l. The sulfate concentration would exceed 250 mg/l 13% of the time (base condition 0%). The total hardness concentration would exceed 250 mg/l 88% of the time (base condition 79%). The chloride concentrations would range between 10 and 50 mg/l seasonally. Under base conditions the chloride ranges between 10 and 20 mg/l.

On the Red River of the North near Halstad, MN (Plate 6G), (Plate 6I) the median TDS concentration under the base condition is about 430 mg/l. With outlet operations from Pelican Lake constrained to 300 cfs and 300 mg/l sulfate the TDS median would increase slightly. During the first ten years of operation the TDS concentration would exceed 500 mg/l 10% of the time (base condition is 3%). The sulfate concentration would not exceed 250 mg/l. The total hardness concentration would exceed 250 mg/l 88% of the time (base condition 86%). The chloride concentrations would remain below 70 mg/l with only a slight increase over baseline conditions.

On the Red River of the North near Emerson, MAN (Plate 6H), (Plate 6I) the median TDS concentration under the base condition, excluding the overflow period, is about 470 mg/l. With outlet operations from Pelican Lake constrained to 300 cfs and 300 mg/l sulfate the TDS median would not change. During the first ten years of operation the TDS concentration would exceed the 500 mg/l IJC objective 12% of the time (base condition is 8%) and would not exceed 600 mg/l. During the first 10 years of operation the sulfate concentration would not exceed 250 mg/l. The total hardness concentration would exceed 250 mg/l 71% of the time (base condition 61%).

Selected Plan, Pelican Lake Outlet, 300 cfs, 300 mg/l SO4 Constraint, 600 cfs Channel Capacity, Moderate 1455 Scenario

In Lake Effects

The in lake water quality effect of outlet operations from Pelican Lake In the Moderate 1455 Future Scenario (Plate 6B) would be less dramatic than in the Wet Scenario because it doesn't prevent a natural overflow from happening. TDS concentrations would increase slightly throughout the lake chain due to the outlet intercepting and diverting water that would otherwise tend to "freshen" the lake.

Downstream Effects

On the upper Sheyenne River near Cooperstown, ND (Plate 6J), (Plate 6I) the median TDS concentration under the base condition is about 600 mg/l. With outlet operations from Pelican Lake constrained to 300 cfs and 300 mg/l sulfate the TDS median would increase slightly. The TDS concentration would exceed 500 mg/l 83% of the time (base condition is 79%). The sulfate median would increase from about 150 mg/l to about 200 mg/l with annual peaks not exceeding 300 mg/l. The sulfate would exceed 250 mg/l 33% of the time (base condition 0%). Chloride concentrations would range between 8 and 55 mg/l seasonally. In the base condition chloride concentrations range between 8 and 25 mg/l.

In Lake Ashtabula above Valley City - Plates 6J and 6K describe the waters entering and discharging from Lake Ashtabula during the 50-year simulations (Cooperstown and Valley City plots respectively). The plots in Plate 6D zoom in on the first three years of operation and illustrate the dilution and storage effects of the reservoir. At the upper end of the lake the concentrations of TDS, sulfate, chloride, and other dissolved constituents would increase and decrease rapidly with the onset and cessation of outlet operations so that the winter and spring conditions would be the same as the base condition. Within the reservoir pool and in the discharge from the dam the concentrations would increase and decrease more gradually and the elevated concentrations would be sustained through the winter until the spring snowmelt season. Each winter during the time of reservoir draw-down for flood control storage there would be a majority component of Devils Lake water in the reservoir pool and in the discharge.

On the upper Sheyenne River near Valley City, ND (Plate 6K), (Plate 6I) the median TDS concentration under the base condition is about 480 mg/l. With outlet operations from Pelican Lake constrained to 300 cfs and 300 mg/l sulfate the TDS median would increase to about 550 mg/l with annual peaks above 700. The TDS concentration would exceed 500 mg/l 78% of the time (base condition is 34%). The sulfate median would increase from about 130 mg/l to about 180 mg/l. The sulfate would exceed 250 mg/l 8% of the time (base condition 0%). Total hardness would exceed 250 mg/l 90% of the time (base condition 87%). Chloride concentrations would range between 10 an 45 mg/l seasonally. In the base, condition chloride concentrations range between 10 and 18 mg/l.

On the Red River of the North near Halstad, MN (Plate 6L), (Plate 6I) the median TDS concentration under the base condition is about 420 mg/l. With outlet operations from Pelican Lake constrained to 300 cfs and 300 mg/l sulfate the TDS median would slightly increase. The 500 mg/l TDS standard would be exceeded 6% of the time (base condition is 4%). The 250 mg/l sulfate standard would not be exceeded. The 250 mg/l total hardness standard would be exceeded 89% of the time (base condition 87%). Chloride concentrations would be slightly increased. Generally water quality effects during relatively dry seasons would be less severe on the Red River of the North because the 300 mg/l sulfate constraint reduces the volume of water being discharged from Pelican Lake.

On the Red River of the North near Emerson, MAN (Plate 6M), (Plate 6I) with outlet operations from Pelican Lake constrained to 300 cfs and 300 mg/l sulfate the TDS concentrations would be slightly increased. The 500 mg/l IJC objective would be exceeded 13% of the time (base condition is 11%). Sulfate concentrations would remain under 150 mg/l. There would be slight changes in hardness and chloride concentrations.

West Bay Outlet 300, Constrained, 480 Unconstrained

In Lake Effects

In Lake Effects (Plate 6) Outlet operations from West Bay would affect water quality in Devils Lake by exporting salt to the Sheyenne River, diverting some of the freshening inflow into the eastern basins, and by preventing the large eastward mass movement of salt associated with overflow from Stump Lake. In the Main Bay there appears to be very little change in water quality caused by either of the outlet strategies during the wet (first 22 years) part of the wet scenario. That is because there would be abundant inflow to serve both the pumping and the dilution function. Although the TDS concentrations would be about the same in the year 2022, the volumes, the lake stages, and the surface areas would be different. The concentration effects would be manifested during the dry part of the wet scenario, as evaporation would remove different proportions of the initial volumes of water. By the end of the dry period (year 2034) the TDS concentration of Main Bay (with 480 cfs operation) would increase by more than 500 mg/l over the no-pump base condition. A lesser effect would be caused by 300 cfs constrained operation. Curiously, with the resumption of the wet cycle in the scenario beginning in year 2035, Main Bay would freshen faster and become fresher in the 480 cfs outlet trace than in both the 300 cfs *and* the base condition traces. In the 480 cfs operation the lake level would drop to about 1435 ft., at which West Bay would be mostly upland and disconnected wetlands. Inflows from the resumed wet cycle would contribute more directly to Main Bay. West Bay would not fill and expand in surface area until a considerable storage demand in Main Bay, East Bay, and East Devils Lake was satisfied. In the 300 cfs and base condition traces the wet cycle would resume with the lake levels at 1446 ft. and 1451 ft. respectively, which means that the freshening inflow would impart most of its diluting effect on a large West Bay and West Bay water would be displaced eastward into Main Bay.

Downstream Effects

On the upper Sheyenne River near Cooperstown, (Plate 7A), (Plate 7B), (Plate 7C) the median TDS concentration under the base condition, excluding the overflow, period is about 650 mg/l. With constrained 300 cfs operations the TDS median would increase to about 750 mg/l with annual peaks above 900 mg/l. During the first ten years of operation the TDS concentration would exceed 600 mg/l 81% of the time (base condition is 60%) and would exceed 900 mg/l 36% of the time (base condition is 0%). The sulfate median would increase from about 160 mg/l (excluding the overflow period) to about 270 mg/l. During the first ten years of operation the sulfate concentration would exceed 200 mg/l 62% of the time (base condition 7%) and would exceed 250 mg/l 57% of the time (base condition 0%). With 480 cfs unconstrained operation would not be much higher than with constrained operation because in both cases the upper Sheyenne River would be essentially “maxed out” with Devils Lake water.

On the Sheyenne River near Valley City, (Plate 7A), (Plate 7B), (Plate 7C) the median TDS concentration under the base condition, excluding the overflow period, is about 500 mg/l. With constrained 300 cfs operations the TDS median would increase to about 700 mg/l with annual peaks above 900 mg/l. During the first ten years of operation the TDS concentration would exceed 600 mg/l 77% of the time (base condition is 20%) and would exceed 800 mg/l 42% of the time (base condition is 0%). The sulfate median would increase from about 140 mg/l (excluding the overflow period) to about 250 mg/l. The sulfateconcentration would exceed 200 mg/l 73% of the time (base condition 1%) and would exceed 250 mg/l 55% of the time (base condition 0%). Unconstrained operation at 480 cfs would produce TDS concentrations above 1000 mg/l 21% of the time and sulfate concentrations above 400 mg/l 25% of the time.

In Lake Ashtabula above Valley City - Plates 7A, 7B, and 7C describe the waters entering and discharging from Lake Ashtabula during the 50-year simulations

(Cooperstown and Valley City plots respectively). The plots in Plate 7D zoom in on the first two years of operation to illustrate the dilution and storage effects of the reservoir. At the upper end of the lake the TDS and sulfate concentrations would increase and decrease rapidly with the onset and cessation of outlet operations so that the winter and spring conditions would be the same as the base condition. Within the reservoir pool and in the discharge from the dam the concentrations would increase and decrease more gradually and the elevated concentrations would be sustained through the winter until the spring snowmelt season. Each winter during the time of reservoir draw-down for flood control storage there would be a majority component of Devils Lake water in the reservoir pool and in the discharge.

On the Red River of the North near Halstad, MN, (Plate 7A), (Plate 7B), (Plate 7C), (Plate 7E) the median TDS concentration under the base condition is about 430 mg/l. With constrained 300 cfs operations the TDS median (excluding the overflow period) would increase to about 480 mg/l with annual peaks above 550 mg/l. During the first ten years of operation the TDS concentration would exceed 500 mg/l 27% of the time (base condition is 4%) and would exceed 600 mg/l 40% of the time (base condition is 0%). The sulfate median (excluding the overflow period) would increase from less than 100 mg/l to about 125 mg/l. The sulfate would exceed 200 mg/l 1% of the time during the first ten years of operation (base condition 0%). Unconstrained operation at 480 cfs would produce TDS concentrations above 600 mg/l 15% of the time (base condition 0%) and sulfate concentrations above 200 mg/l 11% of the time (base condition 1%).

On the Red River of the North at Emerson Manitoba, (Plate 7A), (Plate 7B), (Plate 7C) (Plate 7F) the median TDS concentration under the base condition,excluding the overflow period, is about 470 mg/l. With constrained 300 cfs operations the TDS median would not measurably change. During the first ten years of operation the TDS concentration would exceed 500 mg/l 20% of the time (base condition is 8%) and would not exceed 600 mg/l. The sulfate median (excluding the overflow period) would measurably increase. During the first 10 years of operation the sulfate would exceed 150 mg/l about 2 % of the time. Unconstrained operation at 480 cfs would produce TDS concentrations above 500 mg/l 33% of the time (base condition 8%) and sulfate concentrations above 150 mg/l 10% of the time during the first ten years of operation (base condition 1%).

Pelican Lake Outlet, 300 Constrained, 480 Unconstrained, Wet Scenario

The Pelican Lake outlet alignment was evaluated because it would effectively intercept and divert the relatively fresh inflow to Devils Lake and minimize the downstream water quality effects in most scenarios especially the wet future. One trade-off, however, is that operations would deprive Devils Lake of it's freshening inflow and it would become saltier than it would with a West Bay or east end outlet. In the wet scenario there is ample supply of Pelican Lake water available during the annual 7-month operating season but the advantage "plays out" at the end of the wet years sequence and the outlet effectively draws water from West Bay, which has become saltier, and discharges into a relatively dry downstream condition. In the moderate and dry future scenarios the Pelican Lake advantage plays out much earlier.

In Lake Effects

Outlet operations from Pelican Lake (Plate 9) would affect water quality in Devils Lake by diverting some of the freshening inflow before it has occasion to blend with West Bay water. In the Wet Scenario it would also prevent the large eastward mass movement of salt associated with overflow from Stump Lake. Unlike the West Bay outlet configuration, the effect of Pelican Lake operations would be manifested in the early years. The peak and extended future concentrations in Main Bay and East Bay would also be considerably higher than with West Bay operations. By the end of the dry period (about year 2034) the TDS concentration of Main Bay (with 480 cfs operation) would increase by more than 1000 mg/l over the no-pump base condition. A lesser effect would be caused by 300 cfs constrained operation except that with the resumption of the wet cycle the 300 cfs operation would ultimately have a higher concentration effect in Main Bay which may be explained in part by the different storage histories of the 480 and 300 cfs operations as discussed in a prior paragraph with regard to West Bay operations.

Downstream Effects

On the Sheyenne River near Cooperstown, (Plate 10A), (Plate 10B), (Plate 10C) the median TDS concentration under the base condition, excluding the overflow period, is about 650 mg/l. With constrained 300 cfs operations from Pelican Lake the TDS median would not change. The TDS concentration during the first 10 years would exceed 600 mg/l 68% of the time (base condition is 60%). The sulfate median (excluding the overflow period) would increase from about 160 mg/l to about 200 mg/l. The sulfate would exceed 200 mg/l 42% of the time (base condition 8%) and would exceed 250 mg/l 14% of the time (base condition 0%). With 480 cfs unconstrained operation the TDS and sulfate effects would not be much different than with constrained operation during the first twenty years. Water quality effects of operation would be much greater beginning in the decade of the 2020's because Pelican Lake would begin to get salty due to lack of inflow. Continued operations to achieve the drawdown objective would cause water quality effects much worse than the West Bay outlet configuration (compare Plate 7A).

On the Sheyenne River near Valley City, (Plate 10A), (Plate 10B), (Plate 10C) the median TDS concentration under the base condition, excluding the overflow period, is about 500 mg/l. With constrained 300 cfs operations from Pelican Lake the TDS median would increase to about 600 mg/l with annual peaks above 800 mg/l during the first twenty years of operation. The TDS concentration would exceed 600 mg/l 48% of the time (base condition is 20%) and would not exceed 800 mg/l. The sulfate median, excluding the overflow period, would increase from about 140 mg/l to about 180 mg/l.

During the first ten years of operation the sulfate would exceed 200 mg/l 40% of the time (base condition 1%) and would exceed 250 mg/l 13% of the time (base condition 0%). Unconstrained operation at 480 cfs would produce TDS concentrations above 800 mg/l 12% of the time and sulfate concentrations above 300 mg/l 13% of the time. Water quality effects would be much greater beginning in the decade of the 2020's because Pelican Lake would begin to get salty due to lack of inflow. Continued operations to achieve the drawdown objective would cause water quality effects much worse than the West Bay outlet configuration.

In Lake Ashtabula above Valley City - Plates 10A, 10B, and 10C describe the waters entering and discharging from Lake Ashtabula during the 50-year simulations (Cooperstown and Valley City plots respectively). The plots in Plate 10D zoom in on the first five years of operation and illustrate the dilution and storage effects of the reservoir. At the upper end of the lake the TDS and sulfate concentrations would increase and decrease rapidly with the onset and cessation of outlet operations so that the winter and spring conditions would be the same as the base condition. Within the reservoir pool and in the discharge from the dam the concentrations would increase and decrease more gradually and the elevated concentrations would be sustained through the winter until the spring snowmelt season. Each winter during the time of reservoir draw-down for flood control storage there would be a majority component of Devils Lake water in the reservoir pool and in the discharge.

On the Red River of the North near Halstad, MN, (Plate 10A), (Plate 10B), (Plate 10C),(Plate 10E) the median TDS concentration under the base condition, excluding the overflow period, is about 430 mg/l. With constrained 300 cfs operations from Pelican Lake the TDS median would not change during the first twenty years of operation. During the first ten years of operation the TDS concentration would exceed 500 mg/l 11% of the time (base condition is 3%). The sulfate median would increase slightly to about 100 mg/l. The sulfate concentration would rarely exceed 150 mg/l. Unconstrained operation at 480 cfs would produce TDS concentrations above 500 mg/l 21% of the time during the first ten years of operation (base condition 3%). Sulfate concentrations would not exceed 250 mg/l during the first twenty years of operation. Water quality effects would be much greater beginning in the decade of the 2020's because Pelican Lake would begin to get salty due to lack of inflow. Continued operations to achieve the drawdown objective would cause water quality effects similar to the West Bay outlet configuration.

On the Red River of the North at Emerson Manitoba, (Plate 10A), (Plate 10B), (Plate 10C), (Plate 10F) neither constrained nor unconstrained operations would produce measurable changes in TDS and sulfate during the first twenty years of operation. During the decade of the 2020's unconstrained operations would produce some elevated TDS concentrations but not at levels outside the range of the base condition. Sulfate peaks, however, would increase into the 200 to 300 mg/l range.

East Devils Lake Outlet, 480 cfs Unconstrained, Wet Scenario

The East Devils Lake outlet scenarios were run only for the 480 cfs unconstrained operation. It is not practical to consider the constrained operation based on the 450 mg/l sulfate standard because very little Devils Lake water could be discharged under such a constraint. The plots presented in the following plates include the uncontrolled overflow effects for the purpose of comparing the magnitude of effects. [And the red ink looks nice.]

In Lake Effects

Outlet operations from East Devils Lake (Plate 11) under the Wet Scenario would affect water quality in Devils Lake by conserving all of the freshening inflow and exporting a much larger mass of dissolved solids compared with West Bay outlet operations. The Main Bay, East Bay, and East Devils Lake would all freshen to a quality similar to that of the upper basin lakes and the Sheyenne River.

Downstream Effects

On the upper Sheyenne River near Cooperstown, (Plate 12A),(Plate 12B), (Plate 12C) the median TDS concentration under the base condition is about 650 mg/l. With unconstrained 480 cfs operations the TDS median would increase to about 1100 mg/l during the first 10 years of operation with annual peaks in the range of 1500 to 2000 mg/l. The TDS concentration would exceed 900 mg/l 61% of the time (base condition is 0%). The sulfate median would increase from about 160 mg/l to about 450 mg/l.

On the Sheyenne River near Valley City, (Plate 12A),(Plate 12B), (Plate 12C) The median TDS concentration under the base condition is about 500 mg/l. With unconstrained 480 cfs operations the TDS median would increase to about 1200 mg/l during the first 10 years of operation with annual peaks in the range of 1200 to 2000 mg/l. The TDS concentration would exceed 600 mg/l 90% of the time (base condition is 20%) and would exceed 1000 mg/l 64% of the time (base condition is 0%). The sulfate median would increase from about 140 mg/l to about 500 mg/l. The sulfate would exceed the 450 mg/l standard 58% of the time.

On the Red River of the North near Halstad, MN, (Plate 12A), (Plate 12B), (Plate 12C) the median TDS concentration under the base condition is about 430 mg/l. With unconstrained 480 cfs operations the TDS median would increase to about 550 mg/l with annual peaks in the range of 700 to 1100 mg/l. The TDS concentration would exceed 500 mg/l 59% of the time (base condition is 4%) and would exceed 700 mg/l 20% of the time (base condition is 0%). The sulfate median would increase from less than 100 mg/l to about 150 mg/l. The sulfate would exceed the 250 mg/l standard 18% of the time (base condition 0%). The magnitude of effects would be very similar to that of a natural overflow.

On the Red River of the North at Emerson Manitoba, (Plate 12A),(Plate 12B), (Plate 12C) the median TDS concentration under the base condition is about 470 mg/l. With unconstrained 480 cfs operations the TDS median would increase to about 500 mg/l. The TDS concentration would exceed 500 mg/l 48% of the time (base condition is 8%) and would exceed 600 mg/l 18% of the time. The sulfate objective of 250 mg/l would be exceeded 2% of the time. The magnitude of effects would be very similar to that of a natural overflow.

Pelican Lake Diversion, 480 cfs Constrained, PL2 and PL3 Plans, Wet Scenario

The Pelican Lake diversion alternatives differ from the Pelican Lake outlet alternatives and all other outlet alternatives in that they do not involve discharge of Devils Lake water at any time. Channel A is diverted through the upper basin chain of lakes unless the combined Big Coulee and Channel A flow exceeds 2000 cfs. If combined flow exceeds 2000 cfs, excess flow is allowed through Channel A. Highway 19 serves as a control structure with outlet (diversion) water drawn from north of the highway. The highway is overtopped at elevation 1454 ft. and is not raised, however, when the highway is overtopped and Devils Lake declines back below 1454 ft, the control structure is assumed to be operational again. The diversion is assumed to become operational in the year 2006 rather than 2005 because one year is added to the planning schedule for design and completion of the EIS. The pumps are operated at 480 cfs during May through November constrained by 600 cfs channel capacity and 250 mg/l sulfate concentration at the point of insertion into the Sheyenne River. In the PL2 plan Pelican Lake water in excess of pumping is allowed to flow into Devils Lake and the two lakes rise together within .1 ft. When the level of Pelican Lake declines below Devils Lake the water is not allowed to flow from Devils Lake back into Pelican Lake unless the control structure is overtopped. In the PL3 plan inflow in excess of pumping is held in Pelican Lake until it the1454 ft. control is overtopped. Devils Lake is allowed to decline accordingly.

In Lake Effects

Operation of a diversion from Pelican Lake (Plate 13), similar to the Pelican Lake outlet plans, would affect water quality in Devils Lake by diverting some of the freshening inflow before it has occasion to blend with West Bay water. In the Wet Scenario it would also prevent the large eastward mass movement of salt associated with overflow from Stump Lake. Devils Lake water quality responds by not freshening. Plans PL2 and PL3 have very similar effects except in the last 15 years of the scenario in which the wet cycle resumes. It is a period in which PL2 would allow a 5-ft rise of Devils Lake whereas PL3 would prevent it (Plate 14).

Downstream Effects

On the Sheyenne River at Valley City (Plate 15A), (Plate 15 B), (Plate 15C) the median TDS concentration under the base condition, excluding the overflow period, is about 500 mg/l. With constrained 480 cfs operations from Pelican Lake under the PL2 plan the TDS median would increase to about 520 mg/l with annual peaks not exceeding those of the base condition during the first 10 years of operation. During the first ten years of operation the TDS concentration would exceed 600 mg/l 28% of the time (base condition is 20%) and would not exceed 700 mg/l. The sulfate median would increase from about 90 mg/l to about 140 mg/l. The sulfate would exceed 200 mg/l 26% of the time (base condition 0%) and would not exceed 250 mg/l. The effects of the PL3 plan would be essentially the same as the PL2 plan during the first 10 years of operation.

On the Red River of the North near Halstad (Plate 15A), (Plate 15 B), (Plate 15C) the median TDS concentration and the range of concentration under the PL2 plan remain about the same as the base condition (excluding the period of overflow). During the first ten years of operation the TDS concentration would exceed 500 mg/l 7% of the time (base condition is 4%) and would not exceed 600 mg/l. The sulfate median would be only slightly increased. The sulfate would not exceed 200 mg/l. The effects of the PL3 plan would be essentially the same as the PL2 plan during the first 10 years of operation.

On the Red River of the North at Emerson (Plate 15A), (Plate 15 B), (Plate 15C) the median TDS concentration and the range of concentration under the PL2 plan remain about the same as the base condition (excluding the period of overflow). During the first ten years of operation the TDS concentration would exceed 500 mg/l 14% of the time (base condition is 10%) and would not exceed 600 mg/l. The sulfate median would be only slightly increased. The sulfate would not exceed 150 mg/l. The effects of the PL3 plan would be essentially the same as the PL2 plan during the first 10 years of operation.

Effects of Operations for Moderate 1455 Scenario

The following analysis describes the in-lake and downstream effects of different outlet configurations and operating plans for a less wet future scenario in which Devils Lake rises only to elevation 1455 ft. and then declines (See hydrographs in Plate 1). The scenario does not have a resumed wet cycle as does the Wet Scenario. The downstream water quality effects are different than in the Wet Scenario in that there is much less freshening inflow, evaporation concentration is greater, the Pelican Lake advantage is short-lived, operations constrained by the downstream sulfate objective become highly restricted so that only relatively small volumes can be discharged, and high volume unconstrained outlet operations from the west end draw a more concentrated salty water westward.

West Bay Outlet, 300 Constrained, 480 Unconstrained, Moderate 1455

In Lake Effects

Outlet operations from West Bay under the Moderate 1455 Scenario would have little effect on TDS in the Main Bay during the first 25 years of the scenario (Plate 16). In the extended future, however, 480 cfs operations would result in a fresher but lower Main Bay (see Plate 1). There would be little discernable effect in East Bay and East Devils Lake.

Downstream Effects

On the upper Sheyenne River near Cooperstown, (Plate 17A), (Plate 17B), (Plate 17C) the median TDS concentration under the base condition is about 600 mg/l. With constrained 300 cfs operations the TDS median would increase to about 800 mg/l with annual peaks above 1000 mg/l. The TDS concentration would exceed 900 mg/l 40% of the time (base condition is 0%) and would exceed 1000 mg/l 10% of the time. The sulfate median would increase from about 150 mg/l to about 250 mg/l. The sulfate would exceed 400 mg/l 6% of the time (base condition 0%). With 480 cfs unconstrained operation the median TDS concentration would increase to 900 mg/l and there would be annual peaks in the range of 1200 to 1400 mg/l. The sulfate standard of 450 mg/l would be exceeded 38% of the time.

On the Sheyenne River near Valley City, (Plate 17A), (Plate 17B), (Plate 17C) **T**he median TDS concentration under the base condition is about 480 mg/l. With constrained 300 cfs operations the TDS median would increase to about 600 mg/l with annual peaks above 800 mg/l. The TDS concentration would exceed 800 mg/l 17% of the time (base condition is 0%). The sulfate median would increase from about 130 mg/l to about 200 mg/l. The sulfate would exceed 300 mg/l 12% of the time. Unconstrained operation at 480 cfs would increase the median TDS concentration to 1000 mg/l. The sulfate standard of 450 mg/l would be exceeded 44% of the time.

On the Red River of the North near Halstad, MN, (Plate 17A), (Plate 17B), (Plate 17C) the median TDS concentration under the base condition is about 420 mg/l. With constrained 300 cfs operations the TDS concentrations would be slightly increased but remain within the range of the baseline condition. The 500 mg/l TDS standard would be exceeded 14% of the time (base condition is 4%). Generally, water quality effects of constrained operation are relatively minor because only a small volume of Devils Lake water is released. Unconstrained operation at 480 cfs would cause exceedance of the TDS standard 63% of the time with peaks in the range of 700 to 1000 mg/l. The 250 mg/l sulfate standard would be exceeded 18% of the time.

On the Red River of the North at Emerson Manitoba, (Plate 17A), (Plate 17B), (Plate 17C) With constrained 300 cfs operations the TDS median would not measurably change. The TDS concentration would exceed 500 mg/l 14% of the time (base condition is 11%). Sulfate concentrations would remain under 150 mg/. With unconstrained operation at 480 cfs the 500 mg/l TDS objective would be exceeded 40% of the time and the sulfate objective would be exceeded 5% of the time.

Pelican Lake Outlet, 300 Constrained, 480 Unconstrained, Moderate 1455 Scenario

In Lake Effects

Outlet operations from Pelican Lake under the Moderate 1455 Scenario would increase the TDS in Main Bay during the first 30 with a relative freshening trend in the later years (Plate 16). East Bay TDS would be slightly more concentrated (about 200 – 400 mg/l over baseline) throughout most of the scenario. East Devils Lake TDS would be elevated about 400 to 1000 mg/l over baseline throughout most of the scenario.

Downstream Effects

On the upper Sheyenne River near Cooperstown, (Plate 19A), (Plate 19B), (Plate 19C) the median TDS concentration under the base condition is about 600 mg/l. With constrained 300 cfs operations the TDS median would increase to about 700 mg/l with annual peaks in the range of 800 to 1000 mg/l. The TDS concentration would exceed 900 mg/l 17% of the time (base condition is 0%). The sulfate median would increase from about 150 mg/l to about 200 mg/l. The sulfate would exceed 400 mg/l 4% of the time (base condition 0%). With 480 cfs unconstrained operation the median TDS concentration would increase to 750 mg/l and there would be annual peaks in the range of 1000 to 1600 mg/l. The sulfate standard of 450 mg/l would be exceeded 18% of the time.

On the Sheyenne River near Valley City, (Plate 19A), (Plate 19B), (Plate 19C) the median TDS concentration under the base condition is about 480 mg/l. With constrained 300 cfs operations the TDS median would increase to about 650 mg/l with annual peaks in the range of 800 to 900 mg/l. The TDS concentration would exceed 800 mg/l 27% of the time (base condition is 0%). The sulfate median would increase from about 130 mg/l to about 230 mg/l. The sulfate would exceed 300 mg/l 26% of the time. Unconstrained operation at 480 cfs would increase the median TDS concentration to 800 mg/l. The sulfate standard of 450 mg/l would be exceeded 22% of the time.

On the Red River of the North near Halstad, MN, (Plate 19A), (Plate 19B), (Plate 19C) the median TDS concentration under the base condition is about 420 mg/l. The 500 mg/l TDS standard would be exceeded 23% of the time (base condition is 4%). Unconstrained operation at 480 cfs would cause exceedance of the TDS standard 48% of the time with peaks in the range of 700 to 1100 mg/l. The 250 mg/l sulfate standard would not be exceeded.

On the Red River of the North at Emerson Manitoba, (Plate 19A), (Plate 19B), (Plate 19C) with constrained 300 cfs operations the TDS median would not measurably change. The TDS concentration would exceed 500 mg/l 16% of the time (base condition is 11%). Sulfate concentrations would remain under 200 mg/. With unconstrained operation at 480 cfs the 500 mg/l TDS objective would be exceeded 28% of the time and the sulfate objective would not be exceeded.

Pelican Lake Diversion, 480 cfs Constrained, PL2 and PL3 Plans, Moderate 1455 Scenario

The Pelican Lake diversion alternatives differ from the Pelican Lake outlet alternatives and all other outlet alternatives in that they do not involve discharge of Devils Lake water at any time. Channel A is diverted through the upper basin chain of lakes unless the combined Big Coulee and Channel A flow exceeds 2000 cfs. If combined flow exceeds 2000 cfs, excess flow is allowed through Channel A. Highway 19 serves as a control structure with outlet (diversion) water drawn from north of the highway. The highway is overtopped at elevation 1454 ft. and is not raised, however, when the highway is overtopped and Devils Lake declines back below 1454 ft, the control structure is assumed to be operational again. The diversion is assumed to become operational in the year 2006 rather than 2005 because one year is added to the planning schedule for design and completion of the EIS. The pumps would be operated at 480 cfs during May through November constrained by 600 cfs channel capacity and 250 mg/l sulfate concentration at the point of insertion into the Sheyenne River. In the PL2 plan Pelican Lake water in excess of pumping is allowed to flow into Devils Lake and the two lakes rise together within .1 ft. When the level of Pelican Lake declines below Devils Lake the water is not allowed to flow from Devils Lake back into Pelican Lake unless the control structure is overtopped.

In Lake Effects

Operation of a diversion from Pelican Lake (Plate 20), similar to the Pelican Lake outlet plans, would affect water quality in Devils Lake by diverting some of the freshening inflow before it has occasion to blend with West Bay water. In the Wet Scenario it would also prevent the large eastward mass movement of salt associated with overflow from Stump Lake. Devils Lake water quality would respond by not freshening.

Effects of Operations for the Moderate 1450 Scenario

The following analysis describes the in-lake and downstream effects of different outlet configurations and operating plans for a less wet future scenario in which Devils Lake does not rise for about 12 years and then rises only to elevation 1450 and then declines (See hydrographs in Plate 1). The downstream water quality effects are different than in the Wet Scenario in that there is much less freshening inflow, evaporation concentration is greater, the Pelican Lake advantage is short-lived, operations constrained by the downstream sulfate objective become highly restricted so that only relatively small volumes can be discharged, and high volume unconstrained outlet operations from the west end draw more salty water westward. *Note: In this scenario the concentration duration statistics using the 10-year time frame are not directly comparable between the constrained 300 cfs and unconstrained 480 cfs operating plans because the unconstrained operation achieves the lake draw-down objective with only 5 years of operation while the constrained operating plan requires continued operation for all of the 10 years.*

West Bay Outlet, 300 Constrained, 480 Unconstrained, Moderate 1450 Scenario

In Lake Effects

Outlet operations from West Bay under the Moderate 1450 Scenario would have little effect on TDS in the Main Bay and East Bay during the entire scenario (Plate 21). East Devils Lake would show a TDS increase of about 800 to 1000 mg/l in the later years with 480 cfs unconstrained operation. In the scenario, only the 480 unconstrained operation would effectively reduce the lake level or significantly changed storage histories and materials flux that affect TDS concentrations (see Plate 1).

Downstream Effects

On the upper Sheyenne River near Cooperstown, (Plate 22A), (Plate 22B), (Plate 22C) the median TDS concentration under the base condition is about 620 mg/l. With constrained 300 cfs operations the TDS median would increase to about 850 mg/l with annual peaks above 1000 mg/l. The TDS concentration would exceed 900 mg/l 36% of the time (base condition is 0%) and would exceed 1000 mg/l 9% of the time. The sulfate median would increase from about 160 mg/l to about 260 mg/l. The sulfate would exceed 400 mg/l 2% of the time (base condition 0%). With 480 cfs unconstrained operation the median TDS concentration would increase to 690 mg/l and there would be annual peaks in the range of 1400 to 1600 mg/l. The sulfate standard of 450 mg/l would be exceeded 22% of the time.

On the Sheyenne River near Valley City, (Plate 22A), (Plate 22B), (Plate 22C) the median TDS concentration under the base condition is about 480 mg/l. With constrained 300 cfs operations the TDS median would increase to about 600 mg/l with annual peaks near 800 mg/l. The TDS concentration would exceed 700 mg/l 31% of the time (base condition is 0%). The sulfate median would increase from about 130 mg/l to about 200 mg/l. The sulfate would not exceed 300 mg/l. Unconstrained operation at 480 cfs would cause TDS peaks as high as 1600 mg/l and sulfate peaks as high as 700 mg/l.

On the Red River of the North near Halstad, MN, (Plate 22A), (Plate 22B), (Plate 22C) the median TDS concentration under the base condition is about 420 mg/l. With constrained 300 cfs operations the TDS concentrations would be slightly increased but remain mostly within the range of the baseline condition. The 500 mg/l TDS standard would be exceeded 9% of the time (base condition is 2%). Generally, water quality effects of constrained operation would be relatively minor because only a small volume of Devils Lake water is released. Unconstrained operation at 480 cfs would cause exceedance of the TDS standard 35% of the time during the first 10 years. *Note: If the exceedance percentage were based on only the five years that the pumps would be operating instead of 10 years the exceedance duration would be closer to 70%.* TDS concentration peaks would be in the range of 800 to 1200 mg/l.

On the Red River of the North at Emerson Manitoba, (Plate 22A), (Plate 22B), (Plate 22C) with constrained 300 cfs operations the TDS median would not measurably change. The TDS concentration would exceed 500 mg/l 13% of the time (base condition is 9%). Sulfate concentrations would remain under 150 mg/. With unconstrained operation at 480 cfs the 500 mg/l TDS objective would be exceeded 34% of the time during the 10-year averaging period. *Note: all of the exceedance days would occur during 5 years of operation. The 5-year exceedance duration would be closer to 70% of the time*. The sulfate objective would be exceeded 1% of the time.

Pelican Lake Outlet, 300 Constrained, 480 Unconstrained, Moderate 1450 Scenario

In Lake Effects

Outlet operations from Pelican Lake would slightly increase TDS concentrations in Main Bay and East Bay (Plate 23). The TDS increase in East Devils Lake would be in the range of 800 to 2000 mg/l over the base condition.

Downstream Effects

On the upper Sheyenne River near Cooperstown, (Plate 24A), (Plate 24B), (Plate 24C) the median TDS concentration under the base condition is about 620 mg/l. With constrained 300 cfs operations from Pelican Lake the TDS median would increase to about 750 mg/l with annual peaks near 1000 mg/l. The TDS concentration would exceed 900 mg/l 29% of the time (base condition is 0%) and would exceed 1000 mg/l 11% of the time. The sulfate median would increase from about 160 mg/l to about 210 mg/l. The sulfate would exceed 400 mg/l 8% of the time (base condition 0%). With 480 cfs unconstrained operation the median TDS concentration would increase to 690 mg/l and would peak in the range of 1500 to 2000 mg/l. The sulfate standard of 450 mg/l would be exceeded 12% of the time.

On the Sheyenne River near Valley City, (Plate 24A), (Plate 24B), (Plate 24C) the median TDS concentration under the base condition is about 480 mg/l. With constrained

300 cfs operations the TDS median would increase to about 650 mg/l with annual peaks near 800 mg/l. The TDS concentration would exceed 700 mg/l 43% of the time (base condition is 0%). The sulfate median would increase from about 130 mg/l to about 230 mg/l. The sulfate would exceed 300 mg/l 20% of the time. Unconstrained operation at 480 cfs would cause TDS peaks as high as 1700 mg/l and sulfate peaks as high as 750 mg/l.

On the Red River of the North near Halstad, MN, (Plate 24A), (Plate 24B), (Plate 24C) the median TDS concentration under the base condition is about 420 mg/l. With constrained 300 cfs operations the TDS concentrations would be slightly increased but remain mostly within the range of the baseline condition. The 500 mg/l TDS standard would be exceeded 18% of the time (base condition is 2%). Generally, water quality effects of constrained operation would be relatively minor because only a small volume of Devils Lake water would be released. Unconstrained operation at 480 cfs would cause exceedance of the TDS standard 26% of the time during the first 10 years. *Note: If the exceedance percentage were based on only the five years that the pumps would be operating instead of 10 years the exceedance duration would be closer to 50%.* TDS concentration peaks would be in the range of 800 to 1000 mg/l.

On the Red River of the North at Emerson Manitoba, (Plate 24A), (Plate 24B), (Plate 24C) with constrained 300 cfs operations the TDS median would not measurably change. The TDS concentration would exceed 500 mg/l 16% of the time (base condition is 9%). Sulfate concentrations would remain under 200 mg/. With unconstrained operation at 480 cfs the 500 mg/l TDS objective would be exceeded 28% of the time during the 10-year averaging period. *Note: all of the exceedance days would occur during 5 years of operation. The 5-year exceedance duration would be closer to 60% of the time*. The sulfate objective would not be exceeded.

Effects of Outlet Operations for Dry Scenario

In the dry scenario the elevation Devils Lake remains in the range of 1444 to 1448 ft for 20 years and then declines steadily for the next 30 years to about 1423 ft. With constrained outlet operations the drawdown objective would be achieved for only one year out of the first 15 years. With unconstrained operation at 480 cfs the outlet would operate for three 3-year episodes during the first 20 years. Because of the short operational time frame, concentration duration statistics are not presented in the plates for the unconstrained operation. Concentration durations for constrained 300 cfs operation are computed based on a 10-year time frame.

West Bay Outlet, 300 Constrained, 480 Unconstrained, Dry Scenario

Downstream Effects

On the upper Sheyenne River near Cooperstown, (Plate 26A), (Plate 26B), (Plate 26C) the median TDS concentration under the base condition is about 620 mg/l. With constrained 300 cfs operations from Pelican Lake the TDS median would increase to about 750 mg/l with annual peaks near 1000 mg/l. The TDS concentration would exceed 900 mg/l 29% of the time (base condition is 0%) and would exceed 1000 mg/l 22% of the time. The sulfate median would increase from about 160 mg/l to about 220 mg/l. The sulfate would exceed 400 mg/l 6% of the time (base condition 0%). With 480 cfs unconstrained operation the median TDS concentrations would exceed 1400 mg/l during the first episode of operation. The other two episodes produce concentrations almost identical to those caused by constrained operations because the quality of Devils Lake water present is about the same. The volume of Devils Lake water is greater, however, which is why the concentration plots for the other downstream reaches show different concentration effects.

On the Sheyenne River near Valley City, (Plate 26A), (Plate 26B), (Plate 26C) the median TDS concentration under the base condition is about 500 mg/l. With constrained 300 cfs operations the TDS median would increase to about 590 mg/l with annual peaks between 700 and 800 mg/l. The TDS concentration would exceed 700 mg/l 19% of the time (base condition is 3%). The sulfate median would increase from about 130 mg/l to about 170 mg/l. The sulfate would exceed 250 mg/l 11% of the time. Unconstrained operation at 480 cfs would cause TDS peaks in the range of 1400 to 1700 mg/l and sulfate peaks in the range of 600 to 750 mg/l. Concentrations would be sustained at high levels for most of the time during each of the operating episodes because of water storage in Lake Ashtabula. The 450 mg/l sulfate standard would be exceeded during much of that time.

On the Red River of the North near Halstad, MN, (Plate 26A), (Plate 26B), (Plate 26C)water quality effects of constrained 300 cfs operations would be almost undetectable. Unconstrained 480 cfs operations would cause TDS concentration peaks in the range of 800 to 1000. Episodes of TDS and sulfate exceeding water quality standards might be sustained for several weeks at a time.

On the Red River of the North at Emerson Manitoba, (Plate 26A), (Plate 26B), (Plate 26C) water quality effects of constrained 300 cfs operations would be undetectable. Unconstrained 480 cfs operations would cause TDS concentration peaks in the range of

600 to 800. Episodes of TDS exceeding the 500 mg/l standard might be sustained for several weeks at a time but would not peak above the range of the baseline condition. Sulfate concentrations could peak above the 250 mg/l objective but would remain below 200 mg/l most of the time.

Pelican Lake Outlet, 300 Constrained, 480 Unconstrained, Dry Scenario

Downstream Effects

Plate 27 and Plate 28 describe the effects of operating from Pelican Lake during the Dry Scenario. For the most part the magnitude of effects (concentrations) are the same as the West Bay outlet effects because, with little inflow to Pelican Lake, outlet operations would effectively draw from West Bay most of the time. The 10-year duration of exceedances for the 480 cfs unconstrained operation is not appropriate and is not presented here because the episode of pumping does not last for 10 years.

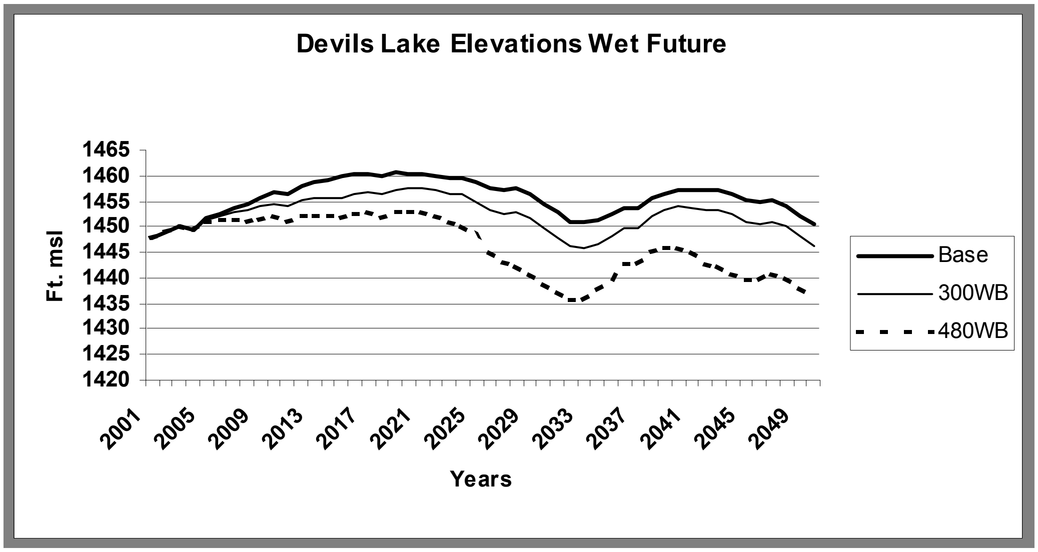
Effects of Nutrient Loading From Pelican Lake Outlet Operations, 300 Constrained, Wet Scenario

Plate 10G describes the change in total phosphorus load during the first ten years of operation compared with the base condition. Outlet operations from Pelican Lake would introduce about 40 metric tons per year. That is an increase of about 60 to 100 percent over the modeled baseline condition on the upper Sheyenne River. The HEC-5Q model treats phosphorus as a non-conservative substance affected by biological retention and release, sedimentation, and benthic flux. The model did not indicate that there would be loss or long term net retention of phosphorus, but indicated that, from year to year, a load of phosphorus approximately equivalent to that introduced by the outlet would show at all points downstream. Over the 45 years of operation for the wet scenario about 1200 metric tons would pass through. Plate 10H describes the relative change in ambient total phosphorus during the summer growing season for the first five operational years. Ambient total phosphorus on the upper Sheyenne River would be sustained at levels above .025 mg/l during the summer months, an increase of up to 100 percent over the baseline conditions. On the lower Sheyenne River even greater relative changes might be seen. On the Red River near Halstad, however, there would be no significant change in the ambient condition, and no significant change at Emerson (not shown).

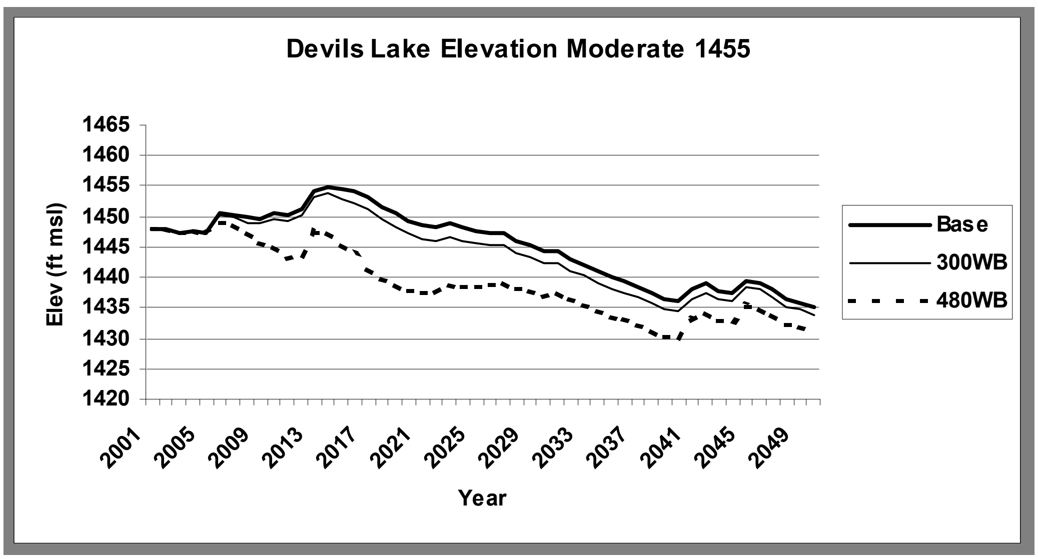
Nitrate nitrogen concentrations in the Sheyenne River and Red River of the North would not significantly change. (Plate 10I).

Lake Ashtabula Reservoir is represented two-dimensionally by the HEC-5Q model, having both longitudinal and vertical segmentation (see Section 4 above). The reservoir reach provides simulation of the effects of transport mechanisms including discrete vertical placement of inflows, and subsequent routing of substances as they are affected by dilution, storage, vertical thermal setup, sedimentation, algae and carbonate chemistry interactions, and outflow placement from different layers. The reservoir model generates daily values in two dimensions for temperature, pH, dissolved oxygen, chlorophyll-a, phosphorus, nitrate nitrogen, ammonia, alkalinity, and other variables that are best viewed using the HEC5GUI graphical user interface. The GUI provides user-interactive browsing and data review using animated graphics and other convenient plotting utilities. Outlet operations can be seen to causes changes in all water quality variables but none of those changes indicate adverse effects in Lake Ashtabula. Plate 10J plots the vertical temperature, dissolved oxygen, and pH profiles for a day in mid-summer in Lake Ashtabula near the dam. Plate 10K plots the chlorophyll-a, phosphorus, and nitrogen data for the same day. The lake is seen to have rather weak thermal stratification and strong dissolved oxygen, pH, chlorophyll, and nitrogen gradients. The with-outlet condition is plotted in red. Using the GUI the observer can view these plots animated on a 5-day time-step over any part or all of the 50-year simulation period. Also plots from multiple segments of the reservoir can be depicted simultaneously. Based on preliminary examination of the data, it appears that the small difference between with- and without-outlet operations is associated more with the different hydraulic regime rather than the different nutrients condition. In effect, the hydraulic residence time of water and its attendant algae population in the epilimnion (near surface layer) may be so shortened that the apparent difference observed at any given time and location may be due to a phase shift in the normal algae population cycle rather than to a change in nutrient availability.

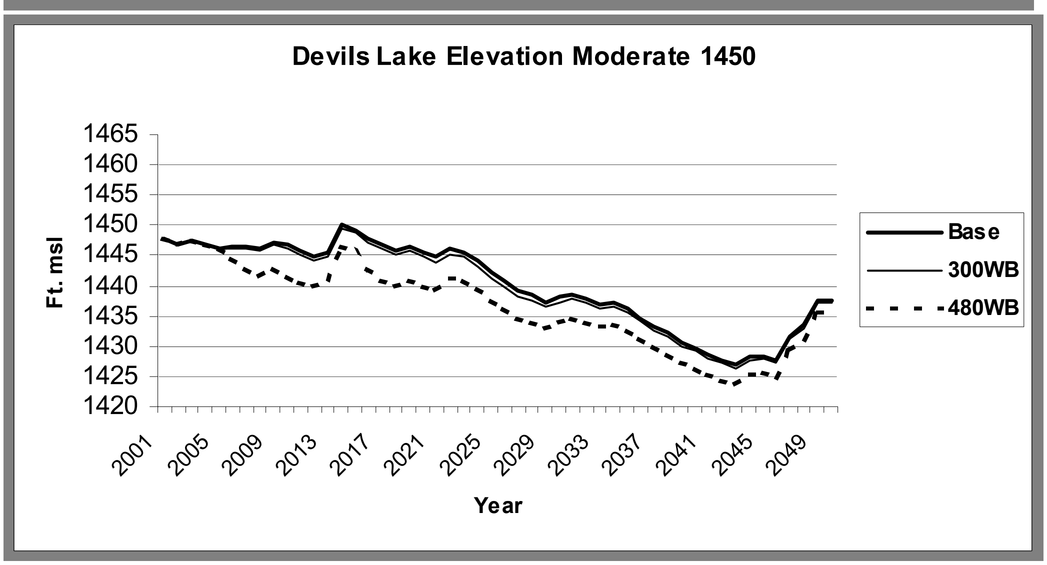
Plate 1



Devils Lake Elevations Wet Future
1465
1460
1455
1450
1445
1440
1435
1430
1425
1420
Ft. msl
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Years
Base
300WB
480WB

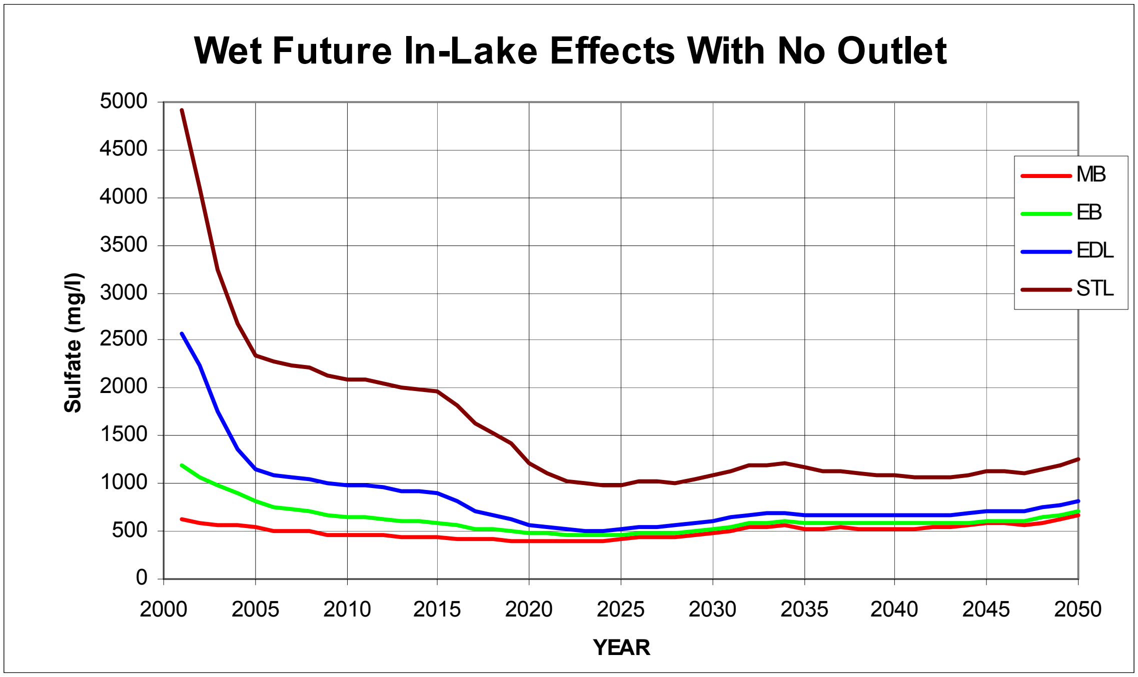


Devils Lake Elevation Moderate 1455
1465
1460
1455
1450
1445
1440
1435
1430
1425
1420
Elev (ft msl)
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Year
Base
300WB
480WB

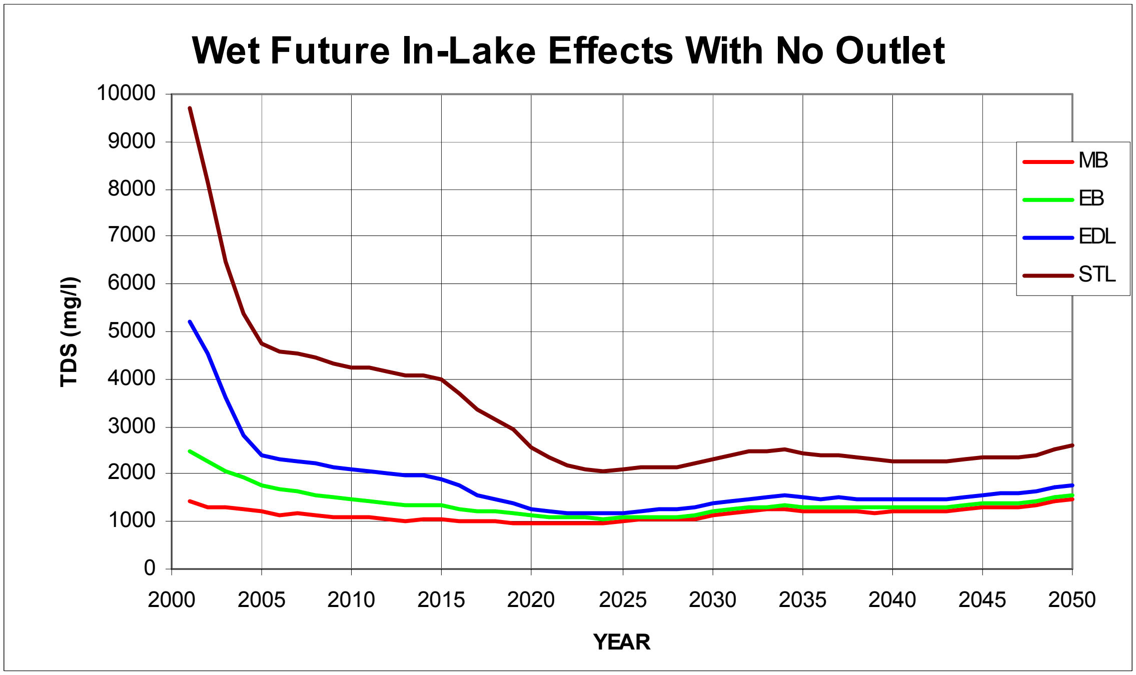


Devils Lake Elevation Moderate 1450
1465
1460
1455
1450
1445
1440
1435
1430
1425
1420
Ft. msl
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Year
Base
300WB
480WB

Plate 2

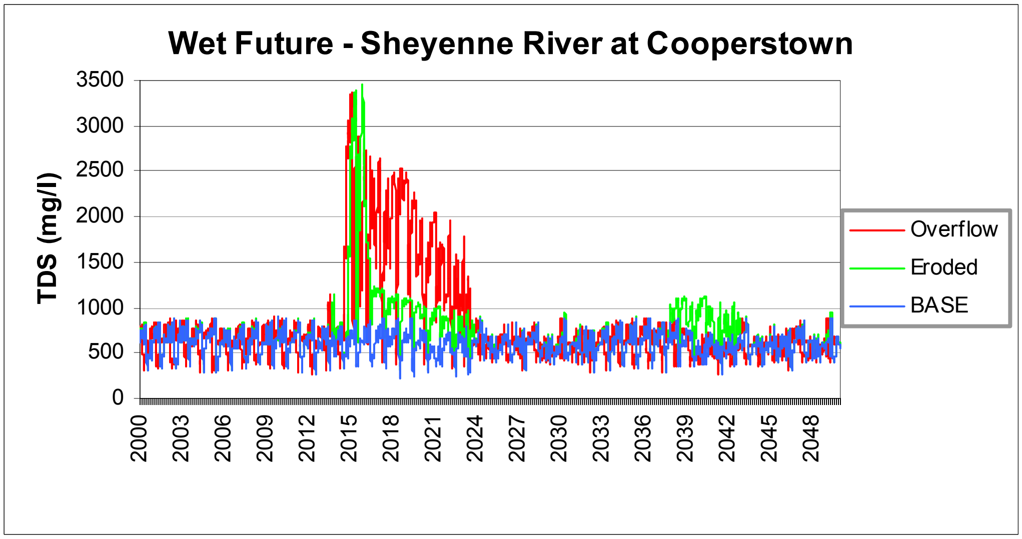


Wet Future In-Lake Effects With No Outlet
Sulfate (mg/l)
YEAR
MB
EB
EDL
STL
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050

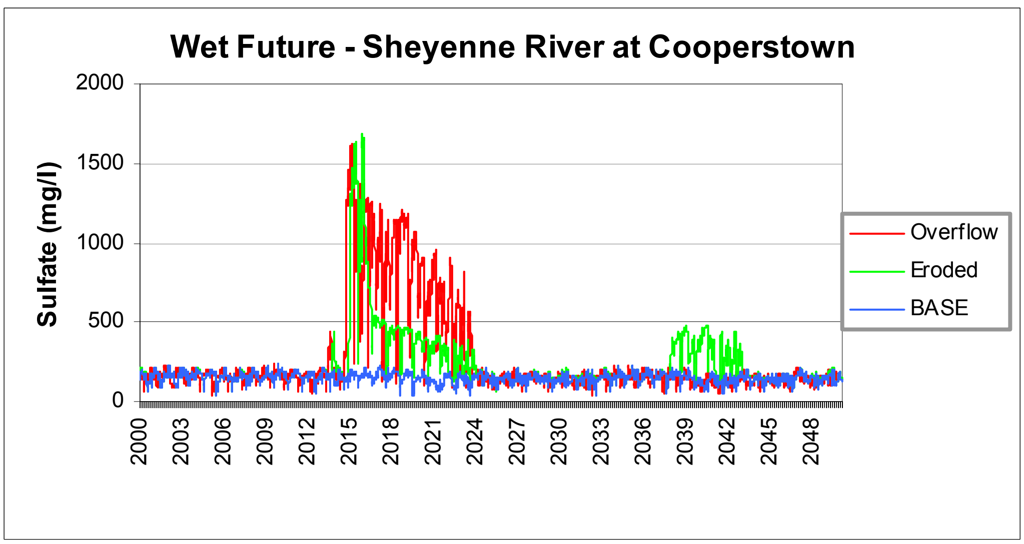


Wet Future In-Lake Effects With No Outlet
TDS (mg/l)
YEAR
MB
EB
EDL
STL
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050

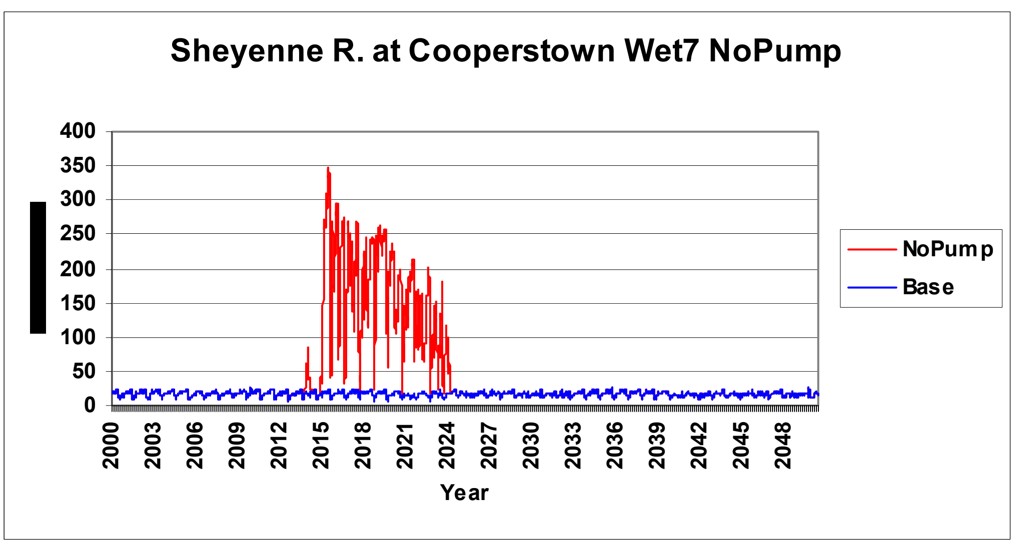
Plate 2.5



Wet Future - Sheyenne River at Cooperstown
TDS (mg/l)
3500
3000
2500
2000
1500
1000
500
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
Overflow
Eroded
BASE

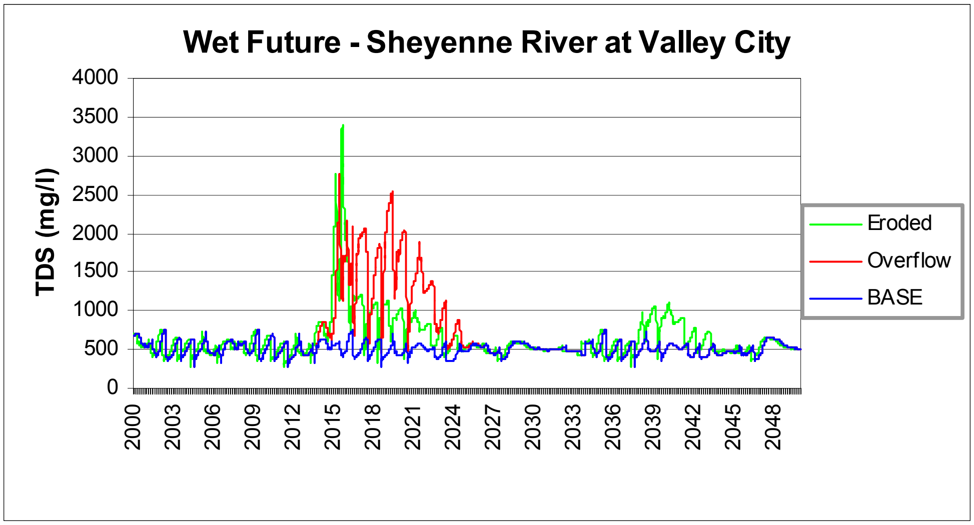


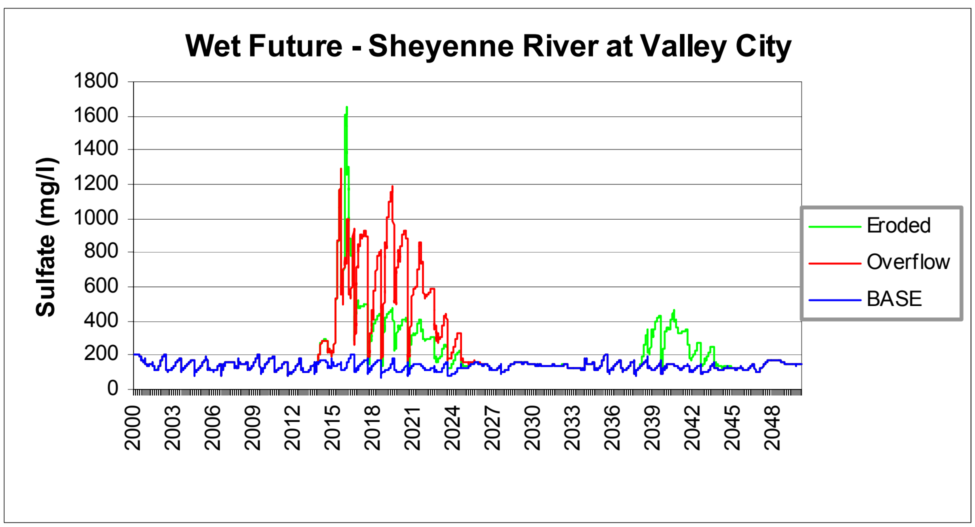
Wet Future - Sheyenne River at Cooperstown
Sulfate (mg/l)
2000
1500
1000
500
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
Overflow
Eroded
BASE



Sheyenne R. at Cooperstown Wet7 NoPump
[redacted]
400
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
Year
NoPump
Base

Plate 3


Wet Future - Sheyenne River at Valley City
TDS (mg/l)
4000
3500
3000
2500
2000
1500
1000
500
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
Eroded
Overflow
BASE


Wet Future - Sheyenne River at Valley City
Sulfate (mg/l)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
Eroded
Overflow
BASE

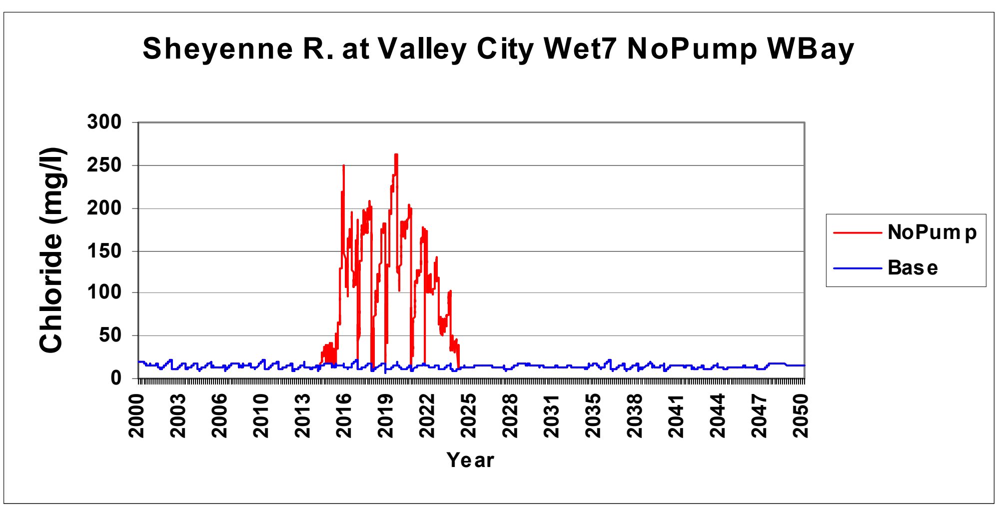
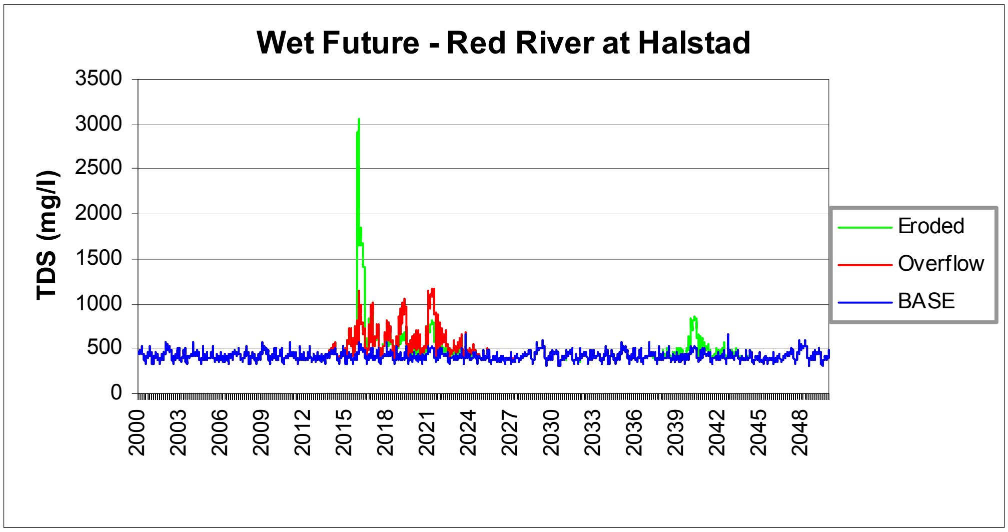
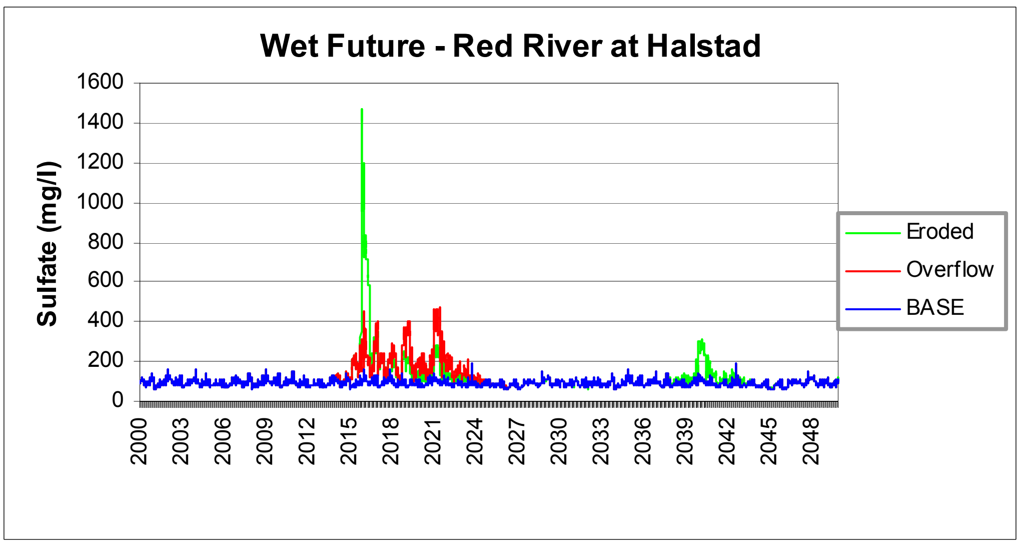

Sheyenne R. at Valley City Wet7 NoPump WBay
Chloride (mg/l)
300
250
200
150
100
50
0
2000
2003
2006
2010
2013
2016
2019
2022
2025
2028
2031
2035
2038
2041
2044
2047
2050
Year
NoPump
Base

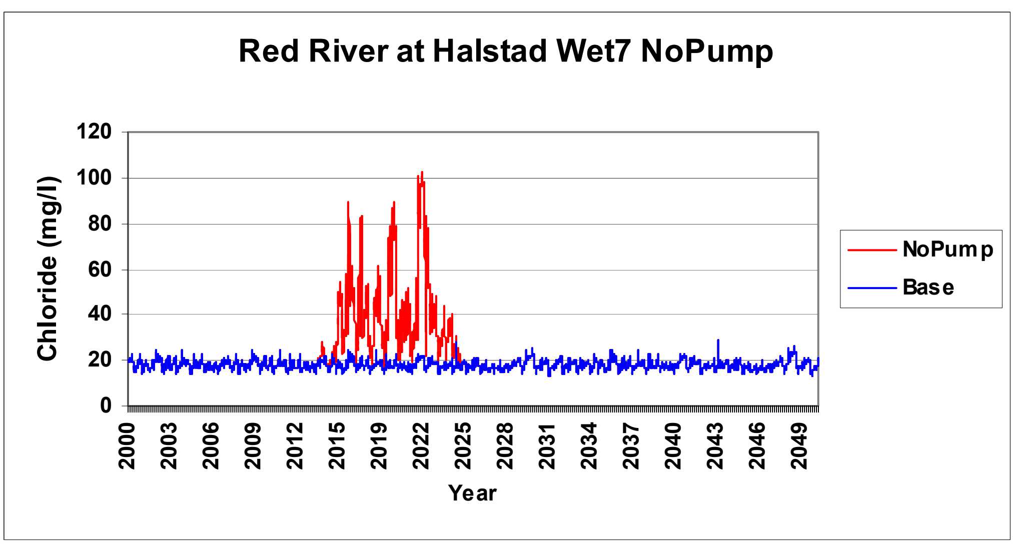
Plate 4



Wet Future - Red River at Halstad
TDS (mg/l)
3500
3000
2500
2000
1500
1000
500
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
Eroded
Overflow
BASE

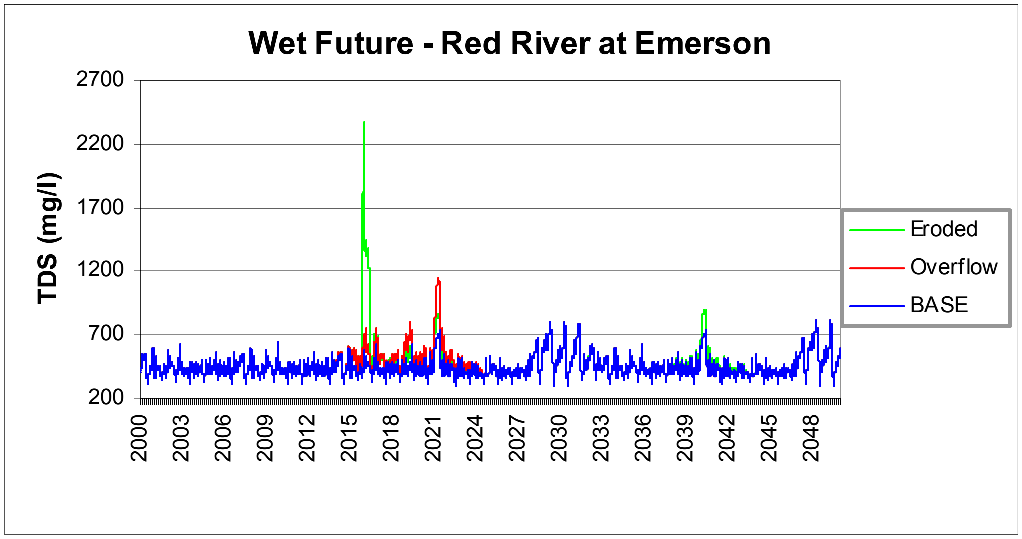


Wet Future - Red River at Halstad
Sulfate (mg/l)
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
Eroded
Overflow
BASE

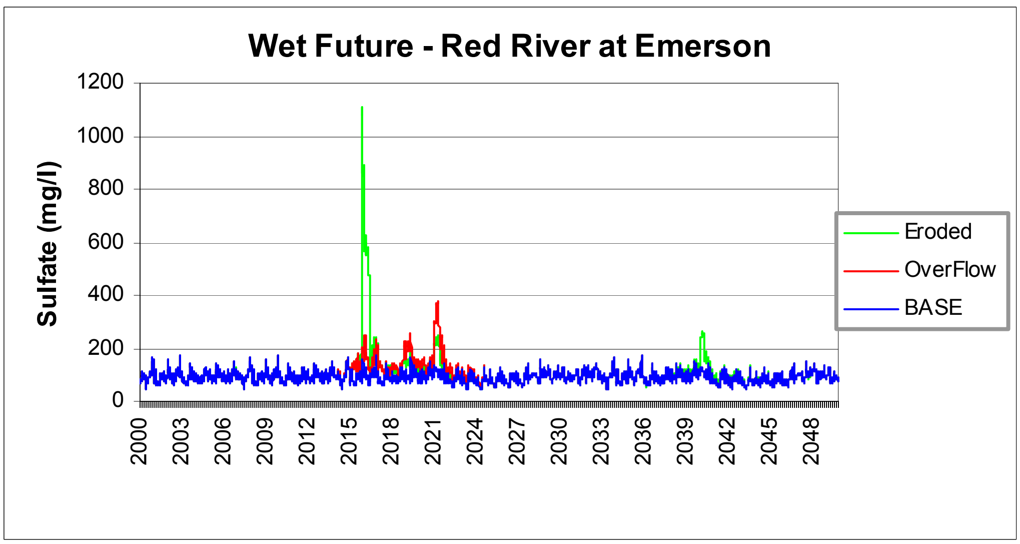


Red River at Halstad Wet7 NoPump
Chloride (mg/l)
120
100
80
60
40
20
0
2000
2003
2006
2009
2012
2015
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
NoPump
Base

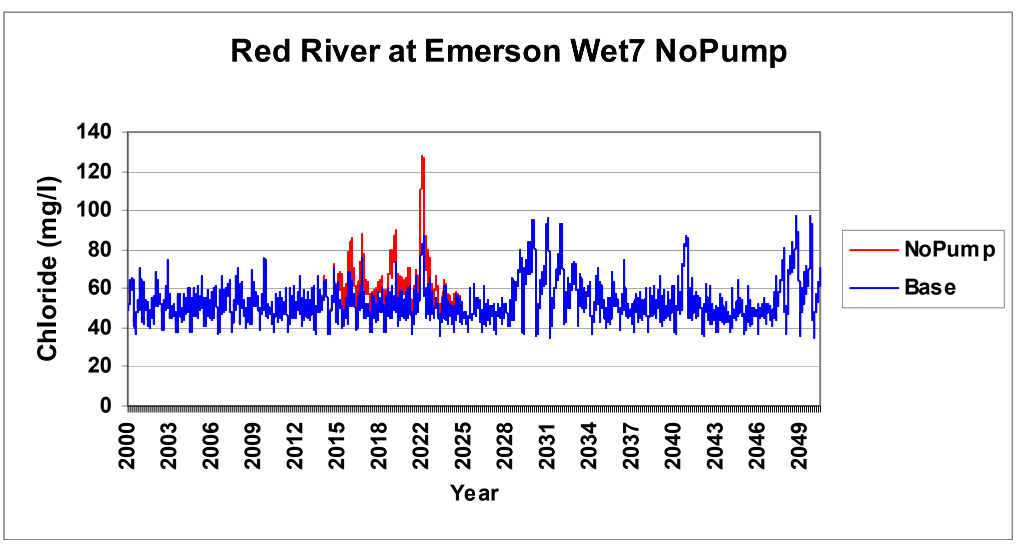
Plate 5



Wet Future - Red River at Emerson
TDS (mg/l)
2700
2200
1700
1200
700
200
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
Eroded
Overflow
BASE

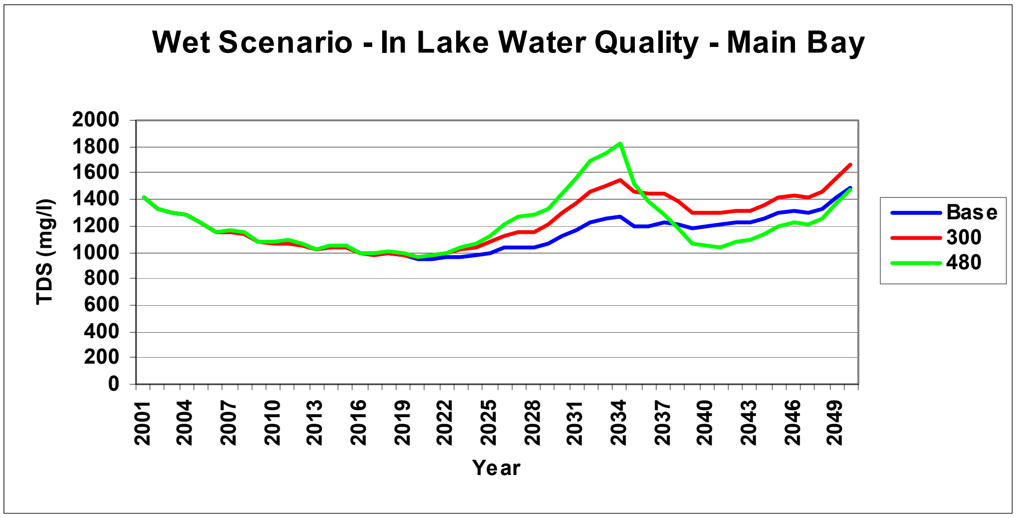


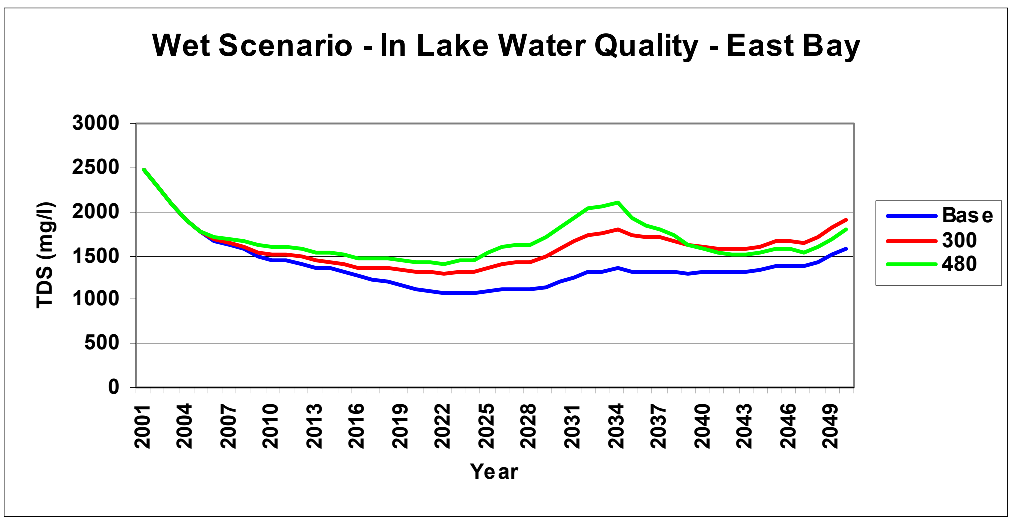
Wet Future - Red River at Emerson
Sulfate (mg/l)
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
Eroded
OverFlow
BASE



Red River at Emerson Wet7 NoPump
Chloride (mg/l)
140
120
100
80
60
40
20
0
2000
2003
2006
2009
2012
2015
2018
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
NoPump
Base

Plate 6


Wet Scenario - In Lake Water Quality - Main Bay
2000
1800
1600
1400
1200
1000
800
600
400
200
0
TDS (mg/l)
2001
2004
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Base
300
480


Wet Scenario - In Lake Water Quality - East Bay
3000
2500
2000
1500
1000
500
0
TDS (mg/l)
2001
2004
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Base
300
480

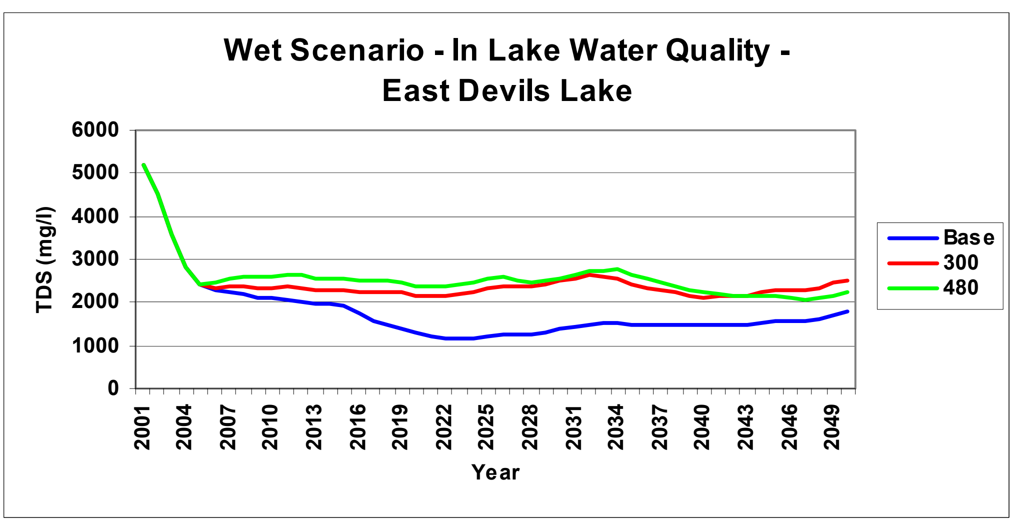
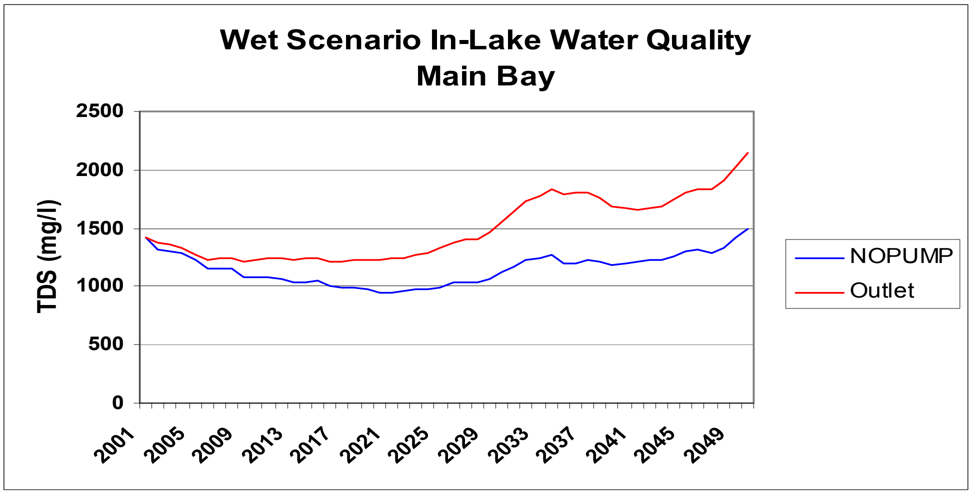
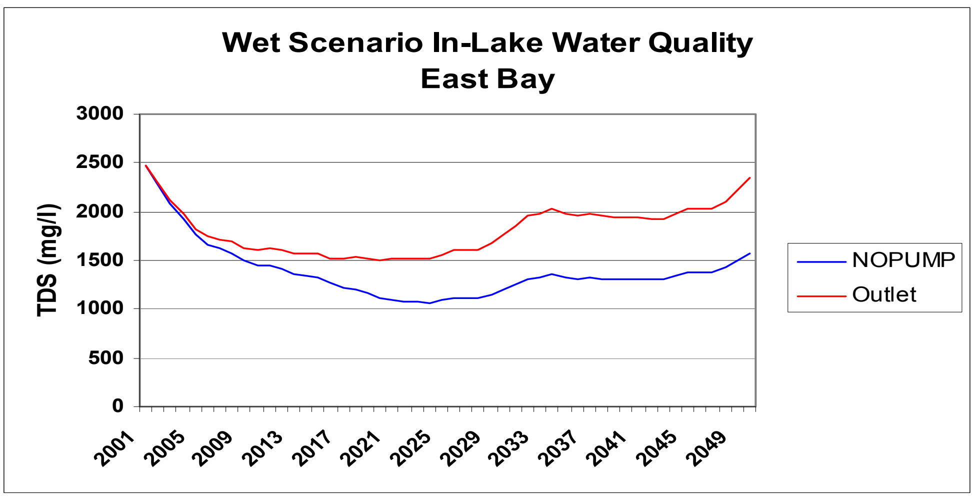

Wet Scenario - In Lake Water Quality -
East Devils Lake
6000
5000
4000
3000
2000
1000
0
TDS (mg/l)
2001
2004
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Year
Base
300
480

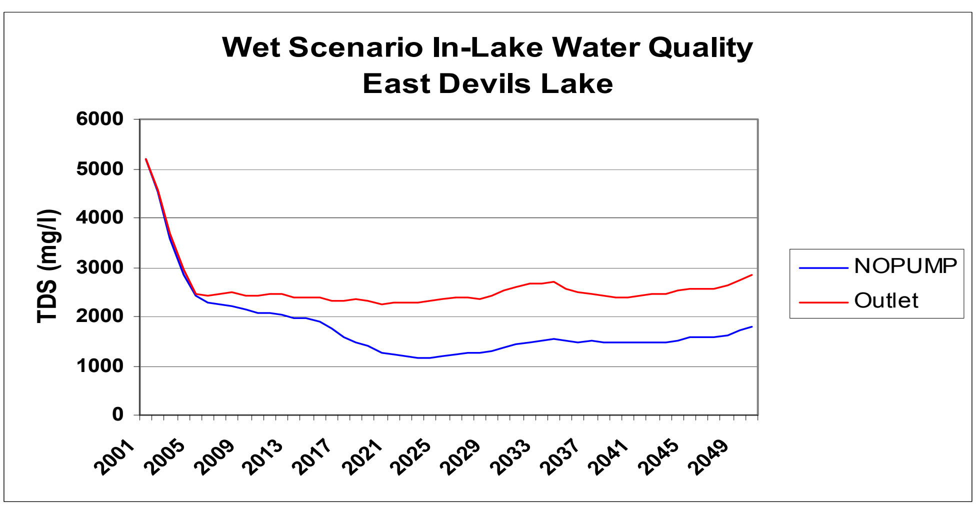
Plate 6A



Wet Scenario In-Lake Water Quality
Main Bay
TDS (mg/l)
2500
2000
1500
1000
500
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
NOPUMP
Outlet

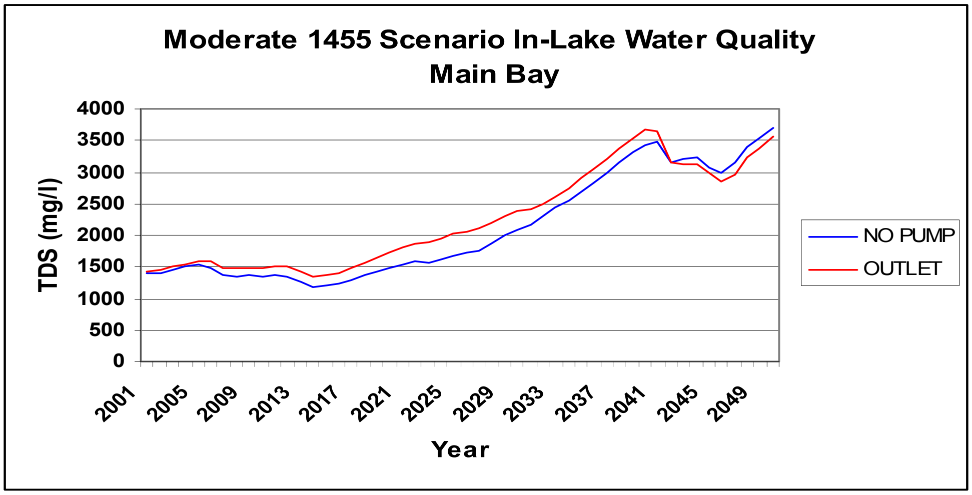


Wet Scenario In-Lake Water Quality
East Bay
TDS (mg/l)
3000
2500
2000
1500
1000
500
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
NOPUMP
Outlet

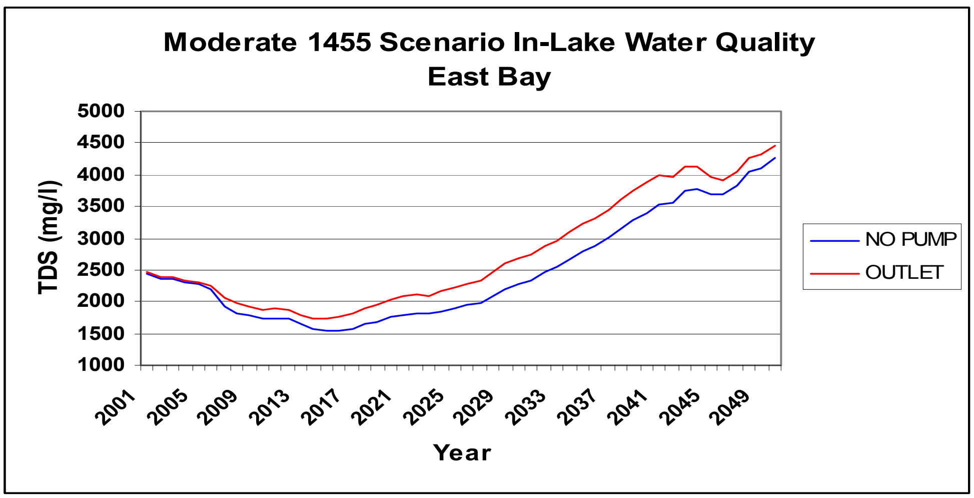


Wet Scenario In-Lake Water Quality
East Devils Lake
TDS (mg/l)
6000
5000
4000
3000
2000
1000
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
NOPUMP
Outlet

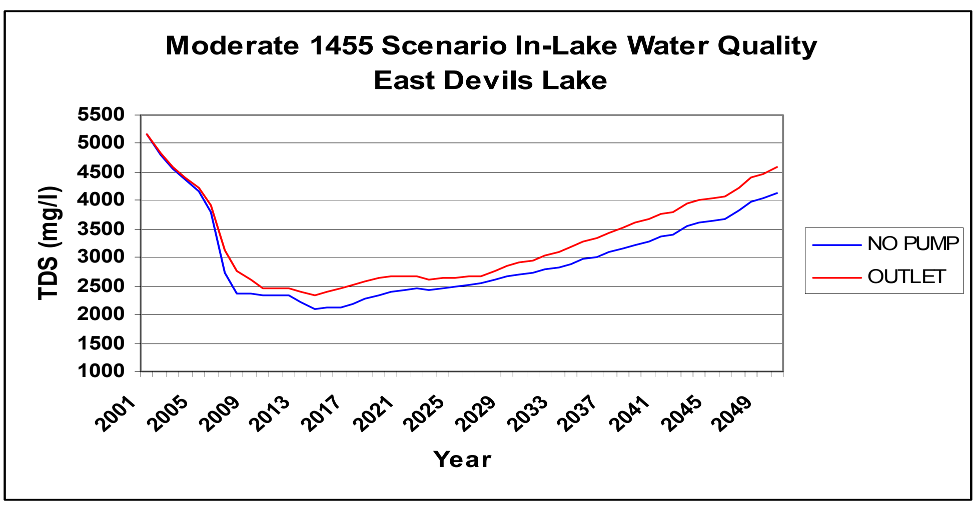
Plate 6B



Moderate 1455 Scenario In-Lake Water Quality
Main Bay
TDS (mg/l)
4000
3500
3000
2500
2000
1500
1000
500
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Year
NO PUMP
OUTLET

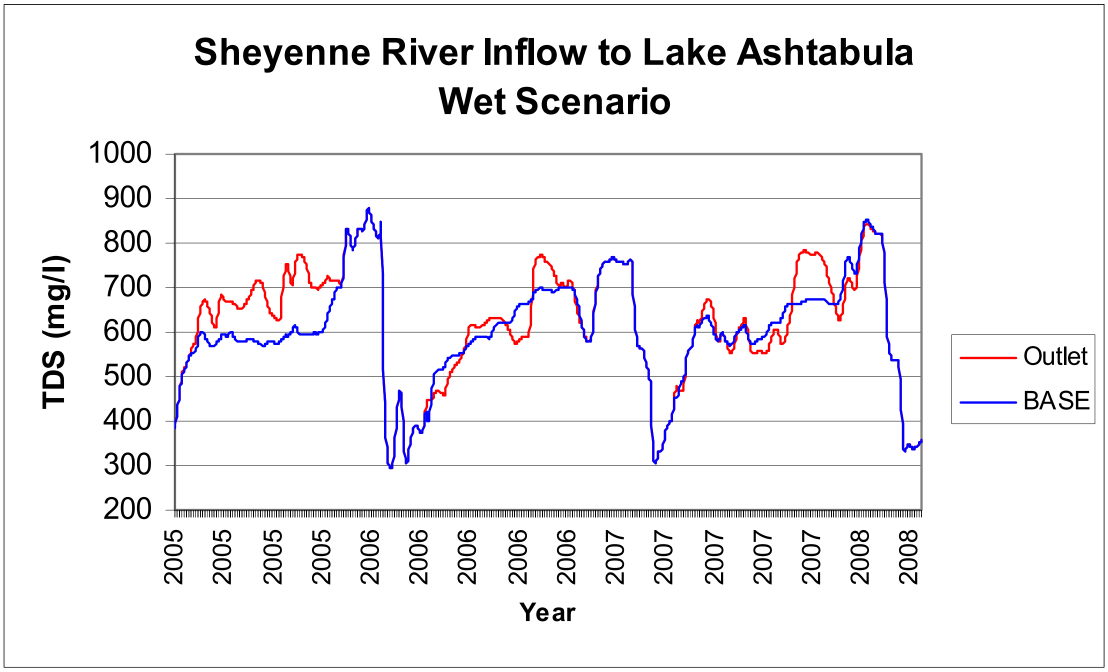


Moderate 1455 Scenario In-Lake Water Quality
East Bay
TDS (mg/l)
5000
4500
4000
3500
3000
2500
2000
1500
1000
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Year
NO PUMP
OUTLET

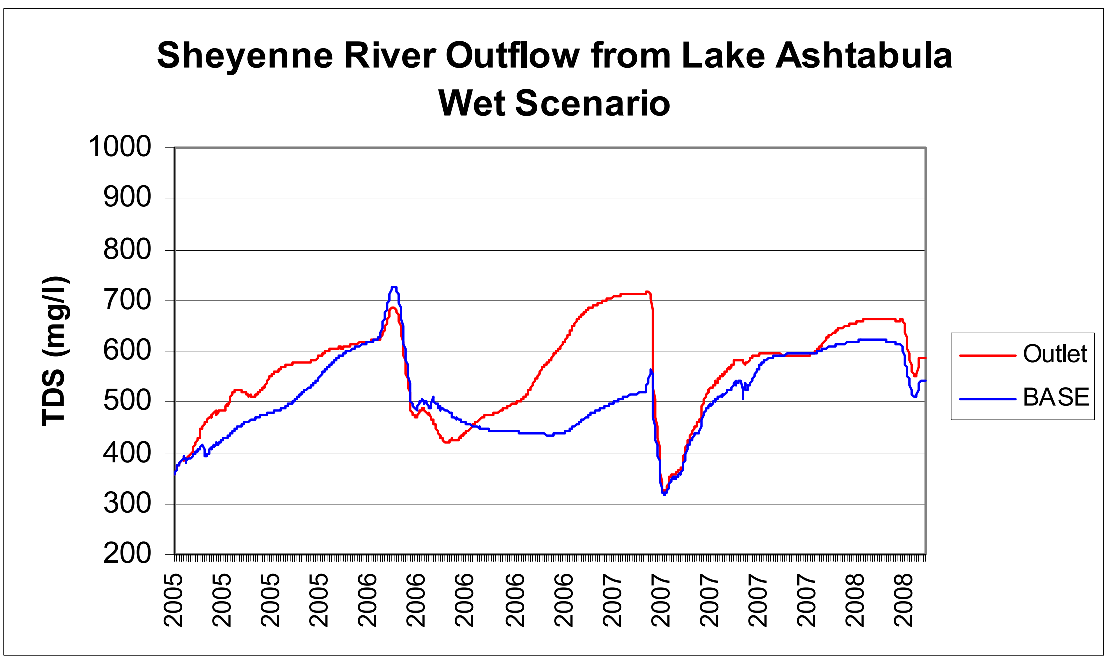


Moderate 1455 Scenario In-Lake Water Quality
East Devils Lake
TDS (mg/l)
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Year
NO PUMP
OUTLET

Plate 6C

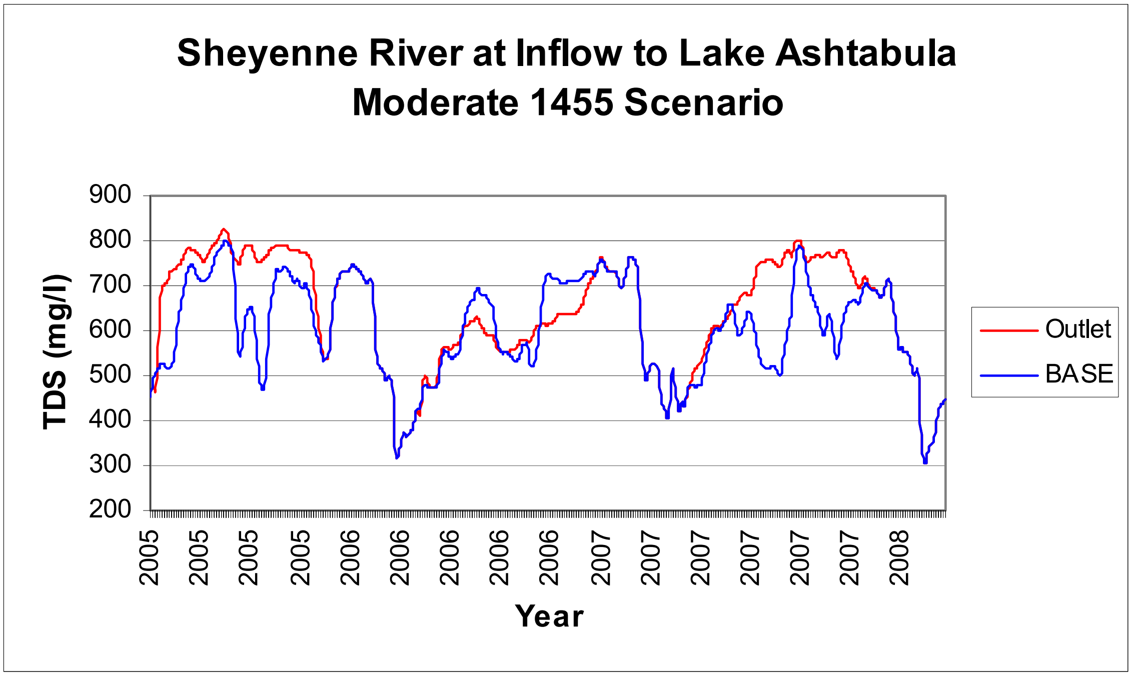


Sheyenne River Inflow to Lake Ashtabula
Wet Scenario
TDS (mg/l)
1000
900
800
700
600
500
400
300
200
2005
2005
2005
2005
2006
2006
2006
2006
2006
2007
2007
2007
2007
2007
2008
2008
Year
Outlet
BASE

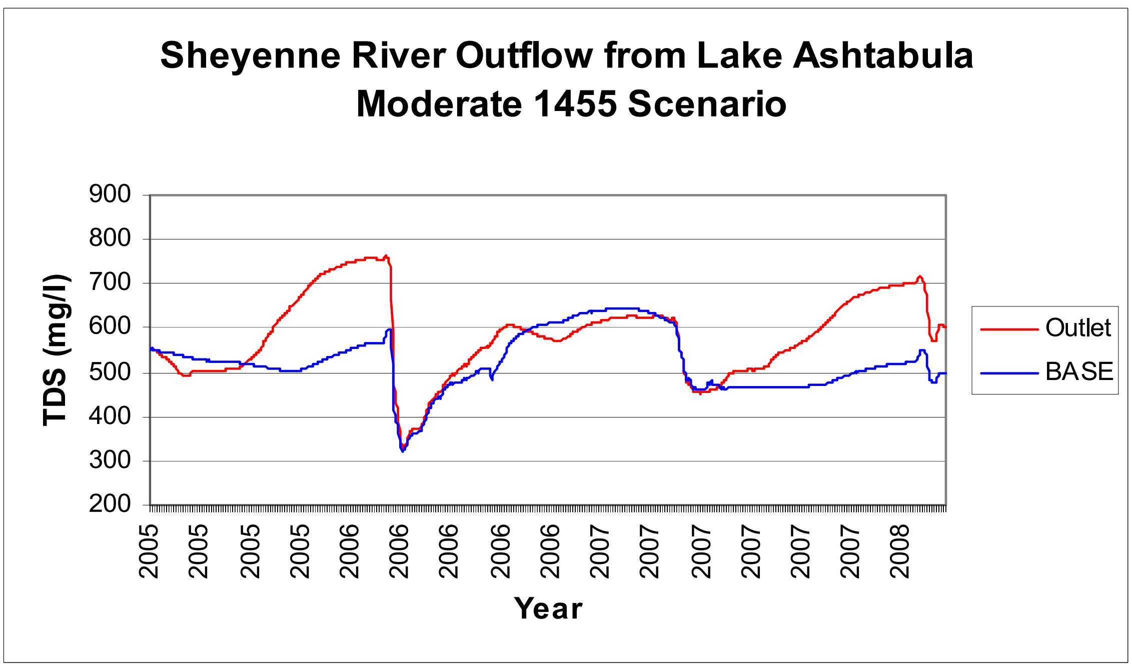


Sheyenne River Outflow from Lake Ashtabula
Wet Scenario
TDS (mg/l)
1000
900
800
700
600
500
400
300
200
2005
2005
2005
2005
2006
2006
2006
2006
2006
2007
2007
2007
2007
2007
2008
2008
Outlet
BASE

Plate 6D

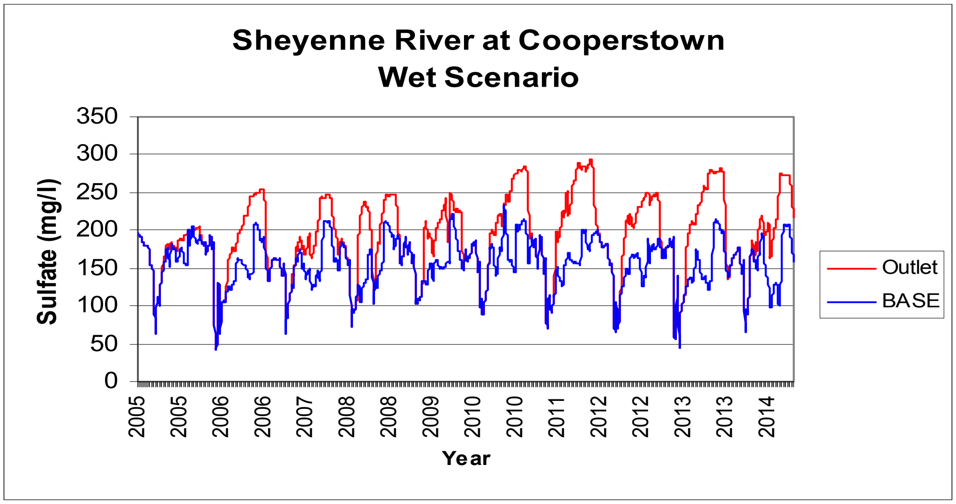


Sheyenne River at Inflow to Lake Ashtabula
Moderate 1455 Scenario
TDS (mg/l)
900
800
700
600
500
400
300
200
2005
2005
2005
2005
2006
2006
2006
2006
2006
2007
2007
2007
2007
2007
2007
2008
Year
Outlet
BASE

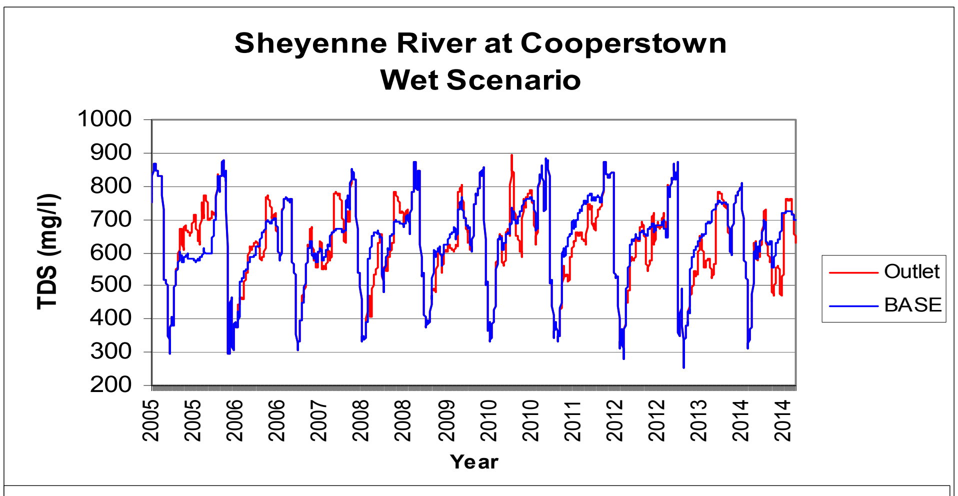


Sheyenne River Outflow from Lake Ashtabula
Moderate 1455 Scenario
TDS (mg/l)
900
800
700
600
500
400
300
200
2005
2005
2005
2005
2006
2006
2006
2006
2006
2007
2007
2007
2007
2007
2007
2008
Year
Outlet
BASE

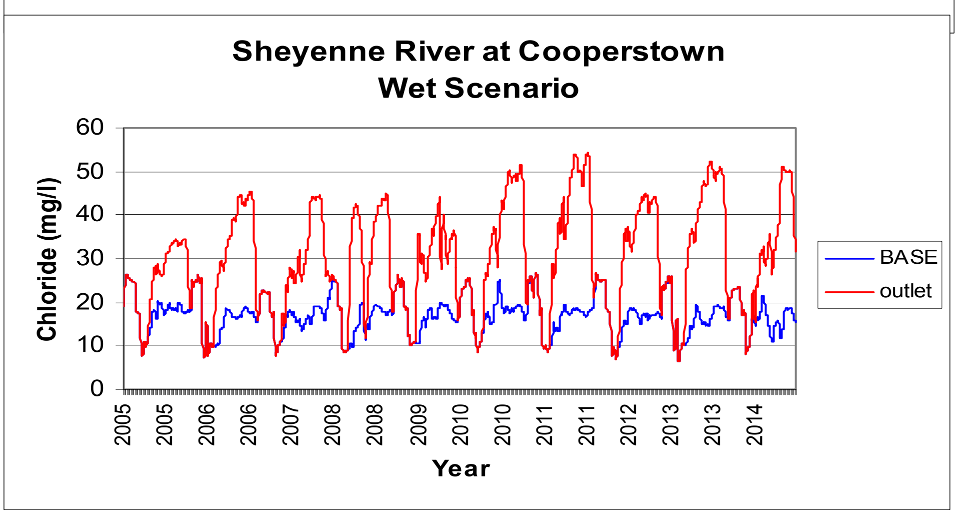
Plate 6E



Sheyenne River at Cooperstown
Wet Scenario
Sulfate (mg/l)
350
300
250
200
150
100
50
0
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2012
2012
2013
2013
2014
Year
Outlet
BASE

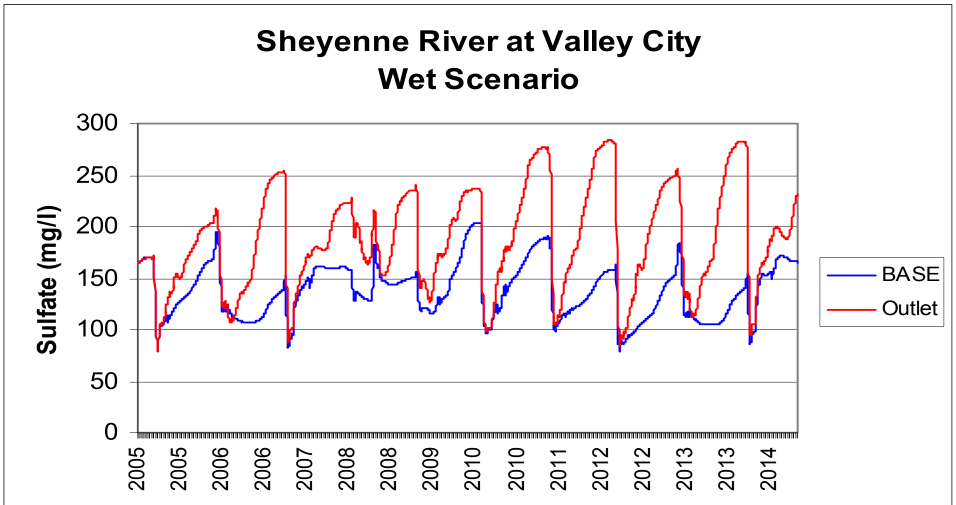


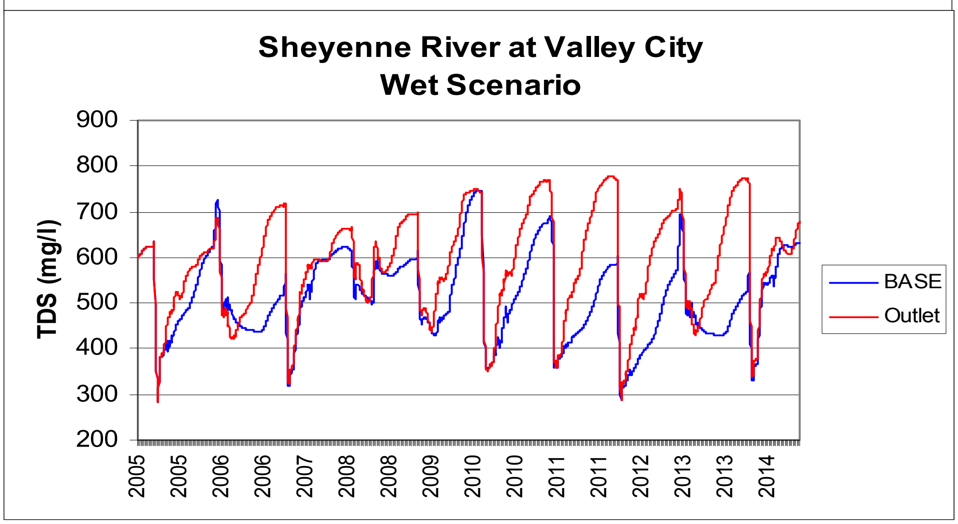
Sheyenne River at Cooperstown
Wet Scenario
TDS (mg/l)
1000
900
800
700
600
500
400
300
200
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2012
2012
2013
2014
2014
Year
Outlet
BASE



Sheyenne River at Cooperstown
Wet Scenario
Chloride (mg/l)
60
50
40
30
20
10
0
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2011
2012
2013
2013
2014
Year
BASE
outlet

Plate 6F


Sheyenne River at Valley City
Wet Scenario
Sulfate (mg/l)
300
250
200
150
100
50
0
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2012
2012
2013
2013
2014
BASE
Outlet


Sheyenne River at Valley City
Wet Scenario
TDS (mg/l)
900
800
700
600
500
400
300
200
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2011
2012
2013
2013
2014
BASE
Outlet

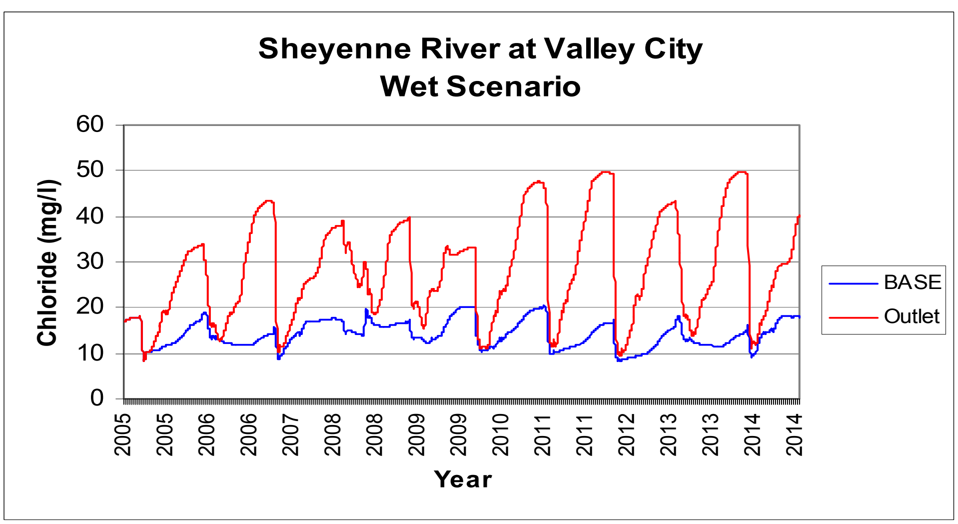
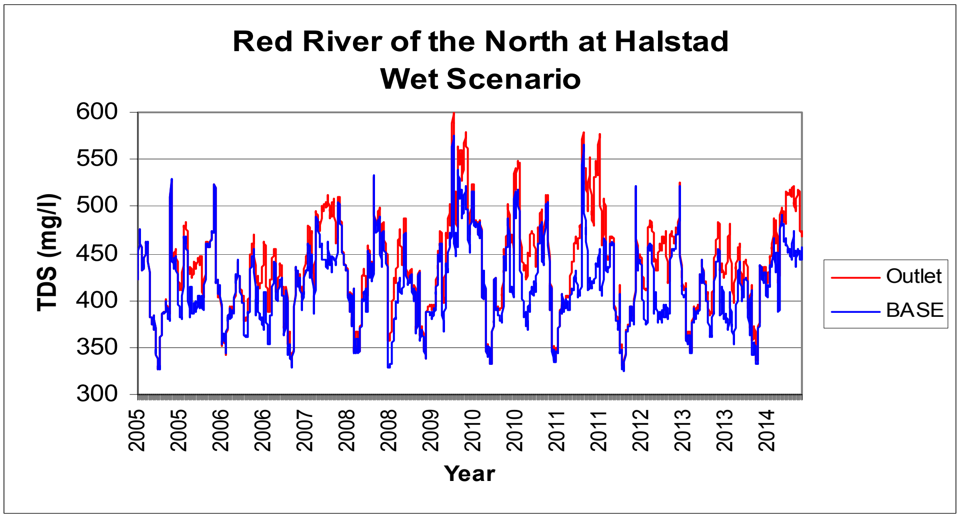
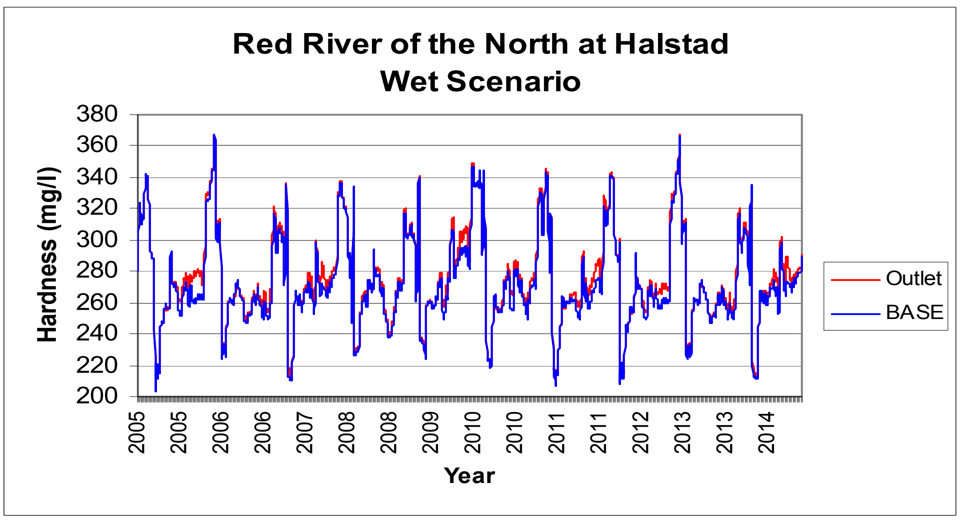

Sheyenne River at Valley City
Wet Scenario
Chloride (mg/l)
60
50
40
30
20
10
0
2005
2005
2006
2006
2007
2008
2008
2009
2009
2010
2011
2011
2012
2013
2013
2014
2014
Year
BASE
Outlet

Plate 6G


Red River of the North at Halstad
Wet Scenario
TDS (mg/l)
600
550
500
450
400
350
300
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2011
2012
2013
2013
2014
Year
Outlet
BASE


Red River of the North at Halstad
Wet Scenario
Hardness (mg/l)
380
360
340
320
300
280
260
240
220
200
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2011
2012
2013
2013
2014
Year
Outlet
BASE

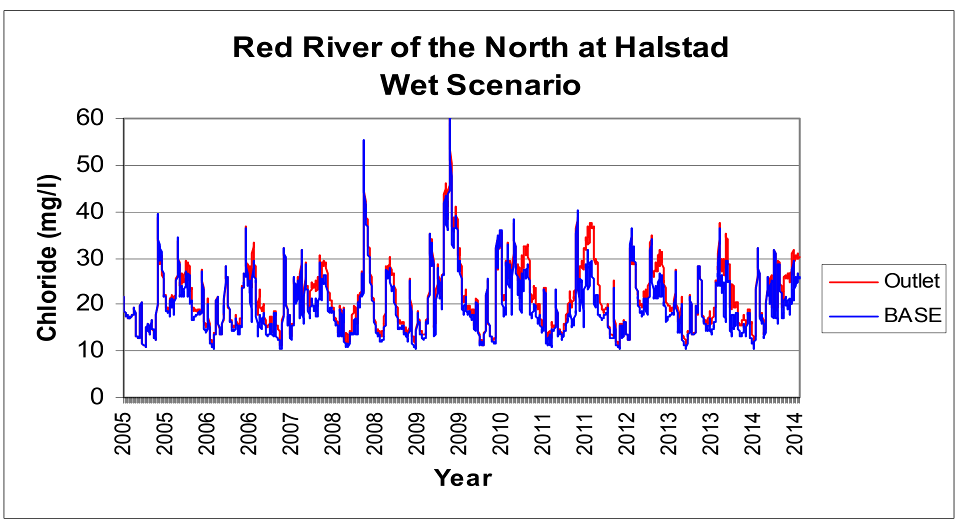
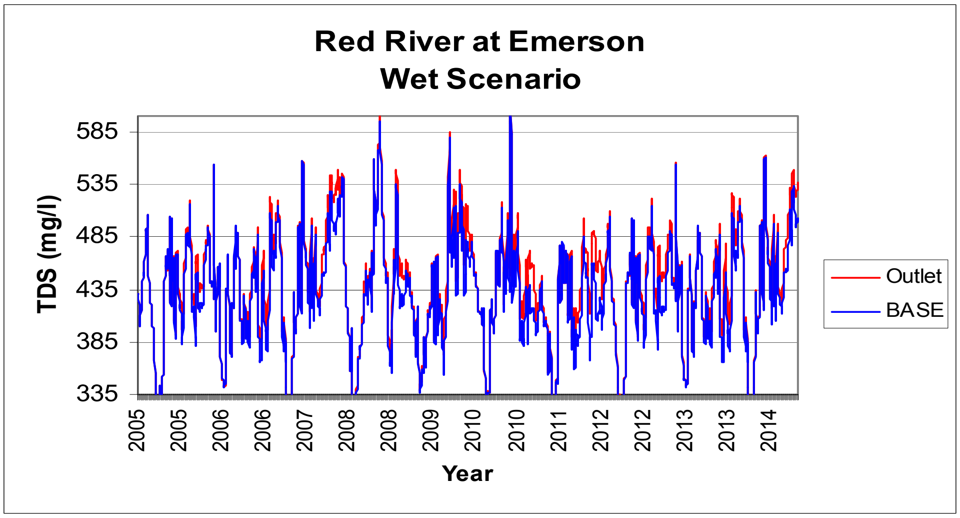
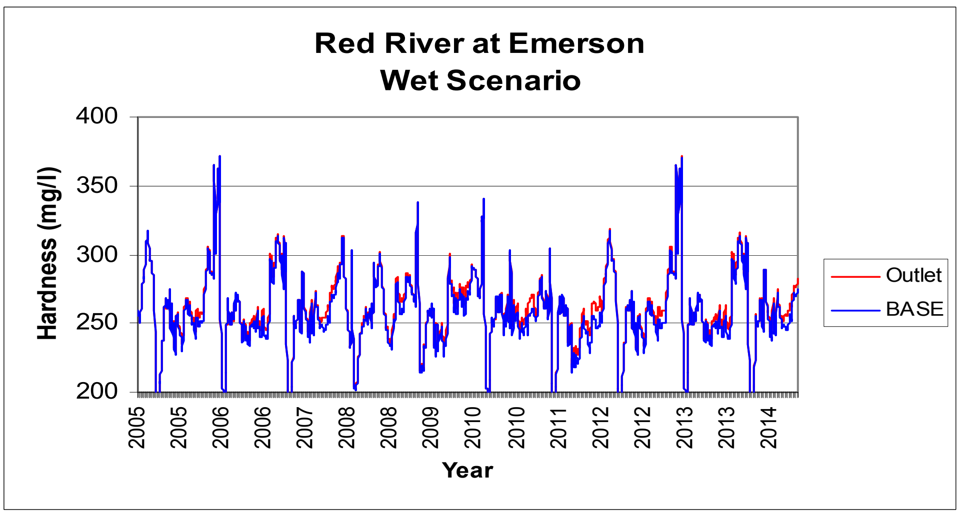

Red River of the North at Halstad
Wet Scenario
Chloride (mg/l)
60
50
40
30
20
10
0
2005
2005
2006
2006
2007
2008
2008
2009
2009
2010
2011
2011
2012
2013
2013
2014
2014
Year
Outlet
BASE

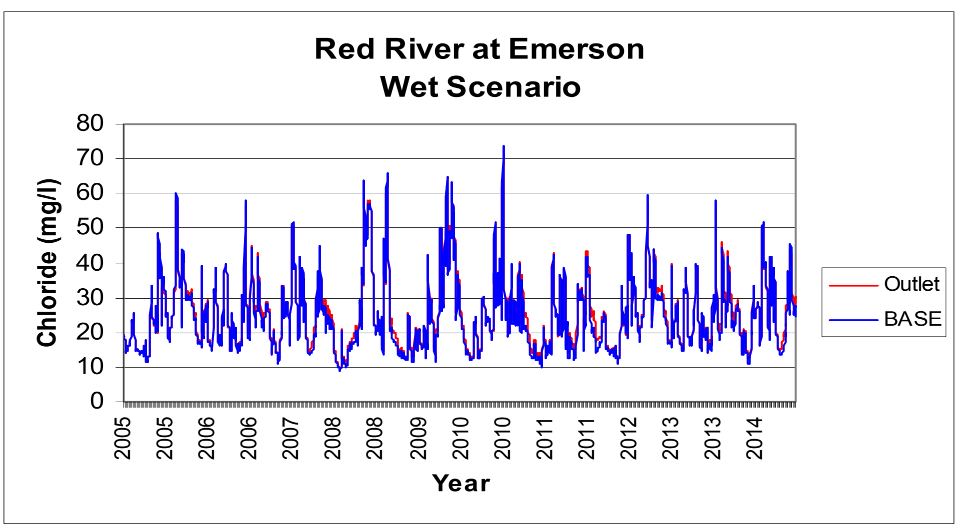
Plate 6H



Red River at Emerson
Wet Scenario
TDS (mg/l)
585
535
485
435
385
335
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2012
2012
2013
2013
2014
Year
Outlet
BASE



Red River at Emerson
Wet Scenario
Hardness (mg/l)
400
350
300
250
200
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2012
2012
2013
2013
2014
Year
Outlet
BASE



Red River at Emerson
Wet Scenario
Chloride (mg/l)
80
70
60
50
40
30
20
10
0
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2011
2012
2013
2013
2014
Year
Outlet
BASE

Plate 6I

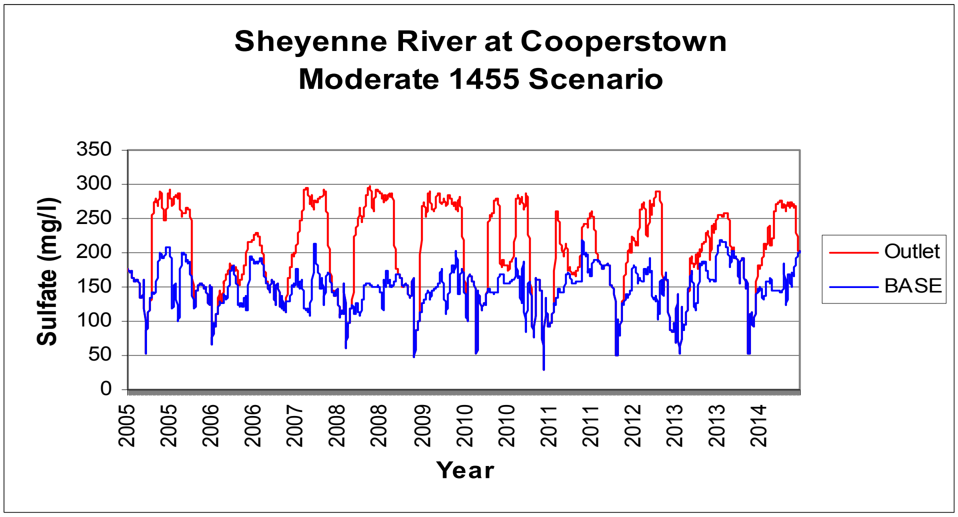
	Pelican Lake Outlet 300 cfs Constrained 300 Sulfate Years 2005 - 2014 Percent of Days Exceeding (conc)					
	TDS Base (>500 mg/l)	TDS (>500 mg/l)	Sulfate Ba (>250 mg/l)	Sulfate (>250 mg/l)	Hardness (>250 mg/l)	Hardness (>250 mg/l)
	Wet Scenario					
Cooperstown	82	86	0	12	88	89
Valley City	52	77	0	13	79	88
Halstad	3	10	0	0	86	88
Grand Forks	0	0	0	0	29	41
Emerson	8	12	0	0	61	71

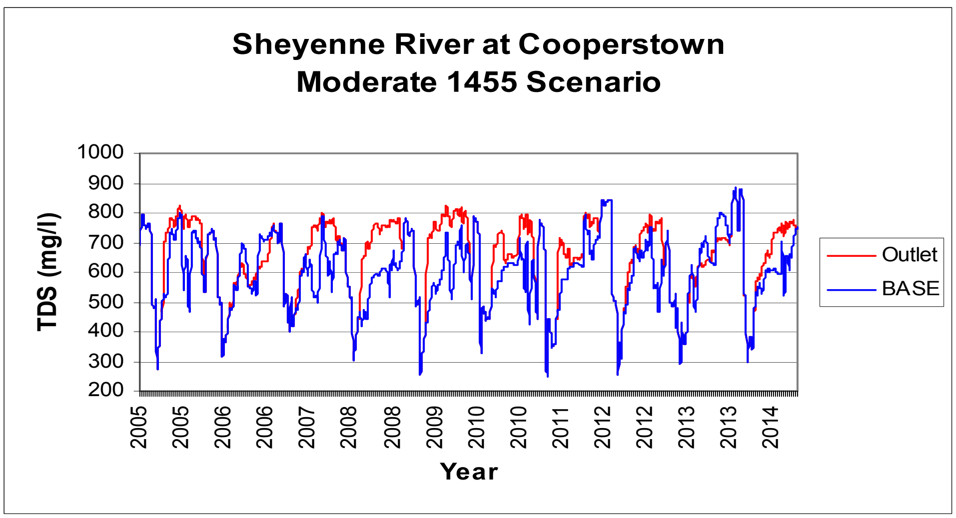
	Pelican Lake Outlet 300 cfs Constrained 300 Sulfate Years 2005 - 2014 Percent of Days Exceeding (conc)					
	TDS Base (>500 mg/l)	TDS (>500 mg/l)	Sulfate Ba (>250 mg/l)	Sulfate (>250 mg/l)	Hardness (>250 mg/l)	Hardness (>250 mg/l)
	Moderate 1455 Scenario					
Cooperstown	79	83	0	33	87	89
Valley City	34	78	0	8	72	90
Halstad	4	6	0	0	87	89
Grand Forks	0	0	0	0	23	28
Emerson	11	13	0	0	53	52

	Pelican Lake Outlet 300 cfs Constrained 300 Sulfate Years 2005 - 2014 Percent of Days Exceeding (conc)					
	TDS Base (>500 mg/l)	TDS (>500 mg/l)	Sulfate Ba (>250 mg/l)	Sulfate (>250 mg/l)	Hardness (>250 mg/l)	Hardness (>250 mg/l)
	Moderate 1450 Scenario					
Cooperstown	83	87	0	26	87	90
Valley City	39	80	0	2	70	90
Halstad	2	5	0	0	87	89
Grand Forks	0	0	0	0	21	23
Emerson	9	11	0	0	43	47

	Pelican Lake Outlet 300 cfs Constrained 300 Sulfate Years 2005 - 2014 Percent of Days Exceeding (conc)					
	TDS Base (>500 mg/l)	TDS (>500 mg/l)	Sulfate Ba (>250 mg/l)	Sulfate (>250 mg/l)	Hardness (>250 mg/l)	Hardness (>250 mg/l)
	Dry Scenario					
Cooperstown	78	83	0	13	88	89
Valley City	49	66	0	0	63	74
Halstad	4	5	0	0	84	86
Grand Forks	0	0	0	0	26	28
Emerson	11	11	0	0	54	57

Plate 6J


Sheyenne River at Cooperstown
Moderate 1455 Scenario
Sulfate (mg/l)
350
300
250
200
150
100
50
0
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2011
2012
2013
2013
2014
Year
Outlet
BASE


Sheyenne River at Cooperstown
Moderate 1455 Scenario
TDS (mg/l)
1000
900
800
700
600
500
400
300
200
2005
2005
2006
2006
2007
2008
2008
2009
2010
2010
2011
2012
2012
2013
2013
2014
Year
Outlet
BASE

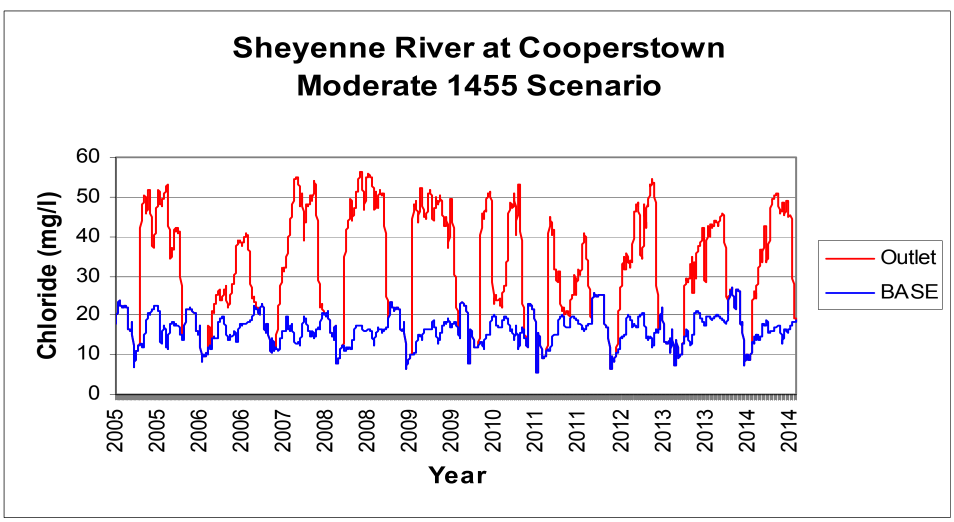
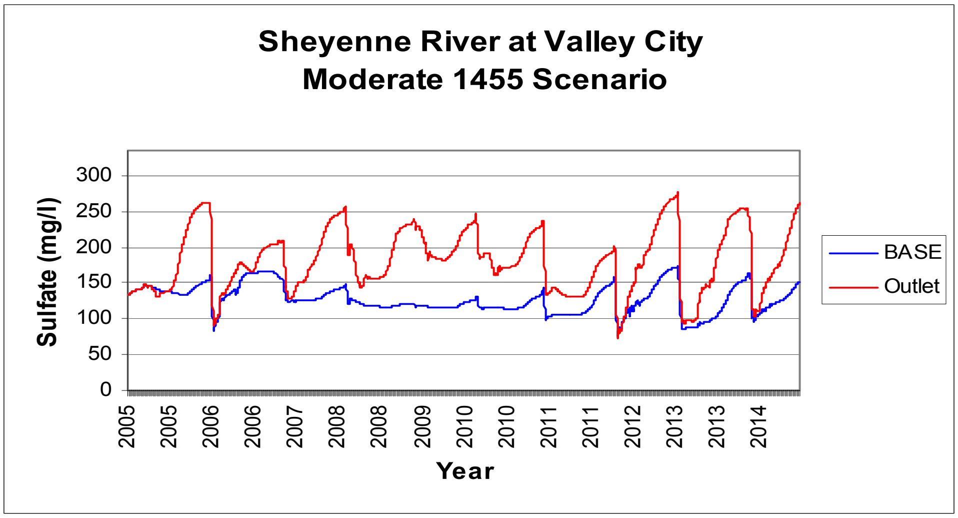
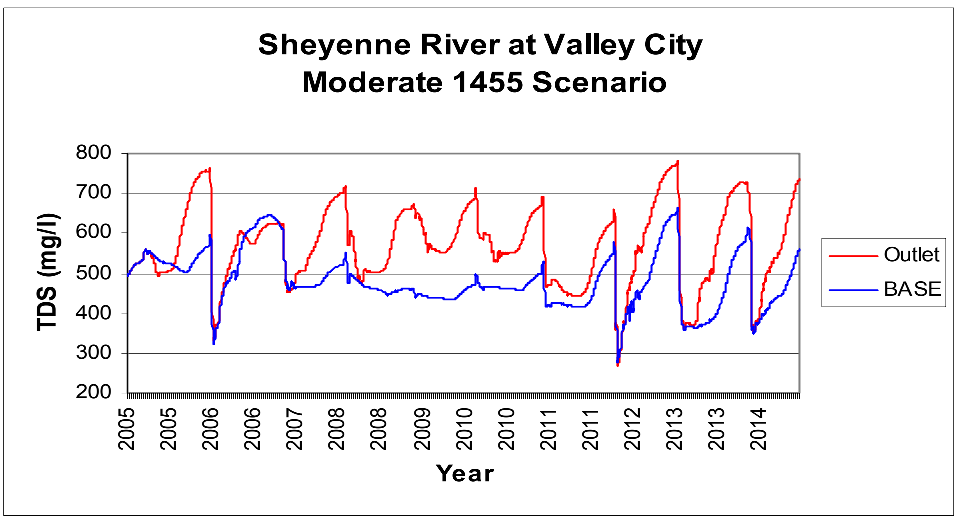

Sheyenne River at Cooperstown
Moderate 1455 Scenario
Chloride (mg/l)
60
50
40
30
20
10
0
2005
2005
2006
2006
2007
2008
2008
2009
2009
2010
2011
2011
2012
2013
2013
2014
2014
Year
Outlet
BASE

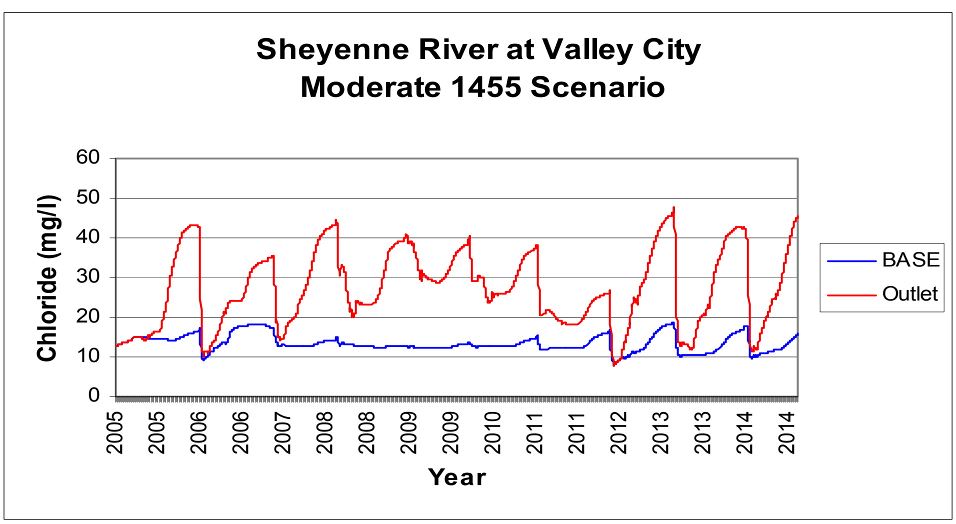
Plate 6K



Sheyenne River at Valley City
Moderate 1455 Scenario
Sulfate (mg/l)
300
250
200
150
100
50
0
2005 2005 2006 2006 2007 2008 2008 2009 2010 2010 2011 2011 2012 2013 2013 2014
Year
BASE
Outlet

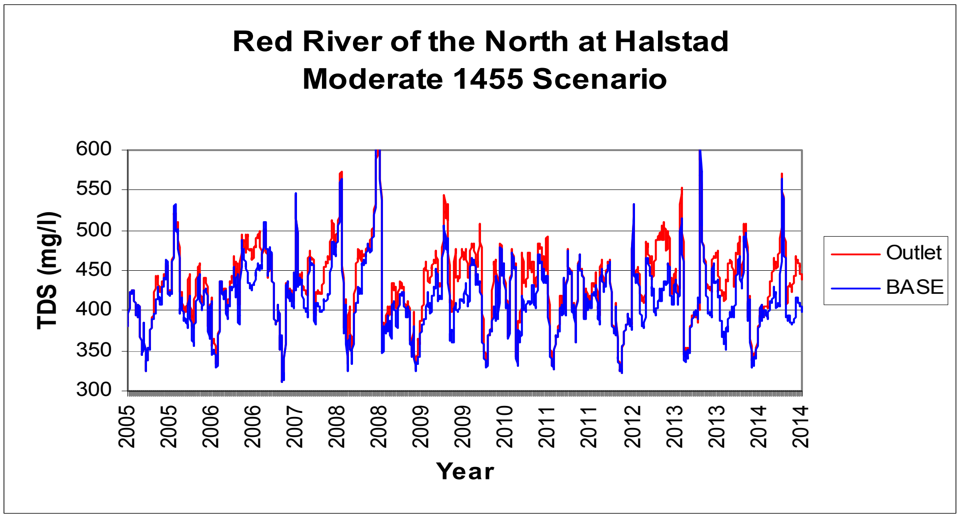


Sheyenne River at Valley City
Moderate 1455 Scenario
TDS (mg/l)
800
700
600
500
400
300
200
2005 2005 2006 2006 2007 2008 2008 2009 2010 2010 2011 2011 2012 2013 2013 2014
Year
Outlet
BASE

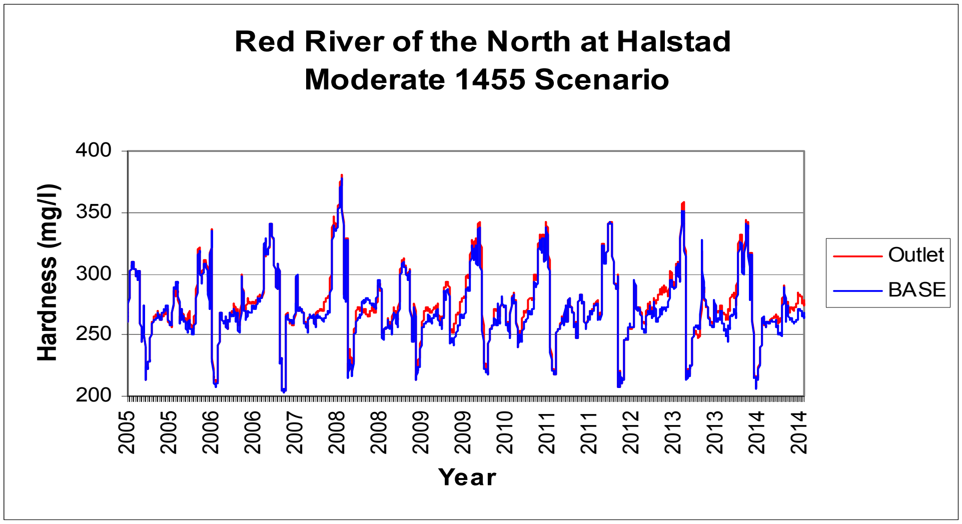


Sheyenne River at Valley City
Moderate 1455 Scenario
Chloride (mg/l)
60
50
40
30
20
10
0
2005 2005 2006 2006 2007 2008 2008 2009 2009 2010 2011 2011 2012 2013 2013 2014 2014
Year
BASE
Outlet

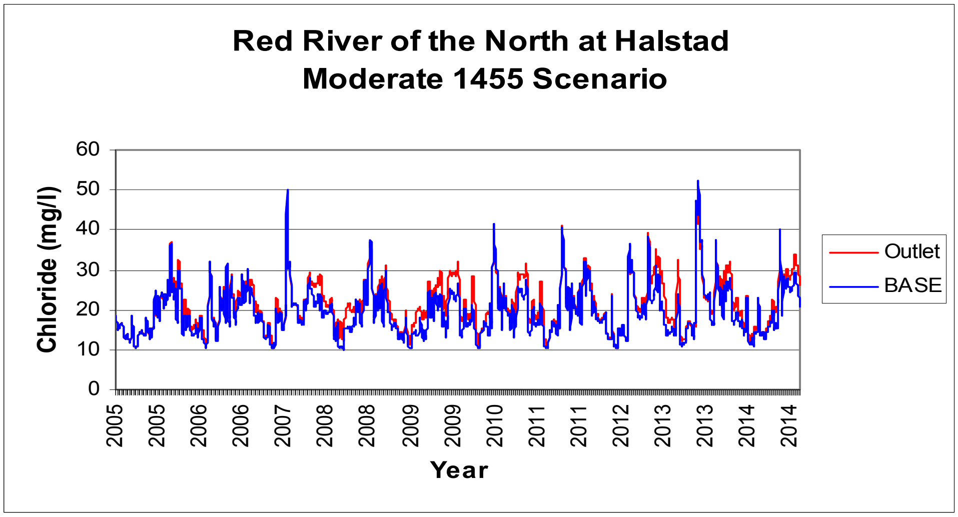
Plate 6L



Red River of the North at Halstad
Moderate 1455 Scenario
TDS (mg/l)
600
550
500
450
400
350
300
2005
2005
2006
2006
2007
2008
2008
2009
2009
2010
2011
2011
2012
2013
2013
2014
2014
Year
Outlet
BASE

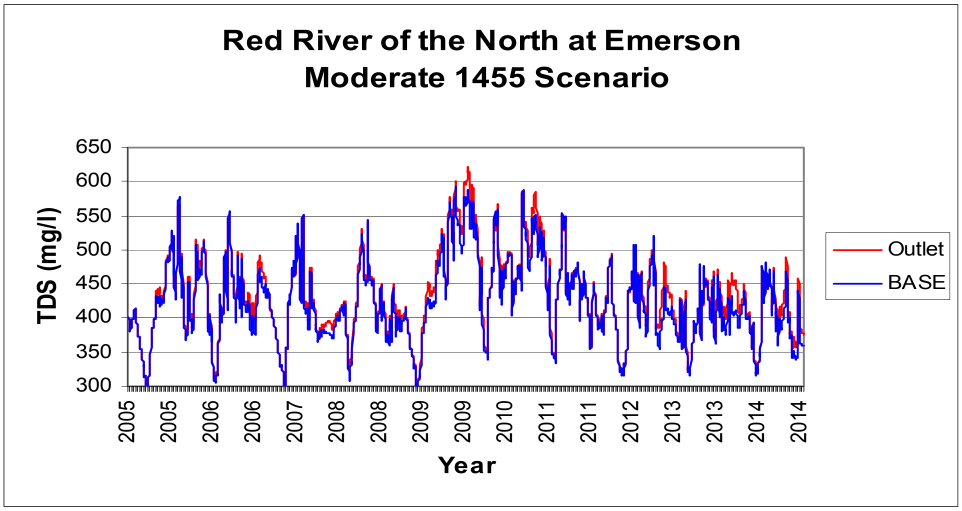


Red River of the North at Halstad
Moderate 1455 Scenario
Hardness (mg/l)
400
350
300
250
200
2005
2005
2006
2006
2007
2008
2008
2009
2009
2010
2011
2011
2012
2013
2013
2014
2014
Year
Outlet
BASE

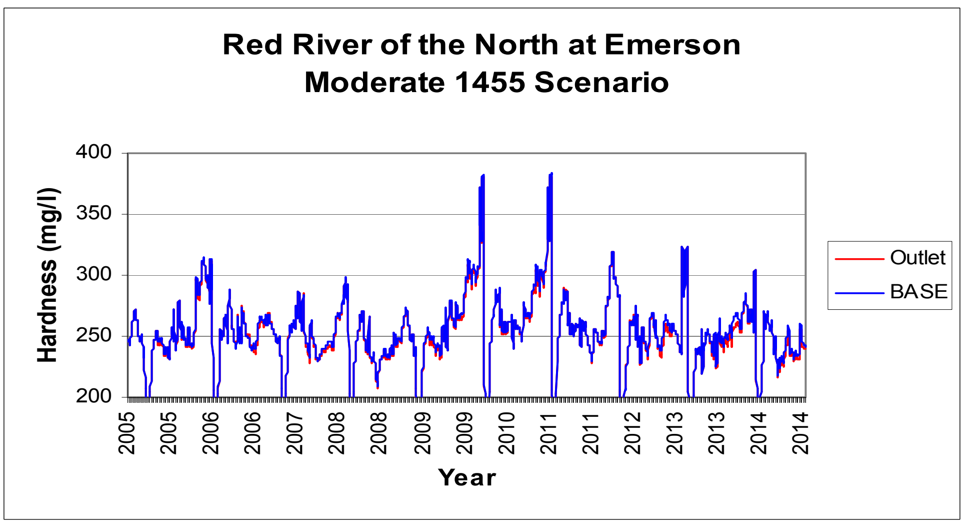


Red River of the North at Halstad
Moderate 1455 Scenario
Chloride (mg/l)
60
50
40
30
20
10
0
2005
2005
2006
2006
2007
2008
2008
2009
2009
2010
2011
2011
2012
2013
2013
2014
2014
Year
Outlet
BASE

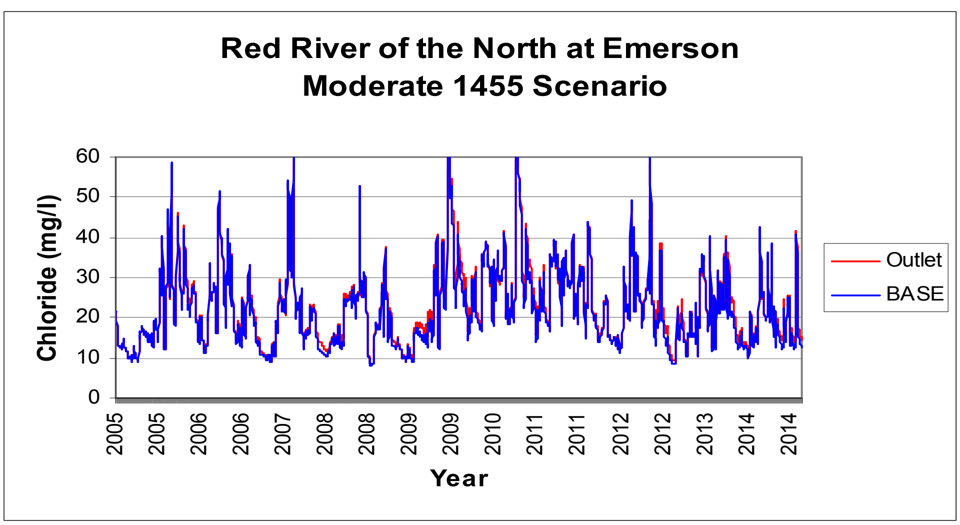
Plate 6M



Red River of the North at Emerson
Moderate 1455 Scenario
TDS (mg/l)
650
600
550
500
450
400
350
300
2005
2005
2006
2006
2007
2008
2008
2009
2009
2010
2011
2011
2012
2013
2013
2014
2014
Year
Outlet
BASE

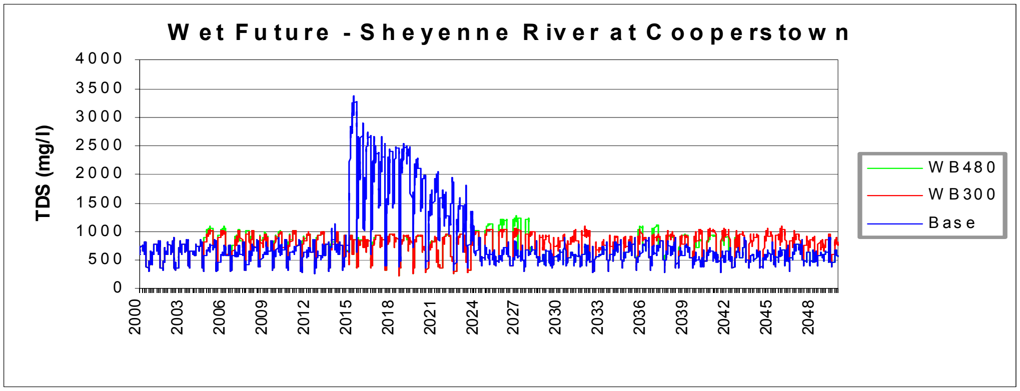


Red River of the North at Emerson
Moderate 1455 Scenario
Hardness (mg/l)
400
350
300
250
200
2005
2005
2006
2006
2007
2008
2008
2009
2009
2010
2011
2011
2012
2013
2013
2014
2014
Year
Outlet
BASE

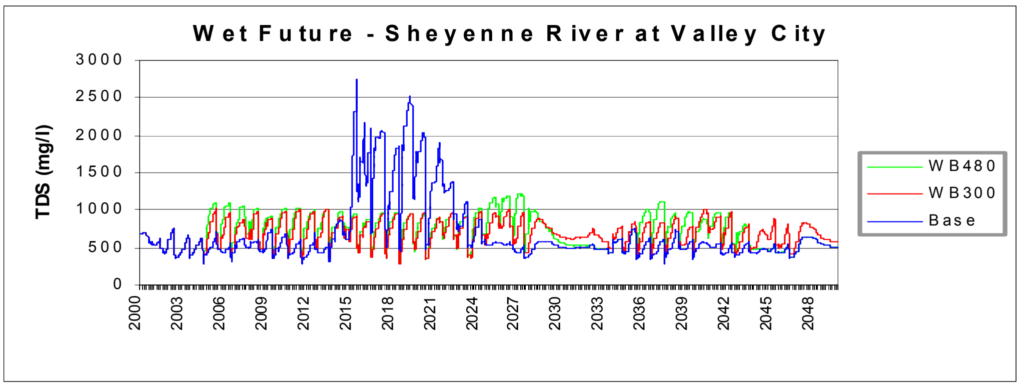


Red River of the North at Emerson
Moderate 1455 Scenario
Chloride (mg/l)
60
50
40
30
20
10
0
2005
2005
2006
2006
2007
2008
2008
2009
2009
2010
2011
2011
2012
2012
2013
2014
2014
Year
Outlet
BASE

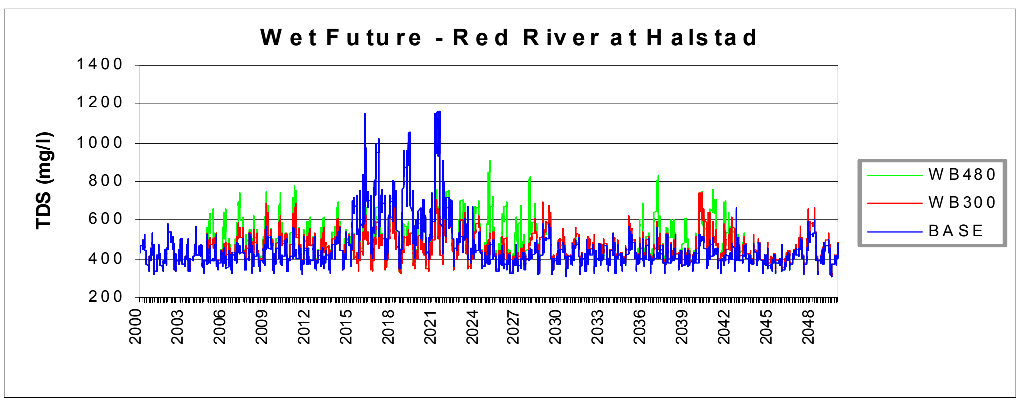
Plate 7A



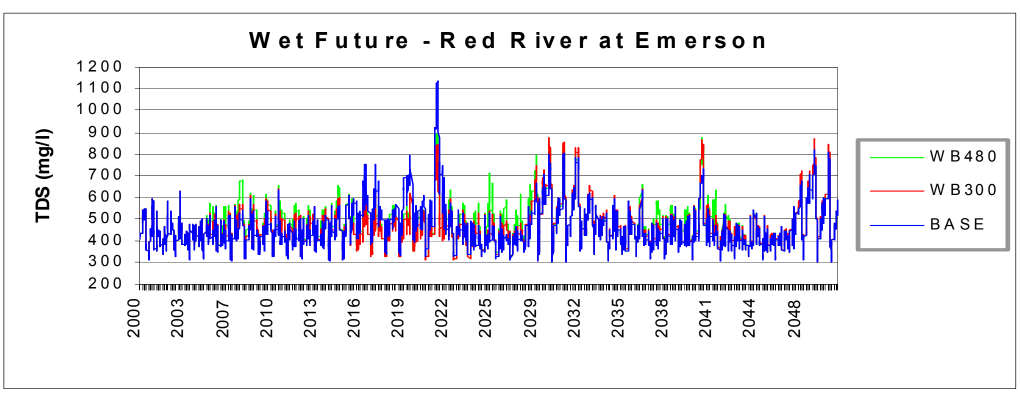
Wet Future - Sheyenne River at Cooperstown
TDS (mg/l)
4000
3500
3000
2500
2000
1500
1000
500
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030 2033 2036 2039 2042 2045 2048
WB480
WB300
Base



Wet Future - Sheyenne River at Valley City
TDS (mg/l)
3000
2500
2000
1500
1000
500
0
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030 2033 2036 2039 2042 2045 2048
WB480
WB300
Base

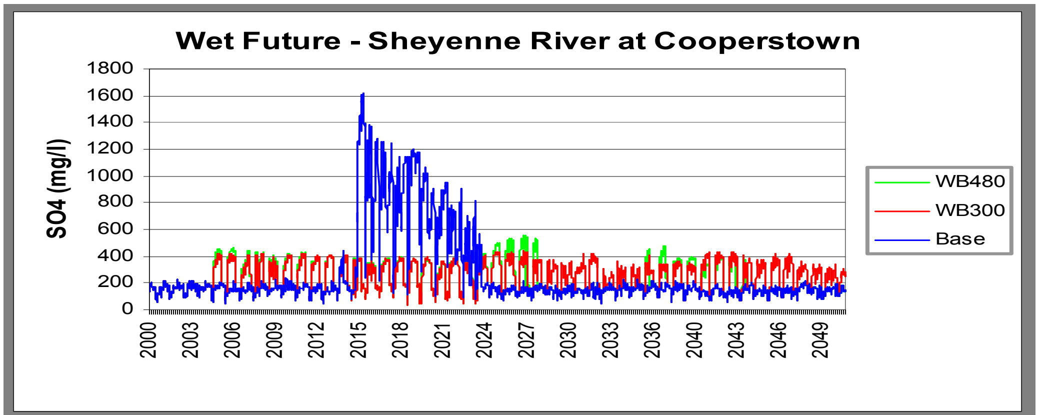


Wet Future - Red River at Halstad
TDS (mg/l)
1400
1200
1000
800
600
400
200
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030 2033 2036 2039 2042 2045 2048
WB480
WB300
BASE

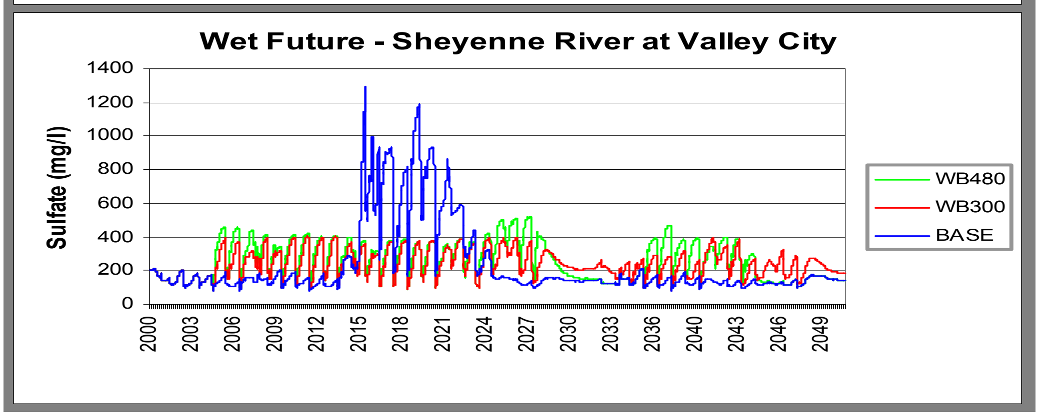


Wet Future - Red River at Emerson
TDS (mg/l)
1200
1100
1000
900
800
700
600
500
400
300
200
2000 2003 2007 2010 2013 2016 2019 2022 2025 2029 2032 2035 2038 2041 2044 2048
WB480
WB300
BASE

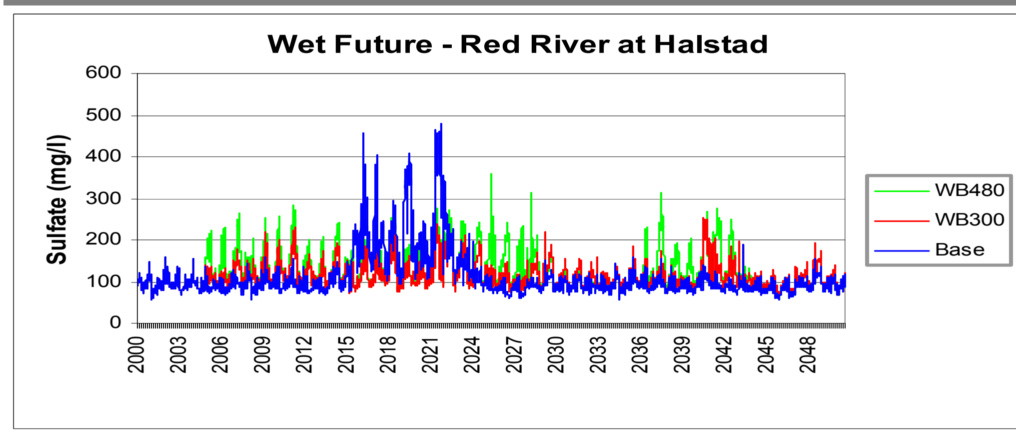
Plate 7B



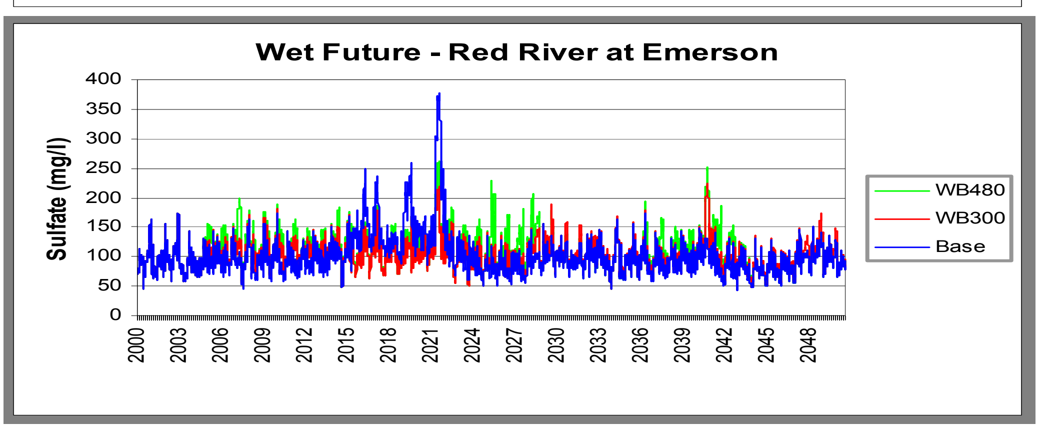
Wet Future - Sheyenne River at Cooperstown
SO4 (mg/l)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
Base



Wet Future - Sheyenne River at Valley City
Sulfate (mg/l)
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE



Wet Future - Red River at Halstad
Sulfate (mg/l)
600
500
400
300
200
100
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
WB480
WB300
Base



Wet Future - Red River at Emerson
Sulfate (mg/l)
400
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
WB480
WB300
Base

Plate 7C

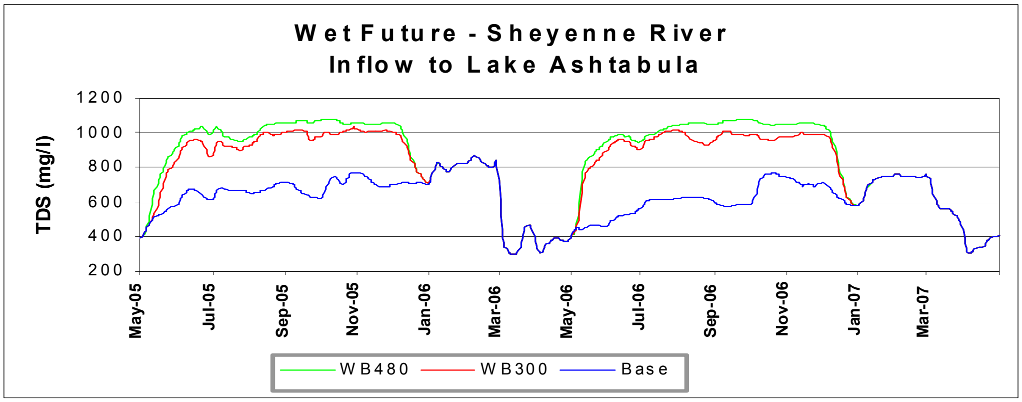
Sheyenne River at Cooperstown Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	91	91	91	>100	94	94	94
>500	82	87	87	>150	62	84	85
>600	60	81	82	>200	7	62	63
>700	32	76	78	>250	0	57	60
>800	9	60	64	>300	0	47	53
>900	0	36	41	>350	0	35	41
>1000	0	6	15	>400	0	11	21
>1100	0	0	0	>450	0	0	2

Sheyenne River at Valley City Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	89	94	94	>100	94	98	99
>500	52	88	90	>150	35	89	91
>600	20	77	84	>200	1	73	83
>700	3	56	73	>250	0	55	73
>800	0	42	58	>300	0	39	58
>900	0	25	42	>350	0	24	41
>1000	0	2	21	>400	0	2	25
>1100	0	0	0	>450	0	0	3

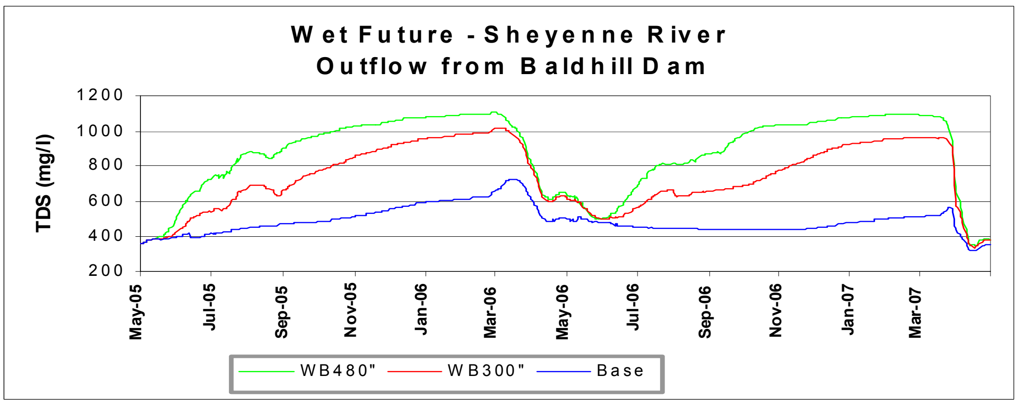
Red River of the North at Halstad Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	61	79	83	>100	27	66	74
>500	4	27	44	>150	0	12	32
>600	0	4	15	>200	0	1	11
>700	0	0	3	>250	0	0	1
>800	0	0	0	>300	0	0	0
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Red River of the North at Emerson Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	74	82	84	>100	33	63	74
>500	8	20	33	>150	1	2	10
>600	0	0	4	>200	0	0	0
>700	0	0	0	>250	0	0	0
>800	0	0	0	>300	0	0	0
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

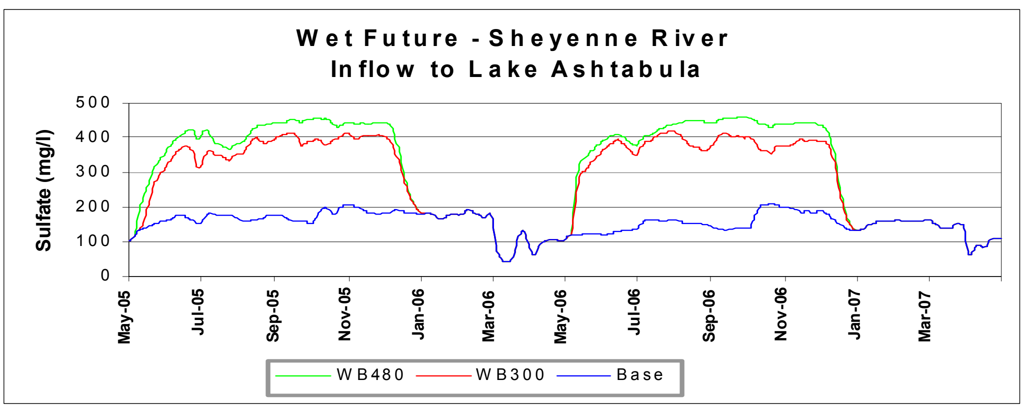
Plate 7D



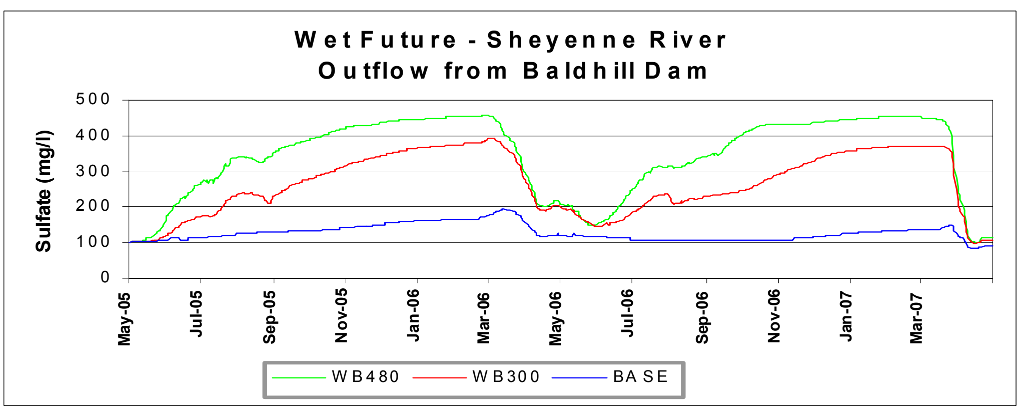
Wet Future - Sheyenne River
Inflow to Lake Ashtabula
TDS (mg/l)
1200
1000
800
600
400
200
May-05
Jul-05
Sep-05
Nov-05
Jan-06
Mar-06
May-06
Jul-06
Sep-06
Nov-06
Jan-07
Mar-07
WB480
WB300
Base



Wet Future - Sheyenne River
Outflow from Baldhill Dam
TDS (mg/l)
1200
1000
800
600
400
200
May-05
Jul-05
Sep-05
Nov-05
Jan-06
Mar-06
May-06
Jul-06
Sep-06
Nov-06
Jan-07
Mar-07
WB480"
WB300"
Base

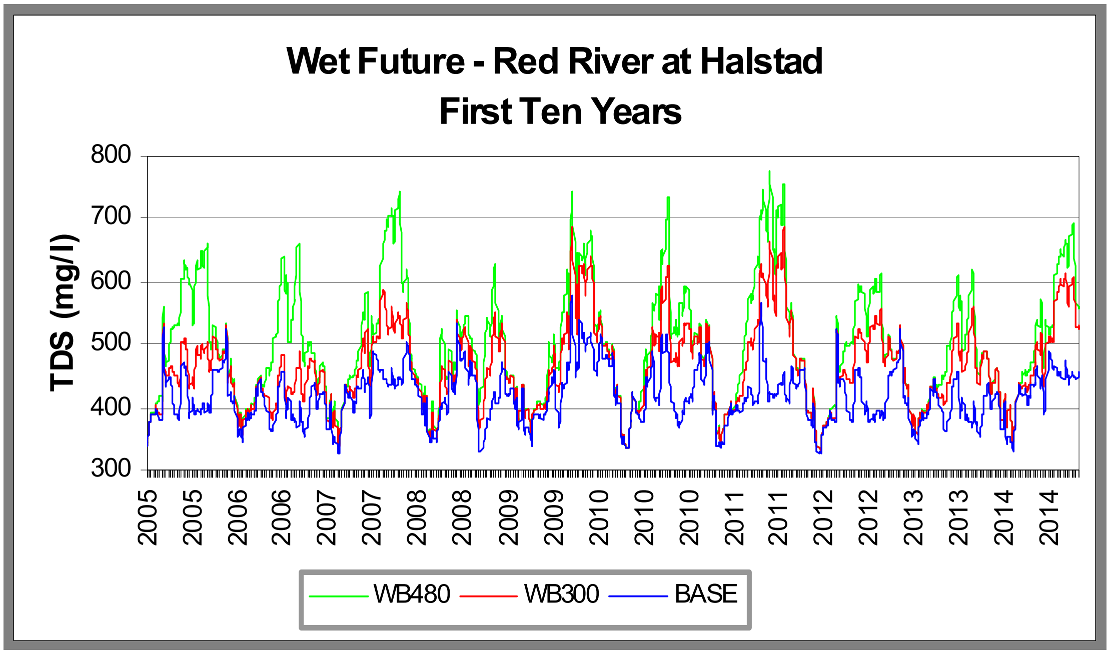


Wet Future - Sheyenne River
Inflow to Lake Ashtabula
Sulfate (mg/l)
500
400
300
200
100
0
May-05
Jul-05
Sep-05
Nov-05
Jan-06
Mar-06
May-06
Jul-06
Sep-06
Nov-06
Jan-07
Mar-07
WB480
WB300
Base

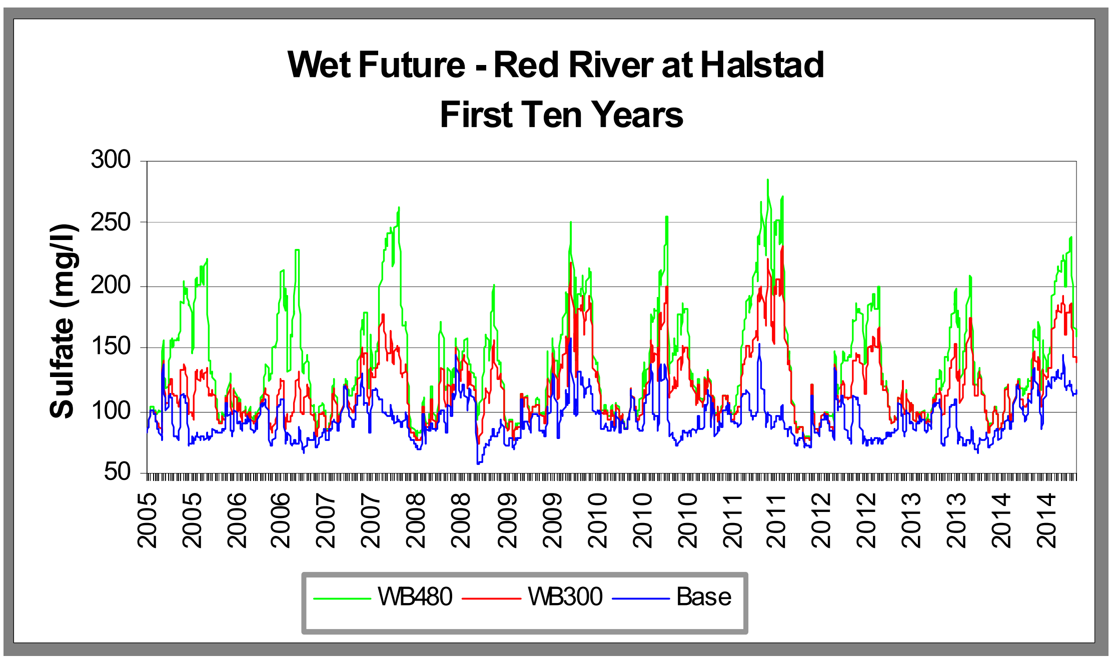


Wet Future - Sheyenne River
Outflow from Baldhill Dam
Sulfate (mg/l)
500
400
300
200
100
0
May-05
Jul-05
Sep-05
Nov-05
Jan-06
Mar-06
May-06
Jul-06
Sep-06
Nov-06
Jan-07
Mar-07
WB480
WB300
BASE

Plate 7E

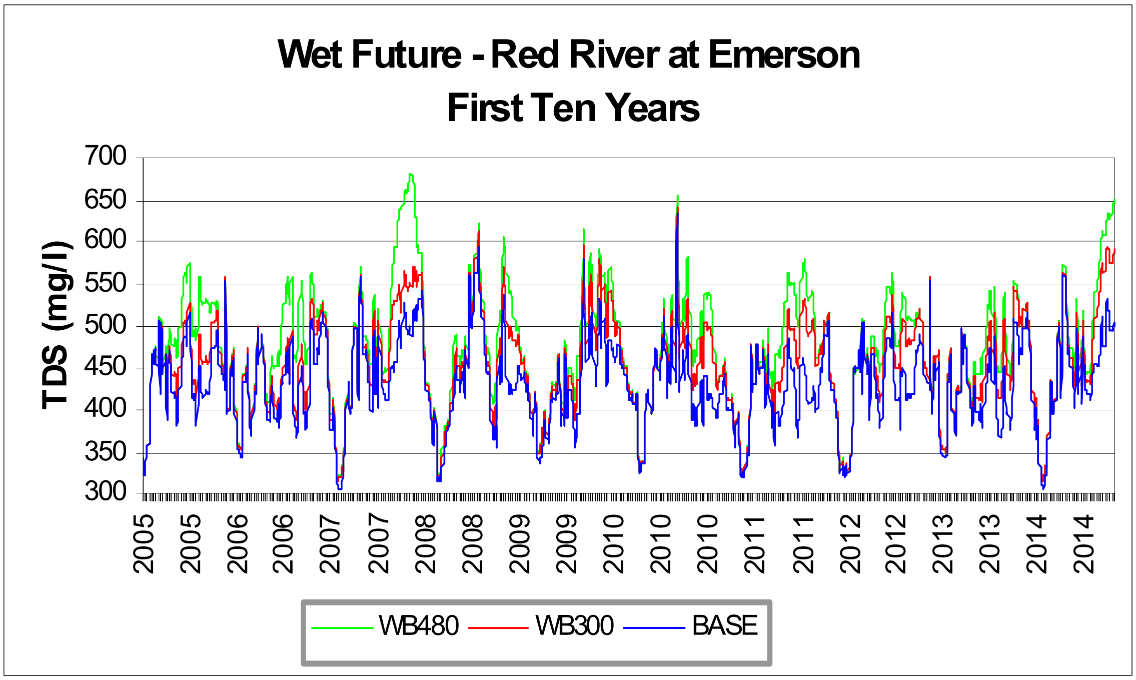


Wet Future - Red River at Halstad
First Ten Years
TDS (mg/l)
800
700
600
500
400
300
2005
2005
2006
2006
2007
2007
2008
2008
2009
2009
2010
2010
2010
2011
2011
2012
2012
2013
2013
2014
2014
WB480
WB300
BASE



Wet Future - Red River at Halstad
First Ten Years
Sulfate (mg/l)
300
250
200
150
100
50
2005
2005
2006
2006
2007
2007
2008
2008
2009
2009
2010
2010
2010
2011
2011
2012
2012
2013
2013
2014
2014
WB480
WB300
Base

Plate 7F


Wet Future - Red River at Emerson
First Ten Years
TDS (mg/l)
700
650
600
550
500
450
400
350
300
2005
2005
2006
2006
2007
2007
2008
2008
2009
2009
2010
2010
2010
2011
2011
2012
2012
2013
2013
2014
2014
WB480
WB300
BASE

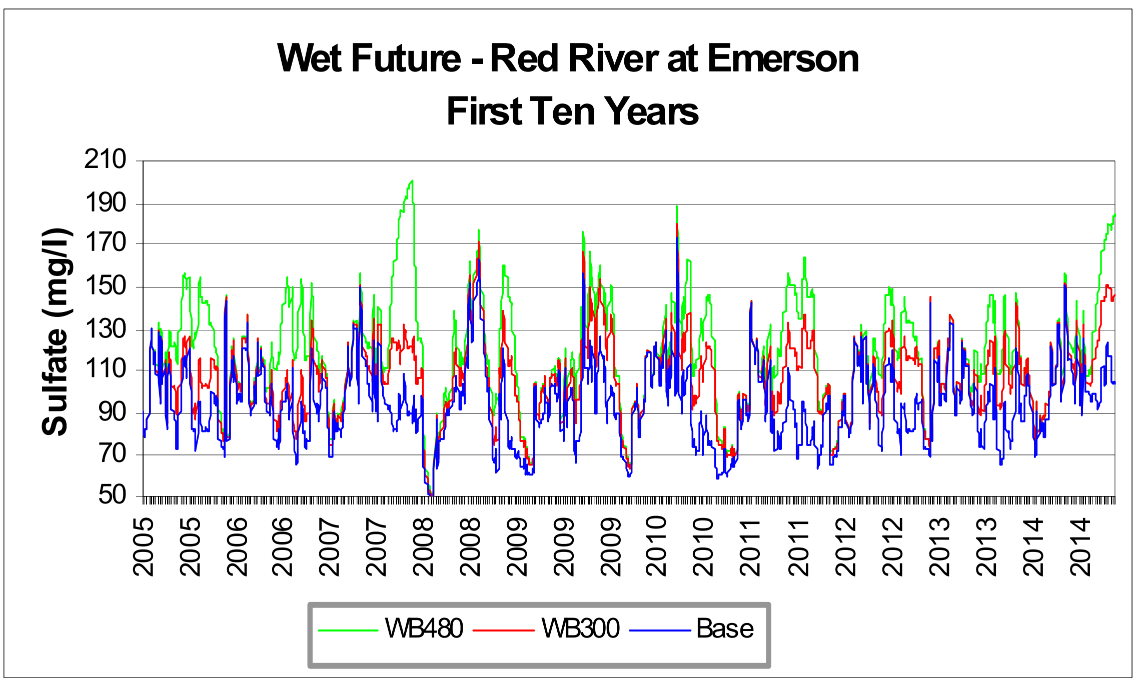
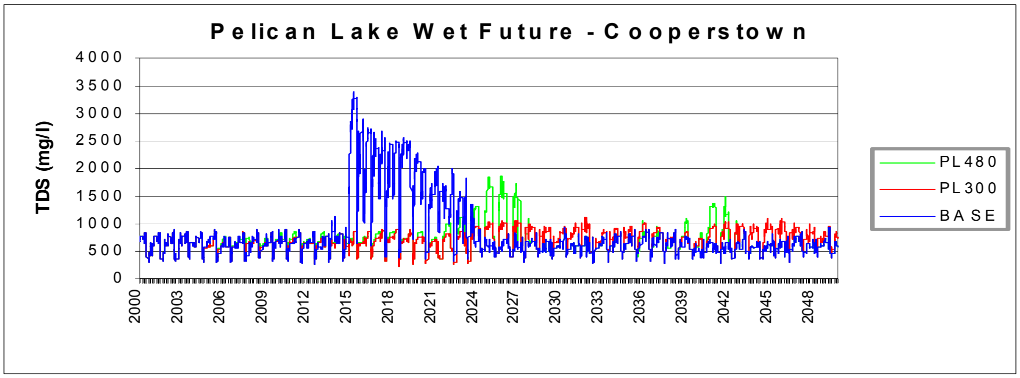
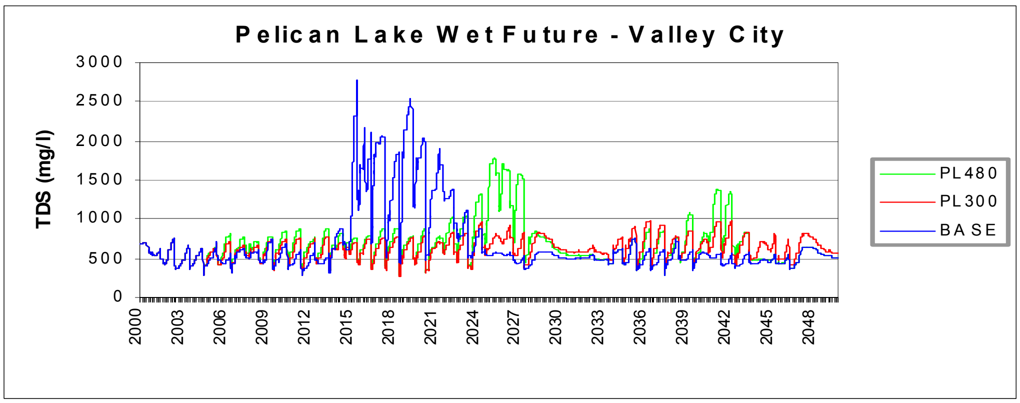

Wet Future - Red River at Emerson
First Ten Years
Sulfate (mg/l)
210
190
170
150
130
110
90
70
50
2005
2005
2006
2006
2007
2007
2008
2008
2009
2009
2009
2010
2010
2011
2011
2012
2012
2013
2013
2014
2014
WB480
WB300
Base

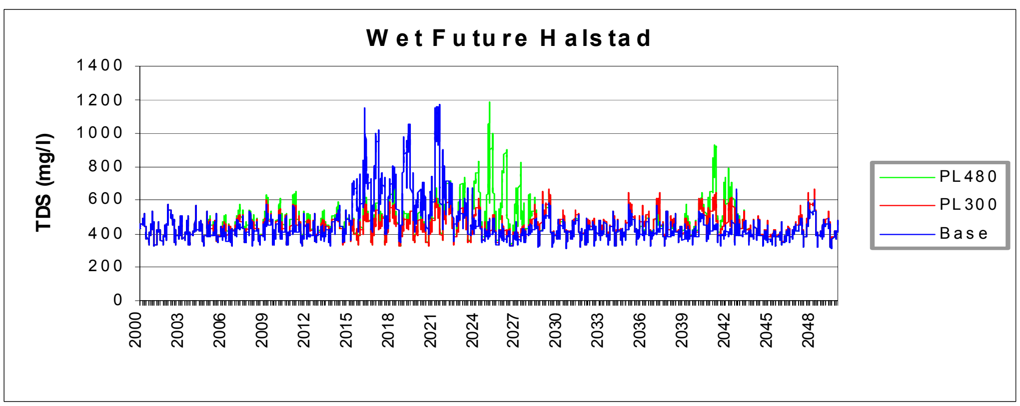
Plate 10A



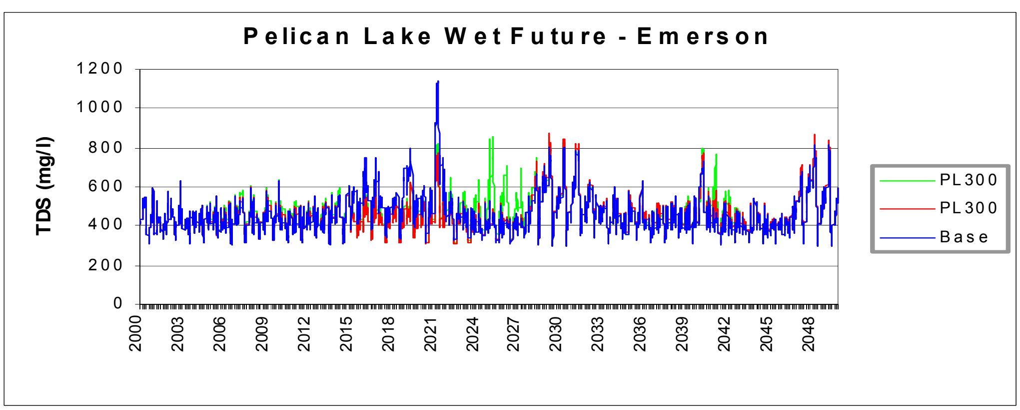
Pelican Lake Wet Future - Cooperstown
TDS (mg/l)
4000
3500
3000
2500
2000
1500
1000
500
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL480
PL300
BASE



Pelican Lake Wet Future - Valley City
TDS (mg/l)
3000
2500
2000
1500
1000
500
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL480
PL300
BASE

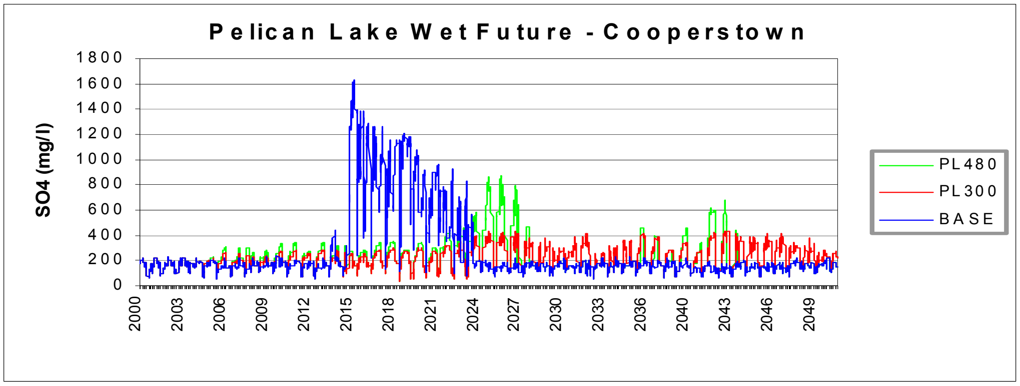


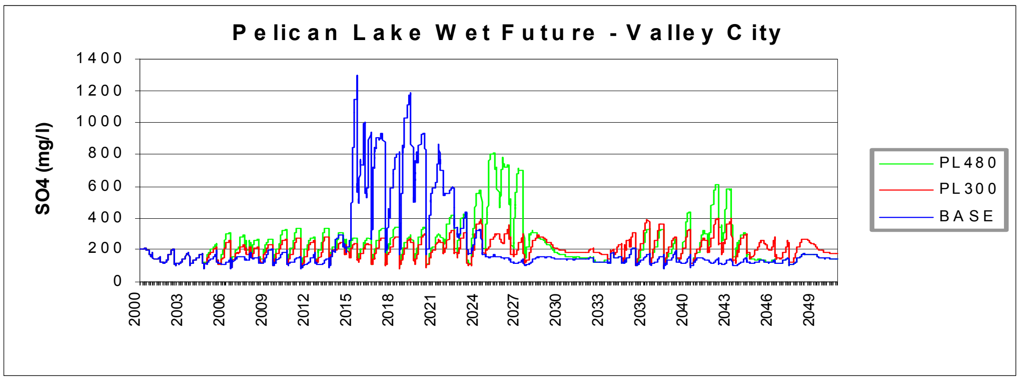
Wet Future Halstad
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL480
PL300
Base

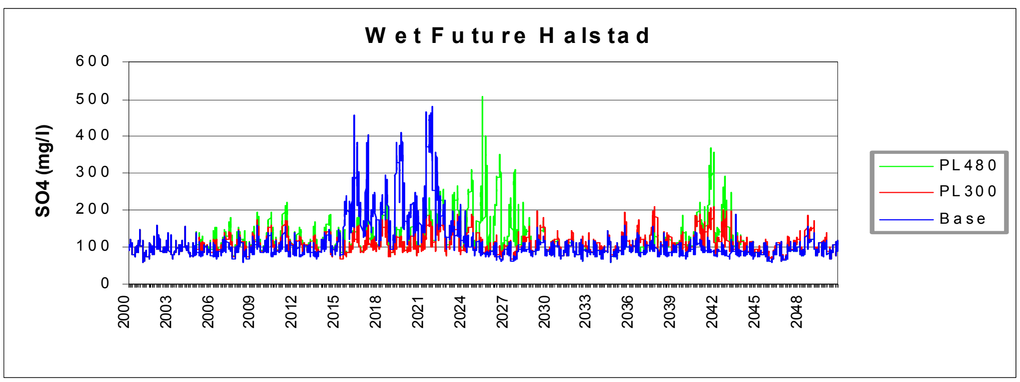


Pelican Lake Wet Future - Emerson
TDS (mg/l)
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL300
PL300
Base

Plate 10B


Pelican Lake Wet Future - Cooperstown
SO4 (mg/l)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE


Pelican Lake Wet Future - Valley City
SO4 (mg/l)
0
200
400
600
800
1000
1200
1400
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE


Wet Future Halstad
SO4 (mg/l)
0
100
200
300
400
500
600
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL480
PL300
Base

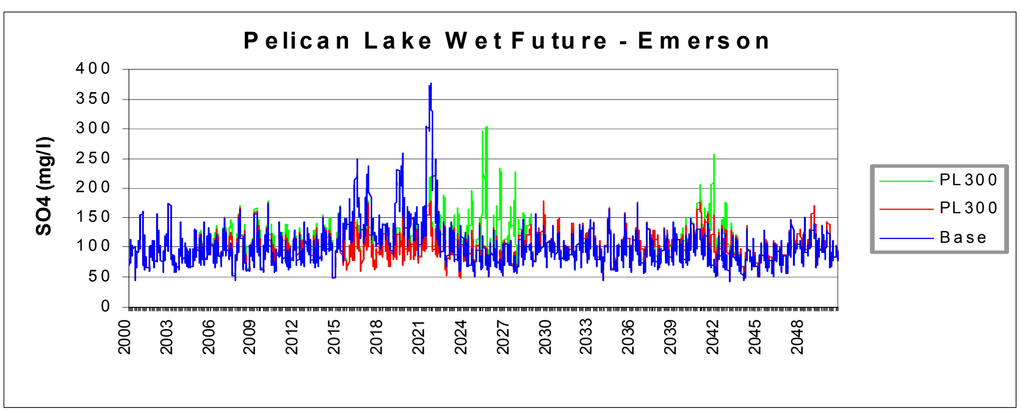
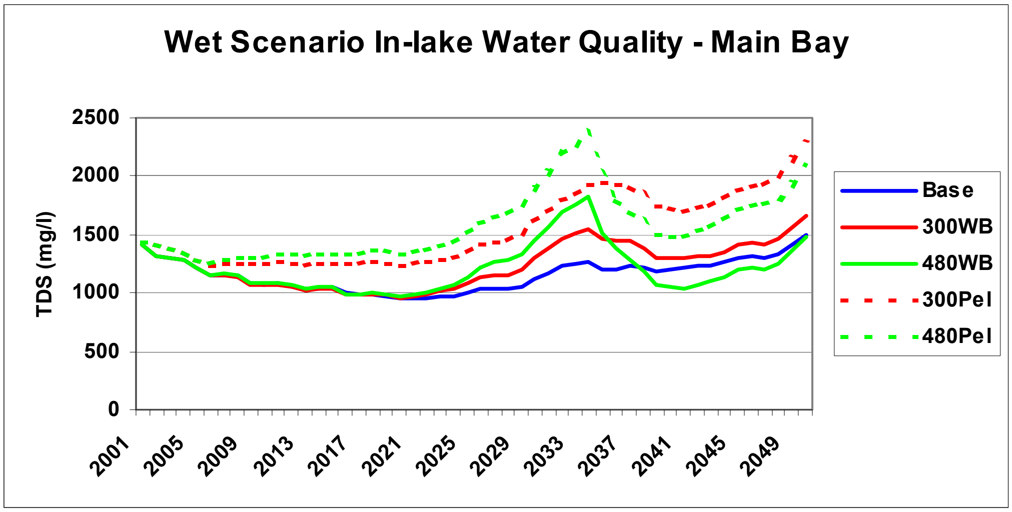
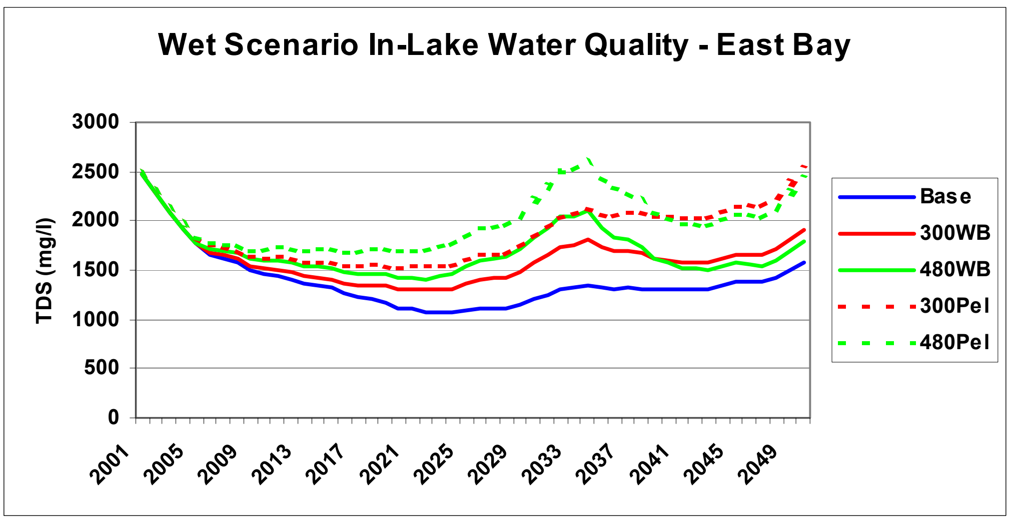

Pelican Lake Wet Future - Emerson
SO4 (mg/l)
0
50
100
150
200
250
300
350
400
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL300
PL300
Base

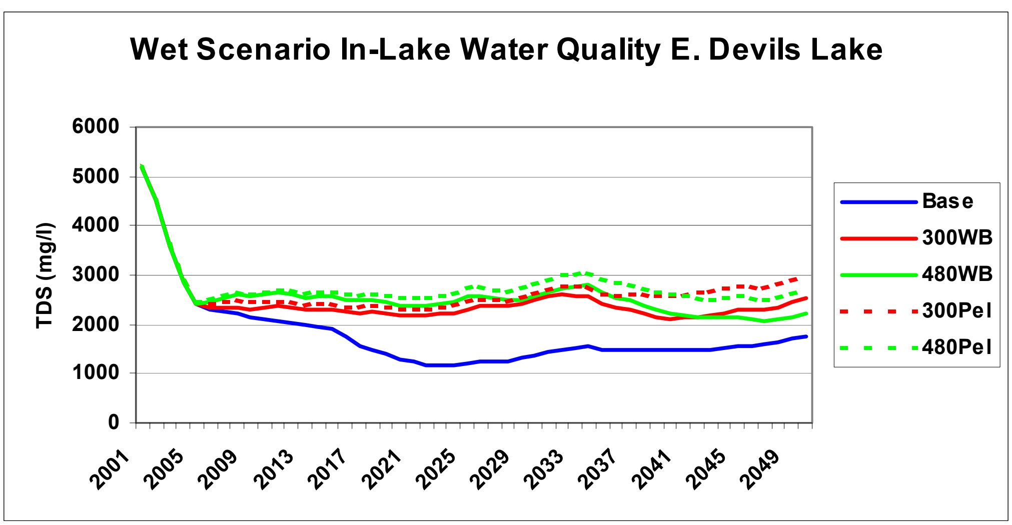
Plate 9



Wet Scenario In-lake Water Quality - Main Bay
TDS (mg/l)
2500
2000
1500
1000
500
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300Pel
480Pel



Wet Scenario In-Lake Water Quality - East Bay
TDS (mg/l)
3000
2500
2000
1500
1000
500
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300Pel
480Pel



Wet Scenario In-Lake Water Quality E. Devils Lake
TDS (mg/l)
6000
5000
4000
3000
2000
1000
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300Pel
480Pel

Plate 10C

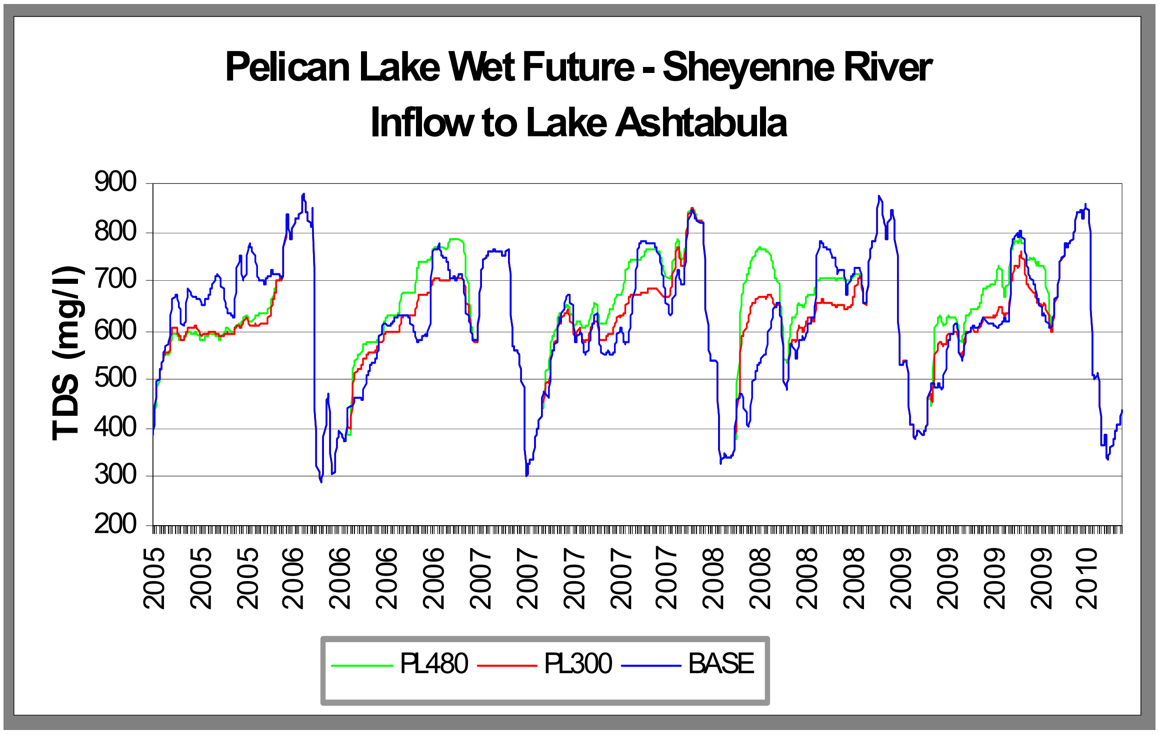
Pelican Lake Outlet Wet Future at Cooperstown Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	91	91	91	>100	94	94	94
>500	82	86	87	>150	62	82	84
>600	60	67	74	>200	7	42	52
>700	32	29	45	>250	0	14	29
>800	9	9	16	>300	0	0	10
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Pelican Lake Outlet Wet Future at Valley City Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	89	93	93	>100	94	97	98
>500	52	77	84	>150	35	76	84
>600	20	48	64	>200	1	40	60
>700	3	17	34	>250	0	13	34
>800	0	0	12	>300	0	0	13
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

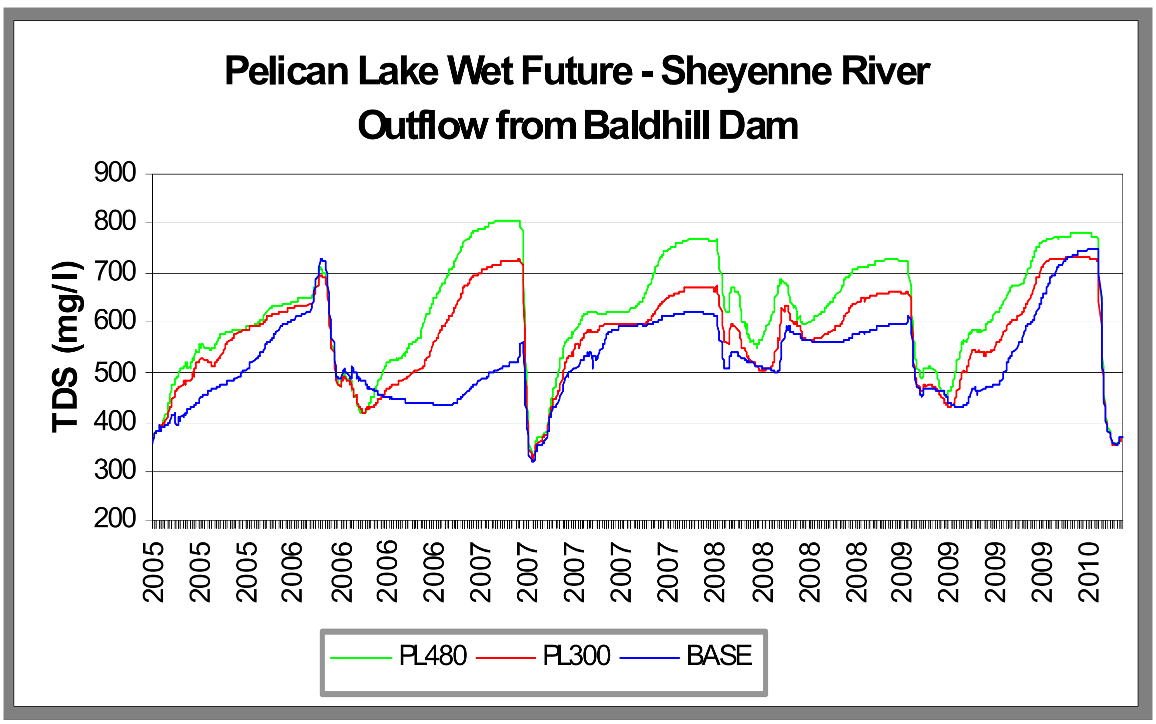
Pelican Lake Outlet Wet Future at Halstad Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	61	76	79	>100	27	50	63
>500	4	11	21	>150	0	2	12
>600	0	0	2	>200	0	0	1
>700	0	0	0	>250	0	0	0
>800	0	0	0	>300	0	0	0
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Pelican Lake Outlet Wet Future at Emerson Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	74	80	83	>100	33	50	62
>500	8	12	17	>150	1	1	1
>600	0	0	0	>200	0	0	0
>700	0	0	0	>250	0	0	0
>800	0	0	0	>300	0	0	0
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Plate 10D

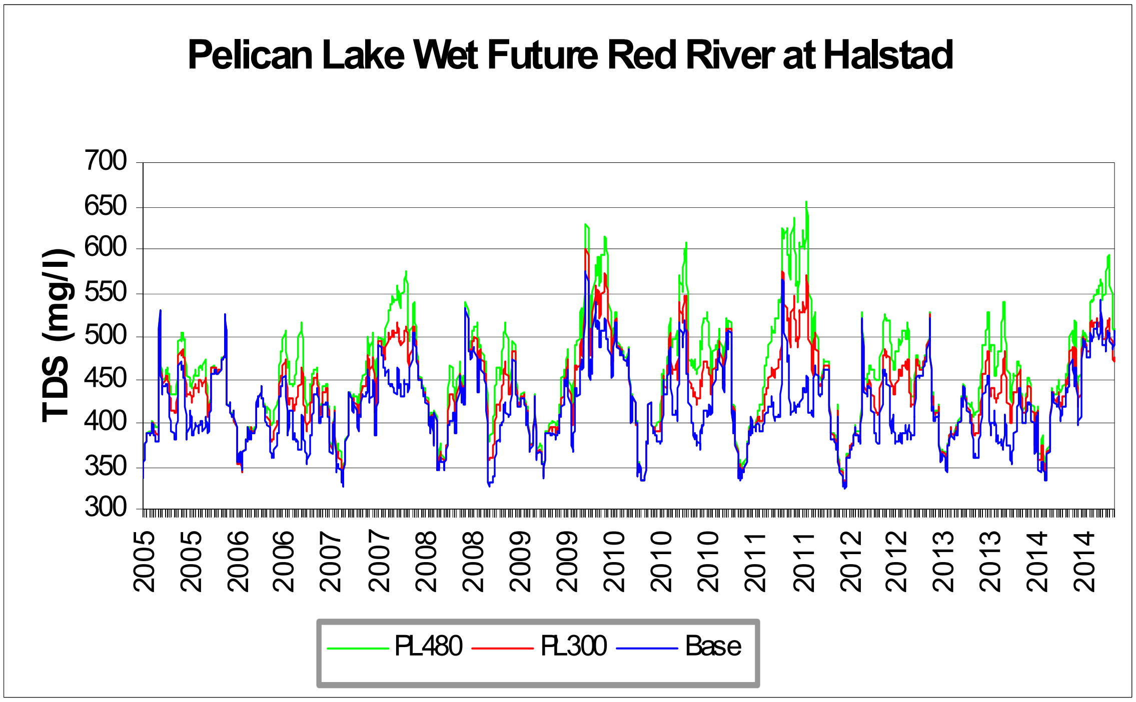


Pelican Lake Wet Future - Sheyenne River
Inflow to Lake Ashtabula
TDS (mg/l)
900
800
700
600
500
400
300
200
2005 2005 2005 2006 2006 2006 2006 2007 2007 2007 2007 2007 2008 2008 2008 2008 2009 2009 2009 2009 2010
PL480
PL300
BASE

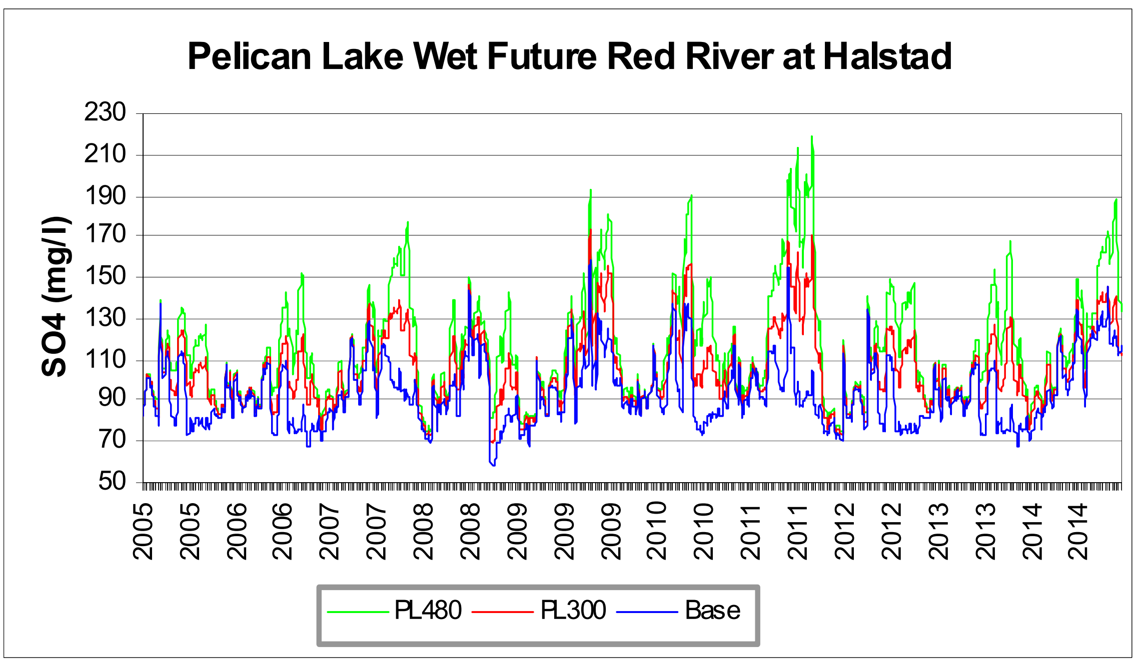


Pelican Lake Wet Future - Sheyenne River
Outflow from Baldhill Dam
TDS (mg/l)
900
800
700
600
500
400
300
200
2005 2005 2005 2006 2006 2006 2006 2007 2007 2007 2007 2007 2008 2008 2008 2008 2009 2009 2009 2009 2010
PL480
PL300
BASE

Plate 10E

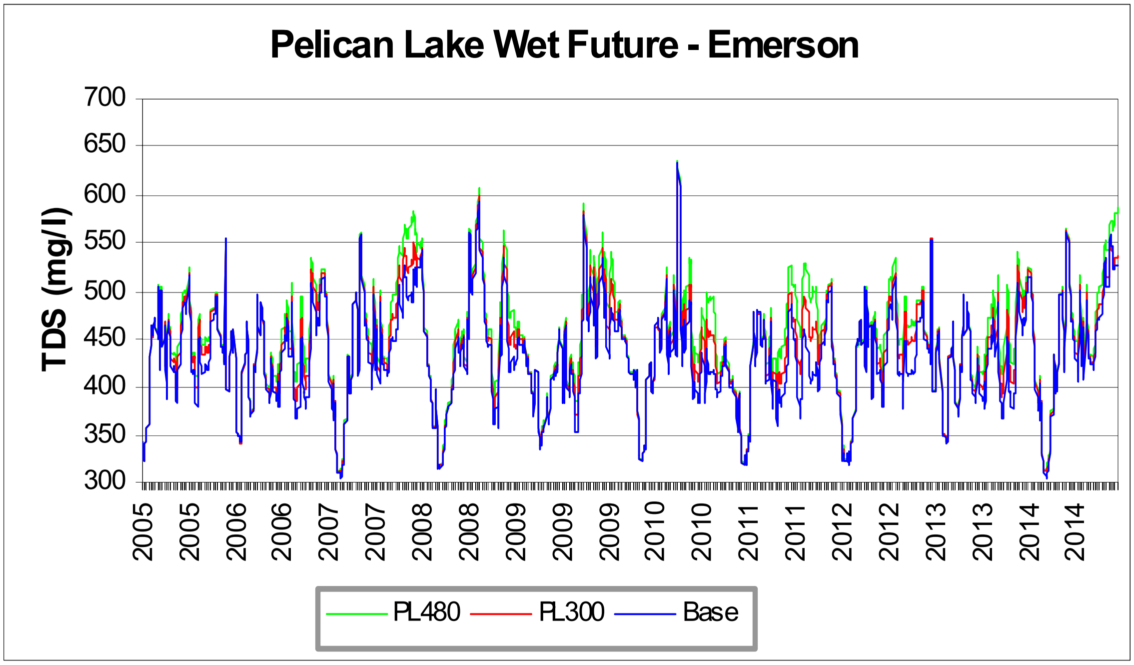


Pelican Lake Wet Future Red River at Halstad
TDS (mg/l)
700
650
600
550
500
450
400
350
300
2005
2005
2006
2006
2007
2007
2008
2008
2009
2009
2010
2010
2010
2011
2011
2012
2012
2013
2013
2014
2014
PL480
PL300
Base

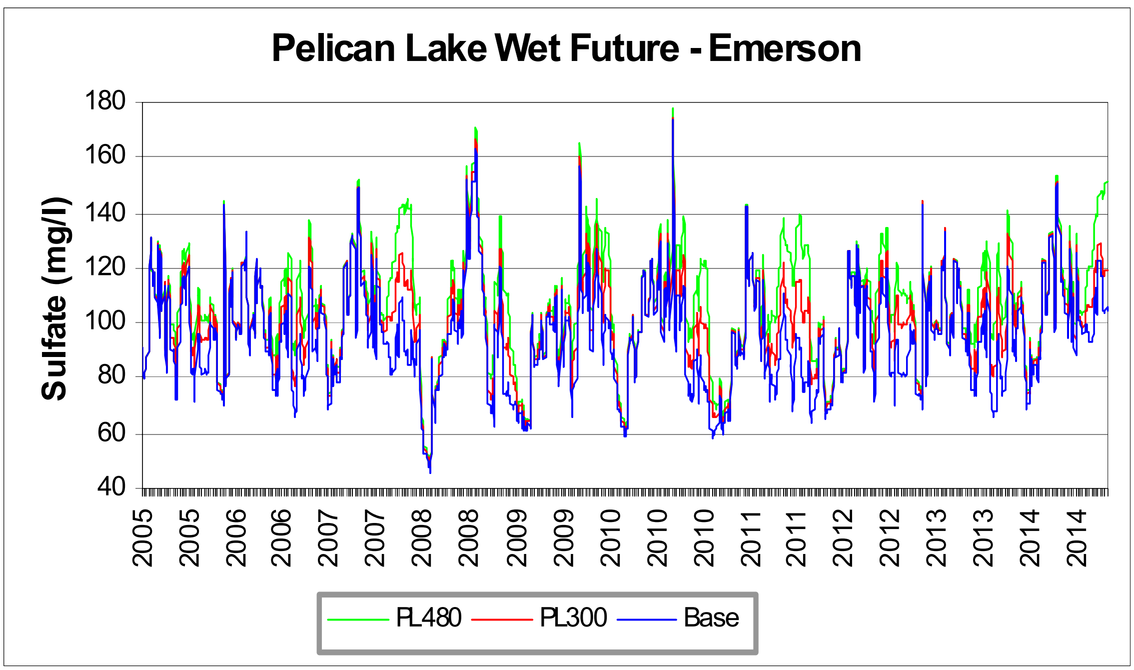


Pelican Lake Wet Future Red River at Halstad
SO4 (mg/l)
230
210
190
170
150
130
110
90
70
50
2005
2005
2006
2006
2007
2007
2008
2008
2009
2009
2009
2010
2010
2011
2011
2012
2012
2013
2013
2014
2014
PL480
PL300
Base

Plate 10F

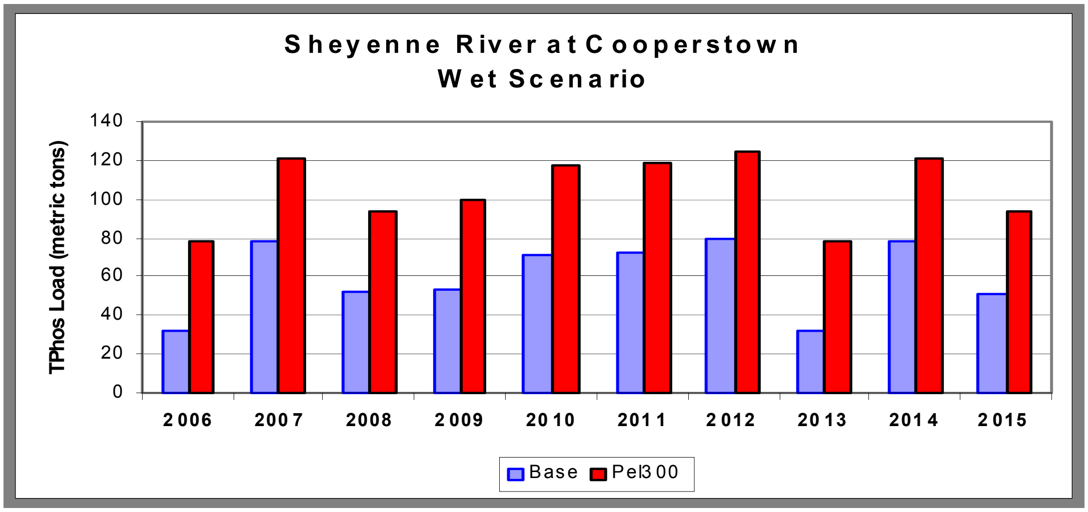


Pelican Lake Wet Future - Emerson
TDS (mg/l)
700
650
600
550
500
450
400
350
300
2005
2005
2006
2006
2007
2007
2008
2008
2009
2009
2009
2010
2010
2011
2011
2012
2012
2013
2013
2014
2014
PL480
PL300
Base

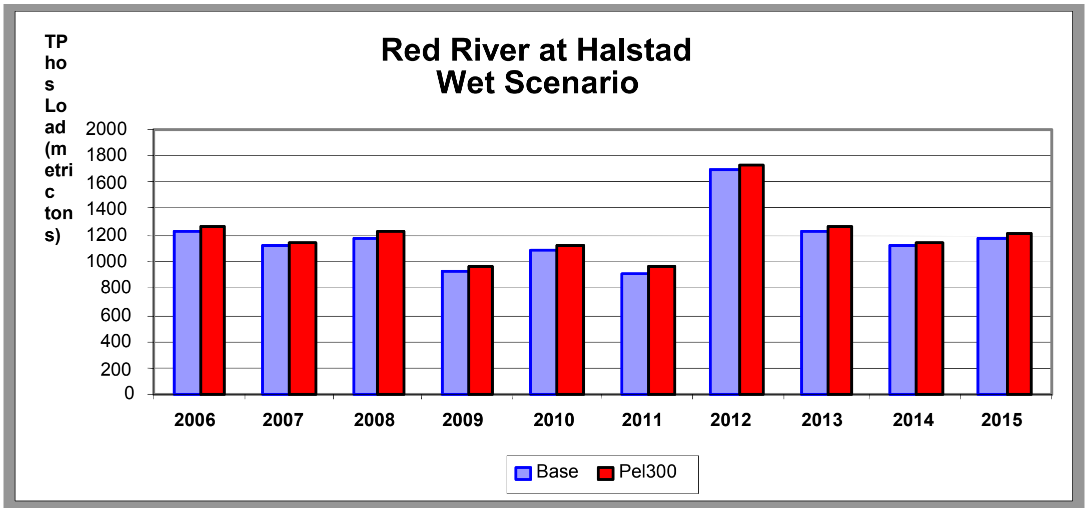


Pelican Lake Wet Future - Emerson
Sulfate (mg/l)
180
160
140
120
100
80
60
40
2005
2005
2006
2006
2007
2007
2008
2008
2009
2009
2010
2010
2010
2011
2011
2012
2012
2013
2013
2014
2014
PL480
PL300
Base

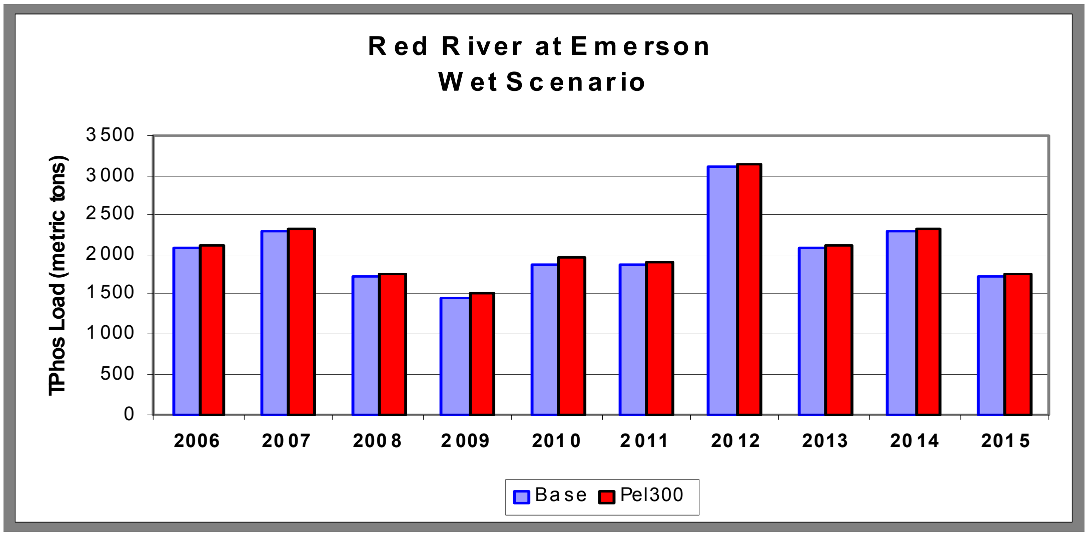
Plate 10G



Sheyenne River at Cooperstown
Wet Scenario
TPhos Load (metric tons)
140
120
100
80
60
40
20
0
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Base
Pel300

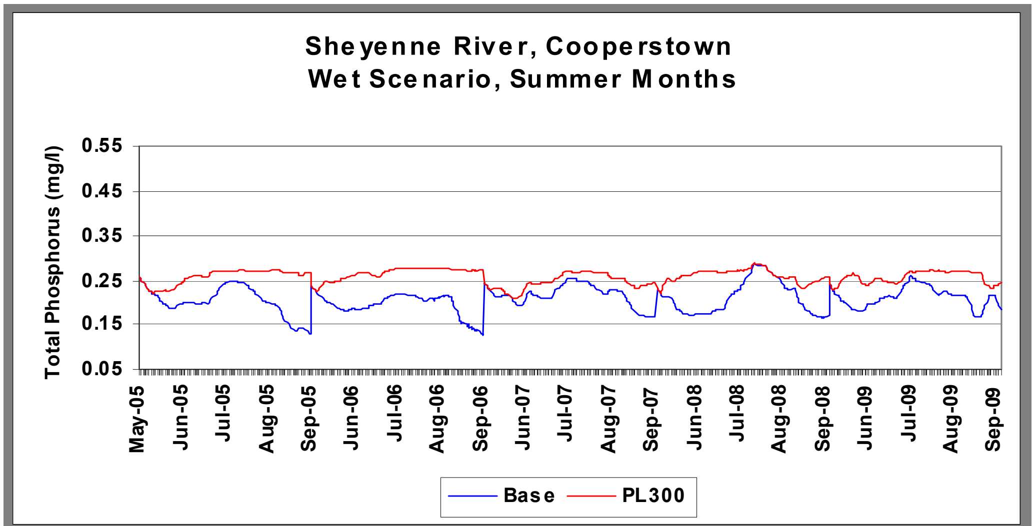


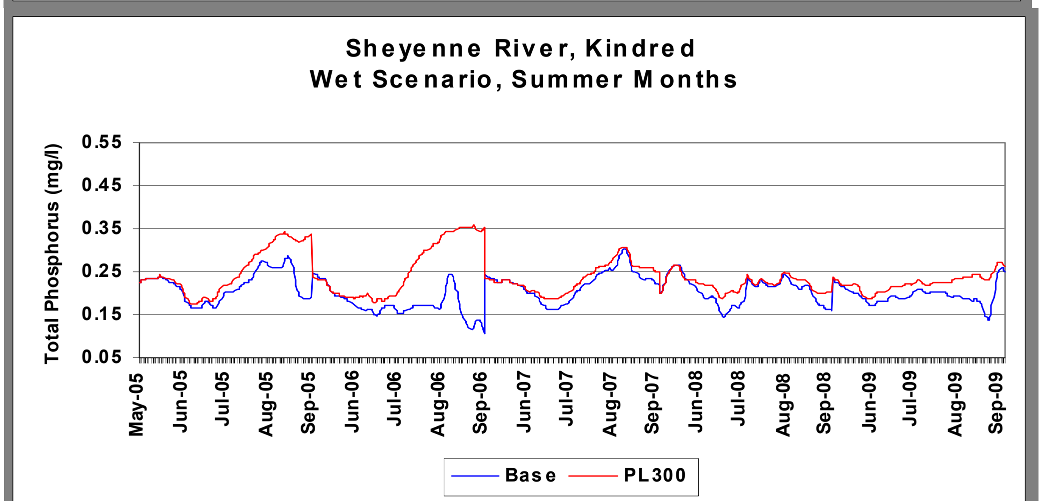
Red River at Halstad
Wet Scenario
TPhos Load (metric tons)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Base
Pel300



Red River at Emerson
Wet Scenario
TPhos Load (metric tons)
3500
3000
2500
2000
1500
1000
500
0
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Base
Pel300

Plate 10H


Sheyenne River, Cooperstown
Wet Scenario, Summer Months
Total Phosphorus (mg/l)
0.55
0.45
0.35
0.25
0.15
0.05
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Jun-06
Jul-06
Aug-06
Sep-06
Jun-07
Jul-07
Aug-07
Sep-07
Jun-08
Jul-08
Aug-08
Sep-08
Jun-09
Jul-09
Aug-09
Sep-09
Base
PL300


Sheyenne River, Kindred
Wet Scenario, Summer Months
Total Phosphorus (mg/l)
0.55
0.45
0.35
0.25
0.15
0.05
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Jun-06
Jul-06
Aug-06
Sep-06
Jun-07
Jul-07
Aug-07
Sep-07
Jun-08
Jul-08
Aug-08
Sep-08
Jun-09
Jul-09
Aug-09
Sep-09
Base
PL300

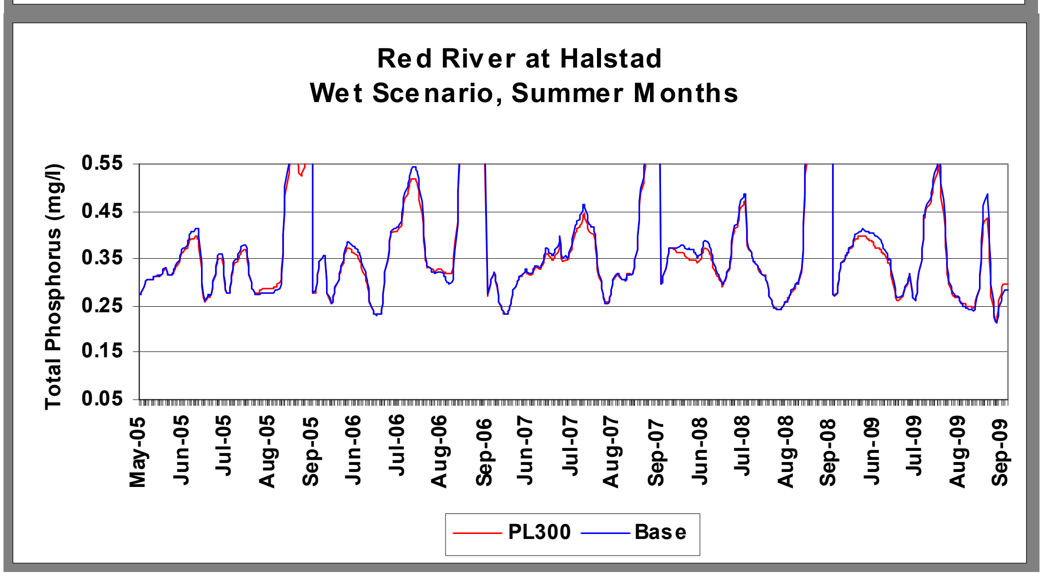
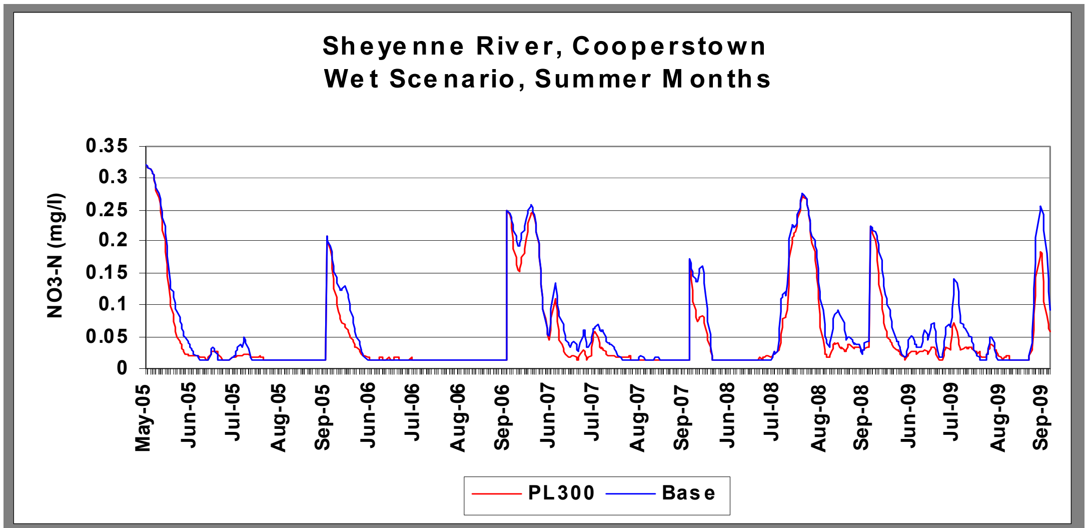
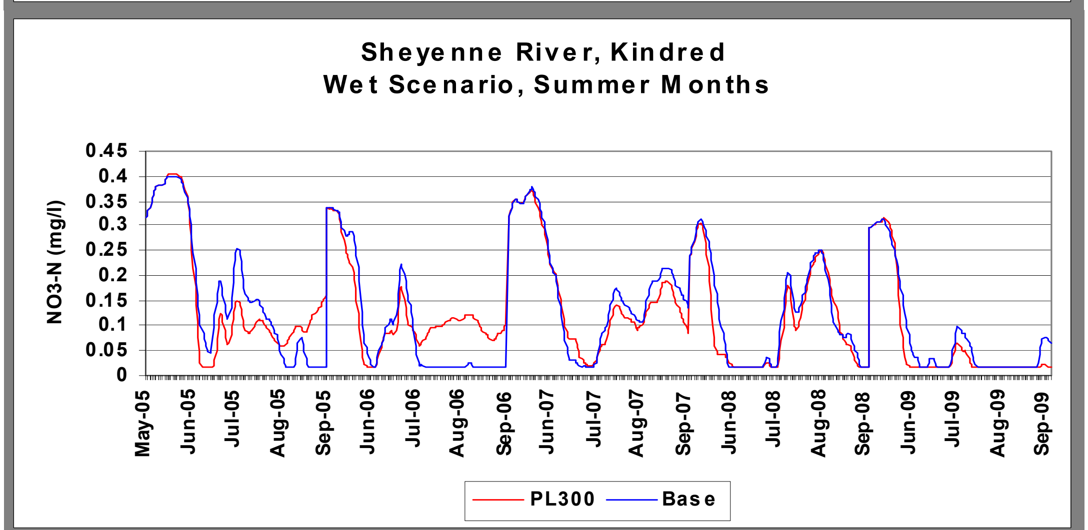

Red River at Halstad
Wet Scenario, Summer Months
Total Phosphorus (mg/l)
0.55
0.45
0.35
0.25
0.15
0.05
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Jun-06
Jul-06
Aug-06
Sep-06
Jun-07
Jul-07
Aug-07
Sep-07
Jun-08
Jul-08
Aug-08
Sep-08
Jun-09
Jul-09
Aug-09
Sep-09
PL300
Base

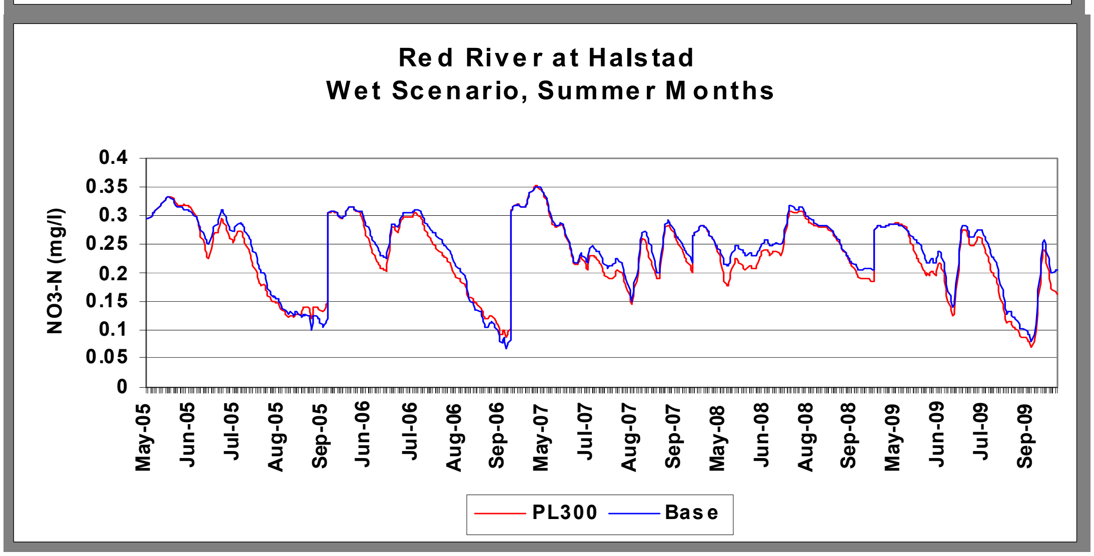
Plate 10I



Sheyenne River, Cooperstown
Wet Scenario, Summer Months
NO3-N (mg/l)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Jun-06
Jul-06
Aug-06
Sep-06
Jun-07
Jul-07
Aug-07
Sep-07
Jun-08
Jul-08
Aug-08
Sep-08
Jun-09
Jul-09
Aug-09
Sep-09
PL300
Base

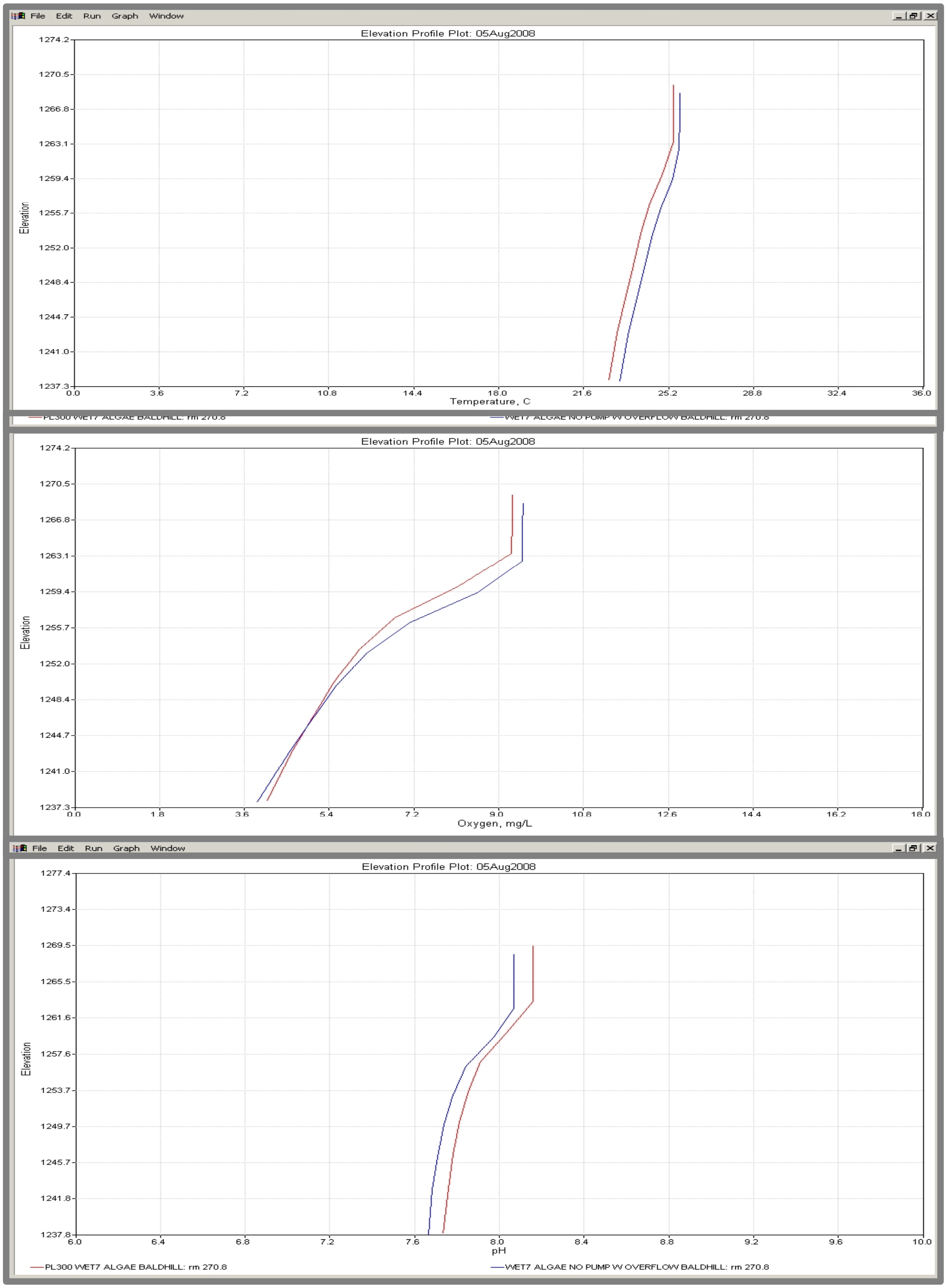


Sheyenne River, Kindred
Wet Scenario, Summer Months
NO3-N (mg/l)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Jun-06
Jul-06
Aug-06
Sep-06
Jun-07
Jul-07
Aug-07
Sep-07
Jun-08
Jul-08
Aug-08
Sep-08
Jun-09
Jul-09
Aug-09
Sep-09
PL300
Base



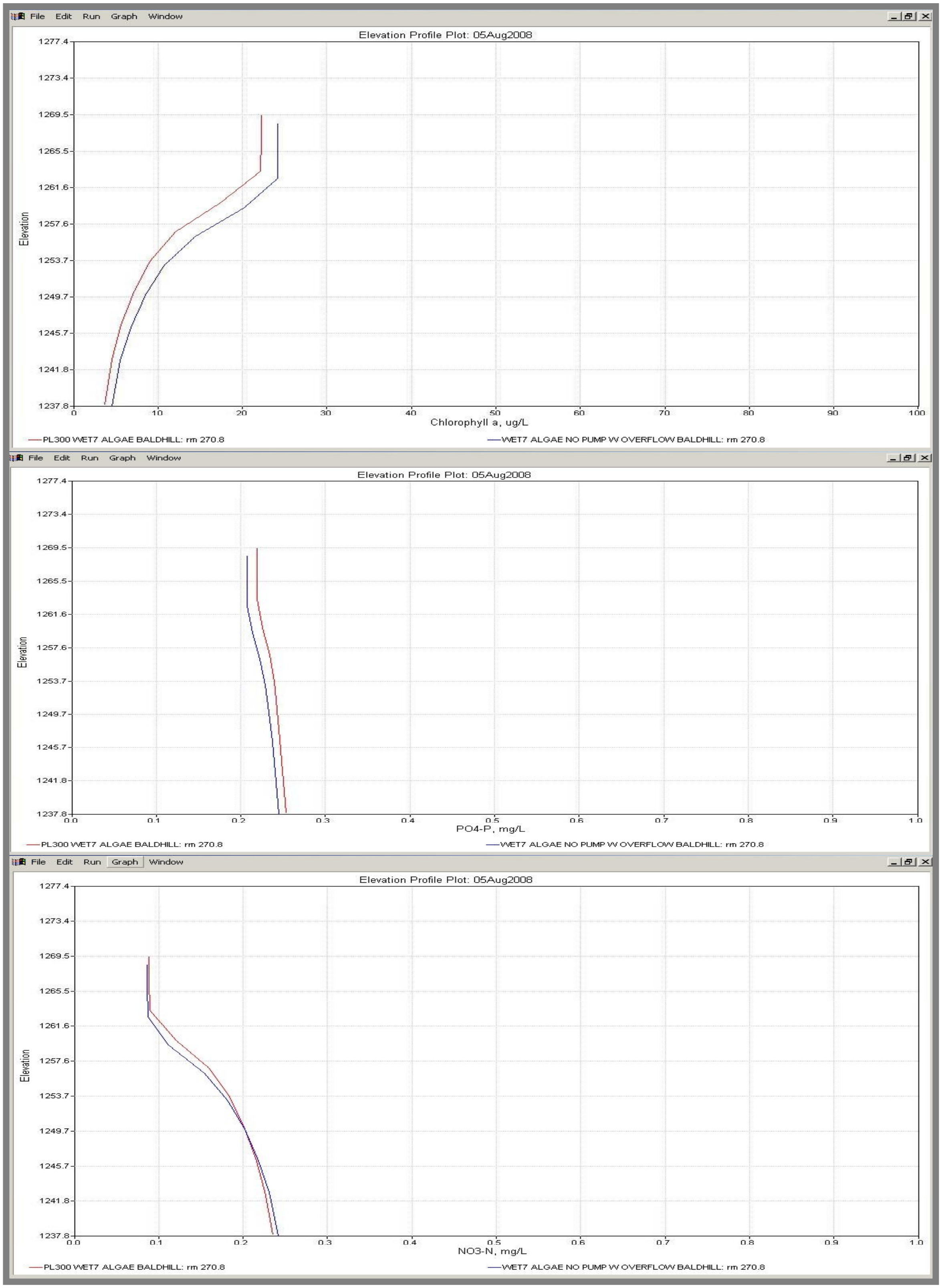
Red River at Halstad
Wet Scenario, Summer Months
NO3-N (mg/l)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Jun-06
Jul-06
Aug-06
Sep-06
May-07
Jul-07
Aug-07
Sep-07
May-08
Jun-08
Aug-08
Sep-08
May-09
Jun-09
Jul-09
Sep-09
PL300
Base

Plate 10J



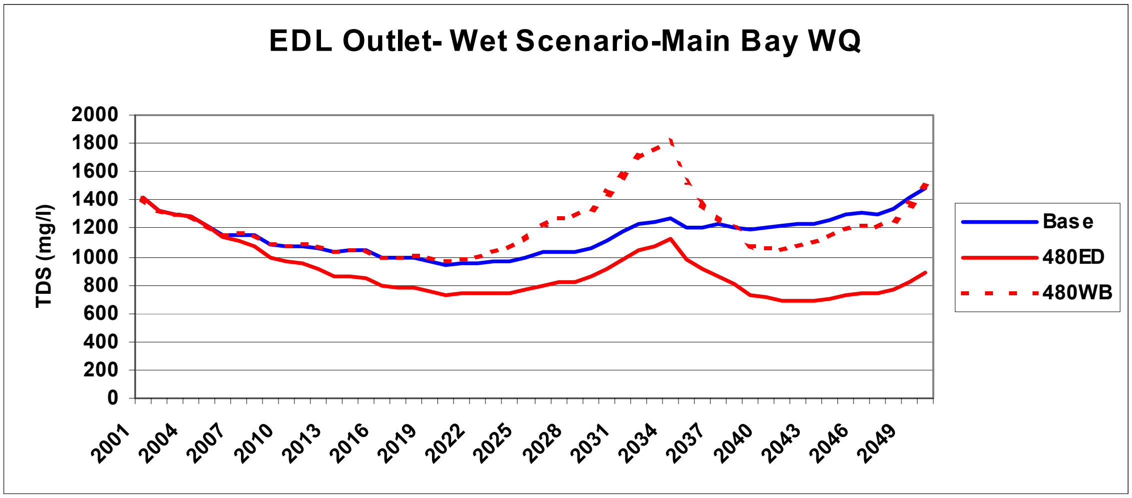
File Edit Run Graph Window
Elevation Profile Plot: 05Aug2008
Elevation
1274.2
1270.5
1266.8
1263.1
1259.4
1255.7
1252.0
1248.4
1244.7
1241.0
1237.3
0.0
3.6
7.2
10.8
14.4
18.0
21.6
25.2
28.8
32.4
36.0
Temperature, C
Elevation Profile Plot: 05Aug2008
Elevation
1274.2
1270.5
1266.8
1263.1
1259.4
1255.7
1252.0
1248.4
1244.7
1241.0
1237.3
0.0
1.8
3.6
5.4
7.2
9.0
10.8
12.6
14.4
16.2
18.0
Oxygen, mg/L
File Edit Run Graph Window
Elevation Profile Plot: 05Aug2008
Elevation
1277.4
1273.4
1269.5
1265.5
1261.6
1257.6
1253.7
1249.7
1245.7
1241.8
1237.8
6.0
6.4
6.8
7.2
7.6
8.0
8.4
8.8
9.2
9.6
10.0
pH
PL300 WET7 ALGAE BALDHILL: rm 270.8
WET7 ALGAE NO PUMP W OVERFLOW BALDHILL: rm 270.8

Plate 10K

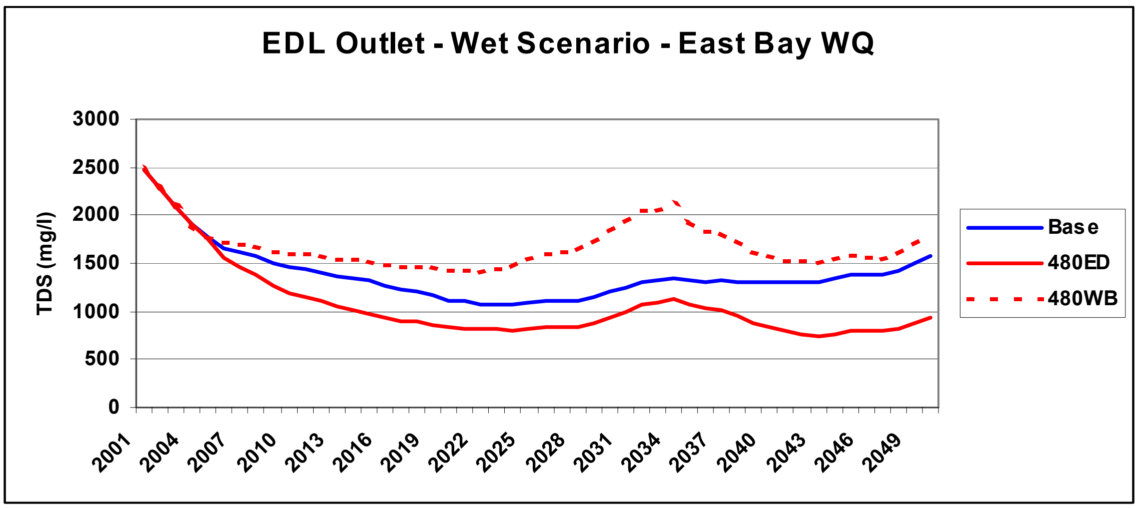


Elevation Profile Plot: 05Aug2008
Elevation
Chlorophyll a, ug/L
PL300 WET7 ALGAE BALDHILL: rm 270.8
WET7 ALGAE NO PUMP W OVERFLOW BALDHILL: rm 270.8
Elevation Profile Plot: 05Aug2008
Elevation
PO4-P, mg/L
PL300 WET7 ALGAE BALDHILL: rm 270.8
WET7 ALGAE NO PUMP W OVERFLOW BALDHILL: rm 270.8
Elevation Profile Plot: 05Aug2008
Elevation
NO3-N, mg/L
PL300 WET7 ALGAE BALDHILL: rm 270.8
WET7 ALGAE NO PUMP W OVERFLOW BALDHILL: rm 270.8

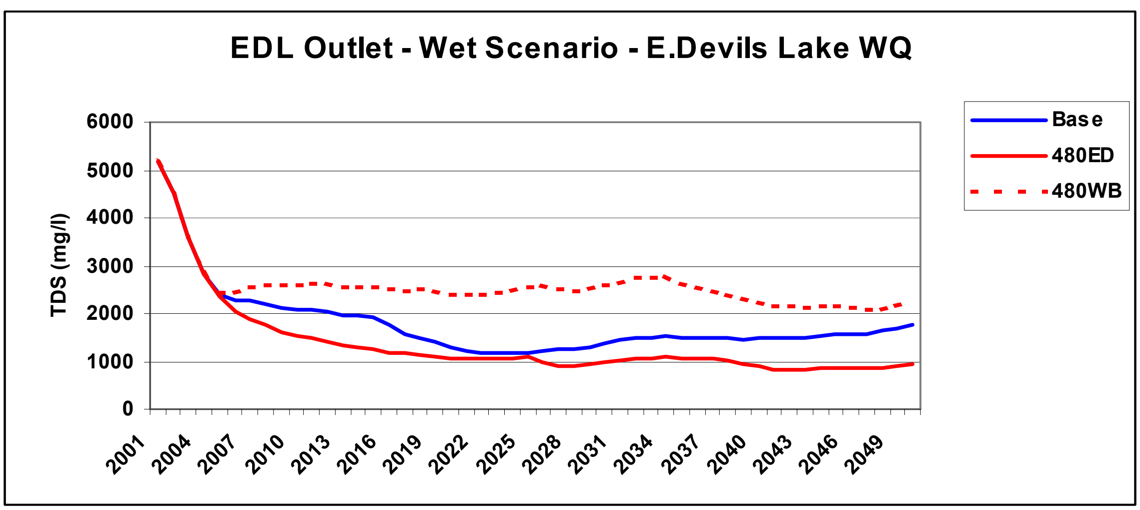
Plate 11



EDL Outlet- Wet Scenario-Main Bay WQ
TDS (mg/l)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2001
2004
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Base
480ED
480WB

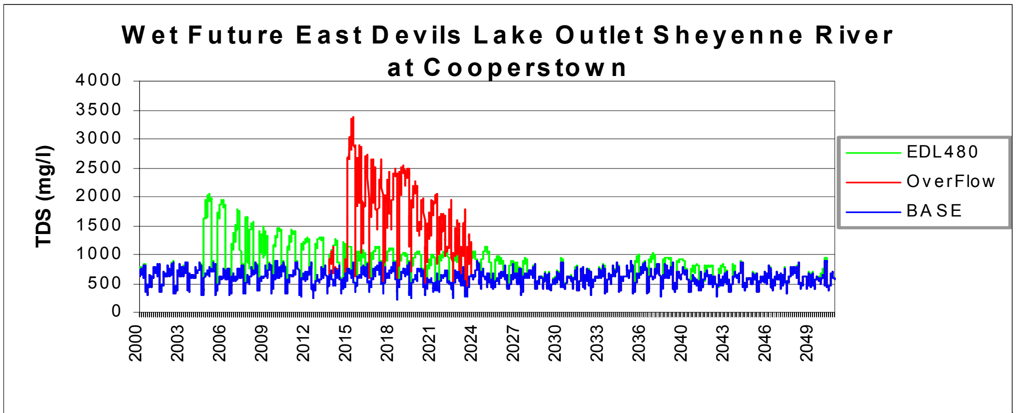


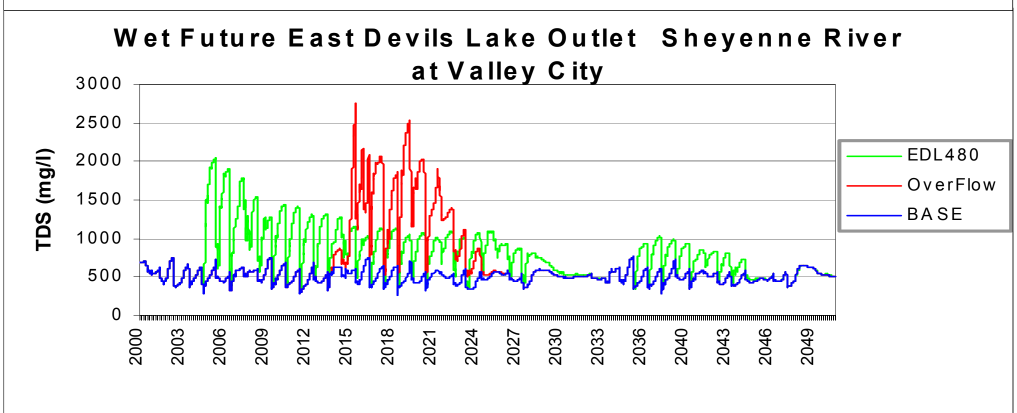
EDL Outlet - Wet Scenario - East Bay WQ
TDS (mg/l)
3000
2500
2000
1500
1000
500
0
2001
2004
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Base
480ED
480WB

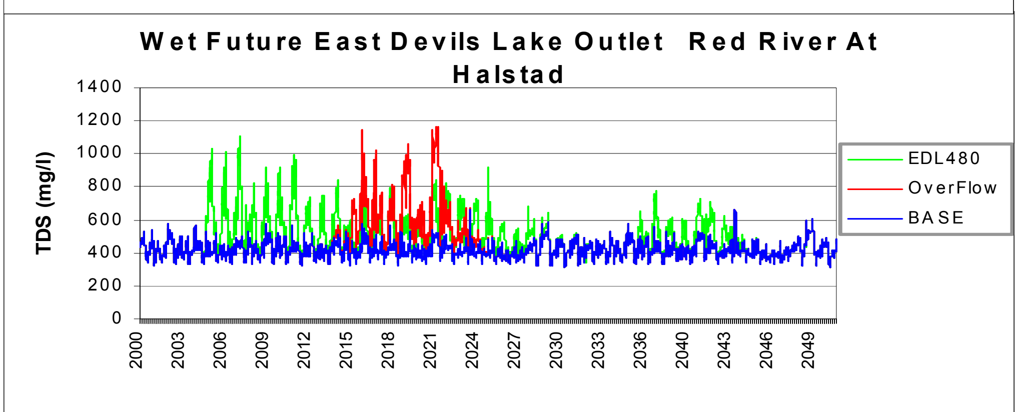


EDL Outlet - Wet Scenario - E.Devils Lake WQ
TDS (mg/l)
6000
5000
4000
3000
2000
1000
0
2001
2004
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Base
480ED
480WB

Plate 12A


Wet Future East Devils Lake Outlet Sheyenne River at Cooperstown
TDS (mg/l)
4000
3500
3000
2500
2000
1500
1000
500
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
EDL480
OverFlow
BASE


Wet Future East Devils Lake Outlet Sheyenne River at Valley City
TDS (mg/l)
3000
2500
2000
1500
1000
500
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
EDL480
OverFlow
BASE


Wet Future East Devils Lake Outlet Red River At Halstad
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
EDL480
OverFlow
BASE

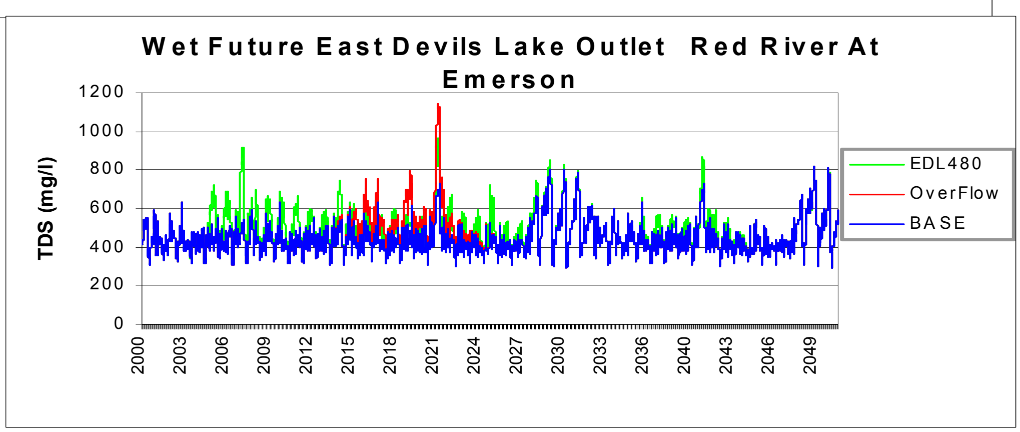
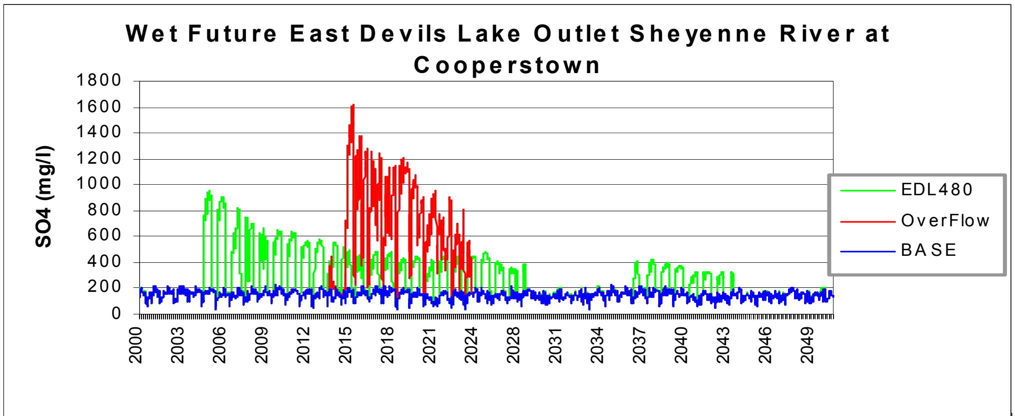
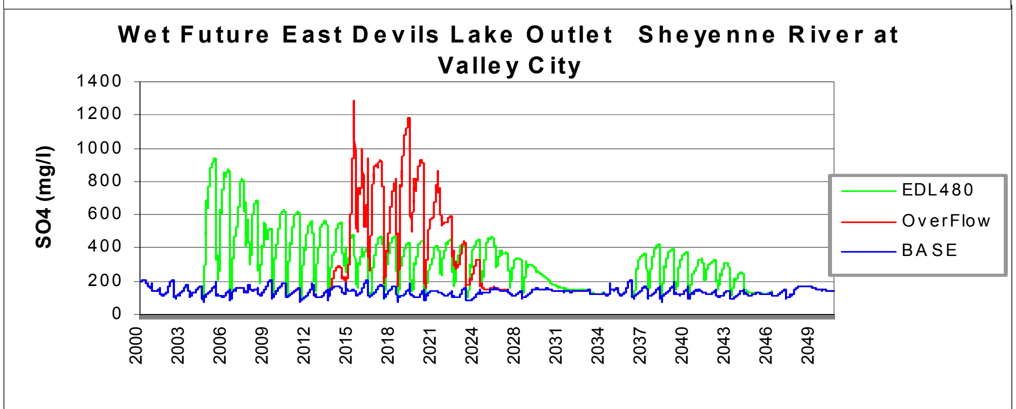
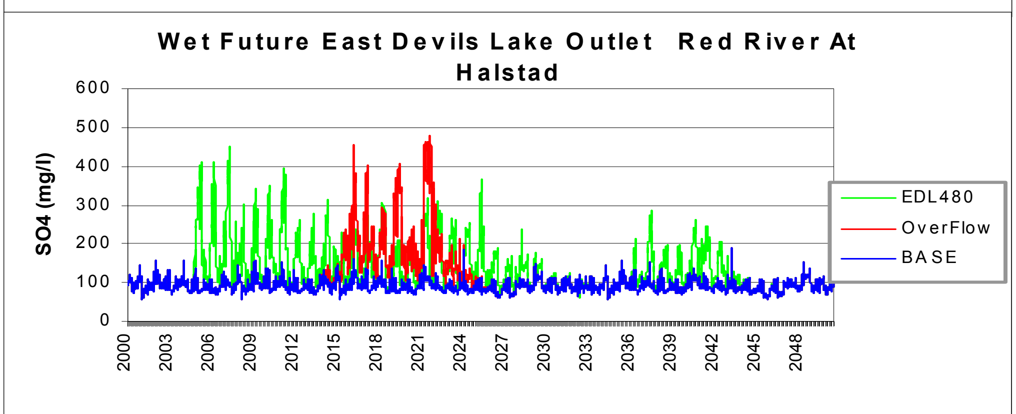

Wet Future East Devils Lake Outlet Red River At Emerson
TDS (mg/l)
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
EDL480
OverFlow
BASE

Plate 12B


Wet Future East Devils Lake Outlet Sheyenne River at Cooperstown
SO4 (mg/l)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2028
2031
2034
2037
2040
2043
2046
2049
EDL480
OverFlow
BASE


Wet Future East Devils Lake Outlet Sheyenne River at Valley City
SO4 (mg/l)
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2028
2031
2034
2037
2040
2043
2046
2049
EDL480
OverFlow
BASE


Wet Future East Devils Lake Outlet Red River At Halstad
SO4 (mg/l)
600
500
400
300
200
100
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
EDL480
OverFlow
BASE

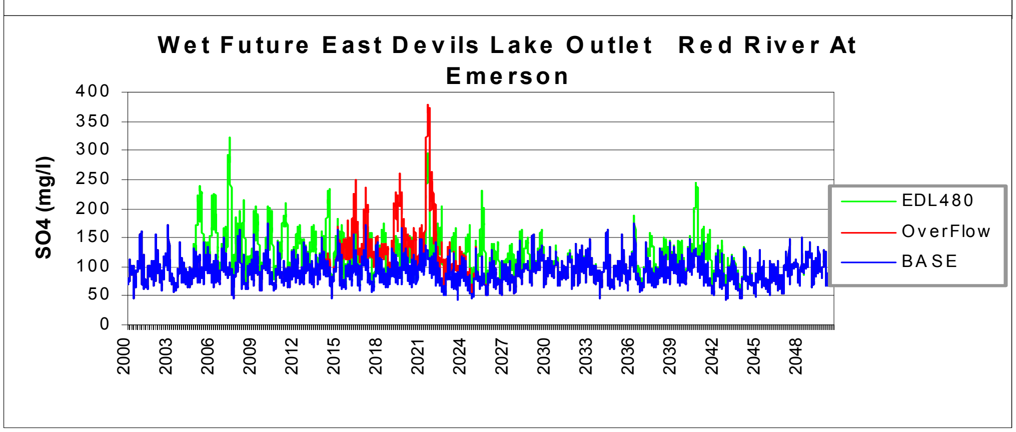

Wet Future East Devils Lake Outlet Red River At Emerson
SO4 (mg/l)
400
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
EDL480
OverFlow
BASE

Plate 12C

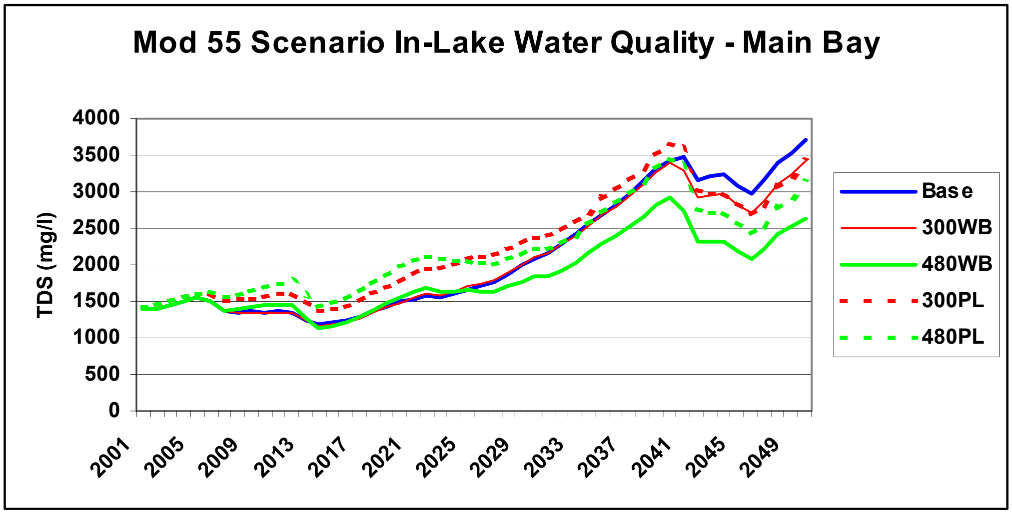
East Devils Lake Outlet Sheyenne River at Cooperstown Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	91	91	91	>100	94	94	94
>500	82	83	88	>150	62	65	86
>600	60	63	83	>200	7	11	66
>700	32	34	80	>250	0	2	64
>800	9	11	73	>300	0	1	62
>900	0	1	61	>350	0	0	59
>1000	0	0	57	>400	0	0	56
>1100	0	0	51	>450	0	0	51

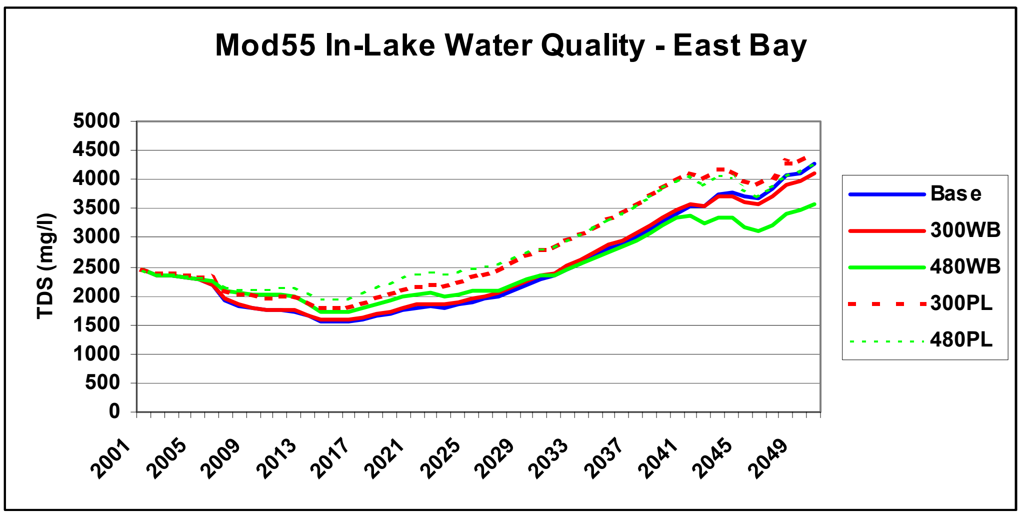
East Devils Lake Outlet Sheyenne River at Valley City Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE		EDL480	SO4	BASE		EDL480
>400	89		97	>100	94		99
>500	52		92	>150	35		93
>600	20		90	>200	1		87
>700	3		83	>250	0		84
>800	0		79	>300	0		79
>900	0		74	>350	0		74
>1000	0		64	>400	0		66
>1100	0		58	>450	0		58

East Devils Lake Outlet Red River of the North at Halstad Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE		EDL480	SO4	BASE		EDL480
>400	61		88	>100	27		86
>500	4		59	>150	0		50
>600	0		36	>200	0		32
>700	0		20	>250	0		18
>800	0		10	>300	0		9
>900	0		5	>350	0		4
>1000	0		1	>400	0		1
>1100	0		0	>450	0		0

East Devils Lake Outlet Red River of the North at Emerson Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE		EDL480	SO4	BASE		EDL480
>400	74		87	>100	33		79
>500	8		48	>150	1		33
>600	0		18	>200	0		9
>700	0		4	>250	0		2
>800	0		2	>300	0		1
>900	0		0	>350	0		0
>1000	0		0	>400	0		0
>1100	0		0	>450	0		0

Plate 16


Mod 55 Scenario In-Lake Water Quality - Main Bay
TDS (mg/l)
4000
3500
3000
2500
2000
1500
1000
500
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300PL
480PL


Mod55 In-Lake Water Quality - East Bay
TDS (mg/l)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300PL
480PL

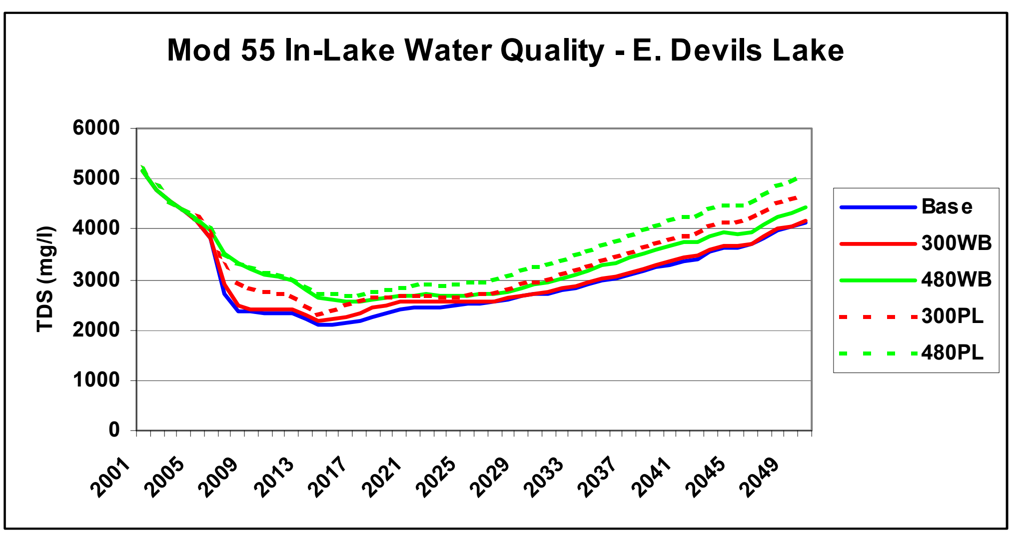

Mod 55 In-Lake Water Quality - E. Devils Lake
TDS (mg/l)
6000
5000
4000
3000
2000
1000
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300PL
480PL

Plate 17A

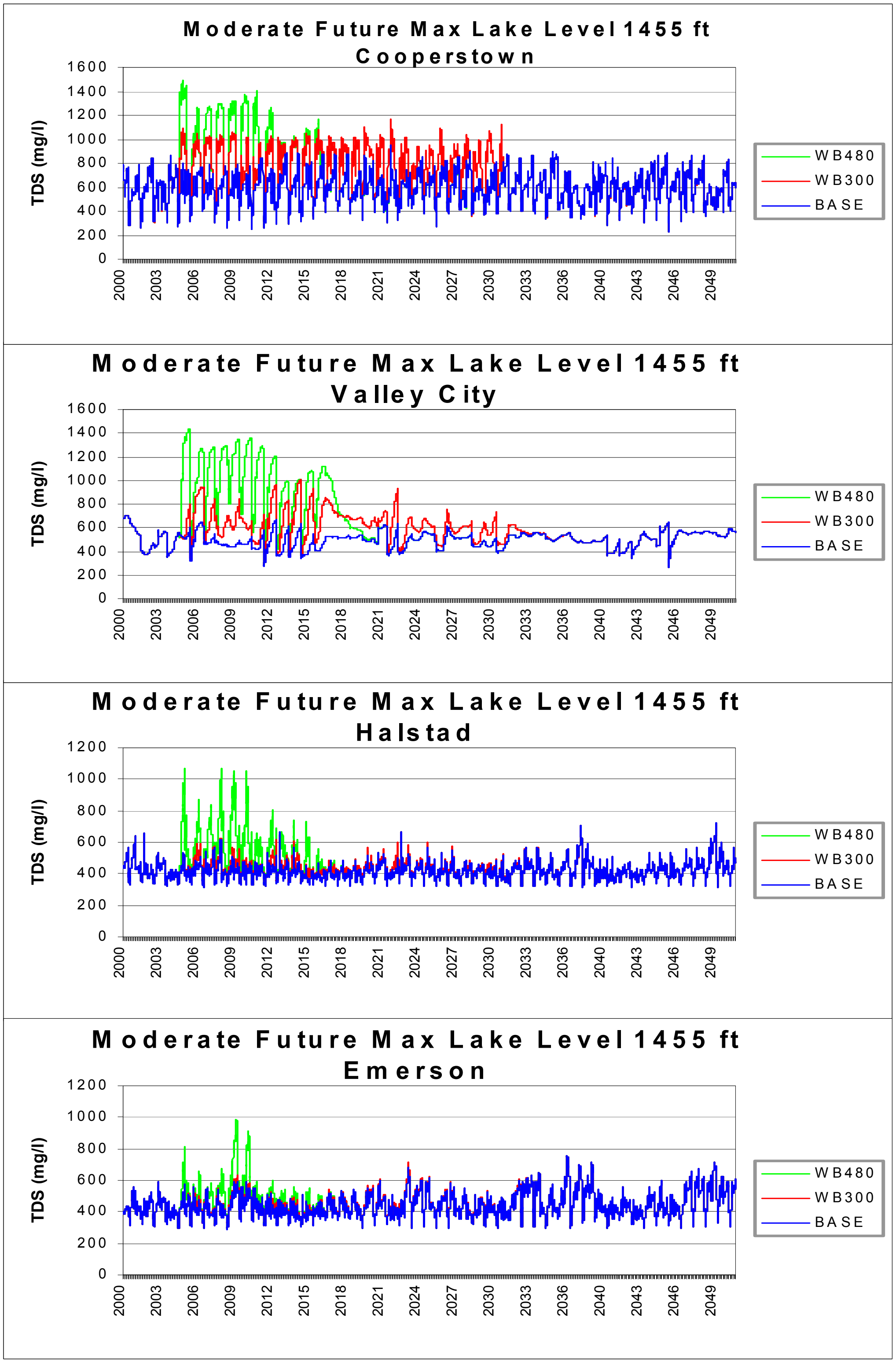
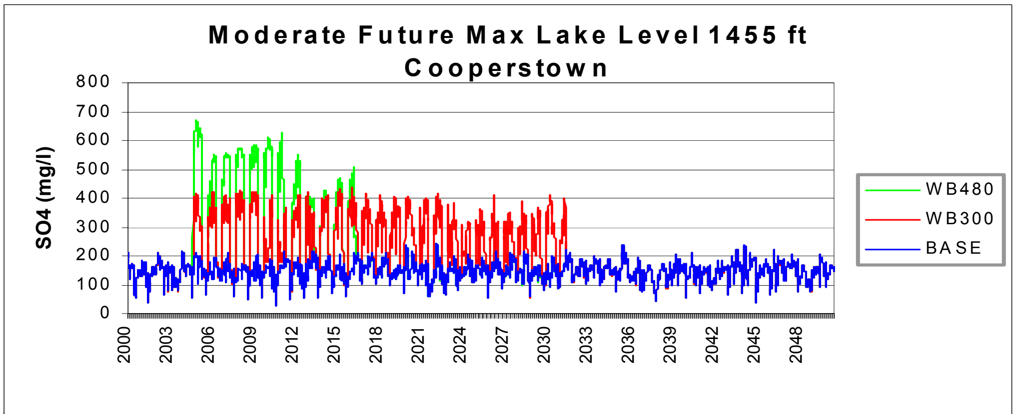
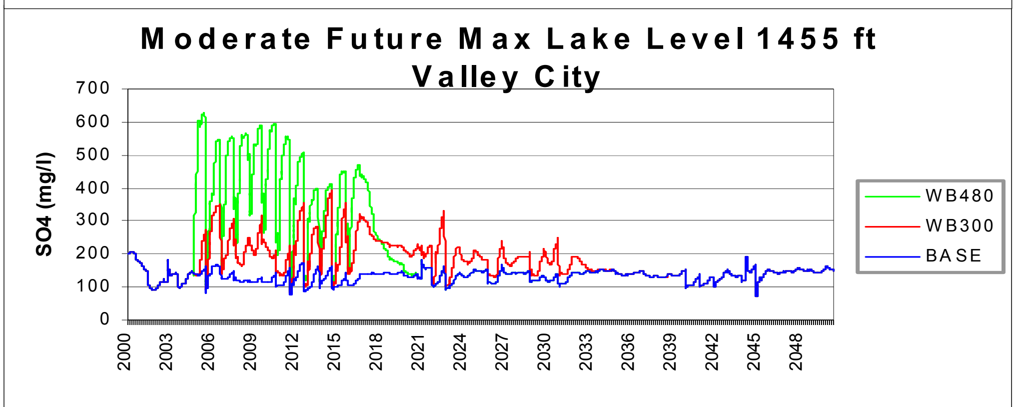
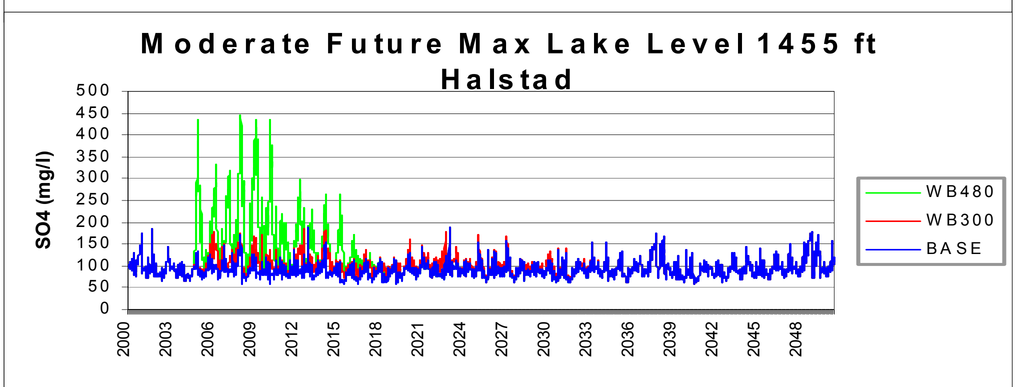

Moderate Future Max Lake Level 1455 ft
Cooperstown
TDS (mg/l)
0
200
400
600
800
1000
1200
1400
1600
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE
Moderate Future Max Lake Level 1455 ft
Valley City
TDS (mg/l)
0
200
400
600
800
1000
1200
1400
1600
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE
Moderate Future Max Lake Level 1455 ft
Halstad
TDS (mg/l)
0
200
400
600
800
1000
1200
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE
Moderate Future Max Lake Level 1455 ft
Emerson
TDS (mg/l)
0
200
400
600
800
1000
1200
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE

Plate 17B


Moderate Future Max Lake Level 1455 ft
Cooperstown
SO4 (mg/l)
800
700
600
500
400
300
200
100
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
WB480
WB300
BASE


Moderate Future Max Lake Level 1455 ft
Valley City
SO4 (mg/l)
700
600
500
400
300
200
100
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
WB480
WB300
BASE


Moderate Future Max Lake Level 1455 ft
Halstad
SO4 (mg/l)
500
450
400
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
WB480
WB300
BASE

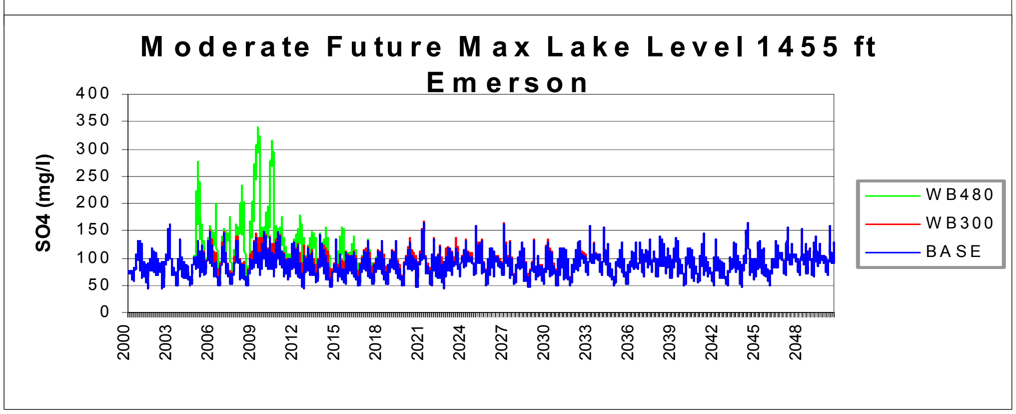

Moderate Future Max Lake Level 1455 ft
Emerson
SO4 (mg/l)
400
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
WB480
WB300
BASE

Plate 17C

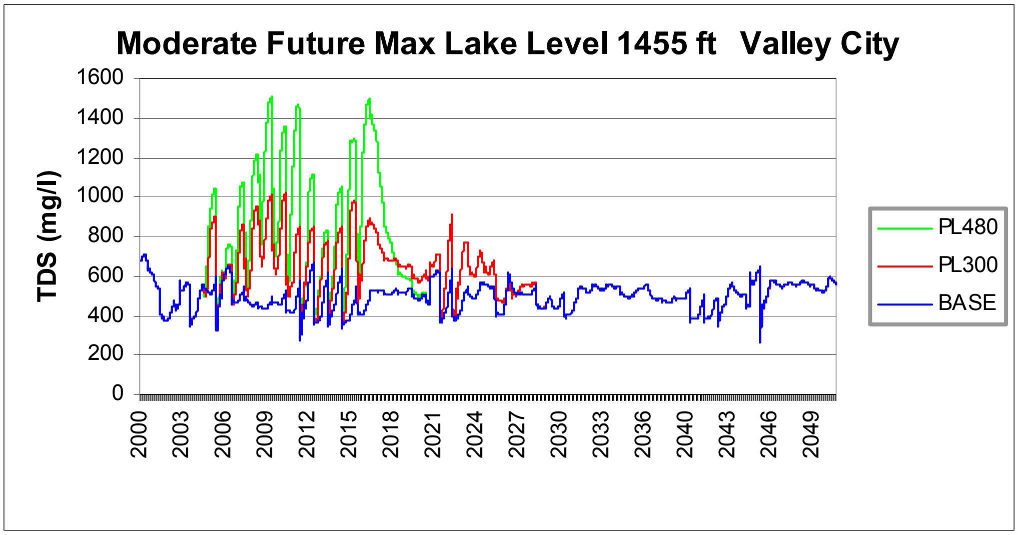
Moderate Future Max Lake Level 1455 ft at Cooperstown Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	93	93	93	>100	92	92	93
>500	79	84	85	>150	52	77	78
>600	54	78	80	>200	4	60	63
>700	24	71	76	>250	0	54	61
>800	3	54	62	>300	0	47	58
>900	0	40	55	>350	0	30	54
>1000	0	10	43	>400	0	6	44
>1100	0	0	38	>450	0	0	38

Moderate Future Max Lake Level 1455 ft at Valley City Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	90	95	98	>100	93	99	99
>500	34	84	94	>150	14	76	90
>600	8	56	87	>200	0	54	87
>700	0	29	82	>250	0	27	83
>800	0	17	75	>300	0	12	76
>900	0	7	67	>350	0	1	68
>1000	0	0	50	>400	0	0	52
>1100	0	0	43	>450	0	0	44

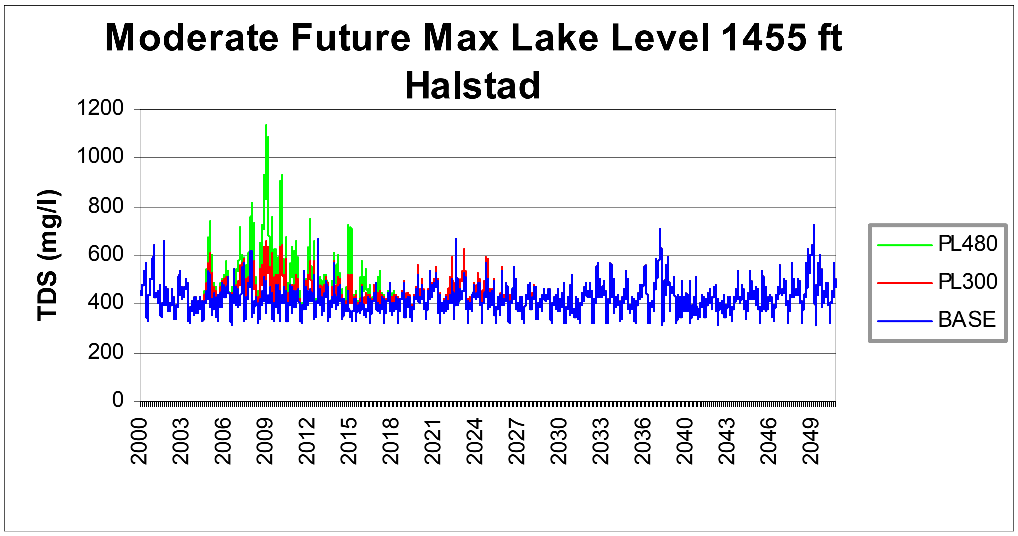
Moderate Future Max Lake Level 1455 ft at Halstad Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	64	77	87	>100	25	50	83
>500	4	14	63	>150	1	4	52
>600	1	1	33	>200	0	0	29
>700	0	0	19	>250	0	0	18
>800	0	0	9	>300	0	0	9
>900	0	0	4	>350	0	0	4
>1000	0	0	1	>400	0	0	1
>1100	0	0	0	>450	0	0	0

Moderate Future Max Lake Level 1455 ft at Emerson Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	62	70	83	>100	28	39	73
>500	11	14	40	>150	0	0	23
>600	0	1	14	>200	0	0	9
>700	0	0	7	>250	0	0	5
>800	0	0	4	>300	0	0	2
>900	0	0	1	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

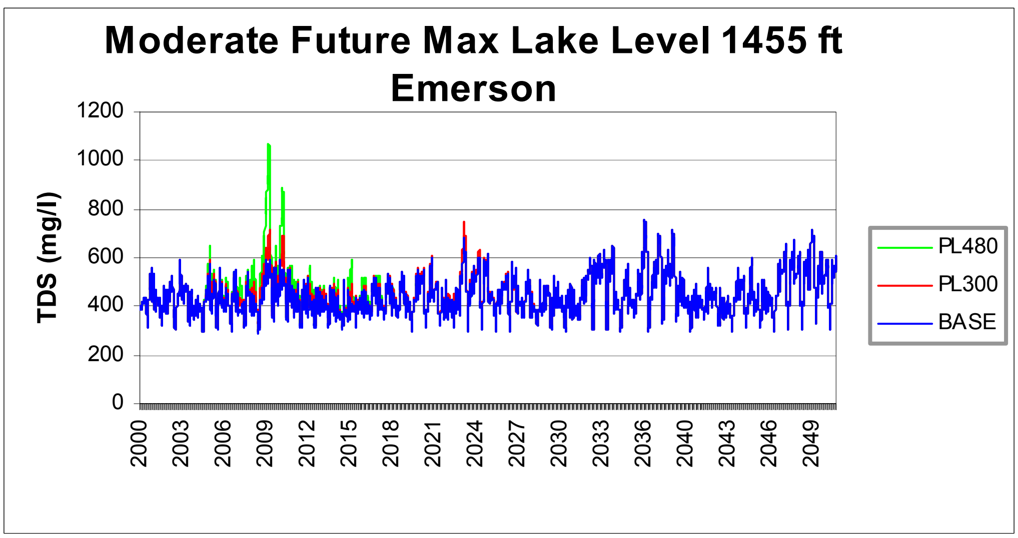
Plate 19A



Moderate Future Max Lake Level 1455 ft Valley City
TDS (mg/l)
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE

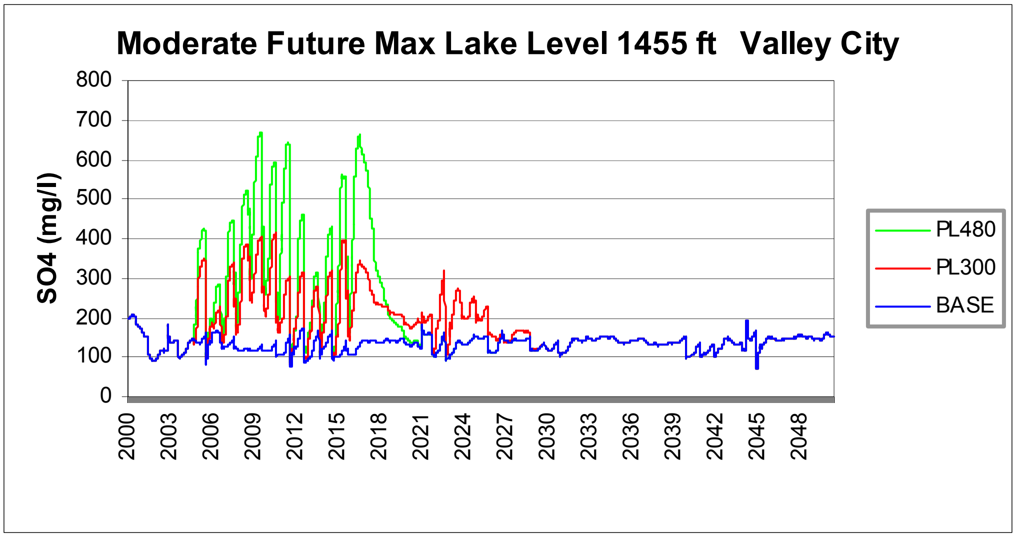


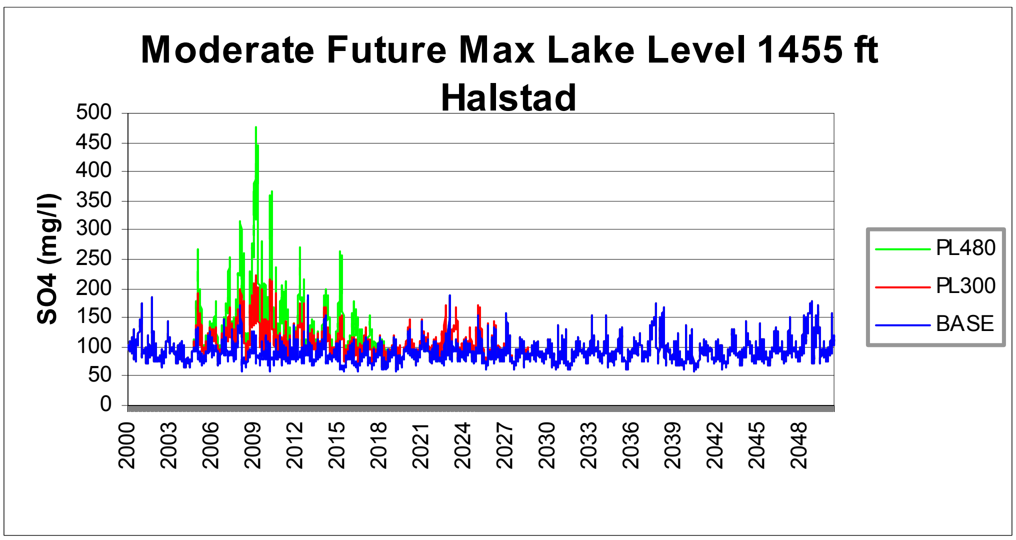
Moderate Future Max Lake Level 1455 ft
Halstad
TDS (mg/l)
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE



Moderate Future Max Lake Level 1455 ft
Emerson
TDS (mg/l)
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE

Plate 19B


Moderate Future Max Lake Level 1455 ft Valley City
SO4 (mg/l)
800
700
600
500
400
300
200
100
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL480
PL300
BASE


Moderate Future Max Lake Level 1455 ft
Halstad
SO4 (mg/l)
500
450
400
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL480
PL300
BASE

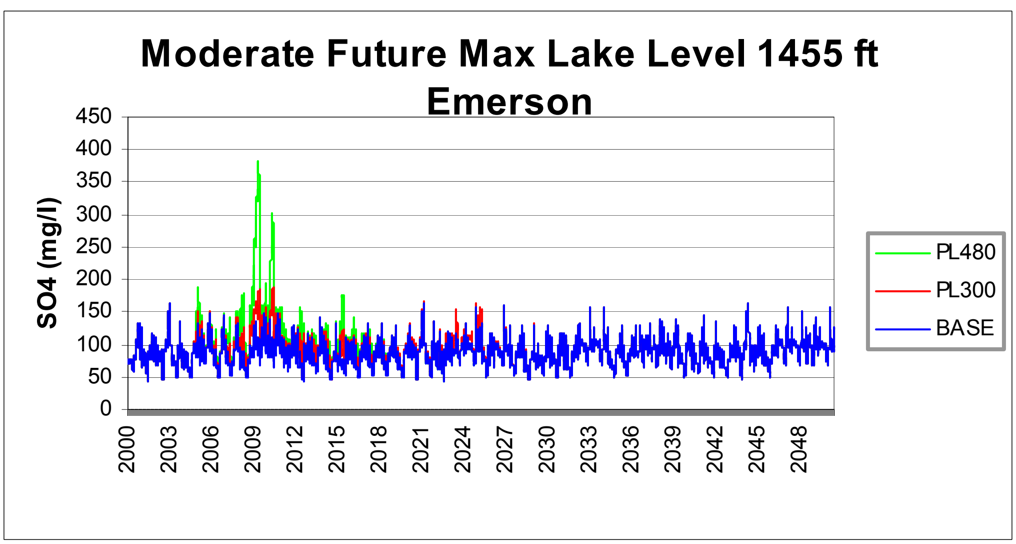

Moderate Future Max Lake Level 1455 ft
Emerson
SO4 (mg/l)
450
400
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL480
PL300
BASE

Plate 19C

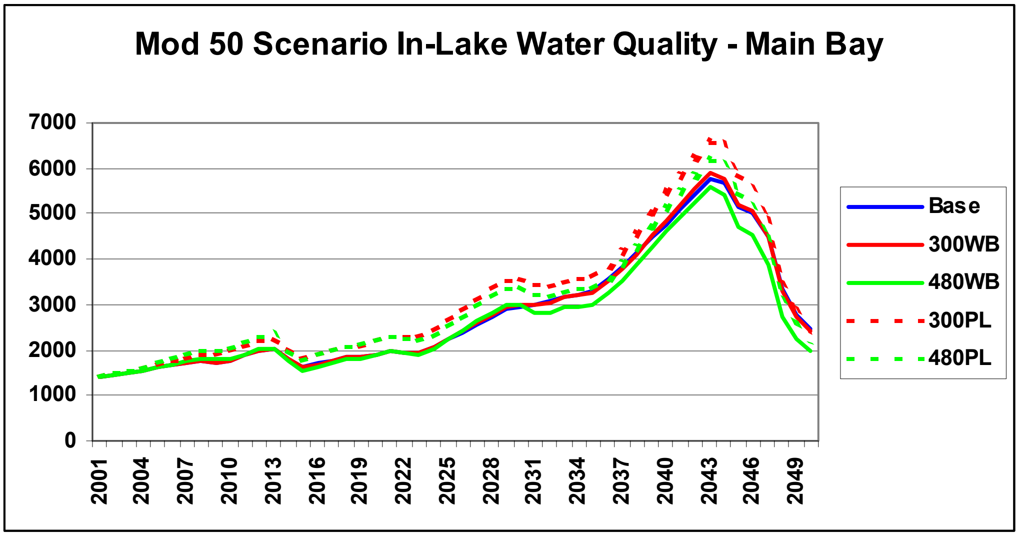
Moderate Future Max Lake Level 1455 ft at Cooperstown Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	93	93	93	>100	92	93	93
>500	79	83	84	>150	52	77	78
>600	54	74	73	>200	4	55	54
>700	24	56	62	>250	0	42	46
>800	3	34	42	>300	0	31	40
>900	0	17	32	>350	0	18	32
>1000	0	6	25	>400	0	7	28
>1100	0	0	17	>450	0	0	18

Moderate Future Max Lake Level 1455 ft at Valley City Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	90	94	97	>100	93	98	99
>500	34	86	90	>150	14	82	86
>600	8	61	74	>200	0	60	72
>700	0	42	62	>250	0	43	63
>800	0	27	49	>300	0	26	51
>900	0	10	41	>350	0	11	42
>1000	0	1	33	>400	0	2	36
>1100	0	0	21	>450	0	0	22

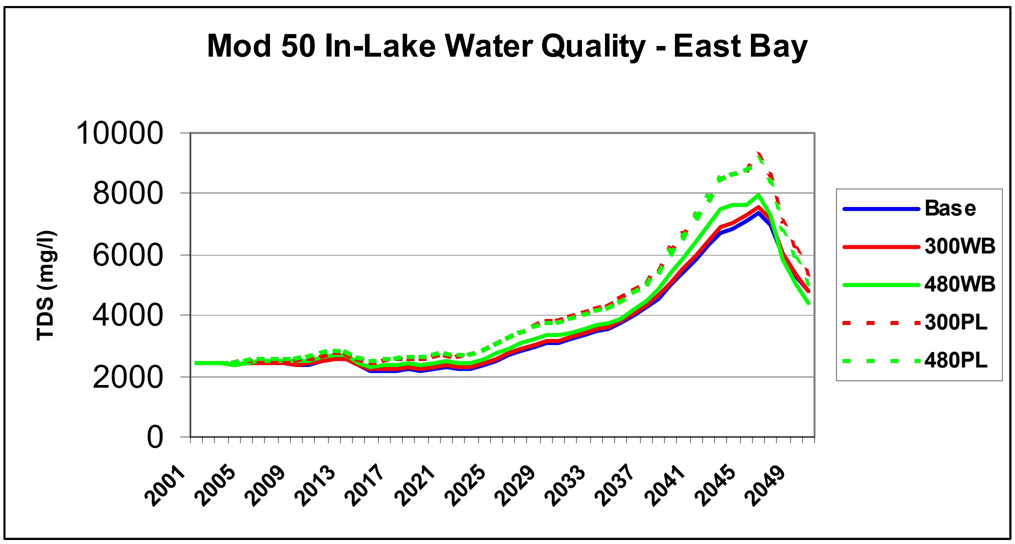
Moderate Future Max Lake Level 1455 ft at Halstad Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	64	82	85	>100	25	69	79
>500	4	23	48	>150	1	14	36
>600	1	2	18	>200	0	1	16
>700	0	0	8	>250	0	0	8
>800	0	0	4	>300	0	0	5
>900	0	0	2	>350	0	0	2
>1000	0	0	1	>400	0	0	1
>1100	0	0	0	>450	0	0	0

Moderate Future Max Lake Level 1455 ft at Emerson Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	62	77	81	>100	28	49	65
>500	11	16	28	>150	0	5	14
>600	0	5	9	>200	0	0	6
>700	0	0	6	>250	0	0	4
>800	0	0	4	>300	0	0	2
>900	0	0	2	>350	0	0	1
>1000	0	0	1	>400	0	0	0
>1100	0	0	0	>450	0	0	0

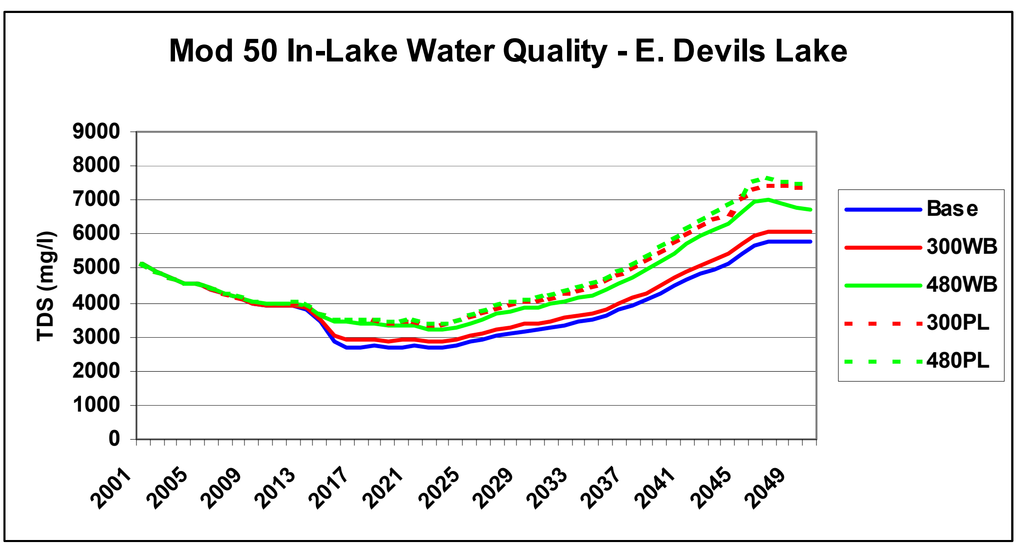
Plate 23



Mod 50 Scenario In-Lake Water Quality - Main Bay
7000
6000
5000
4000
3000
2000
1000
0
2001
2004
2007
2010
2013
2016
2019
2022
2025
2028
2031
2034
2037
2040
2043
2046
2049
Base
300WB
480WB
300PL
480PL

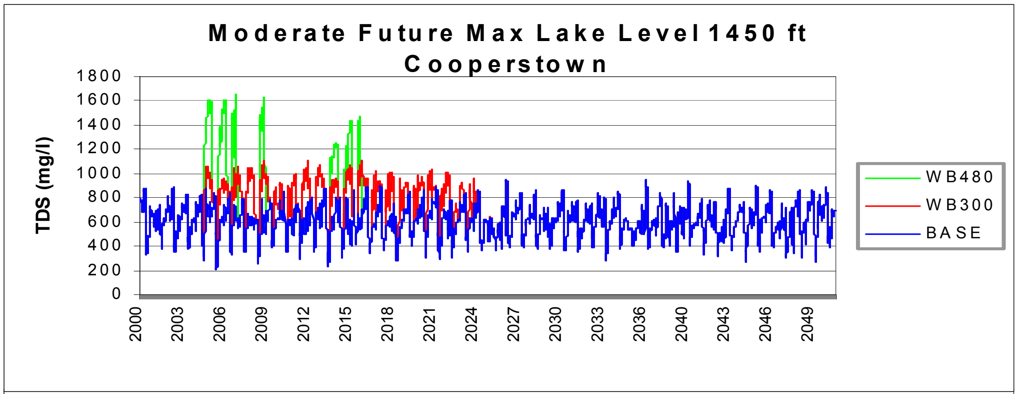


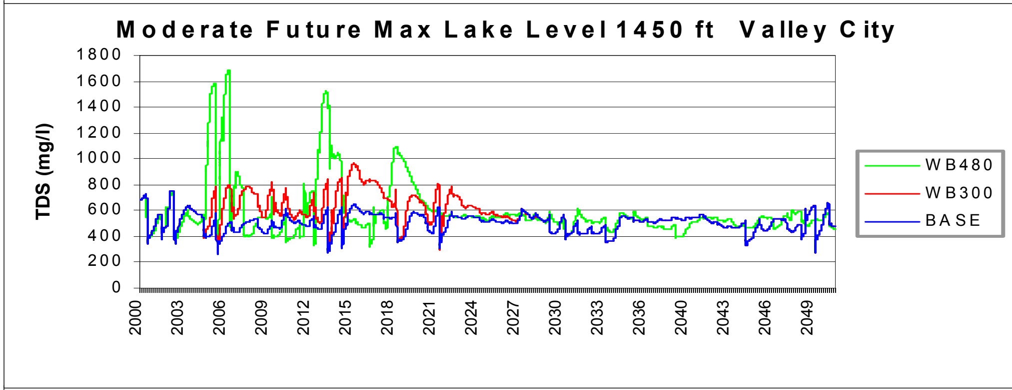
Mod 50 In-Lake Water Quality - East Bay
TDS (mg/l)
10000
8000
6000
4000
2000
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300PL
480PL

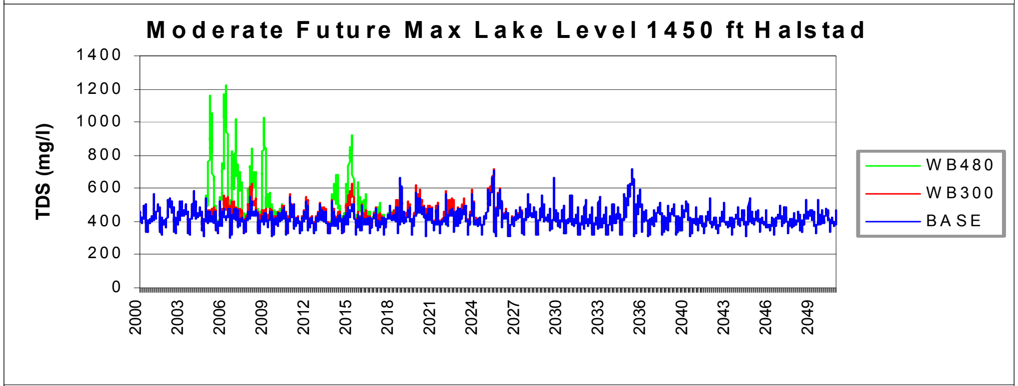


Mod 50 In-Lake Water Quality - E. Devils Lake
TDS (mg/l)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300PL
480PL

Plate 22A


Moderate Future Max Lake Level 1450 ft
Cooperstown
TDS (mg/l)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE


Moderate Future Max Lake Level 1450 ft Valley City
TDS (mg/l)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE


Moderate Future Max Lake Level 1450 ft Halstad
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE

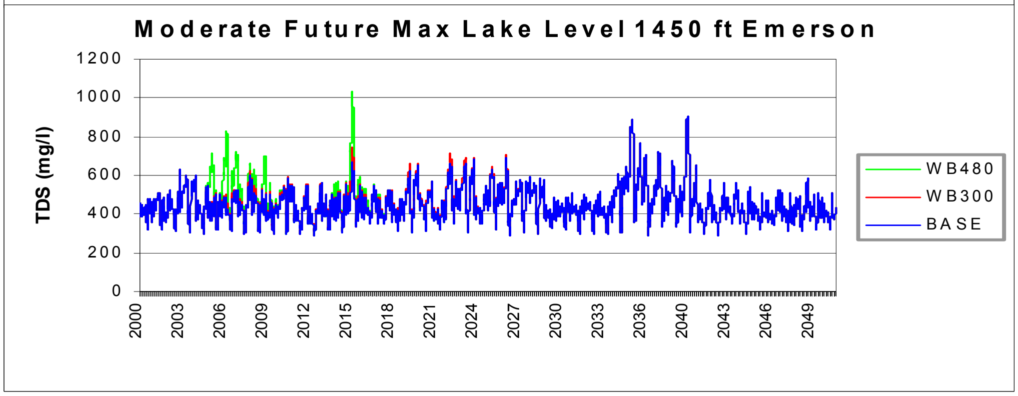
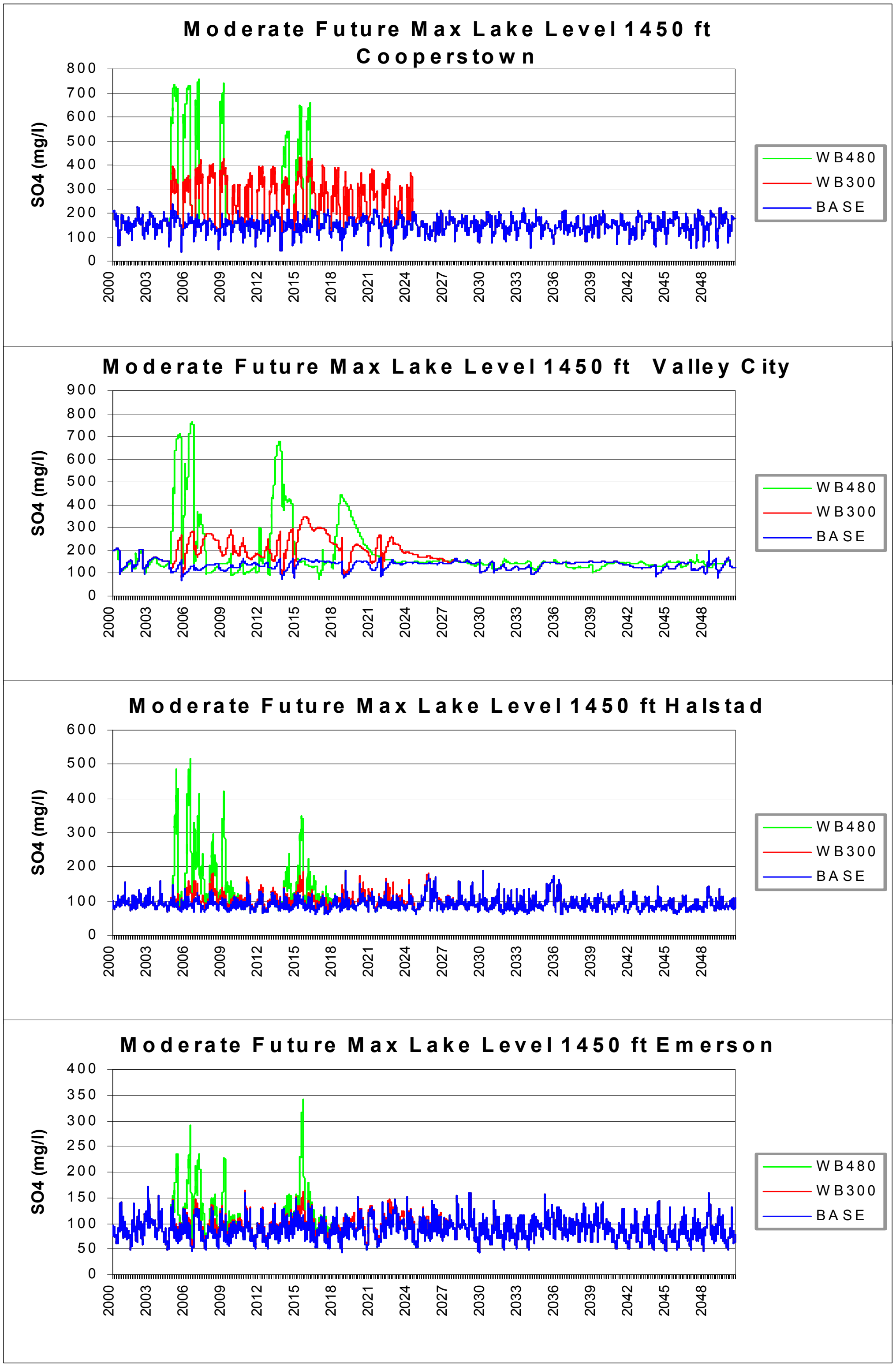

Moderate Future Max Lake Level 1450 ft Emerson
TDS (mg/l)
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE

Plate 22B



Moderate Future Max Lake Level 1450 ft Cooperstown
SO4 (mg/l)
0 100 200 300 400 500 600 700 800
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030 2033 2036 2039 2042 2045 2048
WB480
WB300
BASE
Moderate Future Max Lake Level 1450 ft Valley City
SO4 (mg/l)
0 100 200 300 400 500 600 700 800 900
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030 2033 2036 2039 2042 2045 2048
WB480
WB300
BASE
Moderate Future Max Lake Level 1450 ft Halstad
SO4 (mg/l)
0 100 200 300 400 500 600
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030 2033 2036 2039 2042 2045 2048
WB480
WB300
BASE
Moderate Future Max Lake Level 1450 ft Emerson
SO4 (mg/l)
0 50 100 150 200 250 300 350 400
2000 2003 2006 2009 2012 2015 2018 2021 2024 2027 2030 2033 2036 2039 2042 2045 2048
WB480
WB300
BASE

Plate 22C

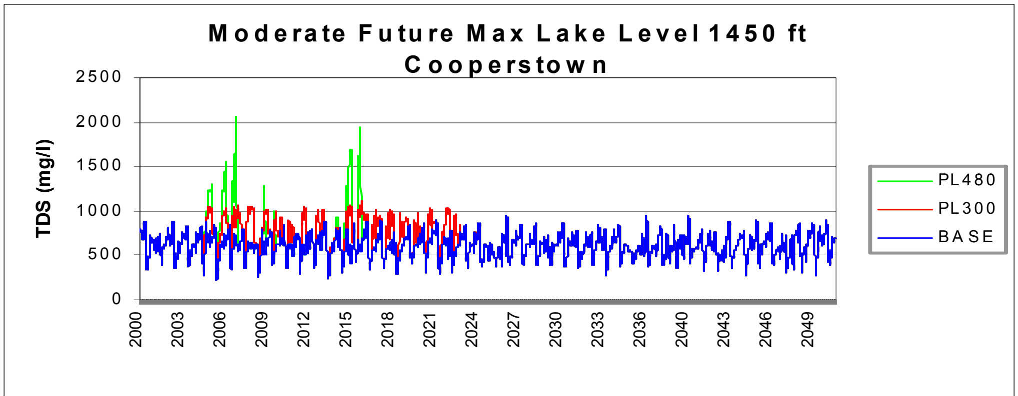
Moderate Future Max Lake Level 1450 ft at Cooperstown Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	93	93	93	>100	94	94	94
>500	83	88	87	>150	57	83	70
>600	60	82	70	>200	4	63	29
>700	26	75	45	>250	0	57	27
>800	5	60	32	>300	0	44	26
>900	0	36	26	>350	0	17	25
>1000	0	9	24	>400	0	2	24
>1100	0	0	22	>450	0	0	22

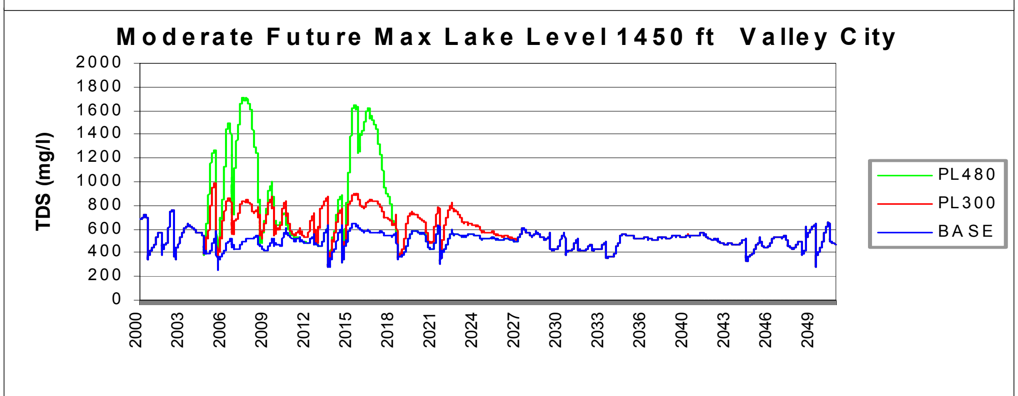
Moderate Future Max Lake Level 1450 ft at Valley City Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	89	96	90	>100	95	98	95
>500	39	89	65	>150	8	90	50
>600	1	50	45	>200	0	48	43
>700	0	31	41	>250	0	23	38
>800	0	2	35	>300	0	0	35
>900	0	0	30	>350	0	0	32
>1000	0	0	28	>400	0	0	28
>1100	0	0	20	>450	0	0	21

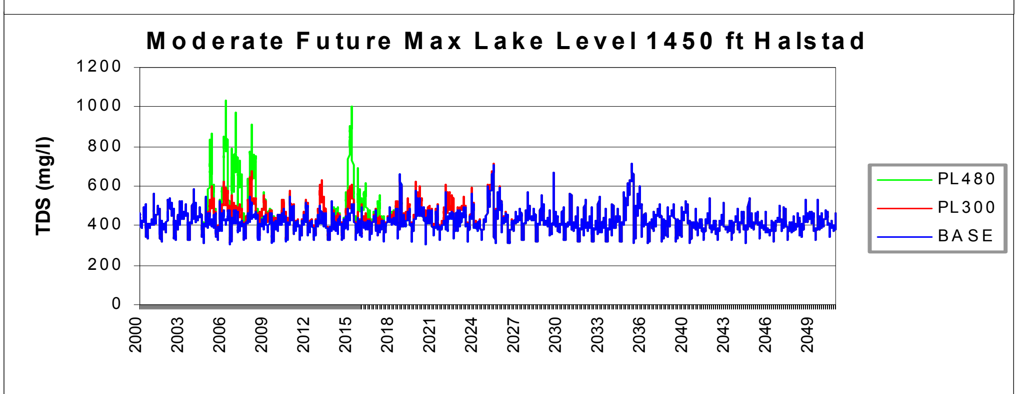
Moderate Future Max Lake Level 1450 ft at Halstad Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	63	74	78	>100	21	44	57
>500	2	9	35	>150	0	2	30
>600	0	0	21	>200	0	0	18
>700	0	0	12	>250	0	0	11
>800	0	0	9	>300	0	0	8
>900	0	0	6	>350	0	0	5
>1000	0	0	3	>400	0	0	3
>1100	0	0	1	>450	0	0	1

Moderate Future Max Lake Level 1450 ft at Emerson Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	65	70	74	>100	19	27	48
>500	9	13	34	>150	0	0	15
>600	0	1	11	>200	0	0	7
>700	0	0	2	>250	0	0	1
>800	0	0	0	>300	0	0	0
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Plate 24A


Moderate Future Max Lake Level 1450 ft
Cooperstown
TDS (mg/l)
0
500
1000
1500
2000
2500
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE


Moderate Future Max Lake Level 1450 ft Valley City
TDS (mg/l)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE


Moderate Future Max Lake Level 1450 ft Halstad
TDS (mg/l)
0
200
400
600
800
1000
1200
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE

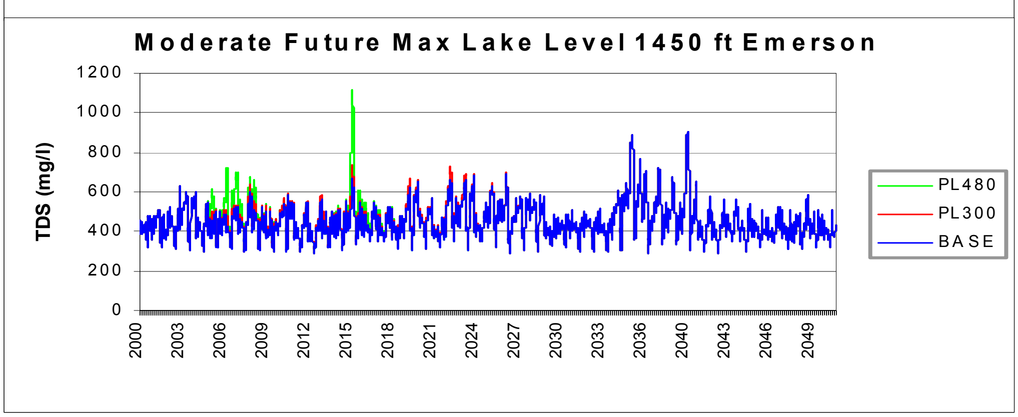
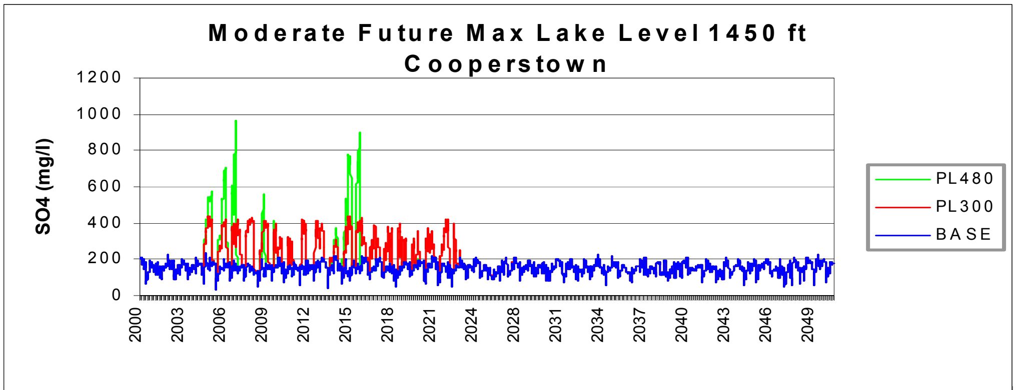
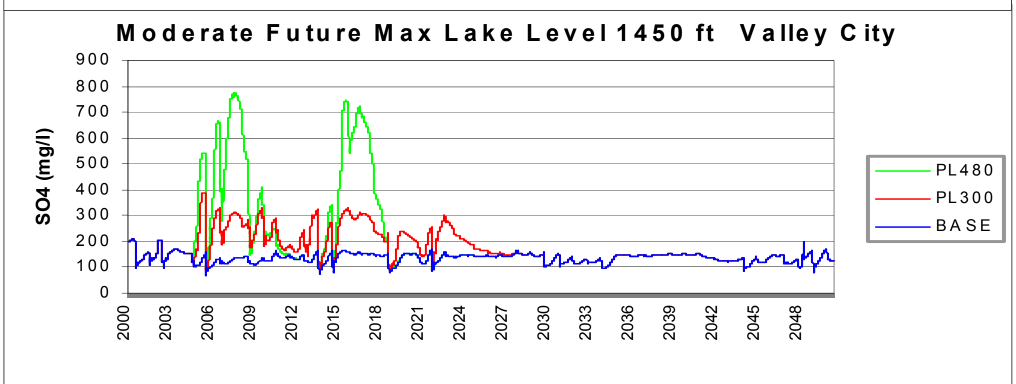
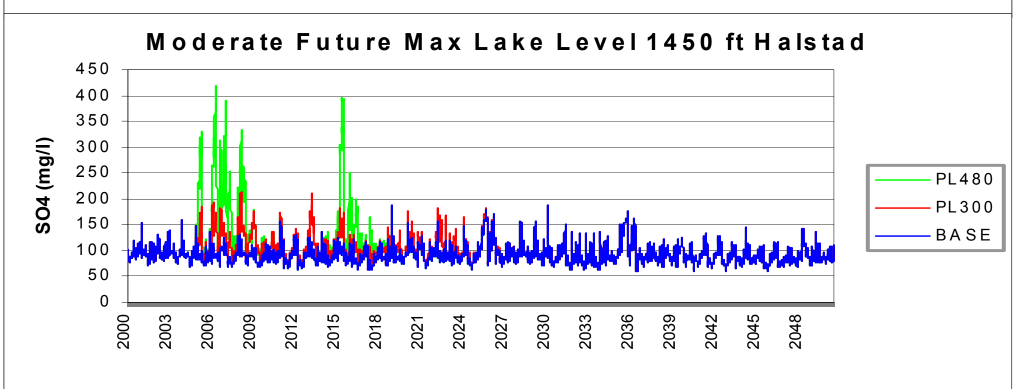

Moderate Future Max Lake Level 1450 ft Emerson
TDS (mg/l)
0
200
400
600
800
1000
1200
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE

Plate 24B


Moderate Future Max Lake Level 1450 ft
Cooperstown
SO4 (mg/l)
0
200
400
600
800
1000
1200
2000
2003
2006
2009
2012
2015
2018
2021
2024
2028
2031
2034
2037
2040
2043
2046
2049
PL480
PL300
BASE


Moderate Future Max Lake Level 1450 ft Valley City
SO4 (mg/l)
0
100
200
300
400
500
600
700
800
900
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL480
PL300
BASE


Moderate Future Max Lake Level 1450 ft Halstad
SO4 (mg/l)
0
50
100
150
200
250
300
350
400
450
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL480
PL300
BASE

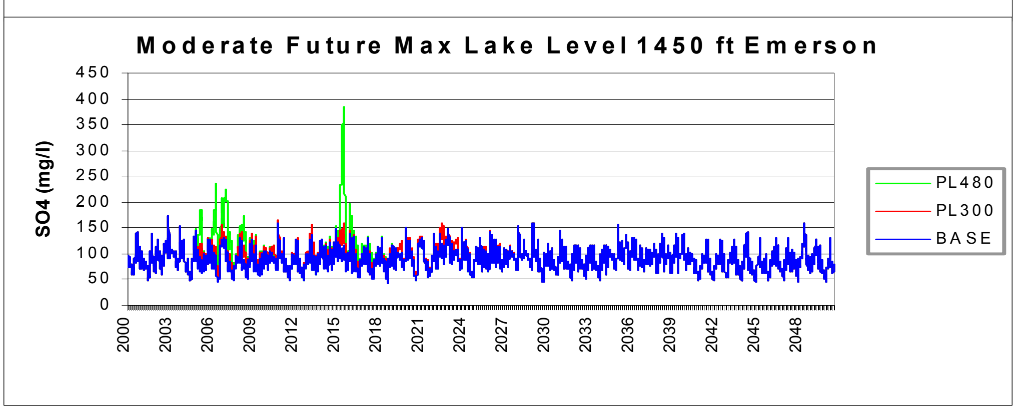

Moderate Future Max Lake Level 1450 ft Emerson
SO4 (mg/l)
0
50
100
150
200
250
300
350
400
450
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL480
PL300
BASE

Plate 24C

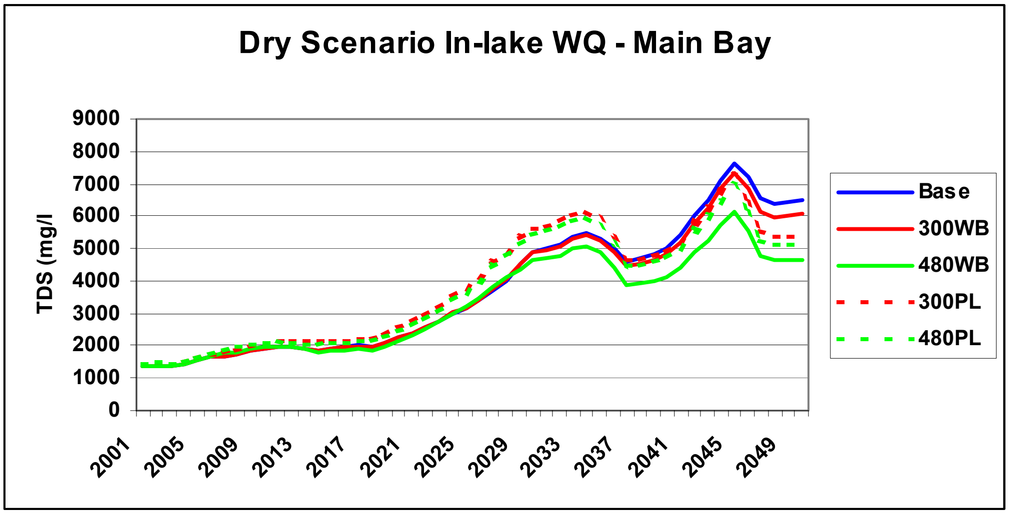
Moderate Future Max Lake Level 1450 ft at Cooperstown Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	93	93	93	>100	94	94	94
>500	83	87	86	>150	57	80	70
>600	60	79	66	>200	4	55	26
>700	26	66	40	>250	0	47	22
>800	5	46	24	>300	0	36	19
>900	0	29	15	>350	0	26	14
>1000	0	11	13	>400	0	8	13
>1100	0	0	11	>450	0	0	12

Moderate Future Max Lake Level 1450 ft at Valley City Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	89	96	97	>100	95	98	98
>500	39	91	81	>150	8	91	75
>600	1	61	57	>200	0	62	55
>700	0	43	44	>250	0	41	43
>800	0	23	37	>300	0	20	38
>900	0	3	32	>350	0	3	33
>1000	0	0	28	>400	0	0	28
>1100	0	0	26	>450	0	0	27

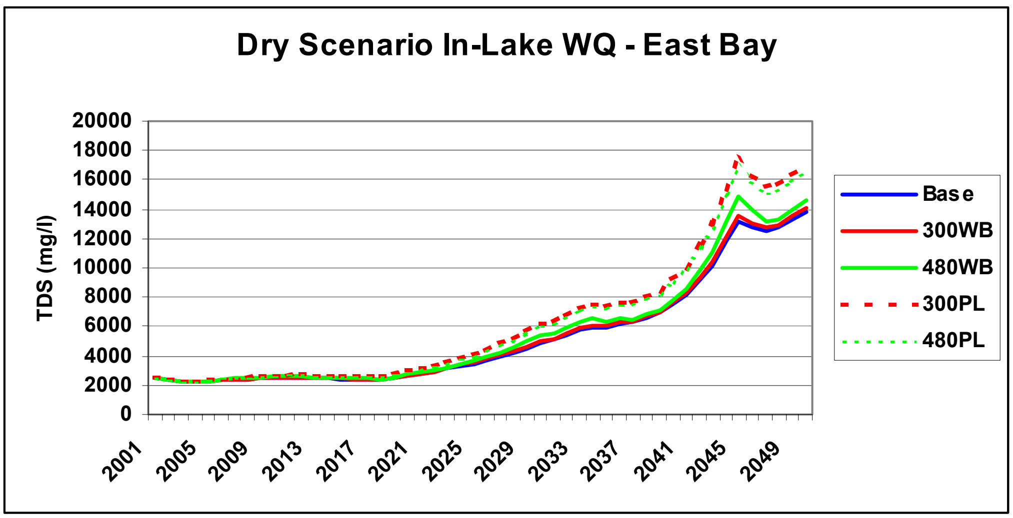
Moderate Future Max Lake Level 1450 ft at Halstad Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	63	76	76	>100	21	54	53
>500	2	18	26	>150	0	10	21
>600	0	2	16	>200	0	0	15
>700	0	0	9	>250	0	0	7
>800	0	0	4	>300	0	0	3
>900	0	0	1	>350	0	0	1
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Moderate Future Max Lake Level 1450 ft at Emerson Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	PL300	PL480	SO4	BASE	PL300	PL480
>400	65	73	72	>100	19	37	45
>500	9	16	28	>150	0	1	10
>600	0	1	6	>200	0	0	3
>700	0	0	0	>250	0	0	0
>800	0	0	0	>300	0	0	0
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

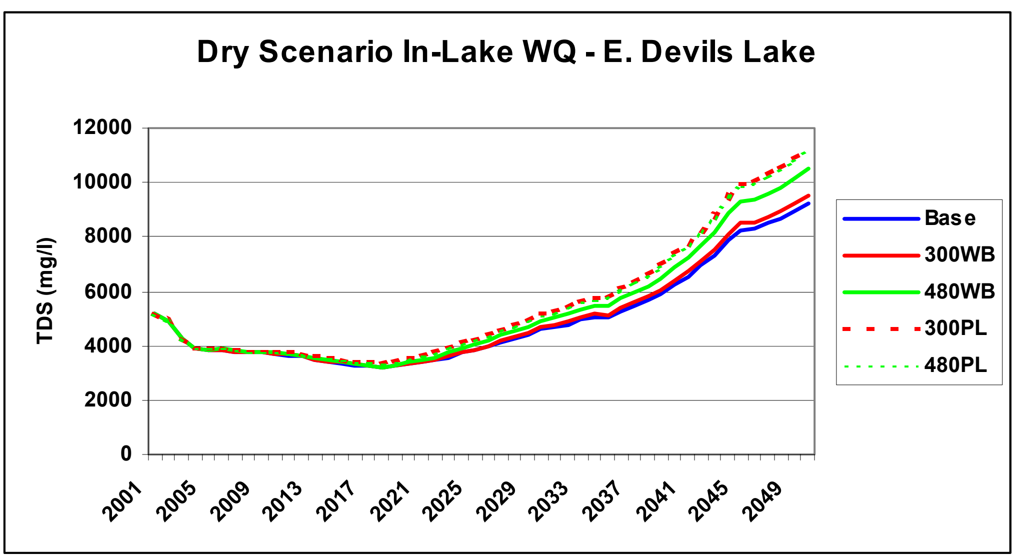
Plate 25



Dry Scenario In-lake WQ - Main Bay
TDS (mg/l
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300PL
480PL

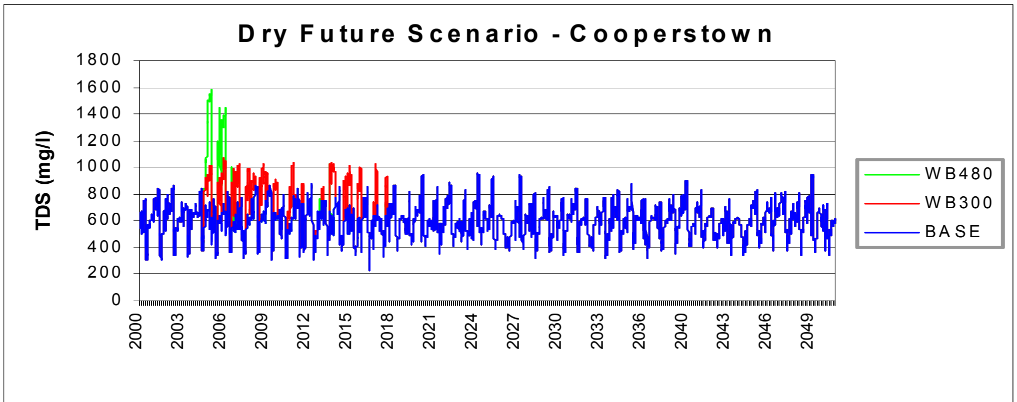


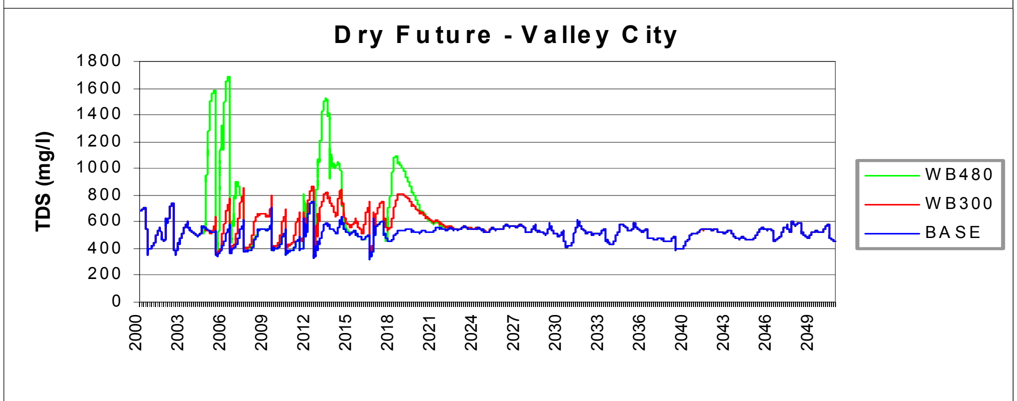
Dry Scenario In-Lake WQ - East Bay
TDS (mg/l)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300PL
480PL

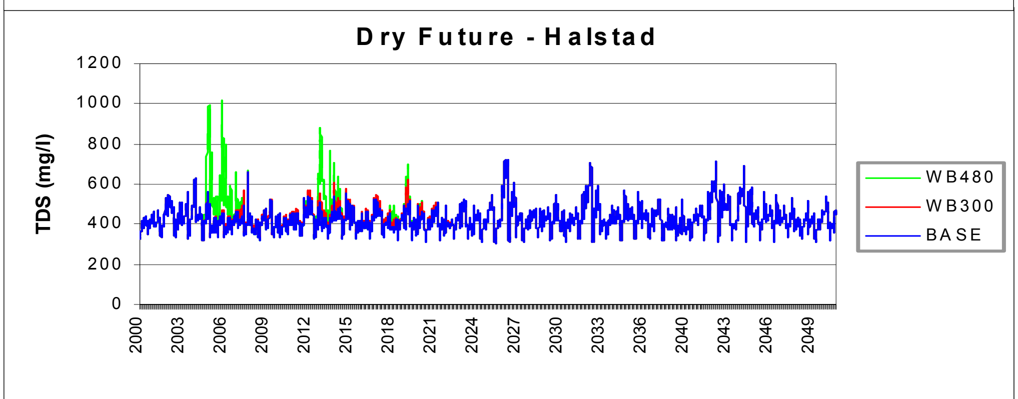


Dry Scenario In-Lake WQ - E. Devils Lake
TDS (mg/l)
12000
10000
8000
6000
4000
2000
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
300WB
480WB
300PL
480PL

Plate 26A


Dry Future Scenario - Cooperstown
TDS (mg/l)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE


Dry Future - Valley City
TDS (mg/l)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE


Dry Future - Halstad
TDS (mg/l)
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE

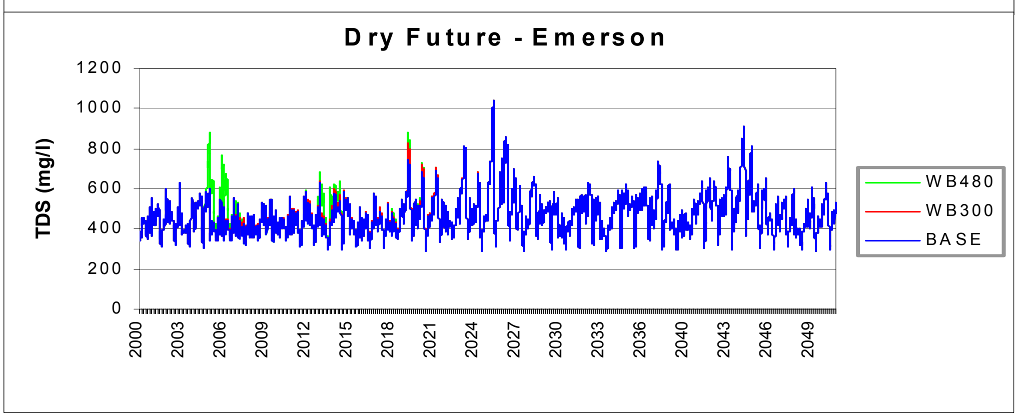
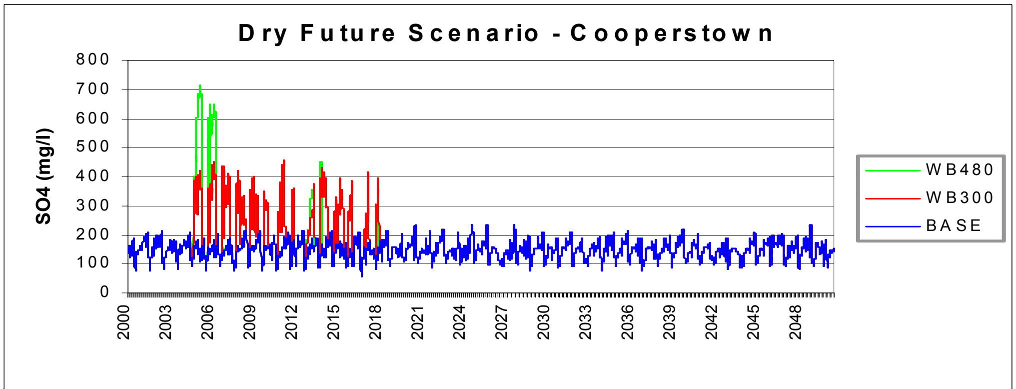
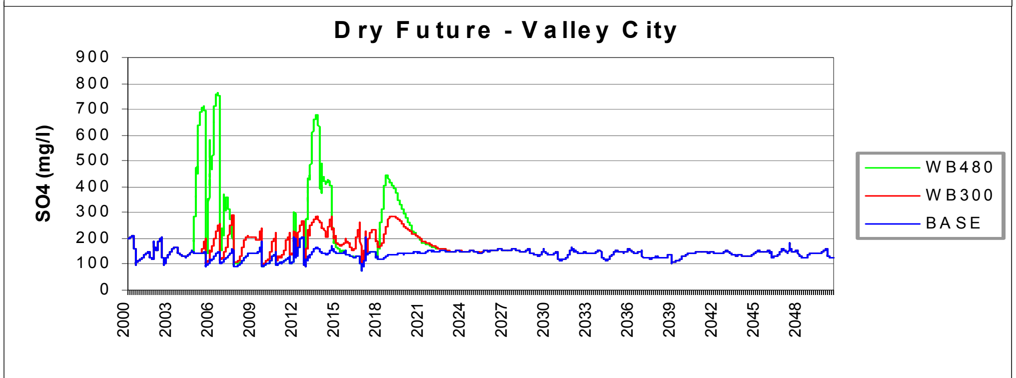
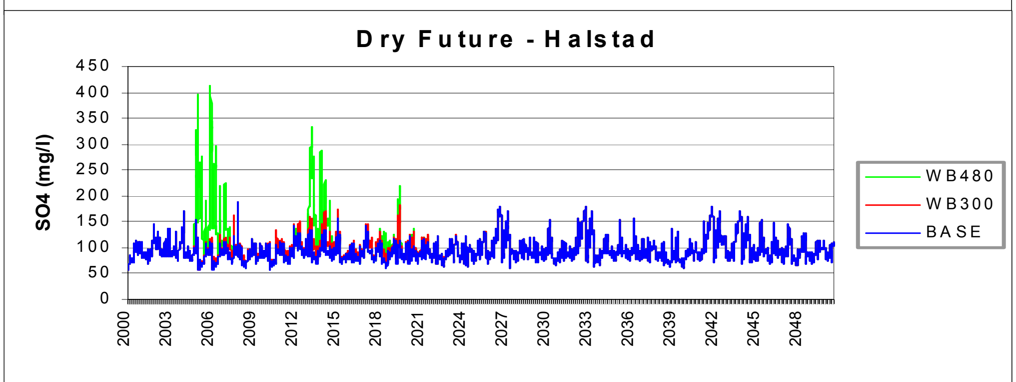

Dry Future - Emerson
TDS (mg/l)
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
WB480
WB300
BASE

Plate 26B


Dry Future Scenario - Cooperstown
SO4 (mg/l)
800
700
600
500
400
300
200
100
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
WB480
WB300
BASE


Dry Future - Valley City
SO4 (mg/l)
900
800
700
600
500
400
300
200
100
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
WB480
WB300
BASE


Dry Future - Halstad
SO4 (mg/l)
450
400
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
WB480
WB300
BASE

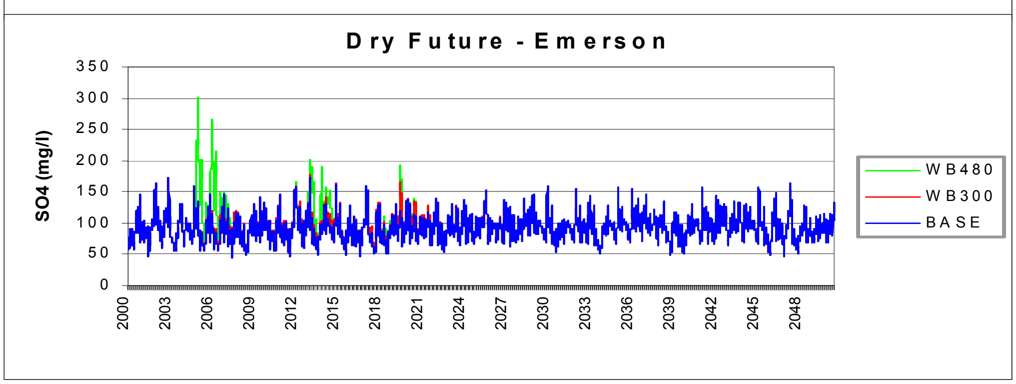

Dry Future - Emerson
SO4 (mg/l)
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
WB480
WB300
BASE

Plate 26C

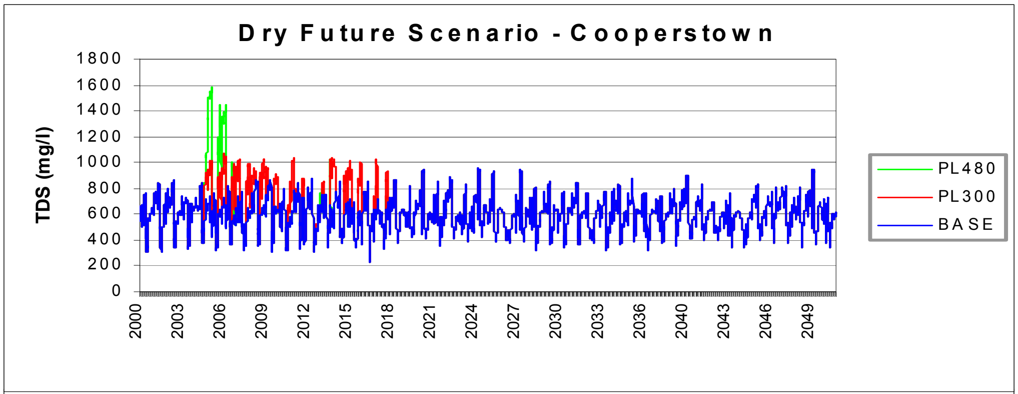
Dry Future Scenario at Cooperstown Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	91	91	91	>100	91	91	91
>500	78	84	82	>150	52	78	63
>600	55	74	61	>200	5	55	24
>700	22	59	37	>250	0	44	16
>800	6	45	20	>300	0	34	16
>900	0	22	12	>350	0	21	14
>1000	0	6	10	>400	0	6	11
>1100	0	0	9	>450	0	0	10

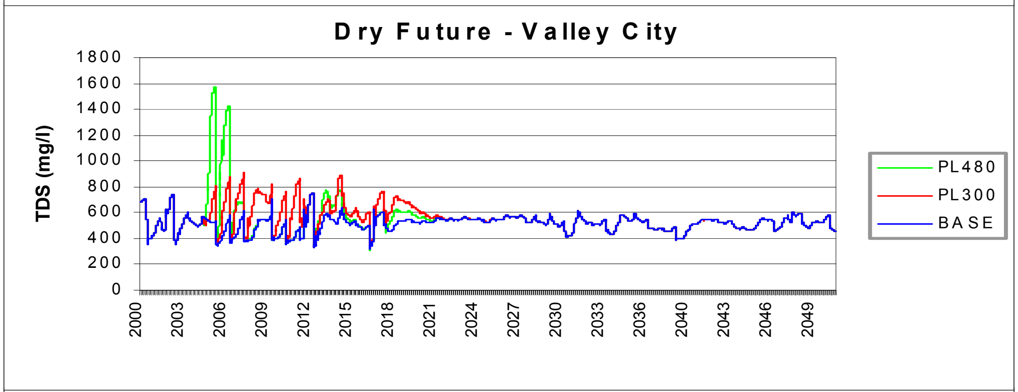
Dry Future Scenario at Valley City Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	78	94	90	>100	90	98	95
>500	49	68	65	>150	12	60	50
>600	5	45	45	>200	2	37	43
>700	3	19	41	>250	0	11	38
>800	0	6	35	>300	0	0	35
>900	0	0	30	>350	0	0	32
>1000	0	0	28	>400	0	0	28
>1100	0	0	20	>450	0	0	21

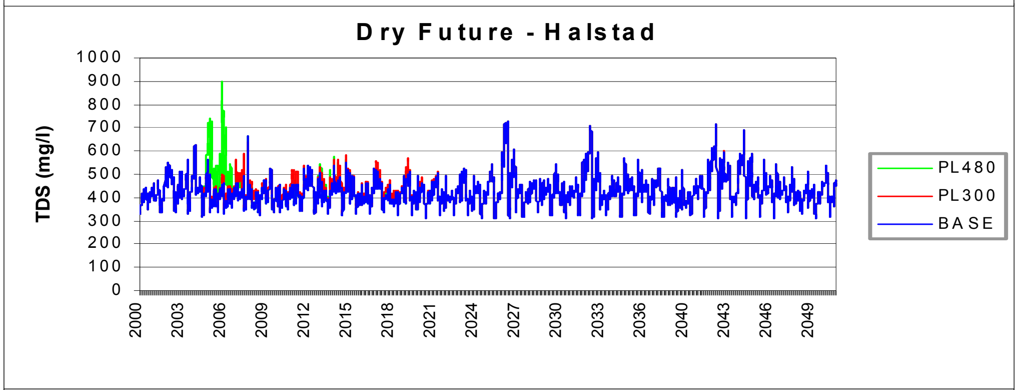
Dry Future Scenario at Halstad Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	57	67	72	>100	22	36	52
>500	4	6	28	>150	0	2	20
>600	0	0	13	>200	0	0	12
>700	0	0	7	>250	0	0	7
>800	0	0	3	>300	0	0	3
>900	0	0	1	>350	0	0	1
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Dry Future Scenario at Emerson Percent of Time Exceeded (Years 2005 - 2014)							
TDS	BASE	WB300	WB480	SO4	BASE	WB300	WB480
>400	67	70	76	>100	25	31	46
>500	11	13	27	>150	1	1	13
>600	0	0	7	>200	0	0	4
>700	0	0	3	>250	0	0	1
>800	0	0	0	>300	0	0	0
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Plate 27


Dry Future Scenario - Cooperstown
TDS (mg/l)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE


Dry Future - Valley City
TDS (mg/l)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE


Dry Future - Halstad
TDS (mg/l)
1000
900
800
700
600
500
400
300
200
100
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE

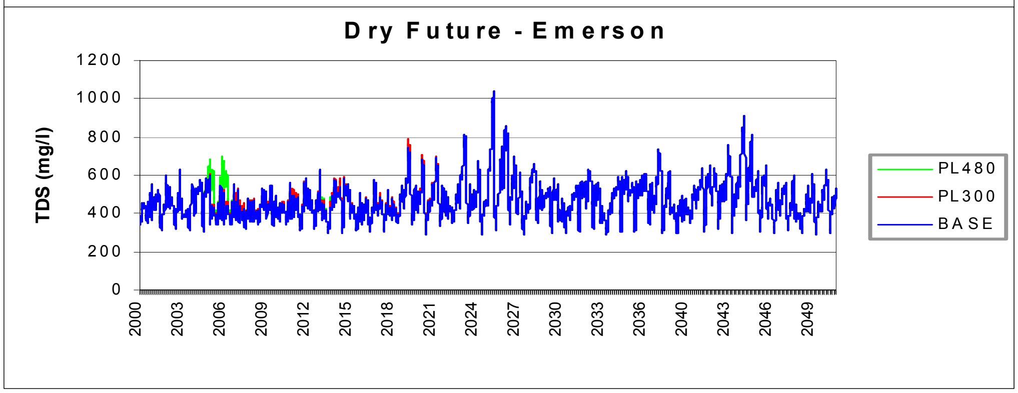

Dry Future - Emerson
TDS (mg/l)
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL480
PL300
BASE

Plate 28

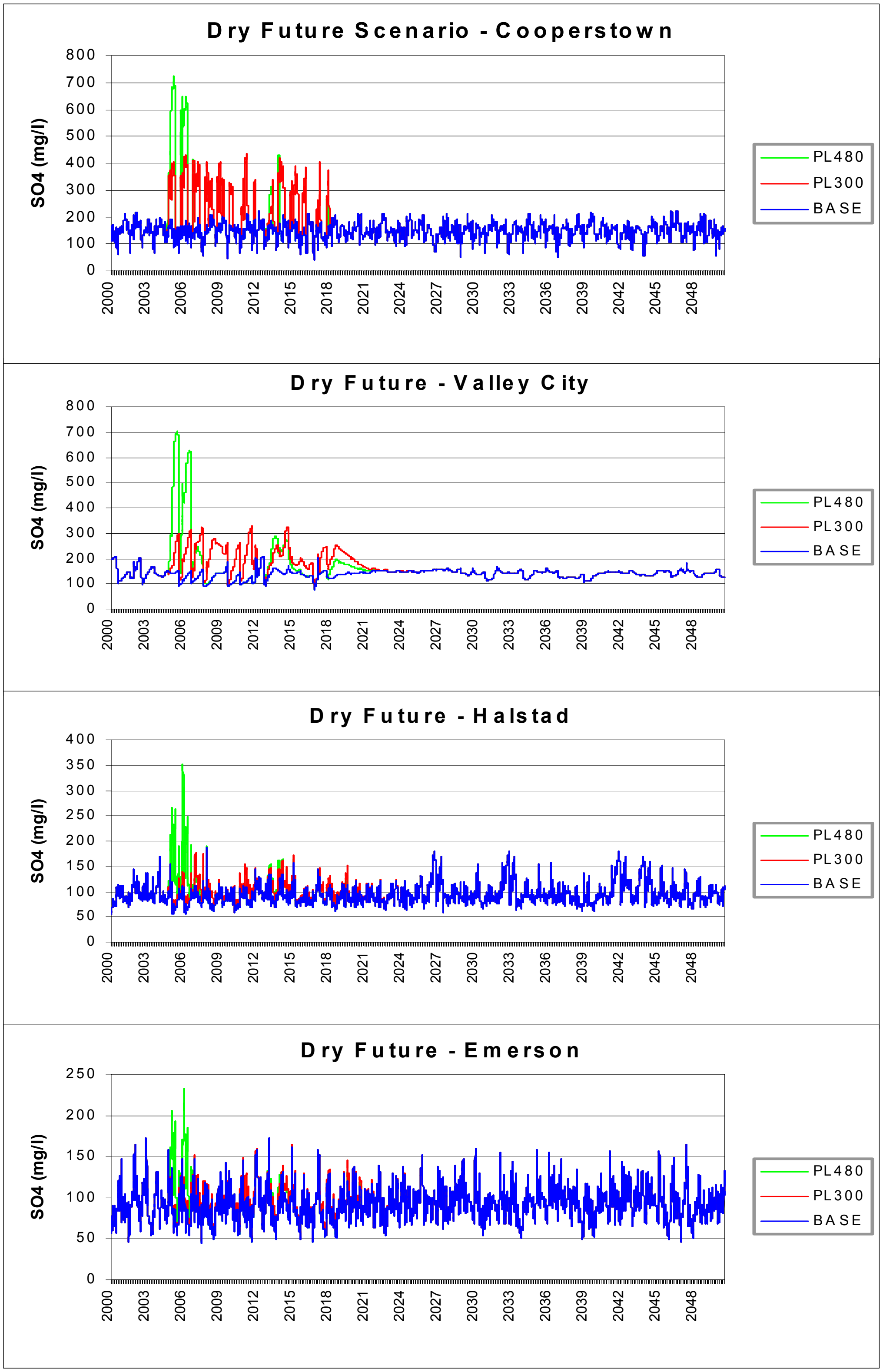
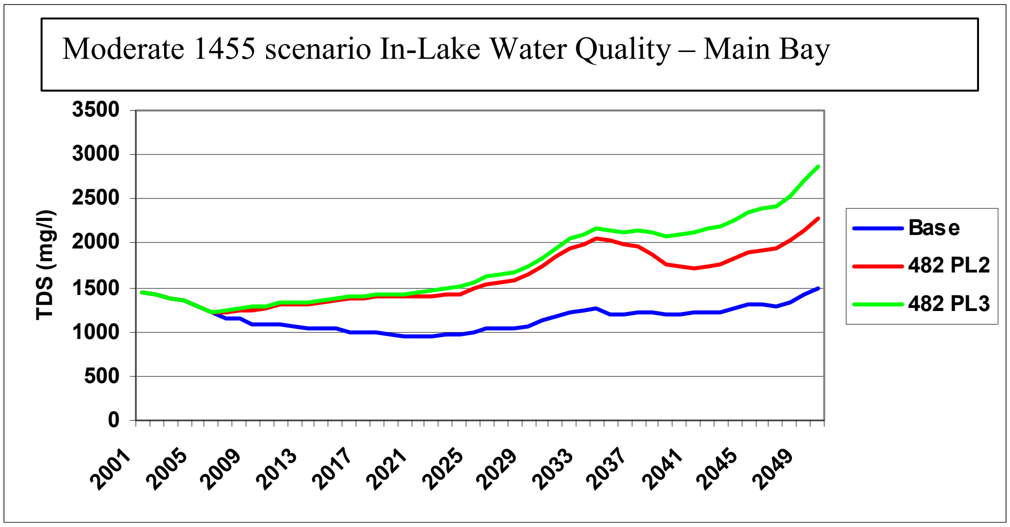
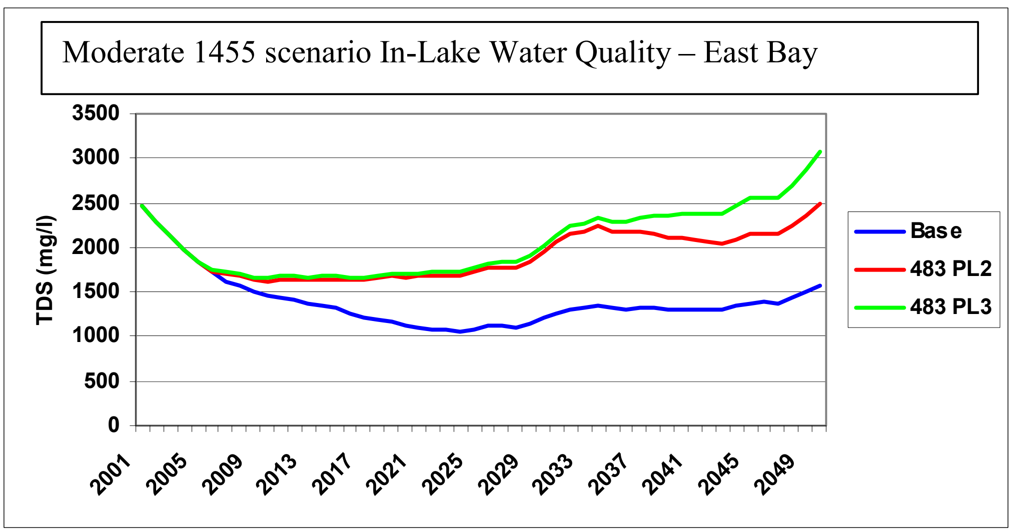

Dry Future Scenario - Cooperstown
SO4 (mg/l)
PL480
PL300
BASE
Dry Future - Valley City
SO4 (mg/l)
PL480
PL300
BASE
Dry Future - Halstad
SO4 (mg/l)
PL480
PL300
BASE
Dry Future - Emerson
SO4 (mg/l)
PL480
PL300
BASE

Plate 20


Moderate 1455 scenario In-Lake Water Quality – Main Bay
TDS (mg/l)
3500
3000
2500
2000
1500
1000
500
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
482 PL2
482 PL3


Moderate 1455 scenario In-Lake Water Quality – East Bay
TDS (mg/l)
3500
3000
2500
2000
1500
1000
500
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
483 PL2
483 PL3

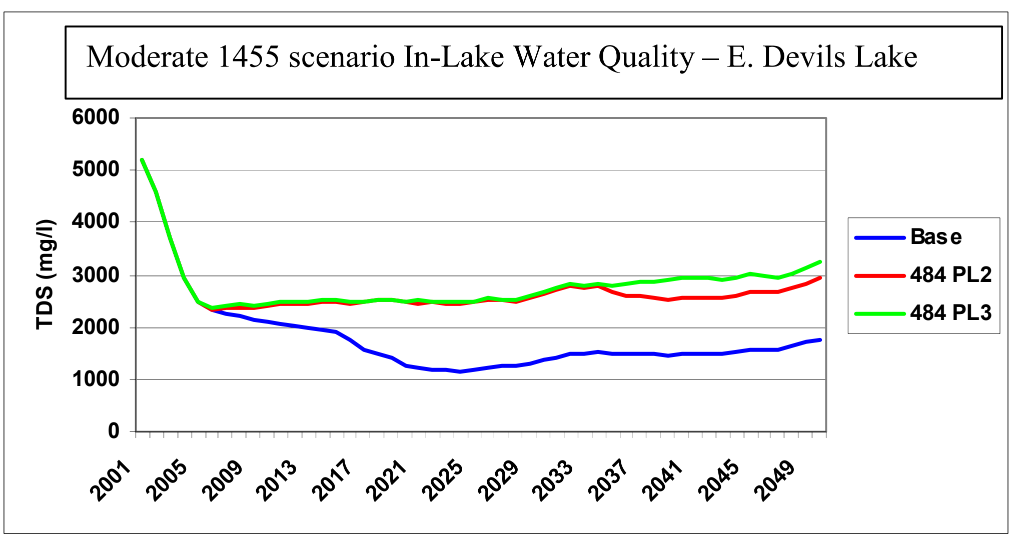
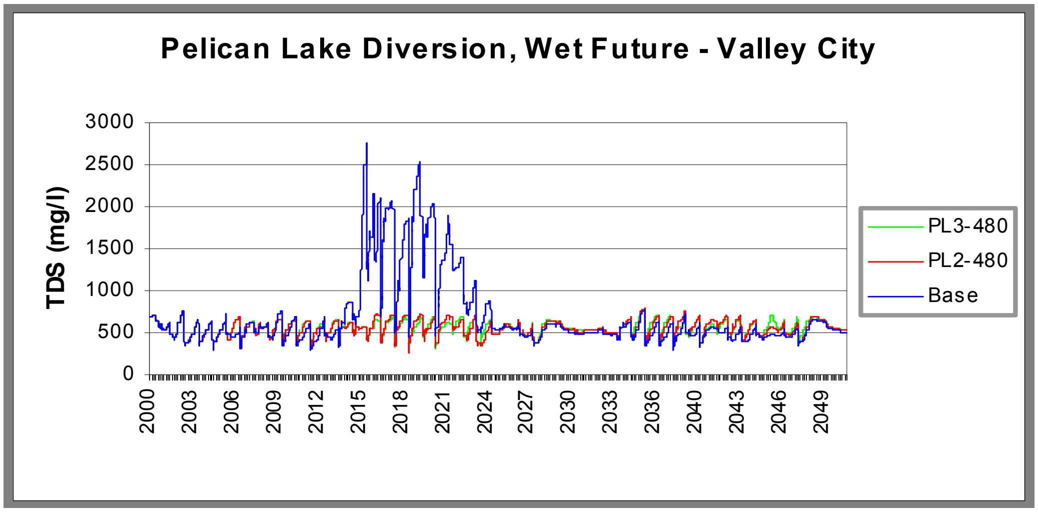
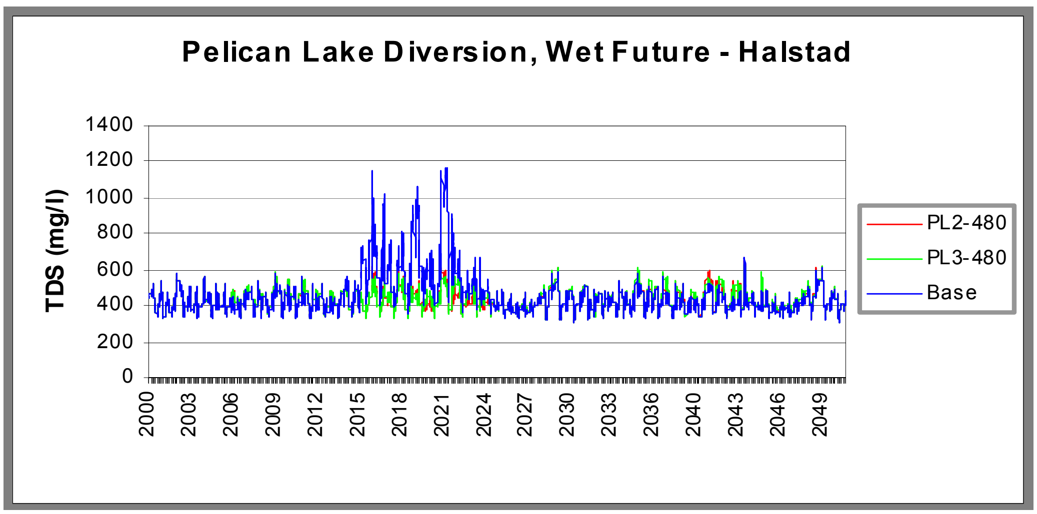

Moderate 1455 scenario In-Lake Water Quality – E. Devils Lake
TDS (mg/l)
6000
5000
4000
3000
2000
1000
0
2001
2005
2009
2013
2017
2021
2025
2029
2033
2037
2041
2045
2049
Base
484 PL2
484 PL3

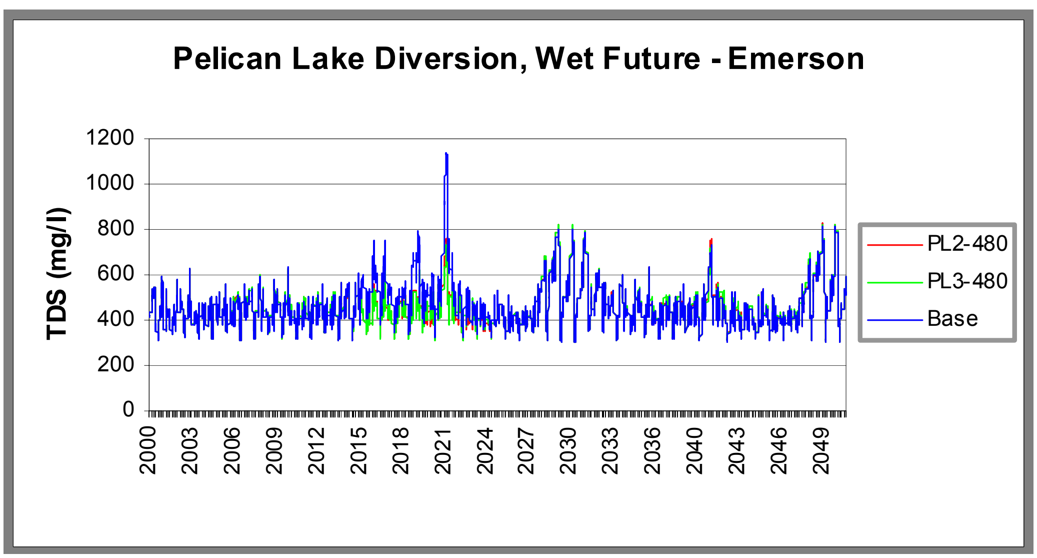
Plate 15A



Pelican Lake Diversion, Wet Future - Valley City
TDS (mg/l)
3000
2500
2000
1500
1000
500
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL3-480
PL2-480
Base

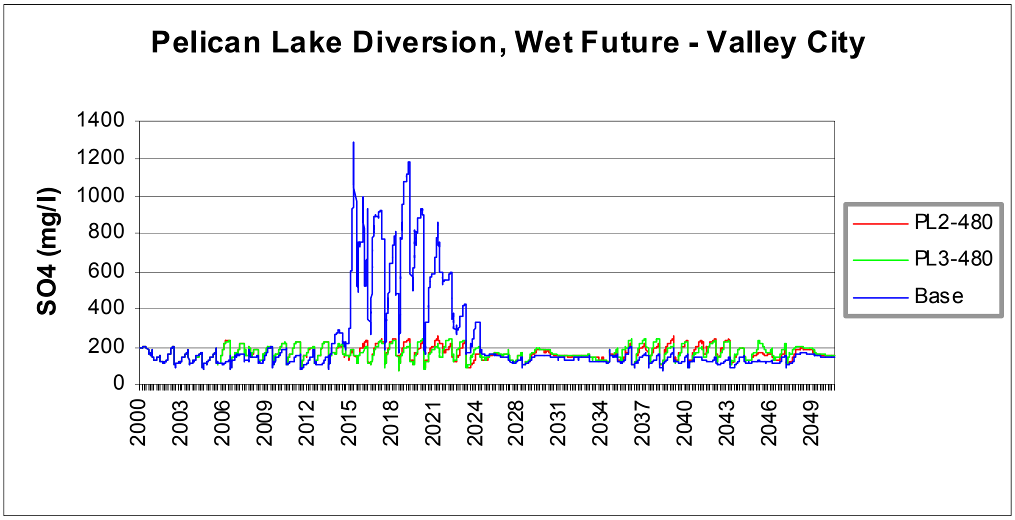


Pelican Lake Diversion, Wet Future - Halstad
TDS (mg/l)
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL2-480
PL3-480
Base

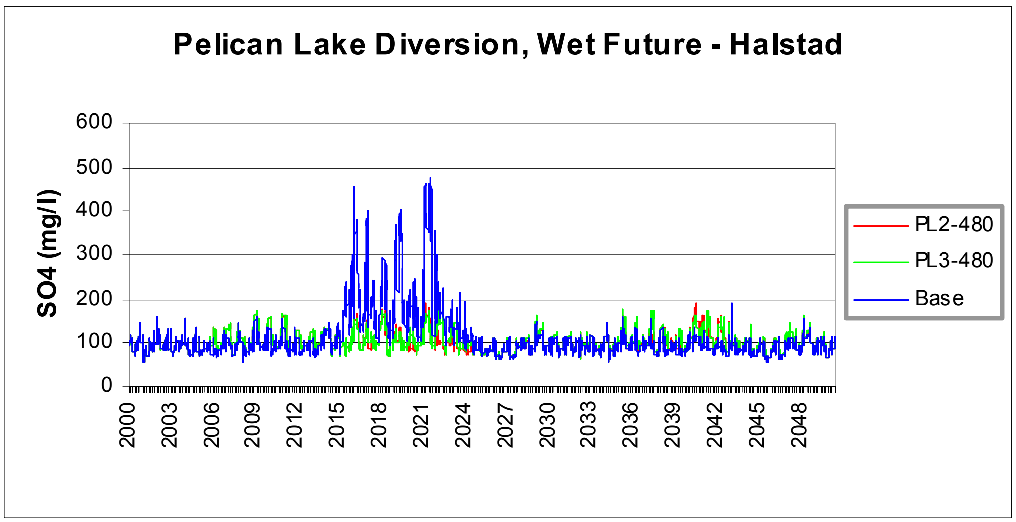


Pelican Lake Diversion, Wet Future - Emerson
TDS (mg/l)
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2040
2043
2046
2049
PL2-480
PL3-480
Base

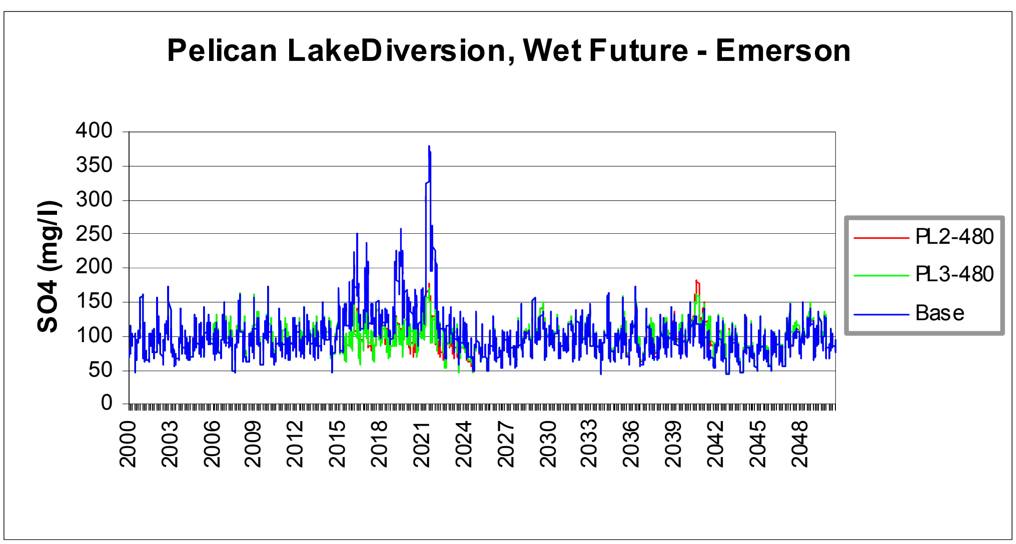
Plate 15B



Pelican Lake Diversion, Wet Future - Valley City
SO4 (mg/l)
1400
1200
1000
800
600
400
200
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2028
2031
2034
2037
2040
2043
2046
2049
PL2-480
PL3-480
Base



Pelican Lake Diversion, Wet Future - Halstad
SO4 (mg/l)
600
500
400
300
200
100
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL2-480
PL3-480
Base



Pelican LakeDiversion, Wet Future - Emerson
SO4 (mg/l)
400
350
300
250
200
150
100
50
0
2000
2003
2006
2009
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039
2042
2045
2048
PL2-480
PL3-480
Base

Plate 15C

Pelican LakeDiversion PL2&PL3, Wet Future at Valley City
Percent of Time Exceeded
(Years 2006 - 2015)

TDS	BASE	PL3-480	PL2-480	SO4	BASE	PL3-480	PL2-480
>400	91	94	94	>100	34	97	97
>500	57	77	76	>150	1	77	76
>600	20	29	28	>200	0	28	26
>700	3	0	0	>250	0	0	0
>800	0	0	0	>300	0	0	0
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Pelican Lake Diversion PL2&PL3 Wet Future at Halstad
Percent of Time Exceeded
(Years 2006 - 2015)

TDS	BASE	PL3-480	PL2-480	SO4	BASE	PL3-480	PL2-480
>400	63	76	76	>100	28	52	51
>500	4	8	7	>150	0	2	2
>600	0	0	0	>200	0	0	0
>700	0	0	0	>250	0	0	0
>800	0	0	0	>300	0	0	0
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Pelican Lake Diversion PL2-PL3 Wet Future at Emerson
Percent of Time Exceeded
(Years 2006 - 2015)

TDS	BASE	PL3-480	PL2-480	SO4	BASE	PL3-480	PL2-480
>400	73	80	80	>100	34	52	52
>500	10	14	14	>150	1	1	1
>600	0	0	0	>200	0	0	0
>700	0	0	0	>250	0	0	0
>800	0	0	0	>300	0	0	0
>900	0	0	0	>350	0	0	0
>1000	0	0	0	>400	0	0	0
>1100	0	0	0	>450	0	0	0

Section 7 - Downstream Water Users Study Effect of Outlets

The following is excerpt is the Executive Summary from Devils Lake ND Downstream Surface Water Users Study; Barr, March 1999. Information from that study was used in the Economic Analysis of Devils Lake Alternatives, Barr, July 2001, for modeling the costs damage estimates for the water quality-dependent features of the economic analysis;

Executive Summary from Barr Report

Because of the relatively high concentration of dissolved solids in Devils Lake, pumping water from the lake into the Sheyenne River will affect the water quality of the river. It will also affect the water quality in the Red River of the North, into which the Sheyenne River drains. This study addresses the potential impacts that the changes in water quality may have on users of the water from the rivers.

For this study, the river water users were separated into four groups: (1) Municipal water treatment facilities, (2) Industrial river water users, (3) Other permitted river water users, and (4) Non-permitted river water users. A separate analysis was conducted for each of the four groups. While the analysis was general, the costs presented in this report are based specifically on sample water quality time series ("trace") data provided by the Corps.

Municipal Water Treatment Facilities – Based on analysis of the available data regarding the operations of the eight affected municipal water treatment facilities, a computer spreadsheet model was developed to estimate each facility's annual increase in cost that can be expected due to the change in water quality. Cost increases will result from increased softening costs (due to increased chemical feed rates and increases in sludge handling and disposal), and increased capital and operations costs if treatment or an alternative water supply is required to restore the treatment facility finished water quality to without-outlet conditions.

Modeling showed the total annualized cost for increased softening will range from $25,000 per year to $56,000 per year, depending on the modeled water quality future. The total annualized cost for capital improvements or alternate source water development required to bring the with-outlet product water to the water quality of without-outlet product water ranged from $1,757,000 per year to $3,304,000 per year. In most cases, treatment by ion-exchange was found to be the least-cost alternative if without-outlet product water quality is required.

Industrial Water Users – Interviews were conducted with all of the industrial river water users along the Sheyenne River and the Red River of the North. Only two were expected to incur increased costs as a result of the Devils Lake outlet operations. The sugar beet processing facility is expected to have increased lime softening costs as a result of the outlet. The coal-fired power plant's increased costs relate to additional need for ion exchange water purification for boiler water. Based on one of the sample water quality data sets, annualized costs would be expected to be $1,200 per year for the sugar beet processing facility and $30,700 per year for the power plant.

Other Permitted River Water Users – For this portion of the study, permit holders along the Sheyenne River and Red River of the North were first identified and characterized. Two hundred one (201) permits (excluding municipal and industrial permits) were listed along the affected reaches of the two rivers. Ninety-six percent of the permittees used the water for irrigation (which is defined to include livestock watering), and the remaining 4 percent were for other uses. Interviews were conducted with a representative sample of 20 percent of the permit holders. Approximately half of those interviewed expressed concern over possible changes in water quality, but approximately 25 percent were unconcerned. Research into salinity effects on plants and animals showed that limited potential exists for adverse effects. Potentially affected uses were identified – these include irrigation of approximately 17 square miles of corn, certain plants and vegetables, and possible fish and livestock production. Water supply alternatives considered included a change to less sensitive crops, private well installation, connection to municipal or rural water supply systems, and relocation. However, if an alternative water supply is in fact required, payment to compensate for reduced yields may be the only practical option.

Non-Permitted River Water Users – A principal difficulty in characterizing the potential effects on non-permitted users was locating those users; agency listings of such users are unavailable. Permits for river water use are required only when certain withdrawal thresholds are reached. Twenty-five non-permitted users along the affected reaches of the two rivers were located and interviewed. Most of the non-permitted group uses the water for watering lawns, private landscape, or relatively small-scale fruit and vegetable plots. Nine of those interviewed reported using the water for livestock. Water supply alternatives identified included a change to less sensitive crops, private well installation, connection to municipal or rural water supply systems, and relocation. Alternative water supply costs expected by users varied greatly; verification of these estimates was not within the scope of this study.

Downstream Water Users Study – Effect of Natural Overflow

The following excerpt is the Summary and Conclusions from Potential Impacts of a Stump Lake Spill on Downstream Water Users – Addendum to the Devils Lake, North Dakota Downstream Surface Water Users Study – March 1999, Barr, September 2000;

Summary and Conclusions From Barr Report

Examination of Trace 2415 (developed in April 1999) provides a means by which to examin the potential consequences of an overflow from Stump Lake, It must be kept in mind that the Trace 2414 data is only an example of what sort of flows and water quality might be expected in the event of an overflow. Should an overflow actually take place, the flow rate, flow duration, and resultant constituent concentrations in the Sheyenne River and the Red River of the North will be different from those indicated by Trace 2415.

Nevertheless, examination of the 50 years of Trace 2415 data provides an idea of what water quality changes may occur, and the sorts of flow patterns that may occur. Trace 2415 data shows a primary overflow period in the years 2016 through 2023, with minor spills from Stump Lake occurring in the later years. For the water quality constituents modeled, the concentration changes are extreme during the overflow period, particularly in the farthest upstream reaches of the Sheyenne River. The dilution provided by the Red River of the North and its tributaries reduces the peak concentrations as the overflow plume moves downstream. As a result, adverse effects on water users can be expected to be less severe as one continues downstream.

An overflow from Stump Lake will cause peaks in the concentrations of dissolved solids in the river water. The elevated concentrations will certainly have consequences for downstream user sof river water. These impacts will depend on what the river water is used for, the timing and seasonality of the use, the amount of withdrawal, and (as was mentioned) the distance downstream from the point at which overflow water enters the Sheyenne River.

Municipal Water Treatment Facilities – For the MWTF's, the impacts will vary according to the location of the water treatment facility, and the ability of the facility to readily switch to an alternative raw water source. The MWTF at Balley City will be most strongly affected, with the MWTFs at Fargo and Grand Forks also experiencing difficulties in providing safe and aesthetically acceptable drinking water during the overflow periods. The existing river water withdrawal and water treatment regimes at these MWTFs will be insufficient to provide acceptable drinking water for the communities. Alternative raw water sources, ion exchange treatment, and/or provision of bottled water will be necessary.

The MWTFs farther downstream – those at Grafton, Drayton, Pembina, Morris, and Letelier – will experience relatively less severe problems, and for shorter durations, when an overflow occurs. Existing treatment methods may be sufficient for bringing the treated water within acceptable limits during some of the overflow periods. Provision of bottled water is also likely to be required at times, at least for at-risk individuals.

Industrial Users – Only three of the eleven permitted industrial users are likely to experience adverse effects as a result of a Stump Lake overflow. For one of those potentially affected industrial users (the paper mill, located farthest from the Sheyenne

River), the effects of the overflow may be relatively minor and inconsequential. For the power plant and the sugar beet processing facility, it may be possible to use selective withdrawals, increased treatment, or alternative water sources to mitigate the adverse effects of the overflow.

Other Permitted Users – Most of the non-MWTF, non-industrial permitted users of river water use the water for irrigation of crops and garden plants, or for watering livestock. The high TDS and sulfate levels resulting from an overflow from Stump Lake have the potential for harming both plants and animals. Of all the crop acreage currently irrigated with river water, 98 percent of the irrigated barley acreage, 85 percent of the irrigated corn acreage, and 9 percent of the irrigated wheat acreage will potentially be affected by the high TDS concentrations. Fish hatcheries will also be potentially affected by the high TDS concentrations in the river water. The degree of the adverse effects will depend on the soil type, the particular plant or animal species for which the water is used, and the timing and amount of the river water withdrawal.

Non-Permitted Users – The ill effects of a stump Lake overflow on non-permitted river water users will be similar to those experienced by the non-MWTF, non-industrial permitted users. Although data is scarce with respect to this group, most of the non-permitted users appear to use river water for small-scale irrigation of lawns and gardens. As with the permitted users, the effects on non-permitted users will depend on the type of plant for which the water is used, and the timing and amount of the river water withdrawal.

Section 8 – Upper Basin Storage Study

The Devils Lake Upper Basin Storage Evaluation was conducted for the U.S. Army Corps of Engineers, St. Paul District, by WEST Consultants, Inc., and Polaris Group, Inc. The primary purpose of this study is to assess the impacts of upper basin storage restoration alternatives on the inflows to Devils Lake. The upper basin storage alternative under consideration is the restoration of "drained" depressions. A vast amount of geographic and historical data was collected to (1) delineate and classify the depressions, and (2) develop a physically-based hydrologic model to simulate the hydrologic functions of the depressions.
Given the limitations in the available data and other project constraints, some simplifications and assumptions were made during the analysis. These assumptions were appropriate given the objective and time constraints of this study. Since the results of this study indicate that depression restoration can reduce the volume of runoff entering Devils Lake, further studies should be conducted to more accurately quantify the runoff reduction resulting from depression restoration. A summary of the results and recommendations for future studies are presented in the following sections.

Depression Delineation and Classification

Depressions were delineated and classified for the entire 2,616 square mile upper basin watershed (exclusive of Stump Lake and local Devils Lake drainage area). A digital elevation model (DEM) was used to determine the location, area, and volume of depressions in the upper basin subwatersheds. Using the flow chart in Section 3 (see **Figure 3-1**), the depressions were categorized as *possibly intact*, *possibly drained*, *lake* or *other* based on aerial photos, National Wetlands Inventory (NWI) data, flow direction data, and digital quad maps. The modifier "possibly" was added to the "intact" and "drained" classifications because field verification was not performed during this study. Depressions that were not captured by the DEM were added and classified based on the aerial photos and NWI data. It should be noted that the NWI wetland definition and the resulting NWI polygons do *not* include depressions that were completely drained prior to 1979. Therefore, any completely drained depressions not captured by the DEM nor by the NWI data are not incorporated into the data set. The average depth (and volume) for each of the non-DEM depressions was estimated based on an average depth-area relationship developed from all of the DEM-derived depressions. A comprehensive quality assurance review of the classified depressions was conducted for the entire upper basin. The results of the classifications were compared to previous studies.
The depressions described as "possibly drained" in this report may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as "possibly drained." In a similar manner, depressions labeled as "possibly intact" could be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as "possibly intact" because water in a shallow depression could be fully lost to evaporation. A summary of

the possibly intact and possibly drained depressions identified in this study is included in the following table:

Depression Type	Count	Area **(acres)**	Volume **(acre-ft)**
Possibly Intact [1, 2]	63,458	201,990	481,604
Possibly Drained [1, 3]	52,210	92,429	132,729
Total	*115,668*	*294,419*	*614,333*

Notes:

(1) Based upon the available data and classification procedure, these depressions were classified as either "intact" or "drained." However, because field verification was not performed, the modifier "possibly" was adopted.

(2) "Possibly intact" depressions may be fully intact, mostly intact, or likely intact (i.e., appears intact, but not definitively so). The presence of standing water was not a prerequisite for classifying a depression as "possibly intact" because water in a shallow depression could be fully lost to evaporation.

(3) "Possibly drained" depressions may be fully drained, mostly drained, partially drained, likely drained (i.e., appears drained, but not definitively so), filled-in, or otherwise non-intact or non-functional. The clear presence of a man-made drain was not a prerequisite for classifying a depression as "possibly drained."

Due to the comprehensive nature of the depression delineation and classification process, the results given in the above table represent very reasonable estimates of upper basin depression area and volume. Overall, however, the estimates of intact and drained depression area and volume totals are believed to be conservative (i.e., underestimated) to some degree for the following reasons: (1) the added NWI polygons do not represent the maximum depression area; (2) a number of DEM depression polygons appeared to be smaller in area than the corresponding depressions on the aerial photos (The underestimated area and volume from the DEM was only partly offset by the presence of larger-than-appropriate DEM depression polygons); and (3) there were areas, especially within the 10-foot contour interval region, where depressions were missed by both the DEM grid and the NWI data set. For these reasons, it is likely that a more intensive analysis would result in a greater number of depressions.

Although the depression delineation and classification conducted during this study were extensive and detailed, there were some limitations to the methods. These limitations, with varying degrees of importance, include the following: (1) no field verification was conducted due to time constraints and the presence of snow cover during the study period; (2) partial drainage was not accounted for; (3) some individual depression classifications are subject to interpretation; (4) classification was based upon aerial photos representing one point in time; (5) a small number of the aerial photos were darker than normal, making the depressions more difficult to categorize; and (6) the resolution of the aerial photos was not fine enough to identify the location of fully drained depressions not captured by the DEM nor the NWI data and the location of some of the drainage ditches.

While there are some limitations to the classification process, there are also a number of important advantages of this classification process, including: (1) depressions were individually delineated and classified over the entire upper basin watershed; (2) physically-based delineation was conducted using the DEM, thus minimizing the need for extrapolation; (3) visual verification of depressions using aerial photos was utilized; (4) supplementary data (NWI, quad maps, flow direction) was incorporated; and (5) quality assurance/quality control was performed.

The accuracy of the delineation and classification of some of the individual depressions was limited by the available data and project constraints. For future studies, it is recommended that this work be refined as follows:

- Obtain historical aerial photos, preferably from the 1950's when drainage activity was minimal, to assist in identifying depressions in those areas missed both by the DEM grid and NWI data. These historical photos could also be compared to current photos to verify the depression classification.

- Perform extensive field verification to locate drainage ditches, determine the functionality of the farmed depressions, and verify the depression classification.

- Utilize the 1997 color infrared photography, which is higher resolution than the DOQ's used in this study, to refine the depression delineation and classification, but this would be very labor intensive because the data is not available in digital format.

- Obtain more refined soil data to develop relationships between depression area and hydric soils.

- Include more classifications such as "partly drained." Separate depressions that have drainage ditches from those that have been disturbed by other activities such as farming.

- Obtain higher resolution digital terrain data, especially in those areas currently modeled from the 10-foot contour interval data.

Hydrologic Model

Originally, the hydrologic model of the Devils Lake basin was going to be developed using the HEC Hydrologic Modeling System (HEC-HMS), Version 2.1.1 (Hydrologic Engineering Center, U.S. Army Corps of Engineers, 2001). However, it was determined that the HEC-HMS model could not reasonably be configured to adequately model the hydrologic function of the depressions. Therefore, a custom hydrologic model, the Pothole-River Networked Watershed Model (PRINET), was developed to simulate the depression storage, soil storage, and runoff in the Devils Lake basin. The PRINET application was written in Microsoft Visual Basic 6.0 (Visual Basic For Applications) inside a Microsoft Access database. The model used geographic data to develop the drainage patterns and subbasins. Most of the hydrologic calculations use the same algorithms as HEC-HMS.

Six subwatersheds, encompassing the upper basin of Devils Lake, were modeled by PRINET (see Figure 5-1, in Section 5). Each subwatershed was divided into numerous subbasins. There were 9,078 subbasins modeled in the upper basin and the average subbasin area was 0.29 square miles. The subbasins in each subwatershed were networked; that is, the exact sequence of flow between subbasins was specified for each subwatershed.

The computational sequence and the hydrologic processes modeled are summarized below. The model performs the following ten computations on daily basis:

1. Determine precipitation and evaporation for each day.
2. Add precipitation to the soil moisture and to the depressions.
3. Determine infiltration of precipitation into the soil, and update the soil moisture level accordingly.
4. Any precipitation that does not infiltrate runs off into intact depression storage. A separate accounting is made of on-river depressions (those that intersect the river network) and off-river depressions (those that do not intersect the river network).
5. If upstream subwatersheds exist, they are modeled as sources of flow into the downstream subwatershed model at the appropriate location.
6. Evaporation is calculated for each subbasin's intact depressions and the water storage volume is reduced accordingly.
7. Evapotranspiration is calculated for each subbasin's soil and the moisture level is reduced accordingly.
8. Percolation is determined for subbasins where the soil is sufficiently saturated to permit percolation.
9. When the depression water volume of a subbasin's off-river depression storage exceeds the off-river depression storage capacity, the excess runs off into the on-river intact depression storage of the same subbasin.
10. When depression water volume of a subbasin's on-river depressions exceeds depression storage capacity, the water flows into the intact on-river depression storage of the next downstream subbasin, or to the outlet of the subwatershed if there are no downstream subbasins.

Hydrologic Model Calibration

The PRINET model was calibrated to historic streamflows. The Devils Lake upper basin was divided into 12 different regions for calibration based on subwatershed boundaries and the location of streamflow gages. Since wetland drainage was allowed before the implementation of the wetland conservation provisions (i.e., "Swampbuster") in 1985, the amount of intact depression storage would be different before and after 1985. Therefore, the PRINET model calibration period was conducted for water years 1985 through 1999, a period with minimal changes to the depression topography and drainage network found in the upper basin. However, in order to provide a sufficient warm-up period, the model runs started on October 1, 1978 (start of water year 1979).

The overall calibration approach included the following primary objectives: (1) matching the total computed and observed volumes to within approximately one to two percent for the entire calibration period (1985-99), and (2) matching the pattern of dry, low runoff years in the late 1980s and the wet, high runoff years in the mid-to-late 1990s. The same hydrologic parameters were used for the entire calibration period; no parameters were varied annually to account for year-to-year differences. The number of parameters varied by calibration region was kept to a minimum.

Alternative Analysis

Eleven climatic scenarios were used to simulate future conditions with and without depression restoration. Possibly drained depressions having an average depth of greater than or equal to 0.5 feet were candidates for restoration. There were 13,464 restoration candidates (26 percent of the total number of possibly drained depressions) having a total surface area of 79,762 acres (86 percent of the total possibly drained depression surface area) and a total volume of 127,835 acre-feet (96 percent of the total possibly drained depression volume). Different levels of restoration (25, 50, 75, and 100 percent by volume of the restoration candidates) were analyzed.

Depressions were restored in each subwatershed. Each subwatershed had the same percentage of restored volume as the corresponding restoration scenario. For example, for 50 percent restoration (Scenario C), 50 percent by volume of the possibly drained depressions from Comstock was restored and 50 percent by volume of the possibly drained depressions from Starkweather was restored and so forth for each subwatershed.

The scenarios were constructed by **randomly** selecting depressions that had been classified as possibly drained and converting these depressions to possibly intact. The selection process was not optimized by drainage area or location. To construct the 25 percent restoration scenario model (Scenario B), enough restoration candidate depressions were randomly chosen in each subwatershed modeled until 25 percent of the total volume of restoration candidates was achieved for that subwatershed. These were converted to possibly intact depressions. To construct the 50 percent restoration scenario model (Scenario C), additional depressions, randomly selected, were added to this set until 50 percent of the total restoration volume was achieved for each subwatershed. The 100 percent restoration scenario (Scenario E) models had all restoration candidates reclassified as possibly intact.

The surface area and volume of the restored depressions for the different restoration levels are summarized in the following table:

RESTORATION LEVEL	25% (Scenario B)		75% (Scenario D)	100% (Scenario E)
Area Restored, acres	19,472	39,681	59,872	79,762
Volume Restored, acre-ft	31,431	63,608	94,850	127,835

When a depression was restored, the total depression volume to the pour point was restored. Though not considered in this study, additional volume could be retained in each depression by constructing berms, gated structures, or tie backs to higher ground. Since the contributing drainage areas are modeled for each of the depressions (see Section 4), only the runoff from the area that drains to the depression fills the depression. Some depressions may have large contributing areas that may cause overtopping whereas some depressions may not. Depending upon the depression surface area and evaporation rate, the amount of storage carry-over from year to year will vary with the depression characteristics. Generally, the annual available depression storage is less than the total depression storage.

The annual flow reductions resulting from depression restoration vary significantly for individual water years. In dry years, the percent of flow reduction is larger than in wet years. The following table shows the average annual flow reduction for each restoration scenario and climate sequence. The average annual runoff reduction is less than the restored volume.

		No Restoration		Restoration Level			
				25% (B, 31,431 acre-ft and 19,472 acres restored)	**50%** (C, 63,608 acre-ft and 39,681 acres restored)	**75%** (D, 94,850 acre-ft and 59,872 acres restored)	**100%** (E, 127,835 acre-ft and 79,762 acres restored)
Climate Sequence	**Water Years**	**Total Runoff** (acre-ft)	**Average Annual Runoff** (acre-ft)	**Average Annual Runoff Reduction** (acre-ft)			
001	2003-2020	3,101,720	172,318	7,294	14,007	20,754	27,173
002	2003-2020	2,017,254	112,070	7,058	13,496	18,737	23,702
003	2003-2020	1,688,607	93,812	6,714	12,653	17,729	23,056
004	2003-2020	1,292,294	71,794	6,150	11,704	16,909	21,638
005	2003-2020	2,888,905	160,495	7,869	15,246	22,303	29,533
006	2003-2020	1,279,228	71,068	5,661	10,185	14,174	18,291
007	2003-2020	2,259,557	125,531	7,395	14,013	19,727	25,404
008	2003-2020	1,594,247	88,569	6,601	12,802	18,098	23,328
009	2003-2020	1,632,394	90,689	7,151	12,881	18,089	23,545
010	2003-2020	2,051,472	113,971	6,464	12,111	17,511	22,745
Average		1,980,568	110,032	6,836	12,910	18,403	23,841
As Percent of Restored Volume				22%	20%	19%	19%
Runoff Reduction Volume / Area Restored				4.2 in	3.9 in	3.7 in	3.6 in
WET	2003-2035	8,737,679	264,778	7,959	15,643	23,502	31,193
As Percent of Restored Volume				25%	25%	25%	24%

One method of presenting the impact of restoration on runoff reduction is by evaluating the ratio of the reduction in annual runoff volume to the area restored. For example, for the 25 percent restoration level (B), the average runoff reduction is 6,826 acre-ft. Since 19,472 acres were restored, this yields 6,826 acre-ft / 19,472 acres = 0.35 feet = 4.2 inches. This value primarily represents the difference between storage and evaporation in the restored depressions and the percolation and evapotranspiration from the soil area before restoration. It does not represent the average evaporation from a depression, which was approximately 20 or more inches per year.

The PRINET model did not include a soil moisture algorithm beneath the depressions. Instead, the depressions were modeled as hard-bottom "bowls." Consequently, infiltration of water from a depression into the soil and evapotranspiration from the soil in the dry portions of a depression (when the depression was less than 100 percent full) were not modeled. Therefore, the model could be underpredicting the net total evaporation (free surface evaporation plus evapotranspiration from the soil) in the depressions.

Given the current classifications of "possibly intact" and "possibly drained" depressions, the runoff reduction values reported in this study are conservative for two reasons:

- The depressions restored in the 25, 50, and 75 percent restoration scenarios were selected randomly within each subwatershed. The restoration level was uniform across all subwatersheds (e.g., for the 25 percent restoration scenario, 25 percent by volume of the restoration candidates in the Comstock subwatershed was restored, 25 percent by volume of restoration candidates in Edmore was restored, and so forth for each subwatershed). Incremental optimization of the depressions selected for restoration was not performed. It is expected that the runoff reduction volumes would increase for the scenarios having less than 100 percent restoration if the restoration candidates were selected using an optimization routine (i.e., determine which depressions would result in the largest runoff reduction). Potential optimizations include selection by contributing drainage areas, by location (restoring depressions in subwatersheds having high runoff and a larger percentage of "possibly drained" depressions or restoring on-river depressions before off-river), and by depression size or volume.

- Since the net total evaporation from the depressions was probably underpredicted, the annual runoff reduction with depression restoration could be underestimated.

Future Studies

Since the results of this study indicate that depression restoration can reduce the volume of runoff entering Devils Lake, further studies should be conducted to more accurately quantify the runoff reduction resulting from depression restoration. The recommendations for the refinement of the depression delineation and classification were discussed previously.

The hydrologic model, PRINET, was developed in accordance with the study goals to simulate soil and depression storage in the Devils Lake basin. Some simplified algorithms for depression storage and evaporation, snowmelt and frozen ground were incorporated into the model. These algorithms were appropriate for this study. However, the following model refinements are recommended for more detailed analyses:

- The PRINET model did not include a soil moisture algorithm beneath the depressions. Instead, the depressions were modeled as hard-bottom "bowls." Consequently, infiltration of water from a depression into the soil and evapotranspiration from the soil in the dry portions of a depression (when the depression was less than 100 percent full) were not modeled. Therefore, the model could be underpredicting the net total evaporation (free surface evaporation plus evapotranspiration from the soil) in the depressions. A soil moisture accounting algorithm with infiltration and evapotranspiration should be added to the model.

- The Devils Lake evaporation was applied to the depression. Since the depressions are significantly smaller water bodies, the depression evaporation may differ from the Devils Lake evaporation. Some evaporation measurements for different depression sizes would be useful in determining the rate of evaporation from the depressions compared to pan evaporation measurements and the evaporation from Devils Lake.

- A relationship of surface area versus storage was developed for the depressions. This relationship was in the envelope of area-storage curves provided for several of the upper basin lakes. The digital elevation models could be used to refine the area-storage relationships of the depressions.

- The degree-day method was used to simulate snowmelt in PRINET. A more rigorous energy budget algorithm could be developed if the required data are available.

- An infiltration/season break was incorporated in the model to simulate frozen and unfrozen ground conditions (i.e., low and high infiltration conditions). A 30-day moving average of the average daily temperature is used to transition between the two conditions. The volume of runoff is very sensitive to the infiltration break. A more physically-based algorithm should be incorporated into the hydrologic model.

If the hydrologic model is modified, the model must be re-calibrated to observed data before it is used to evaluate depression restoration.

For the restoration scenarios with less than 100 percent depression restoration, the restoration candidates were selected randomly within each subwatershed. Incremental optimization of the depressions selected for restoration was not performed. It is expected that the runoff reduction volumes associated with depression restoration would increase if an optimization routine was used to select the depressions for restoration. Potential optimization parameters are contributing drainage area, depression location, depression size or depression volume.

REFERENCES

West Consultants, INC.& Polaris Group, Final Report, Devils Lake Upper Basin Storage Evaluation, San Diego, CA, 30 April, 2001.

Section 9 – Sheyenne River Hydraulics Model and Flooded Outline Analysis

This section describes the hydraulic models, flow events, water surface profiles, flooded outlines and flooded acres, that were developed to examine the effects of a proposed Devils Lake outlet to the Sheyenne River. The downstream effects of a natural overflow of Devils Lake on Tolna Coulee and the Sheyenne River were also examined.

The full documentation including water surface profiles and flooded outlines for the entire 205 mile reach of the Upper Sheyenne River is available in a separate December 2002 report entitled Devils Lake, North Dakota Integrated Planning Report and Environmental Impact Statement, Sheyenne River, Water Surface Profiles from Lake Ashtabula to Peterson Coulee.

1. Upper Sheyenne River

1.1. Hydraulic Model Development

The hydraulic model of the Upper Sheyenne River covers 205 river miles from Lake Ashtabula to the junction with Peterson Coulee. The model consists of approximately 320 cross sections and includes 42 bridges and 4 low-head dams. The geometric data for the model is based on Light Detection and Ranging (LIDAR) data obtained in 2001 of the above water areas and sounding data at the channel cross sections surveyed in 1940, 1941 and 1944. The LIDAR data has a 5 meter resolution. The North Dakota State Water Commission (NDSWC) resurveyed the same channel cross sections in 1996 and found little change from the historical cross sections (NDSWC 1997). ArcView and GeoRAS were used to georeference the HEC-RAS model and cut cross sections through the LIDAR data. The channel data was then spliced into the HEC-RAS model using available features in the HEC-RAS software.

The HEC-RAS model was initially calibrated to the USGS gages at Warwick and Cooperstown, ND. The model was further calibrated to the water surface profile when the LIDAR data was flown on May 8, 2001 and the 1996 spring flood event.

1.2. Flow Events Modeled

Flows were kept constant along the reach of the river, with the exception of the inflow point at Tolna Coulee. Three flow events were modeled on the Upper Sheyenne River. A section of the water surface profile of the Upper Sheyenne River is shown in Figure A9-1 as a sample.

As Devils Lake rises it naturally overflows into Stump Lake, which naturally overflows into Tolna Coulee. Tolna Coulee then carries the water to the Sheyenne River.

1.2.1. Operation of Devils Lake Outlet

This scenario was modeled to examine effects of a proposed constructed Devils Lake outlet on the Sheyenne River. Water from the Devils Lake outlet is inserted into the

Sheyenne River at Peterson Coulee. Since this model starts at Peterson Coulee, this scenario is modeled as a constant discharge of 600cfs in the Upper Sheyenne River as this is the maximum flow at the insertion point that would occur while the outlet is operating.

1.2.2. Natural Overflow of Devils Lake With Tolna Coulee Protected
This scenario was modeled to examine effects of a natural overflow of Devils Lake through Tolna Coulee, assuming that Tolna Coulee would be protected from erosion. An existing conditions flow of 400cfs on the Sheyenne River upstream of Tolna Coulee was chosen to represent summer conditions in a wet cycle. This was also the flow when the aerial photography and LIDAR was flown. There is no way to determine flooded areas for lower flow events. The natural overflow from Devils Lake is expected to be 550-600cfs if Tolna Coulee is protected from erosion. Therefore, a flow of 600cfs through Tolna Coulee was used, resulting in a flow of 1,000cfs in the Sheyenne River downstream of Tolna Coulee.

1.2.3. Natural Overflow of Devils Lake With Erosion of Tolna Coulee
This event was modeled to examine effects of a natural overflow of Devils Lake through Tolna Coulee, assuming that the high area in Tolna Coulee would erode up to 9 feet. An existing conditions flow of 400cfs on the Sheyenne River upstream of Tolna Coulee was chosen to represent summer conditions in a wet cycle. This was also the flow when the aerial photography and LIDAR was flown. There is no way to determine flooded areas for lower flow events. The natural overflow from Devils Lake is expected to be 6,000cfs if Tolna Coulee is eroded. Therefore, a flow of 6,000cfs through Tolna Coulee was used, resulting in a flow of 6,400cfs in the Sheyenne River downstream of Tolna Coulee.

1.3. Flooded Area Analysis
The HEC-RAS results were exported and brought into ArcView using GeoRAS. The resulting water surface profiles were created as a surface in ArcView. The LIDAR data was subtracted from the water surface and all the areas that were at or below the water surface were plotted as a flooded area. A section of the flooded outline of the Upper Sheyenne River for the operation of the Devils Lake outlet is shown in Figure A9-2 as a sample.

1.3.1. Flooded Area Resulting from the Operation of a Devils Lake Outlet
The flooded area of the Upper Sheyenne River with a flow of 600cfs is 11,573 acres. The shoreline of the Upper Sheyenne River was used to come up with the area within the natural channel area of 8,083 acres. Therefore, the increase in flooded area over the natural channel area as a result of a Devils Lake Outlet is 3,490 acres.

1.3.2. Flooded Area Resulting from a Natural Overflow of Devils Lake
Flooded areas for the natural overflow scenarios were plotted for use in an animation program, but the results were not calculated.

2. Tolna Coulee

2.1 Hydraulic Model Development
The hydraulic model of Tolna Coulee covers 16 river miles from its mouth at the Sheyenne River to the junction with Stump Lake. The model consists of 79 cross sections and includes 8 bridges and 2 low-head dams. LIDAR data, with a 5 meter resolution, and a USGS Digital Elevation Model (DEM), with a 30 meter resolution, was used for the valley and floodplain geometry. Channel cross sections were surveyed in 1986 by the Corps of Engineers. ArcView and GeoRAS were used to georeference the HEC-RAS model and cut cross sections through the valley and floodplain. The channel data was then spliced into the HEC-RAS model using available features in the HEC-RAS software. The model was calibrated to the rating curve at Tolna Dam.

2.2. Flow Events Modeled
Two flow events were modeled on Tolna Coulee to examine the effects of a natural overflow of Devils Lake on Tolna Coulee. The first natural overflow scenario had a flow of 600cfs and assumed that the high area of Tolna Coulee would be protected from erosion. The second natural overflow scenario had a flow of 6,000cfs and assumed that the high area of Tolna Coulee would erode up to 9 feet.

2.3. Flooded Area Analysis
The HEC-RAS results were exported and brought into ArcView using GeoRAS. The resulting water surface profiles were created as a surface in ArcView. The LIDAR data was subtracted from the water surface and all the areas that were at or below the water surface were plotted as a flooded area. Flooded areas for the natural overflow scenarios were plotted for use in an animation program, but the results were not calculated.

3. Lower Sheyenne River

3.1. Hydraulic Model Development
The hydraulic model of the Lower Sheyenne River covers approximately 520 river miles from the USGS gage at Horace above the diversion to Baldhill Dam. The model consists of approximately 867 cross sections and includes 36 bridges and 4 low-head dams. The geometric data for the model is based on channel cross sections surveyed in 1940, 1941 and 1944. The North Dakota State Water Commission (NDSWC) resurveyed the same channel cross sections in 1996 and found little change from the historical cross sections (NDSWC 1997).

The model was calibrated to the USGS gages at below Baldhill Dam, Lisbon, Kindred and Horace above the diversion.

3.2. Flow Events Modeled
Flows were kept constant along this reach of the river. The following flows were modeled; 100, 300, 600, 1000, 1500, 2000, 3000 and 7000 cfs.

3.3. Flooded Area Analysis
A surface of the water surface profile for each flow event was created in ArcView. The LIDAR data was subtracted from the water surface and all areas at or below the water

surface were plotted as a flooded area. There is no flooded area shown in places where the water surface (and thus the flows values) were greater on the day the LIDAR data was flown than the hypothetical flows being modeled. For example, the flow at some parts of the area studied was about 700 cfs when the LIDAR data was flown resulting in little or no flooded area showing up (including the channel itself) for the 100, 300 and 600 cfs profiles in some places. The aerial extent of the flooded outlines for 1000 cfs and above were verified as a good match with aerial orthophotos of the 1993, 1996 and 1997 floods, some of which were scanned into the computer and used as an overlayment in ArcView.

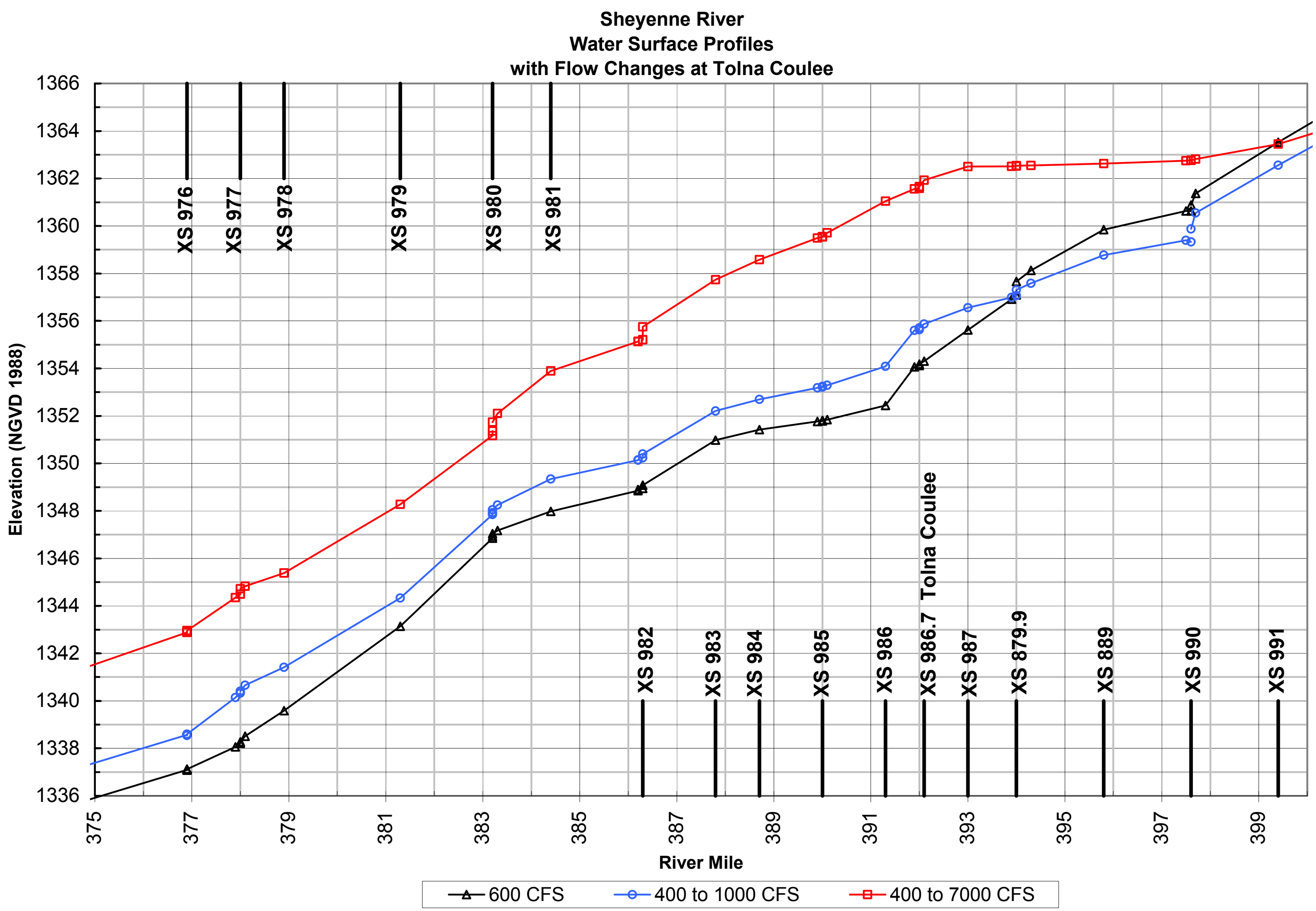
3.4. New HEC-RAS Model Being Developed

A new HEC-RAS model is currently being built as part of the Baldhill Dam Pool Raise that will utilize the 2001 LIDAR data and will be of the same level of detail as the Upper Sheyenne River HEC-RAS model.

REFERENCES

North Dakota State Water Commission. 1997. Upper Sheyenne River Channel Capacity Study. Devils Lake Feasibility Study Project No. 416-1. Bismark, North Dakota.

St. Paul District, U.S. Army Corps of Engineers. 2002. Devils Lake, North Dakota Integrated Planning Report and Environmental Impact Statement, Sheyenne River, Water Surface Profiles from Lake Ashtabula to Peterson Coulee. St. Paul, Minnesota.



Sheyenne River
Water Surface Profiles
with Flow Changes at Tolna Coulee
Elevation (NGVD 1988)
River Mile
1366
1364
1362
1360
1358
1356
1354
1352
1350
1348
1346
1344
1342
1340
1338
1336
375
377
379
381
383
385
387
389
391
393
395
397
399
XS 976
XS 977
XS 978
XS 979
XS 980
XS 981
XS 982
XS 983
XS 984
XS 985
XS 986
XS 986.7
Tolna Coulee
XS 987
XS 879.9
XS 889
XS 990
XS 991
600 CFS
400 to 1000 CFS
400 to 7000 CFS

Figure A9- 1

Devils Lake Outlet - Sheyenne River Flooded Area for 600 cfs
Vicinity of Tolna Coulee

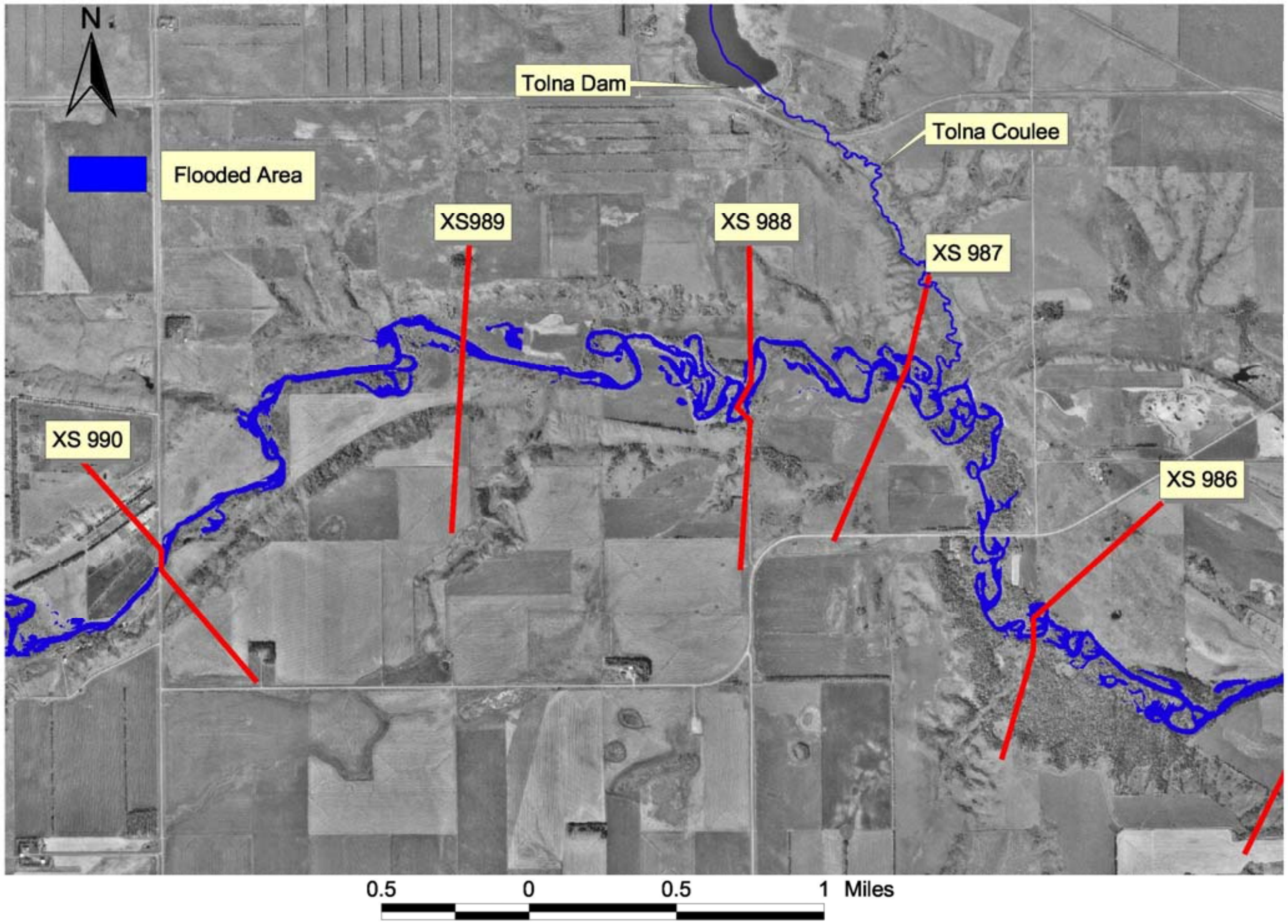


Figure A9-2

Section 10 -Sheyenne River Geomorphology Study

A geomorphology study of the Sheyenne River was done by West Consultants, Inc. to evaluate the effects of a proposed outlet on the Sheyenne River. The following text is a summary of the predicted outlet effects from the report. Reference: West Consultants, Inc. 2001. "Sheyenne River Geomorphology Study."

Predicted Project Effects

General

Specific analyses to estimate changes in the geomorphology of the Sheyenne River for both future without project (no pumping) and with project (pumping) conditions were described in previous chapters of the report. This chapter summarizes the overall impact of the proposed project on the River.

Changes in Channel Dimensions

Changes in channel dimensions were predicted by selecting the dominant (or channel forming) discharge at each precision cross section (Chapter 4) and applying these to regime equations (Chapter 5). The SAM stable channel methodology, using the Brownlie D_{50} equation for sediment concentration, was found to predict channel parameters for existing conditions closest to those observed. Therefore, this relationship was also used to predict future channel dimensions. In addition, it was noted that from 1940 to 1998, for most of the precision cross sections, hydraulic parameters were changing in a direction consistent with regime equation predictions.

For future conditions, top width, average depth, and slope were examined for six different scenarios which were classified by future climatic conditions (moderate or wet) and the amount of pumping considered (no pump, 300 cubic feet per second (cfs) constrained, and 480 cfs unconstrained).

Under moderate climate pumping scenarios, top widths are expected to change only slightly from no pumping futures: up to 3 feet for the 300 cfs scenario and 4 feet for the 480 cfs scenario. For wet future pumping scenarios, top widths also will increase only 3-5 feet over the no pumping scenario results. Changes in depth are predicted to be negligible for all of the pumping versus no pumping futures. Adjustments in channel slope are also expected to be very minor.

The acres eroded to an increase in average channel width by trace is shown on the following page in Table A10-1. Each scenario is labeled first by the future climate and then by the pumping amount to yield the following abbreviations for the 6 scenarios: Mdnp, Md300, Md480, Wtnp, Wt300, and Wt480.

Table A10-1
Acres Eroded Due to Increase in Average Channel Width by Trace

Reach	Mdnp	Md300	Md480	Wtnp	Wt300	Wt480
A	7.6	15.2	20.4	76.5	89.3	102.1
B	0	0.5	4	65.9	68.6	75.3
C	0	0	0	200.5	211.3	211.3
D	0	0	0	108.3	108.3	110.3
E	0	0	0	109.1	115.4	126
F	0	0	0	131.2	131.2	138.2
H2	0	0	0	33.8	33.8	38
H3	0	0	0	75.9	75.9	79.8
I	0	0	0	102.9	102.9	108.1
J	0	0	0	139.7	139.7	139.5
K	0	0	0	47.6	47.6	48.1
Total	**7.6**	**15.7**	**24.5**	**1091.3**	**1123.9**	**1176.6**

Changes in Planform

Comparison between the river planform in 1998 and as early as 1951 shows that the river appears to be in a quasi-stable state. The proposed change in flow in the river will affect this stable state and the river will attempt to establish a new stable state. According to theoretical calculations the river will change its meander length, meander amplitude, and channel shape to accomplish this.

Theoretical equations that predict meander length and amplitude as a function of channel width were applied using 1998 channel widths and the results then compared with measured values from the 1998 orthophotographs. The comparison showed mixed agreement between the computed and measured values. However, as the focus of the study is on the *change* in these parameters between no pump and pumping conditions, and because other methods are not currently available, the equations were applied to future pump and no pump alternatives under both climatic scenarios. In general, changes due to project conditions were small, with higher (480 cfs) pumping scenario causing greater change than the lower (300 cfs) one.

Changes in the predicted meander length between the with and without pumping futures are relatively small for the moderate climate scenarios. Maximum changes of 33 feet and 44 feet were predicted for the Md300 and Md480 scenarios, respectively. These changes would be applied to the entire meander length, between 500 and 1,500 feet for existing conditions. The results for the wet climate scenarios follow a similar pattern, with a predicted maximum increase in meander length of 28 feet and 57 feet for the Wt300 and Wt480 scenarios, respectively.

The predicted change in meander amplitude between with and without project conditions is also small, with maximum values of 14 feet and 19 feet for the Md300 and Md480 scenarios, respectively. Maximum predicted changes between with and without project conditions are 12 feet and 24 feet for the Wt300 and Wt480 scenarios, respectively. These predicted changes would be applied to existing meander amplitudes, measuring 60 to 650 feet under current conditions.

The acres eroded due to changes planform changes caused by pumping for each scenario are shown below in Table A10-2.

Table A10-2.
Acres Eroded Due to Planform Changes Caused by Pumping by Trace

Reach	Md300-Mdnp	Md480-Mdnp	Wt300-Wtnp	Wt480-Wtnp
A	19.6	32.9	33.1	65.7
B	1.2	10.1	7.9	24.5
C	0	0	28.6	28.6
D	0	21.6	0	6.4
E	0	9.7	16.9	44
F	4.6	22.3	0	18.2
H2	2.6	2.6	0	10.5
H3	15.5	20.8	0	10.3
I	4.7	17.5	0	13.1
J	4.9	3.3	0	0.1
K	0	4.6	0	1.3
Total	**53.1**	**145.4**	**86.5**	**229.1**

Width Adjustment

In order to estimate a maximum probable lateral erosion rate, channel bends were analyzed in each of the reaches from the 7.5 minute USGS topographic maps and the 1998 orthophoto data sets. Channel bends are under direct attack from the current and will experience more lateral movement over time than straighter reaches of the river. The observed lateral movement of channel bends ranged from a minimum of zero (i.e., the bend did not move appreciably during the time period) to a maximum of 27 meters over a period of 38 years for a bend in reach C2. The maximum computed lateral erosion rate was therefore 27/38 = 0.7 m/yr or 2.3 ft/yr.

The time for width change adjustment was computed for each reach and trace by calculating a maximum probable lateral erosion rate at channel bends. Because the average adjustment rate for a reach will most probably be slower that the maximum observed bend erosion rate, the adjustment time is expected to be greater than the values shown. However, even if the actual erosion rates are assumed to be one-half of the maximum rate, the changes predicted to occur will happen within a normal expected project life of 50 to 100 years.

The times shown in Table A10-3 below are conservative because the actual adjustment time will probably take longer than the values shown. (Note that times are not provided for reaches predicted to narrow.)

Table A10-3 Adjustment Time (Years) for Changes in Average Theoretical Channel Widths by Trace

Reach	# Values Averaged	Mdnp	Md300	Md480	Wtnp	Wt300	Wt480
A2	1	0.4	1.3	1.7	6.4	7.3	8.6
B3	2			0.4	8.1	8.6	9
C2	2				10.3	10.7	10.7
D3	6				6.4	6.4	6.4
E2	3				5.6	6	6.4
F2	1				10.7	10.7	11.6
H2	1				6.9	6.9	7.7
H3	1				15.4	15.4	16.3
I4	1				8.6	8.6	9
J1	2				26.2	26.2	26.2
K3	1				15.4	15.4	15.4

System Wide Adjustment

System-wide adjustment will occur when the channel width, meander length and amplitude, and channel slope have all reached quasi-equilibrium conditions. The time to reach equilibrium is much greater than the width adjustment time. System wide adjustment time could actually be many hundreds of years, well beyond a normal project lifetime. Scientific prediction of the adjustment time is not possible given the state of the art. Overall system adjustment will take much longer, perhaps 300 to 1,000 years. Rough calculations were performed assuming that the material removed from a given reach as the channel moves towards equilibrium is transported entirely by the increased flows. The calculation gave a conservative estimate of the time needed to reach system-wide equilibrium of 332 years.

Changes in Erosion Rates

The rate at which the present channel will adjust and reach a new quasi-equilibrium state is extremely difficult to predict. Variations in bank material, vegetation, bank failure mechanisms, and sediment supply to a reach (among other factors) increase the uncertainty of any predictions (effects of vegetation are treated in more detail in Chapter

8). However, it can be assumed that increased erosion would occur due to increased discharges until a new state of stability is reached.

The current erosion rate was calculated to be 27 acres per year for the length of the Sheyenne River studied. This rate takes into account only erosion occurring while the river is in its current quasi-stable state. After the river is removed from this steady state it is difficult to determine what time period is necessary to establish a new steady state. It can however be assumed that erosion rates will increase during that time, particularly in the wet scenarios where the difference between predicted and current theoretical calculations is the largest.

A rough estimate of changes in erosion rates can be computed. The change in erosion rate due to width changes was calculated by dividing the acres eroded (Table A10-1) by the adjustment time (Table A10-3) for each reach and trace. The change in erosion rate due to width changes is shown in Table A10-4 on the following page. Readers should keep in mind the adjustment time over which the erosion rate will be applied. An erosion rate may be higher, but only occur over a very small span of time. The erosion rates shown are in acres per year.

Table A10-4.
Erosion Rate Due to Increase in Average Channel Width by Trace

Reach	Mdnp	Md300	Md480	Wtnp	Wt300	Wt480
A	19.0	11.7	12.0	12.0	12.2	11.9
B	N/A	N/A	10.0	8.1	8.0	8.4
C	N/A	N/A	N/A	19.5	19.7	19.7
D	N/A	N/A	N/A	16.9	16.9	17.2
E	N/A	N/A	N/A	19.5	19.2	19.7
F	N/A	N/A	N/A	12.3	12.3	11.9
H2	N/A	N/A	N/A	4.9	4.9	4.9
H3	N/A	N/A	N/A	4.9	4.9	4.9
I	N/A	N/A	N/A	12.0	12.0	12.0
J	N/A	N/A	N/A	5.3	5.3	5.3
K	N/A	N/A	N/A	3.1	3.1	3.1
Total	**19.0**	**11.7**	**22.0**	**118.4**	**118.6**	**119.1**

The change in erosion rate due to planform changes was calculated by dividing the acres eroded (Table A10-2) by the system wide adjustment time (332 years) for each reach and trace. The change in erosion rate due to planform changes is shown in Table A10-5 on the following page. The erosion rates shown are in acres per year.

Table A10-5.
Erosion Rate Due to Planform Changes Caused by Pumping by Trace

Reach	Md300	Md480	Wt300	Wt480
A	0.0590	0.0991	0.0997	0.1979
B	0.0036	0.0304	0.0238	0.0738
C	0.00	0.00	0.0861	0.0861
D	0.00	0.0651	0.00	0.0193
E	0.00	0.0292	0.0509	0.1325
F	0.0139	0.0672	0.00	0.0548
H2	0.0078	0.0078	0.00	0.0316
H3	0.0467	0.0627	0.00	0.0310
I	0.0142	0.0527	0.00	0.0395
J	0.0148	0.0099	0.00	0.0003
K	0.00	0.0139	0.00	0.0039
Total	**0.16**	**0.44**	**0.26**	**0.67**

A conservative assumption (that is, one yielding *higher* eroded land results) would be to assume that the planform erosion (due to flow changes) and the historical average (27 acres per year, based on meander migration) are additive. A total erosion rate, shown below in Table A10-6, is estimated by adding the results in Tables A10-4 and A10-5.

Table A10-6.
Total Erosion Rate by Trace

Reach	Mdnp	Md300	Md480	Wtnp	Wt300	Wt480
A	19.0	11.8	12.1	12.0	12.3	12.1
B	0.0	0.0	10.0	8.1	8.0	8.4
C	0.0	0.0	0.0	19.5	19.8	19.8
D	0.0	0.0	0.1	16.9	16.9	17.3
E	0.0	0.0	0.0	19.5	19.3	19.8
F	0.0	0.0	0.1	12.3	12.3	12.0
H2	0.0	0.0	0.0	4.9	4.9	5.0
H3	0.0	0.0	0.1	4.9	4.9	4.9
I	0.0	0.0	0.1	12.0	12.0	12.1
J	0.0	0.0	0.0	5.3	5.3	5.3
K	0.0	0.0	0.0	3.1	3.1	3.1
Subtotal	19.0	11.9	22.4	118.4	118.8	119.8
Historical	27.0	27.0	27.0	27.0	27.0	27.0
Total	**46.0**	**38.9**	**49.4**	**145.4**	**145.8**	**146.8**

The increase in erosion rate due to pumping would be determined by subtracting the no pump trace from the pumping traces. These values range from no increase in erosion rate to an increase of 3.4 acres/year.

Stream Classification

Precision cross sections were classified using the Rosgen system (as described in Chapter 7) for two purposes: 1) to aid in communication when discussing the channel reaches and, 2) to predict approximate rates at which the morphology of the sections might change in response to the future pumping scenarios. In spite of possible limitations in the predictive capability of the Rosgen system, the results are still useful when viewed in conjunction with the regime channel and planform analysis results described in Chapters 5 and 6. Predicted channel adjustment rates could be slower than those estimated from the regime channel and planform analyses for certain cross sections where the Rosgen system predicts slow rates of adjustment.

The Rosgen Classification for the existing Sheyenne River channel based on the 1998 surveyed cross sections is shown in Table A10-7 on the following page.

The book *Applied River Morphology* (Rosgen, 1996) should be consulted for a detailed description of the classification types. Chapter 7 of the report provides a few excerpts from Rosgen's book describing the channel types found in the Sheyenne River.

Regime geometry for future scenarios was predicted using SAM. The width/depth ratio was the only needed Rosgen classification parameter that could change enough to cause a reclassification. The SAM regime width/depth ratios for the historical and future traces are nearly identical at most cross sections resulting in identical Rosgen classifications.

Table A10-8 summarizes the differences between the width/depth categories for the 1998 surveyed cross sections and the SAM regime geometries. The table also provides the Rosgen classification for the SAM regime geometry where it differs from the existing conditions (1998) geometry.

Three of the 21 precision cross sections were classified differently based on the SAM regime geometry when compared to the Rosgen classifications based on the 1998 surveyed cross sections (existing conditions). However, these classification changes are **not** the result of pumping since they apply equally to the SAM predicted historical geometry as well as all the SAM predicted future geometries for the various future flow scenarios.

Table A10-7 Rosgen Classification for 1998 Precision Cross Sections

Reach and section	HEC-RAS section number	Entrench-ment*	Width/depth category**	Sinuosity	Bed material	Rosgen class
A2-f	48	Moderate / Slight	Moderate to High / Low	Very High	Sand	B5c
B3-a	Between 275 & 276	Moderate	Low / Moderate to High	Very High	Sand	B5c
B3-e	276	Moderate	Low / Moderate to High	Very High	Sand	B5c
C2-d	371	Entrenched	Moderate to High	Very High	Sand	G5c
C2-j	372	Moderate	Low / Moderate to High	Very High	Sand	B5c
D3-a	594	Moderate / Entrenched	Moderate to High / Low	Very High	Silt/Clay	B6c
D3-d	595	Slight	Moderate to High / Low	Very High	Silt/Clay	C6c
D3-f	596	Slight	Low	Very High	Silt/Clay	E6
D3-h	597	Slight	Moderate to High / Low	Very High	Silt/Clay	C6c
D3-k	598	Moderate	Moderate to High / Low	Very High	Silt/Clay	B6c
D3-l	599	Moderate	Moderate to High	Very High	Silt/Clay	B6c
E2-a	685	Slight	Moderate to High / Low	Very High	Silt/Clay	C6c
E2-f	686	Slight	Low	Very High	Silt/Clay	E6
E2-j	687	Slight	Moderate to High	Very High	Silt/Clay	C6c
F2-a	952	Slight	Moderate to High / Low	Very High	Sand	C5c
H2-i	980	Slight	Moderate to High	Very High	Gravel	C4c
H3-f	982	Slight	Moderate to High	Very High	Sand	C5c
I4-a	1019	Moderate	Moderate to High	Very High	Sand	B5c
J1-a	1026	Slight	Moderate to High	Low	Silt/Clay	C6c
J1-e	1027	Slight	Moderate to High	Low	Silt/Clay	C6c
K3-j	1045	Slight	Moderate to High	Very High	Sand	C5c
L1-a	1047	Entrenched / Moderate	Moderate to High	Very High	Sand***	F5

* Entrenchment ratios from 1 to 1.4 are "entrenched," those from 1.4 to 2.2 are "moderate," and those greater than 2.2 are "slight." The Rosgen system allows for entrenchments to vary +/- 0.2 from the classification boundaries of 1.4 and 2.2. Therefore, some entrenchment ratios are "borderline," that is, not definitely in any one category. In these cases, the category where the entrenchment ratio lies appears before the slash, and the category that the entrenchment ratio is near appears after the slash.

** The Rosgen system allows for width/depth ratios to vary +/- 2.0 from the boundary of 12. Therefore, some width/depth ratios are not definitely in any one category. Ratios less than 10 are "Low." Those greater than 14 are "Moderate to High." Those ratios from 10 to 12 are classified as "Low / Moderate to High," while those widths over depths from 12 to 14 are classified as "Moderate to High / Low."

*** The D50 channel material of 2.2 mm is very fine gravel, but very near the border with very coarse sand. Based on field trip observations, the channel material was classified as sand.

Table A10-8 Rosgen Classification of Existing Condition (1998) Cross Sections and Predicted SAM Regime Geometry

Reach and section	Rosgen class (1998 cross section)	Rosgen class sensitivity to disturbances in flow or sediment transport	Width/depth category for 1998 cross section	SAM predicted width/depth ratio for historical conditions and all future scenarios	Rosgen class for SAM regime geometry, if different*
A2-f	B5c	Low	Moderate to High / Low	Moderate To High	-
B3-a	B5c	Low	Low / Moderate to High	Moderate To High	-
B3-e	B5c	Low	Low / Moderate to High	Moderate To High	-
C2-d	G5c	Very High	Moderate to High	Moderate To High	-
C2-j	B5c	Low	Low / Moderate to High	Moderate To High	-
D3-a	B6c	Low	Moderate to High / Low	Low*	
D3-d	C6c	High	Moderate to High / Low	Low	E6
D3-f	E6	Low	Low	Moderate To High	C6c
D3-h	C6c	High	Moderate to High / Low	Moderate To High / Low	-
D3-k	B6c	Low	Moderate to High / Low	Low / Moderate To High	-
D3-l	B6c	Low	Moderate to High	Low / Moderate To High	-
E2-a	C6c	High	Moderate to High / Low	Moderate To High / Low	-
E2-f	E6	Low	Low	Moderate To High	C6c
E2-j	C6c	High	Moderate to High	Moderate To High / Low	-
F2-a	C5c	High	Moderate to High / Low	Moderate To High	-
H2-i	C4c	High	Moderate to High	Moderate To High / Low	-
H3-f	C5c	High	Moderate to High	Moderate To High	-
I4-a	B5c	Low	Moderate to High	Moderate To High	-
J1-a	C6c	High	Moderate to High	Moderate To High	-
J1-e	C6c	High	Moderate to High	Moderate To High	-
K3-j	C5c	High	Moderate to High	Moderate To High	-

* Per the Rosgen system, all B streams with moderate entrenchment ratios should have width/depth ratios that are classified as “moderate to high.” In the existing conditions (1998) cross sections, all B classified sections had entrenchment ratios greater than 10. This makes all of them moderate to high, (ratio > 12) or potentially moderate to high within the error limits given by Rosgen (ratio > 10). The D3-a section has a SAM regime predicted width/depth ratio of 9.5 which is clearly in the low category. Rosgen mentions, however, that the B6 stream type has the lowest width/depth ratios of the all B stream types, due to cohesive banks. Because of this, and because the primary categorization is by entrenchment ratio, the SAM regime geometry for D3-a section was classified B6c, unchanged from the 1998 classification.

Vegetation

The increased flows from the pumping scenarios will cause increased stages and durations of inundation. The amount of inundation experienced by various plant species will have a direct effect on plant survivability. In addition to potential weakening of the bank due to vegetative loss, shear stresses and velocities along the bed and banks will also be increased which in turn will increase the rate of bank erosion. It may be expected that the river will widen until a regime condition or dynamic equilibrium is reached. It should be noted that none of the regime methods employed consider the added resistance of banks to erosion due to vegetation. Thus, predicted widening may be less than computed herein if vegetative effects are considered.

Both pumping alternatives have the potential to damage the floodplain vegetation to some extent. However, the 300 cfs constrained pumping alternative would cause much less damage than the 480 cfs unconstrained pumping alternative under either the moderate or the wet climate scenario.

The species listed as "intolerant" and "somewhat tolerant" in Table 8-1 cannot be expected to survive the increased inundation due to the 480 cfs unconstrained pumping alternative for both the moderate and wet scenarios. The 300 cfs constrained pumping alternative can be expected to cause some flooding damage from which the vegetation could be expected to recover, provided flooding is not repeated in consecutive years.

Both pumping alternatives have the potential to prevent the establishment of seed on riverine depositional surfaces. However, the 300 cfs constrained pumping alternative would cause much less damage than the 480 cfs unconstrained pumping alternative for both the moderate and wet climate scenarios.

The effect of long-term channel change on the vegetation will be limited to near-bank riparian vegetation loss in some reaches due to localized bank failures and may be considered minor in nature.

The influence of long-term vegetation changes for the 300 cfs constrained pumping alternative on the channel morphology is expected to be of a minor nature for both the moderate and wet climate scenarios. However, long-term vegetation changes due to the 480 cfs unconstrained pumping alternative could have significant adverse impacts on channel stability for both climate scenarios. The loss of vegetation is thought to have more of an effect on the rate of erosion to reach the predicted ultimate values rather than the values themselves.

Adjustment of the Sheyenne River after Periods of Prolonged Pumping

As described in the preceding sections, pumping of water from Devils Lake to the Sheyenne River is expected to have an effect on the morphology of the latter. New quasi-equilibrium conditions have been predicted for the project scenarios. The time necessary for the transition from one morphologic state to another can only be roughly estimated and will depend on many factors including bank resistance and vegetation. Initial width adjustment is expected to occur relatively quickly, perhaps measured in decades. However, overall adjustment of the Sheyenne River system to new hydrologic conditions (due to pumping and/or climatic shifts) is expected to take hundreds of years.

From the preceding analyses, it appears that the assumption of moderate or wet climatic conditions will have more of an effect on changes in channel behavior than whether or not pumping is occurring. However, between pumping scenarios for a given climate condition, the larger pumping scenario (480 cfs) is predicted to have a much greater effect on channel morphology than the smaller (300 cfs) scenario, especially in regards to impact on vegetation.

Section 11 - Upper Basin Water Management Measures

Introduction

Basin water management has long been recognized as a viable and valuable component of Devils Lake flood control. The North Dakota State Water Commission (NDSWC) considers it an integral element of the recommended overall flood control package along with infrastructure protection and an outlet. For example, this three-pronged approach is cited in the Devils Lake Basin Water Management Plan (**reference 1**) as a necessary and comprehensive approach to alleviate flooding in the basin.

In the context of Devils Lake's flooding, the goal of basin water management is to reduce the volume of runoff that reaches Devils Lake. The focus has been on upper basin storage; however, comprehensive basin water management encompasses a range of activities that can help retain water in the upper basin, including restoring wetlands, creating new holding ponds, eliminating illegal drains, and changing farming practices. Examples of the latter include conservation tillage to retain more moisture in the soil profile, converting cropland to grass or another permanent cover, and manipulating gates on field drains to control flows, especially in the spring, to allow additional water to percolate into the soil.

Side benefits from such water management measures accrue to a multitude of interests – reducing sheet erosion, increasing crop production, improving water quality, increasing wildlife habitat, and reducing flooding.

The effectiveness (or benefit) of basin water management can be measured in terms of the volume of water prevented from reaching Devils Lake. To determine if effectiveness was a function of the location of a retention site in the upper basin, a preliminary study of the Starkweather Coulee subbasin was conducted **(reference 2)**. The Corps found that the region's flat, prairie pothole terrain was characterized by a substantial (18 percent) noncontributing portion, i.e., "landlocked" areas that do not contribute runoff to Devils Lake under normal circumstances. However, the recent successive years of higher than average precipitation and reduced evaporation might have filled some of these mini-closed basin and temporarily converted them into contributing areas. The District also found that site effectiveness is not a function of distance from Devils Lake. Therefore, retention site selection may be based simply on the estimated initial storage and regeneration capacities of sites, i.e., volume restored by evaporation and/or percolation.

Another study was done by the USGS, entitled, "Simulation of Streamflow and Wetland Storage, Starkweather Coulee Subbasin, North Dakota, Water Years 1981-98 **(reference 3)**. The study used digital elevation data to identify wetland area and storage in the Starkweather Coulee subbasin. Using the USGS Precipitation-Runoff Modeling System, the study indicated that significant runoff reduction could be achieved by increasing the spillage thresholds (point of overflow thereby increasing storage).

The Bureau of Reclamation (BOR) conducted a pilot study of the St. Joe-Calio Coulee subbasin entitled, "Wetlands Inventory and Drained Wetlands Water Storage Capacity Estimation for the St. Joe-Calio Coulee Subbasin of the Greater Devils Lake Basin, North Dakota**"(reference 4)**. They used high-resolution aerial photographs to identify drained wetlands throughout the subbasin, taking even higher resolution aerial photographs of 15 percent of the subbasin to develop 1-foot contours, and then extrapolating those results to the remainder of the subbasin. The study indicated that plugging all drains within the basin would store less than the equivalent of five inches off Devils Lake, at current lake levels. The actual impact may be less on Devils Lake because many of the identified drains contribute runoff to small, closed subbasins and some of these drains also contribute runoff to Stump Lake, which is not tributary to Devils Lake.

The Corps of Engineers also assessed the impacts of upper basin storage restoration alternatives on the inflows to Devils Lake **(reference 5)**. The upper basin storage alternative under consideration was the restoration of "possibly drained" depressions. A vast amount of geographic and historical data was collected to (1) delineate and classify the depressions, and (2) develop a physically based hydrologic model to simulate the hydrologic functions of the depressions. Results of this study indicate that depression restoration can reduce the volume of runoff entering Devils Lake (approximately 22 percent of the storage volume). More detailed information from this study is presented in Appendix A, Section 8.

In looking at the implementability of basin water management measures to reduce Devils Lake flooding, it is important to recognize potential adverse impacts from these measures. For instance, farmers may readily agree to store water in a low spot that has been too wet to till for years. However, they are not likely to store water on previously dry land that would take pasture or crop acreage out of production on top of what has already been lost to flooding. The latter has an added negative impact on other elements of the local, agriculture-based economy. Also, landowners note that percolation from retention sites raises the water table, which often brings salts to the surface in the vicinity of the storage site, adversely affecting future crop production. Water storage may also limit access to other fields, increase input or costs, lead to additional depredation, and increase weed problems. Such problems, real or perceived, make the acceptance of such measures on a voluntary and even a compensated basis difficult for the landowner.

The supposition that farm drainage is responsible for the current flooding is generally accompanied by the proposition that artificial drainage into Devils Lake should be restricted before constructing an outlet. And some interests contend that the outlet would encourage even more upper basin drainage. Frustrations and conflicting opinions about basin drainage reached a peak during the record-setting 1997 spring runoff when even local interests with economic ties to the basin's farmers began to raise the issue.

As a first step in addressing the issue, in June 1997, Governor Ed Schafer directed the NDSWC to identify illegal drains in the Devils Lake basin and to work with local water resource boards to close them. The NDSWC found 22,575 drains in the basin draining 41,305 acres of wetlands. Of these drains, 244 (1.1 percent) were earmarked as potentially illegal, i.e., post-1957 nonpermitted drains with a watershed exceeding 80 acres. Descriptions of potentially illegal drains were turned over to the county water resource boards for further investigation and proper action.

The second step is to restore drained wetlands and create more storage potential. To date, Federal and State programs have been on a voluntary, compensated basis. However, some natural resource agencies and special interest groups are suggesting that it is necessary to consider alternatives beyond voluntary and compensated participation, e.g., regulating legal drains such that they could not be operated when Devils Lake exceeded some specified elevation. The practicability and ramifications of this proposal have not been investigated; however, the NDSWC feels that it might cause more severe economic impacts due to lost cropland than damages incurred if the same water reached Devils Lake.

Table A11-1 lists various Federal and State programs that store water or reduce runoff in the basin. As of year 2002, at least 83,000 acre-feet have been restored. There are plans for at least another 9,700 acre-feet. A rough estimate of the equivalent reduction in lake level for the values listed in **Table A11-1** can be made by using results from other studies. For example, for those programs that list only area restored, a factor of 2.1 would estimate the corresponding volume **(reference 5)**. The District determined that the amount of runoff reduction to Devils Lake is only 22 percent of the volume of the storage sites **(reference 5**). To estimate the volume reduction for set-aside land, an estimate of 0.06 foot per acre could be used **(Table A11-4**). Based on these assumptions, the average annual storage reduction on Devils Lake is about 35,000 acre-feet for the values listed in **Table A11-1**. This is equivalent to only about 3-1/2 inches on Devils Lake. This retention capacity would vary from year to year as participants are gained or lost, sites are inundated by Devils Lake, and evaporation and percolation restore site capacity.

Table A11-1 shows retention capacity provided under formal programs. In addition, there is substantial, unquantified storage from existing wetlands, changed tillage practices, and land inundated during the current wet cycle. The Farm Services Agency estimates that over 300,000 acres of farmland in the Devils Lake basin has been rendered unproductive due to wet conditions since 1992. This figure is corroborated by satellite imagery covering about 3,000 square miles (79 percent) of the Devils Lake Basin. On the basis of imagery taken on 17 August 1992, prior to the recent lake rise, the lake itself was about 44,000 acres in size and the area covered by water in the upper basin was nearly 43,000 acres. Imagery taken on 14 July 1997 showed the lake had doubled in size to over 88,000 acres, and the area covered by water in the upper basin had more than tripled to about 152,000 acres.

TABLE A11-1.
Federal and State Programs that Offer Water Retention Benefits

Programs	Area acres	Volume, Acre-feet
Ongoing storage programs;		
NDSWC		
Available Storage Acreage Program (ASAP)		69,500
Extended Storage Acreage Program (ESAP)	400	800
USFWS	6,268	9,130
Natural Resource Conservation Service		
Federal Waterbank Program	3,700	
Wetland Reserve Program (WRP)		N/A
Farm Service Agency Farmable Wetlands Pilot Program (FWP)		N/A
ND Department of Agriculture's State Waterbank Program		N/A
ND Natural Resource Wetlands Trust (NDNRT)	4,086	
Ongoing programs that reduce runoff		
Natural Resource Conservation Service		
Emergency Watershed Protection- Flood Plain Easement Program (EWP)	2,777	
Environmental Quality Incentive Program (EQIP)		N/A
Farm Services Agency's Conservation Reserve Program (CRP)	193,530	
Sustainable Agriculture and Research Education (SARE)		N/A
ND Game and Fish Department		
Habitat Plot Program	2,300	
Private Land Initiative (PLI)		N/A
ND Natural Resource Wetlands Trust (NDNRT)	14,545	
Sweetwater-Morrison Lake		3,500

Programs

The Devils Lake Basin Joint Water Resource Board (DLBJWRB) and the North Dakota State Water Commission (NDSWC) completed the first Devils Lake Basin Water Management Plan in year 1995. That plan was updated in year 2002. The purpose of the plan is to "provide general background on water and land resources, to define water management issues, to update project needs, to state objectives, and to provide strategies designed to manage the Devils Lake Basin in a manner that best meets the needs of all interested parties" **(reference 1**). The most important aspect of the plan is to ensure that all relevant state, federal, and private agencies, make a unified effort to achieve the management strategies and objectives of the plan, which serves as a constant reminder of what actions need to be completed in the basin. It is a working plan that will continually be updated. The NDSWC in association with the DLBJWRB also funds a full-time engineering position.

The 1995 plan concluded that with proper incentives, landowners could store additional water in wetlands in the upper basin during protracted wet periods. Accordingly, a number of agencies have done this such as the North Dakota State Water Commission, the Natural Resource Conservation Service, the North Dakota Natural Resource Trust, and the United States Fish and Wildlife Service National Wildlife Refuge on Lake Alice. Various agencies have or are planning the development, management, and enhancement of wetland acres for wildlife habitat and water storage. Nearly 14,000 acres of wetlands have been restored or set aside. If all proposed projects are constructed, the area of wetlands would increase to more than 27,000 acres.

The NDSWC sponsors the Available Storage Acreage Program (ASAP)/Extended Storage Acreage Program (ESAP). The ASAP program began in 1996. It is designed to provide incentive to landowners to store water that would have contributed to the flooding around Devils Lake. It provided for short-term (1-year) agreements with landowners selected on the basis of storage potential and cost-effectiveness, with negotiated payments and renewable agreements. In 1996, 1997, 1998, and 1999 this program stored 8,000, 22,000, 21,000, and 18,500 acre-feet of water for a total of 69,500 acre-feet. Total cost was $3.5 million dollars. In 1999 this program was revised with the ESAP program. This is a ten-year water-storage program managed by the Devils Lake Basin Joint Water Resource Board. Currently, ESAP is storing 800 acre-feet at a cost of $12,000 per year.

The NDSWC and Devils Lake Basin Joint Water Resource Board built a new outlet control structure for Sweetwater-Morrison Lake in 1999, which is one of the chain of lakes just north of Devils Lake. The new control structure allows the lake to be held ½ foot higher than at present during the summer, temporarily retaining an additional 3,500 acre-feet of runoff over a large surface area. This would increase the amount of water lost to evaporation and therefore, reduce the volume that would ultimately reach Devils Lake. In the fall, Sweetwater-Morrison Lake would then be drawn down to its current prescribed level in preparation for the next spring's runoff.

The US Fish and Wildlife Service (USFWS) has completed 21 wetland development projects on its lands, totaling 6,268 acres in area with potential to store 9,130 acre-feet of water. It has 22 additional projects planned that would total 5,086 acres in area with a total capacity of about 9,713 acre-feet. The total would then be 11,534 acres and 18,843 acre-feet. Development of these sites is opposed by neighboring landowners concerned with soil salinity problems due to higher water levels and increased crop depredation from enhanced bird habitat. **Table A11-2** shows the acreage and volume for the FWS projects as of December 2002.

TABLE A11-2.
USFWS Wetland Restoration Projects

Project	Completed		Proposed		Total	
	Area acres	Vol. ac.-ft.	Area acres	Vol. ac.-ft.	Area acres	Vol. ac.-ft.
Lake Alice Project	4,373	3,394	3,342	6,489	7,715	9,983
Water Management District	1,895	5,736	1,744	3,224	3,689	8,960
Total	6,268	9,130	5,086	9,713	11,354	18,843

The US Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) has its Waterbank Program, which is one of the most popular programs in the Basin. In 2000, the NRCS received $700,000 in Federal Water Bank Program funds. This funding was targeted into the Devils Lake Basin. One hundred applications were received in a two-week sign-up period in May 2000. The funds were obligated into 31 applications (3,700 acres). This left 69 unfunded applications (8,250 acres). Estimated cost to fund these would be approximately $1.6 million.

Another program targeted to address flooding in the Devils Lake Basin is the Emergency Watershed Protection – Flood plain Easements Program (EWP). Since 1997, thirteen easements have been completed enrolling 2,777 acres into the program.

A third program offered by the NRCS is the Wetland Reserve Program (WRP). Due to the easement requirements of the program, there has been reluctance on the part of individual landowners to participate. The WRP offers two options in North Dakota – 10-year or 30-year easements and associated lump sum payments.

Another program (not specifically targeted to the Devils Lake Basin) is the Environmental Quality Incentive Program (EQIP). The NRCS had designated the Devils Lake Basin as a priority area in FY 1997 and has funded 35 contracts.

The US Department of Agriculture's Farm Services Agency runs the Conservation Reserve Program (CRP), which is not really a water storage program; however, it offers runoff reduction by landowners setting aside their land. The CRP offers 10- or 15-year agreements and annual payments to landowners. According to the NRCS, there are currently 1,552 CRP contracts on 193,530 acres in the Devils Lake Basin.

In June 2001 the USDA commenced the Farmable Wetlands Pilot (FWP) Program in a six-state area. It is a voluntary program to restore up to 100,000 acres of farmable wetlands in the State of North Dakota and associated buffers by improving the land's hydrology and vegetation. Participants enroll eligible land in the FWP through the Conservation Reserve Program (CRP).

In looking at new and innovative methods of conservation and farming, the NRCS has the Conservation Agriculture Program which uses Sustainable Agriculture and Research Education (SARE) grant funds. They are also involved in association with the Devils Lake Basin Joint Water Resource Board, looking at conservation and management techniques along the Starkweather Coulee and Morrison outlet.

The ND Department of Agriculture's State Waterbank Program makes annual payments to farmers setting aside wetlands and creating adjacent wildlife habitat under 10-year leases. This program has been financially supported by the ND Game and Fish Department and so far has spent $890,000. The ND Game and Fish Department also maintains two Wildlife Management Areas with restored and created wetlands in the upper basin, and administers the Habitat Plot program, which is similar to the CRP, on some 2,300 acres. The Private Land Initiative (PLI) has raised over $660,000 since 1995 for the counties in the basin, and the Game and Fish Department is still expanding the program.

The North Dakota National Resource Trust (NDNRT), a nonprofit conservation organization, has offered one-time incentive payments for new wetland restorations associated with the CRP. The NDWT has restored over 18,000 acres of land in the Devils Lake Basin for various types of habitat, including 4,086 acres of wetlands, 10,608 acres of uplands, and 3,937 acres of conservation tillage. So far $1,391,000 has been spent working with more than 300 producers. They have also developed a demonstration program, the Grand Harbor Watershed Management Project, which has taken nearly a half-mile of land in the Devils lake Basin, and developed and maintained it with the goals of meeting the needs of all interests, agriculture, wildlife enthusiasts, sportsmen, and the various levels of government.

Change in Farming Practices

Some have observed that similar high rain volumes in the watershed in the early 1980's did not result in any appreciable inflow to the lake. This has led to speculation that the recent rise in Devils Lake levels may be due to changes in farm practices or management in the upper basin brought about by changes in USDA farm policies. For example, farm programs such as the Farm Service Agency's Farmable Wetland Pilot Program provides an incentive for farmers to restore wetlands and potholes on their farms This section documents the actual farming practices within the basin with respect to time and evaluates potential benefits due to a change in consumptive use by a corresponding change in cropping patterns.

The U.S.D.A provides statistics on crops through the National Agricultural Statistics Service (NASS). This database was queried to determine the acreage of cropland in the basin. Statistics were retrieved by county and then the portion within the basin was estimated by the percent of the county that is within the basin (except for large lakes). **Table 3** lists these percentages for each county. **Figure A11-1** shows a bar graph of total cropland from 1978 to 1997. From 1978 to 1997, there has been a decline in acreage of 184,000 acres (i.e. from 1,694,000 acres to 1,510,000 acres). Much of this decline can be attributed to land that has been reclaimed by the lake and land that is not farmable due to ponded water in the prairie potholes and other storage areas. In 1978 the lake elevation and surface area (excluding Stump Lake) were 1422 feet msl. and 42,822 acres, respectively. In 1997, the elevation and surface area of Devils Lake was 1,438 feet msl. and 82,038 acres, respectively, resulting in an increase in lake surface area of 39,200 acres (21 percent of the cropland). In addition, the July 1997 satellite imagery of the area showed that the area covered by water in the upper basin was about 152,000 acres. This data indicates that the change in cropland was likely due to inundation, rather than changes in farm policy.

TABLE A11-3.
Percent Each County is
Within Devils Lake Basin

County	County Area (acres)	% of County within Basin
Benson	912462	50
Cavalier	965651	21
Eddy	414476	3
Nelson	647798	0
Pierce	688465	10
Ramsey	842134	90
Rolette	607220	23
Towner	676029	68
Walsh	845930	3

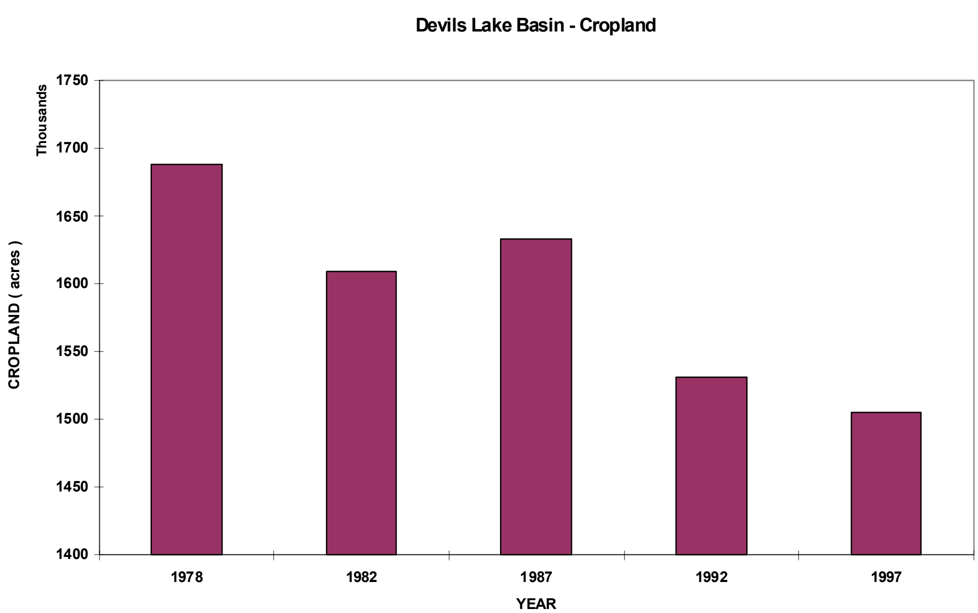


FIGURE A11-1

Figure A11-2 shows a bar graph of cropland and noncropland comprised of fallow, idle, pasture, range, CRP, and non-agriculture land. This data represents the years 1997 to 2001 and was obtained from the USDA NASS. The difference in crop data for 1997, between **Figure A11-2** and **Figure A11-1,** is due to the differences in the data sources. **Figure A11-1** is based on the county inventory and the crop data layer data in **Figure A11-2** is based on satellite imagery. There appears to be no apparent trend in the acreage of cropland or non-cropland during this period.

Figure A11-3 shows the layer for the Devils Lake basin for year 2001. Most cropland in the basin is classified as wheat, sunflowers, canola, and barley.

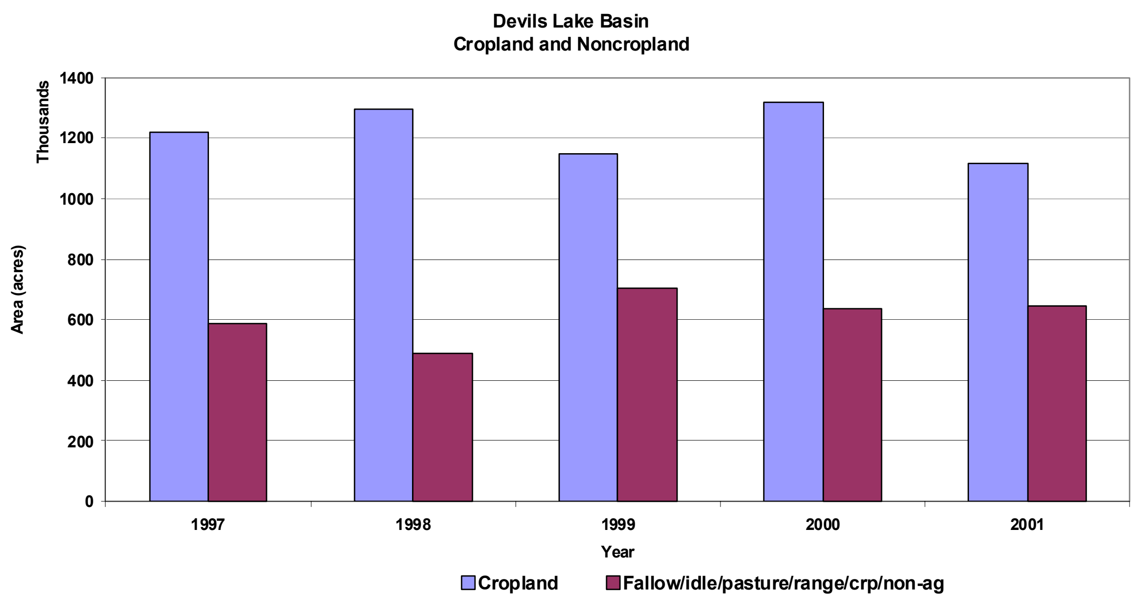
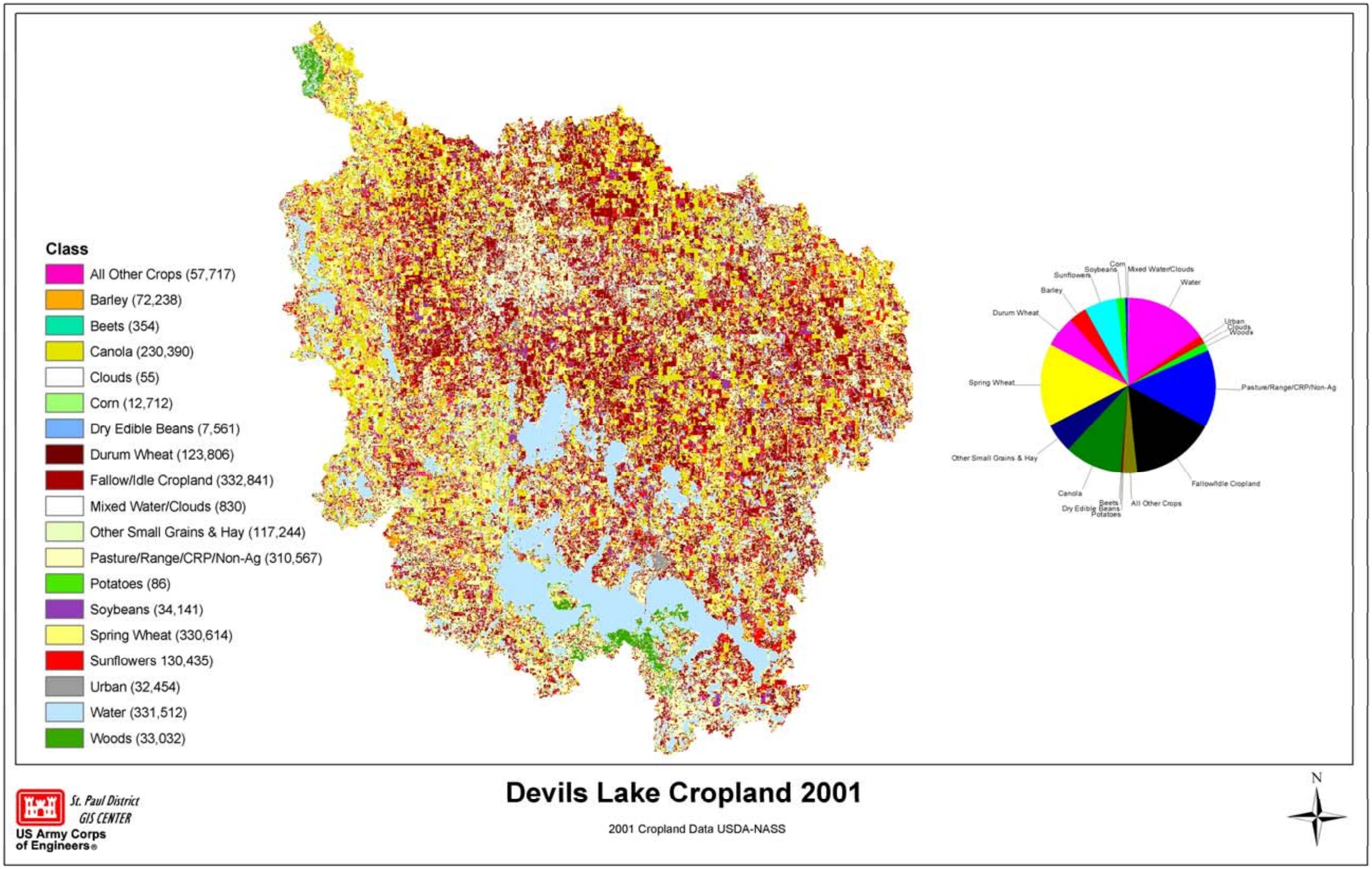


FIGURE A11-2



Devils Lake Cropland 2001

2001 Cropland Data USDA-NASS

FIGURE A11-3

Figure A11-4 shows a time series plot of the land enrolled in the Farm Service Agency Conservation Reserve Program (CRP). The estimate of CRP land in the basin was estimated by prorating the county CRP values by the percent that each county is in the basin. Generally, there was not a significant enrollment until 1997. Since then, CRP acreage increased to a peak of 181,000 acres in 2003. The impact of cropland conversion to CRP land is more likely to reduce runoff because of the infiltration and retention characteristics of CRP land, although the CRP land is about 8 percent of the total area tributary to Devils Lake (excluding Stump Lake). The effect of this conversion would likely be some reduction in runoff to Devils Lake since 1997.

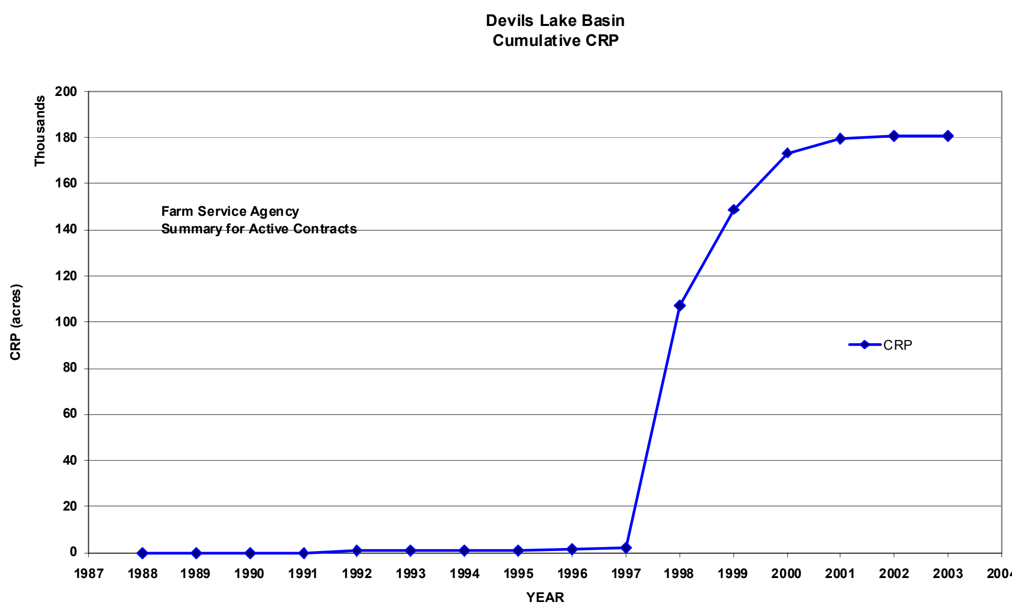


FIGURE A11-4

To assess the potential reduction in runoff resulting from a change in farmland practices, the District used information on cropping patterns in the basin, soil and cover information, and information relative to CRP effectiveness. **Table A11-4** lists the acreage and percentage of crop type for each year from 1997 to 2001 as determined from the crop data layers. Of the crops that are grown within the basin, most of them are wheat, canola, sunflowers and barley. There is no significant change in cropping pattern during this period.

TABLE A11-4.
Crop Type Acreage and Percentage

	1997	%	1998	%	1999	%	2000	%	2001	%
corn	20475	1	5404	0	17929	1	8411	0	12712	1
soybeans	9123	0	3460	0	7115	0	24384	1	34141	2
sunflowers	177000	8	228559	11	249978	12	54771	3	130435	6
barley	194852	9	293984	14	192938	9	218399	10	72238	3
durum wheat	125570	6	213446	10	277312	13	362481	17	123807	6
spring wheat	497603	23	258743	12	178296	8	335488	16	330614	15
other small grains & hay	32306	1	97832	5	29064	1	78439	4	117244	5
canola		0		0		0		0	230390	11
beets	22	0	1010	0	854	0	679	0	354	0
dry edible beans	11435	1	20263	1	78975	4	15708	1	7561	0
potatoes	1037	0	5488	0	4869	0	11342	1	86	0
all other crops	151798	7	168732	8	109841	5	206590	10	57717	3
fallw/idle cropland	320484	15	194506	9	335259	16	201296	9	332841	15
pasture/range/crop/non-ag	264514	12	292331	14	366807	17	433575	20	310567	14
woods		0		0		0	15978	1	33032	2
clouds	23281	1	4547	0	13613	1	476	0	55	0
urban		0	22106	1	22995	1	26326	1	32454	2
water	329147	15	347995	16	270617	13	164245	8	331512	15
mixed water/clouds									830	0
Total (acres)	2158647	100	2158406	100	2156462	100	2158588	100	2158590	100
cropland	1221221		1296921		1147171		1316692		1117299	
fallow/crp	584998		486837		702066		634871		643408	

The Natural Resources Conservation Service (NRCS) publishes Curve Numbers to estimate runoff from rainfall **(reference 6)**. The amount of runoff from a storm event largely depends on detention, infiltration, evapotranspiration, etc., and is related to soil type, vegetative cover and amount of impervious cover. A combination of a hydrologic soil group (soil) and a land use and treatment class (cover) is used to determine the hydrologic soil-cover complex. The effect of the hydrologic soil-cover complex on the amount of rainfall that runs off is represented by a runoff curve number. Therefore, a change in land use will result in a corresponding change in runoff. For example, according to the NRCS, an estimate of the hydrologic curve number for the average cropping rotations would be an 85 for soil Group C. The establishment of dense grass vegetation would have the potential to lower the hydrologic curve number on these same soils to 71. Runoff reductions would be dependent on the severity of a rainfall event.

The conversion of cropland to CRP cover can significantly increase infiltration from rainfall events as indicated above. The cover also has the ability to trap and hold snow, which provides benefits to runoff reduction from snowmelt runoff.

A brief study by the Texas Agricultural Experiment Station looked at the effect on runoff by comparing the average annual precipitation, runoff, and evapotranspiration on a barley-spring wheat rotation on a Barnes Loam soil in Nelson County, ND with daily long-term weather data from Devils Lake **(reference 7)**. **Table A11-5** presents the results of that analysis. The study shows that there was an increase in precipitation, with a corresponding increase in runoff, between 1980-89 and 1990-1996 with the latter time frame producing higher precipitation and runoff of 1.8 inches and 0.25 inches, respectively. This runoff can be attributed to some of the rise to Devils Lake. However, there are many other factors to consider regarding the effect of climate, most notably timing in runoff. The values listed in the table are annual values. In addition runoff from land translates through the watershed in rivulets and streams, exposed to many other hydrologic processes. In addition, runoff values cannot be taken directly as a corresponding reduction in lake volume because of the corresponding change in the net evaporation rate on the lake itself. Detailed soil moisture accounting models would be needed for further evaluation.

The Texas Agricultural Experiment Station did compare the entire period (1956-1996) with a continuous forage cover, like that of the CRP program. The results indicated that the CRP lands are producing 36 percent less runoff than they did under small grain rotations (i.e., a reduction from1.87 inches to 1.18 inches or 0.69 inches).

TABLE A11-5.
Runoff from Barley-Spring Wheat Rotation *

Climate Period	Precipitation (in.)	Evapo-transpiration (in)	Runoff (in.)
1956-1969	16.5	15.0	1.53
1970-1979	15.6	14.5	1.04
1980-1989	19.8	15.5	2.57
1990-1996	21.6	15.9	2.82
1956-1996	17.8	15.1	1.87
1956-1996 (CRP)	17.8	16.4	1.18

* Results from Texas Agricultural Experiment Station

One basin water management measure that has been proposed is a change in farming practice. Cropland in the basin currently comprises approximately 1,100,000 acres. If all of this land were to be converted to CRP (as a best-case scenario), then the reduction in average annual runoff is estimated to be 63,000 acre-feet (assuming a 0.69-inch reduction per acre from **Table A11-5**). The impact on the stage of Devils Lake, assuming this best-case scenario and a direct response on the lake, would be a reduction in stage of 0.5 foot at current lake levels.

Another option would be to change the current cropping pattern to one with higher consumptive use characteristics. **Table A11-6** lists the seasonal consumptive use in inches for selected crops based on the North Dakota Irrigation Guide (**reference 8**). For example, a change in cropping pattern, from small grain to alfalfa, could result in reduced runoff from the land. Likewise, by taking advantage of irrigation one could change from a short season crop such as small grain, which is typically grown in the region, to a longer season crop, which uses more water during the months of August and September. More detailed modeling is required to determine the direct effect on Devils Lake.

TABLE A11-6.
Estimated Seasonal Consumptive Use

Crop	Seasonal Consumptive Use (inches)
Alfalfa	28.38
Corn	23.21
Sugar Beets	24.23
Small Grain	18.61
Potatoes	20.45
Field Beans	17.46
Grass	25.02

In evaluating the implementability of basin water management measures, it is important to recognize potential adverse concerns/impacts associated with these measures. Farmers may not be willing to convert or change to another practice or take more land out of production. An added negative impact is on other elements of the local, agriculturally-based economy.

Irrigation

Irrigation is another basin water management measure that could be used to attenuate the rise of Devils Lake levels. Drawing water directly from the lake, or from upper basin storage areas that would eventually drain into the lake, would have potentially dual benefits - reduced damages at the lake and increased agricultural production within the basin. A concern about the viability of this alternative is that when irrigation is needed the lake or storage areas may be in recession. Conversely, when Devils Lake is high the basin is likely to be saturated with standing water in prairie potholes and irrigation would not be needed or feasible. Another concern is the suitability of soils and water for irrigation. Some soils should not be irrigated and conditional soils should be irrigated under a high level of management, otherwise permanent damage to the soil could result. Source water high in salinity could also potentially damage the soil.

Bartlett and West Engineers of Bismarck, ND did a reconnaissance level investigation on water utilization and management for the Devils Lake Upper basin Joint Board of Directors **(reference 9**). The general purpose of this report was to gather data related to finding a productive use or a way of managing the excess waters, which have been deposited in the Devils Lake Basin. The primary focus was the use of water for irrigation of crops.

The report addressed the following studies:

1) Soils examination
2) Water source examination
3) Water disposal volume examination
4) Conceptual infrastructure location and cost estimate
5) Identification of potential project benefits
6) Identification of potential project obstacles

Of the 5000-quarter sections, at places which would be logical for irrigation development, Bartlett and West Engineers found 2000-quarter sections to be comprised of at least 50 percent potentially irrigable soil. Of those 2000-quarter sections, 960 were comprised of at least 75 percent potentially irrigable soil.

Water sources were identified at four potential locations with potentially irrigable soil. These locations are west of the Chain of Lakes, west of Hurricane Lake, east of the Chain of Lakes, and surrounding the Emergency Outlet locations.

The study developed a conceptual composite crop for irrigated crop production in the basin. The potential water consumption of this composite was compared to the typical dry-land cropping sequence of the area. Potential water disposal volumes ranged from 9.5 inches to 10.5 inches on an annual basis. The study used a crop water use model to simulate the years 1992 to 2001. Average annual water volume disposal of the potential irrigation project is 67,000 acre-feet. This value includes system inefficiencies, post-season evaporation, and leaching or post season storage. More evaluation would have to be done to relate this disposal to a direct effect on Devils Lake level.

Conceptual project infrastructure was developed for the identified areas along with cost estimates. Potential monetary benefits of the project based on the study indicated a 42 percent return on investment. The study indicated that irrigation might be feasible by serving benefits to many factions. This evaluation was based on a reconnaissance level of detail. Recommendations included a test project on a small scale and, if successful, a larger pilot project. The test projects would confirm crop water use results.

There are concerns with irrigation. As mentioned previously, during wet climatic conditions, it is most likely that many potential irrigable areas would have ponded water or saturated soil moisture conditions. A 1997 photo image of the area was overlaid with the potential locations identified for irrigation projects. Standing water was in most of these areas. Another concern is the compatibility of soils in this area for irrigation. Potential irrigation sites were located where at least 50 percent of the quarter sections are classified as irrigable. The North Dakota Irrigation Guide recommends that the conditional soils should be irrigated only as inclusions of less than 20 percent with irrigable soils or that at least 80 percent of the land should be irrigable. Suitable water quality for the source water is another concern. The locations identified for the potential projects generally are classified as C3-S1 on the Water Quality Classification Chart. This water, although low in sodium (alkali) hazard, is high in salinity hazard. Salt would be added to the soil with each irrigation. If drainage is impaired, a water table may develop and salts can accumulate in the root zone. Adequate drainage is essential to both control the water table and permit leaching water to be removed from the root zone. Salts left in the root zone after irrigation must be moved below the root zone or carried away by drains through the addition of water in excess of the soil capacity.

Summary

There does not appear to be a correlation between changes in farm practice in the basin and the recent rise in Devils Lake levels. However, there has been some decrease in cropland due to inundation. Outside of typical crop rotation, there appears to be no significant change in crop patterns, except for the increase in CRP land in the basin. This change would reduce runoff to Devils Lake, although not significantly since only 8 percent of the contributing area to Devils Lake is in CRP.

The recent rise can best be understood by the concept of contributing drainage area. In the early 1980's, precipitation was similar to that of the 1990's. The lake level began to rise, however by the latter part of the decade a significant drought occurred, which resulted in the Chain of Lakes falling below their run-out elevation. Prairie potholes and small wetlands also became dry. The drainage area above the Chain of Lakes is 65 percent of the total drainage area of Devils Lake. Therefore, if the Chain of Lakes is low, the portion of the total drainage area that could potentially contribute runoff to Devils Lake is 35 percent. This change in drainage area is key to understanding the dramatic changes in the lake's volume subsequent to moderate changes in precipitation.

In the summer of 1993, significant rainfall (greater than 100-yr in magnitude) occurred in the basin. The basin became saturated as lakes in the region and the Chain of Lakes filled to capacity, allowing the rest of the 65 percent of the basin to potentially contribute runoff to Devils Lake. The area in the upper basin that actually does contribute is a function of the degree of wetness in the basin. Numerous prairie potholes and enclosed areas that would not normally contribute runoff until they had reached their capacity characterize this area. Satellite imagery taken in 1992 and 1997 confirm that water in the upper basin had more than tripled to about 152,000 acres.

Dr. John Bluemle, State Geologist, cites geologic evidence of lake rises and falls prior to the introduction of farm drainage practices as evidence that the impact from agriculture, wetland drainage, and road construction is minor. It may contribute to, but be not largely responsible for, the current flooding.

Further information on the cause of the recent rise in Devils Lake is given in the hydro-climatic study by the Utah Water Resources Laboratory and referenced in Appendix A.

In regards to the Corps study on restoration of wetlands/depressions in the upper basin **(reference 5**), most review comments have faulted the study for underestimation of the benefits of this alternative. This underestimation has been largely attributed to the underestimation of the estimate of possibly drained wetlands/depressions in the upper basin. However, it is not pertinent to discuss the numbers and acreages of the different types of wetlands originally in the Devils Lake basin, nor of the numbers, acreages, and types of wetlands that have been drained and their corresponding flood capacity. This was not an inventory type of study. What is pertinent is what exists now and what can be restored as a viable alternative that will ultimately benefit flood damage reduction within the Devils Lake basin.

There are certainly more depressions than the 50 percent level chosen for evaluation (as its title clearly implies); however, identification of more wetlands/depressions in the analysis would not affect the B/C ratio because the benefits for the studied plan (50 percent restoration) are compared to the costs directly associated with this extent of restoration. A larger degree of implementation could have been selected, such as 75 percent or even 100 percent restoration. The costs of implementing this degree of restoration would increase accordingly. If the 50 percent level of restoration does not show promise in a cost-effective way in reducing the inflow volume into Devils Lake then it is most unlikely that an alternative that encapsulates even higher levels of restoration would show viability.

Reducing runoff excess by only 1 inch from the land in the basin would have a significant effect on Devils Lake level if it were basin wide. Although this measure may seem to be small, this option may not be implementable or feasible. There is approximately 1700 square miles of cropland in the basin. If an incentive of only $20 per acre were proposed through a farm policy program, the cost would be $20 million per year. Although irrigation may have some benefit, it may be limited because the land may already be saturated. A prudent approach to more thoroughly examine the effectiveness of irrigation would be a small test project in the upper basin.

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3. Bell, A., D. Eckhardt, and M. Pucherelli, U.S. Department of the Interior, Bureau of Reclamation, Wetlands Inventory and Drained Wetlands Water Storage Capacity Estimation for the St. Joe-Calio Coulee Subbasin of the Greater Devils Lake Basin, North Dakota, Technical Memorandum 8260-99-02. 39pp., 1999.

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7. Griggs, Ray H., Texas Agricultural Experiment Station, "Letter to Lynn Clancy, State Director, Office of US Senator Kent Conrad," March 18, 1998.

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Section 12 – Dry Lake Diversion

Introduction

The Pelican Lake alternatives include pumping plans with a range of pumping capacities and operational constraints- including no constraints. Constraints pertain to limitations on pumping capacity/volume for both high and low flow conditions on the Sheyenne River. For high flow conditions, limitations were placed on pumping so as to not exceed downstream, Upper Sheyenne River, channel capacity (i.e. 600 cfs). For low flow conditions, limitations were imposed on pumping volume so as to not exceed water quality standards at the insertion point on the Sheyenne River (e.g. 450 mg/l SO_4). Based on detailed simulations and study, the best overall Pelican Lake outlet plan (in terms of hydrologic effectiveness and minimum water quality exceedences) is an outlet that has a pumping capacity of 300 cfs, constrained for 600 cfs channel capacity and 300 mg/l sulfate concentration. This plan will reduce the peak lake level of the WET future scenario from an elevation of 1460.59 feet msl for without-project conditions to 1460.1 feet msl for with-project conditions (i.e. a reduction of 0.5 foot.). To improve the effectiveness of this plan, the Corps added the Dry Lake Diversion feature.

Features

The Dry Lake Diversion feature modifies and operates the existing Dry Lake Channel A project and in conjunction with other project features restores a portion of the flow of fresh water from Dry Lake to Pelican Lake via Big Coulee. Channel A is a NDSWC flood control and diversion project that was built in 1979. It currently diverts spring runoff from Dry Lake directly to Six Mile Bay on Devils Lake. The natural flow from Dry Lake was to a chain of lakes, which discharged into Big Coulee, the primary tributary to Pelican Lake and Devils Lake. Dry Lake is located about 8 miles east of Big Coulee and about 5 miles north of the pre-flood location of Devils Lake's Six Mile Bay. Currently all these water bodies (Devils Lake, Pelican Lake, Big Coulee, and Dry Lake) are at about Elevation 1447.0 feet msl.

The Corps analyzed the hydrologic and hydraulic conditions present in the chain of lakes watershed tributary to Devils Lake from the north. Using available information and best judgment to minimize costs and impacts, a proposed plan was developed. The recommended proposed plan consists of the following components:

- A 400 cfs diversion channel and control structure from Dry Lake to Mikes Lake
- A new control structure on Channel A
- Improvements to existing channels, roadways, and control structures in the chain of lakes
- Flowage easements around lakes affected by operation of the project
- Installation of a flow monitoring structure on Big Coulee

Figure A12-1 presents a plan of the recommended project. The recommended project has a total first cost of $9,917,700. An alternative diversion alignment that bypasses the chain of lakes and connects directly to Big Coulee was also briefly investigated. This alignment is shown on **Figure A12-1**. The first cost of this alternative plan is $13,121,900, about $3.2 million more that the recommended plan. For the recommended project, about 63 percent ($6.3 million) of the total cost is attributable to costs for environmental mitigation, cultural resources surveys, and real estate acquisition for operation of the project. More details on the design can be gleaned from **reference 1.**

Rationale

The USGS modeled the Dry Lake Diversion for hydrology and water quality. The model showed that restoring the natural flow of water to Pelican Lake, except during major runoff events, brings more fresh water to Pelican Lake, especially during years of normal and below normal runoff. This operation will permit the outlet to function at greater flow rates and, therefore, be more effective at reducing Devils Lake water levels. For example, for the WET future scenario, the with-project conditions including the diversion resulted in a peak lake level of 1457.5 feet msl, which is 3.1 feet less than without a Pelican Lake outlet and 2.6 feet less than the Pelican Lake project without the diversion

The USGS Devils Lake Outlet model assumed that flows would be diverted from Dry Lake into the Pelican Lake watershed when the flow rate in Big Coulee was less than 2,000 cfs. The 2,000 cfs maximum flow in Big Coulee was selected to avoid additional damages along the coulee. A maximum flood flow of 2,300 cfs occurred in Big Coulee in 1997. Initial USGS modeling indicates that a maximum flow rate of about 1,500 cfs could be diverted from Channel A and back into the Pelican Lake-Big Coulee watershed with this constraint. The modeling also indicates that at times the designated capacity of Big Coulee was used completely and, therefore, Channel A would be occasionally operated to divert flows directly into Devils Lake.

Initial Simulations

Initially, the USGS made two runs of the Devils Lake-Pelican Lake Outlet model to help define design parameters for the Dry Lake Diversion. The first run was to determine the amount of flow diversion from Dry Lake that was included in the model. The period of record examined was from October 1983 through September 1999. This model run showed that discharges in Channel A tend to peak sooner than Big Coulee, so there were some time periods when Channel A flows were much larger than Big Coulee flows.

The second model run was made to determine the effectiveness of diverting Dry Lake/Channel A flows. The model generated annual Devils Lake levels for both wet and moderate future scenarios over 50 years, a pump capacity of 0 or 300 cfs, sulfate constraints of 450 mg/l and 350 mg/l in the Sheyenne River, and with and without diversion of Dry Lake/Channel A flows. This information is summarized in **Table A12-1**. For the 450 mg/l constraint and a wet scenario, the Dry Lake/Channel A diversion makes no difference in peak levels. However, it makes a big difference for the 350 mg/l constraint. The Dry Lake/Channel A diversion also makes a big difference for the moderate scenario for both the 450 mg/l and 350 mg/l constraints.

TABLE A12-1.
Dry Lake Diversion Effectiveness

Future Scenario Condition	DEVILS LAKE OUTLET PUMP CAPACITY (CFS)	Water Quality Constraint (mg/l SO_4)	Dry Lake Diversion (Y/N)	Peak Devils Lake Elevation	Change from No Pump (feet)
Wet	0	N/A	N	1460.59	0.0
Wet	300	450	Y	1457.34	3.25
Wet	300	450	N	1457.34	3.25
Wet	300	350	Y	1457.34	3.25
Wet	300	350	N	1459.07	1.52
Mod	0	N/A	N	1454.88	0.0
Mod	300	450	Y	1450.66	4.22
Mod	300	450	N	1451.99	2.89
Mod	300	350	Y	1451.33	3.55
Mod	300	350	N	1453.35	1.53

To further explain these results, the Corps conducted additional analyses with the model. **Table A12-2** shows the average sulfate concentration in Pelican Lake for the first 10 years of pumping. For the WET scenario and no Dry Lake Diversion, the sulfate concentration is about 350 mg/l and hence the pump output is essentially unconstrained by either the 350 or 450 mg/l sulfate constraint during the first 10 years. For the wet scenario with the Dry Lake Diversion, the sulfate concentration in Pelican Lake is about 100 mg/l lower than the concentration without the diversion. Thus, although the pumps are operating at essentially full capacity for the first 10 years either with or without the diversion, the outlet discharge is considerably fresher with the diversion. If the sulfate standard was lowered to 300 mg/l, the outlet would still be operating at essentially full capacity with the diversion but outlet discharge would be highly constrained without the diversion.

FIGURE A12-1

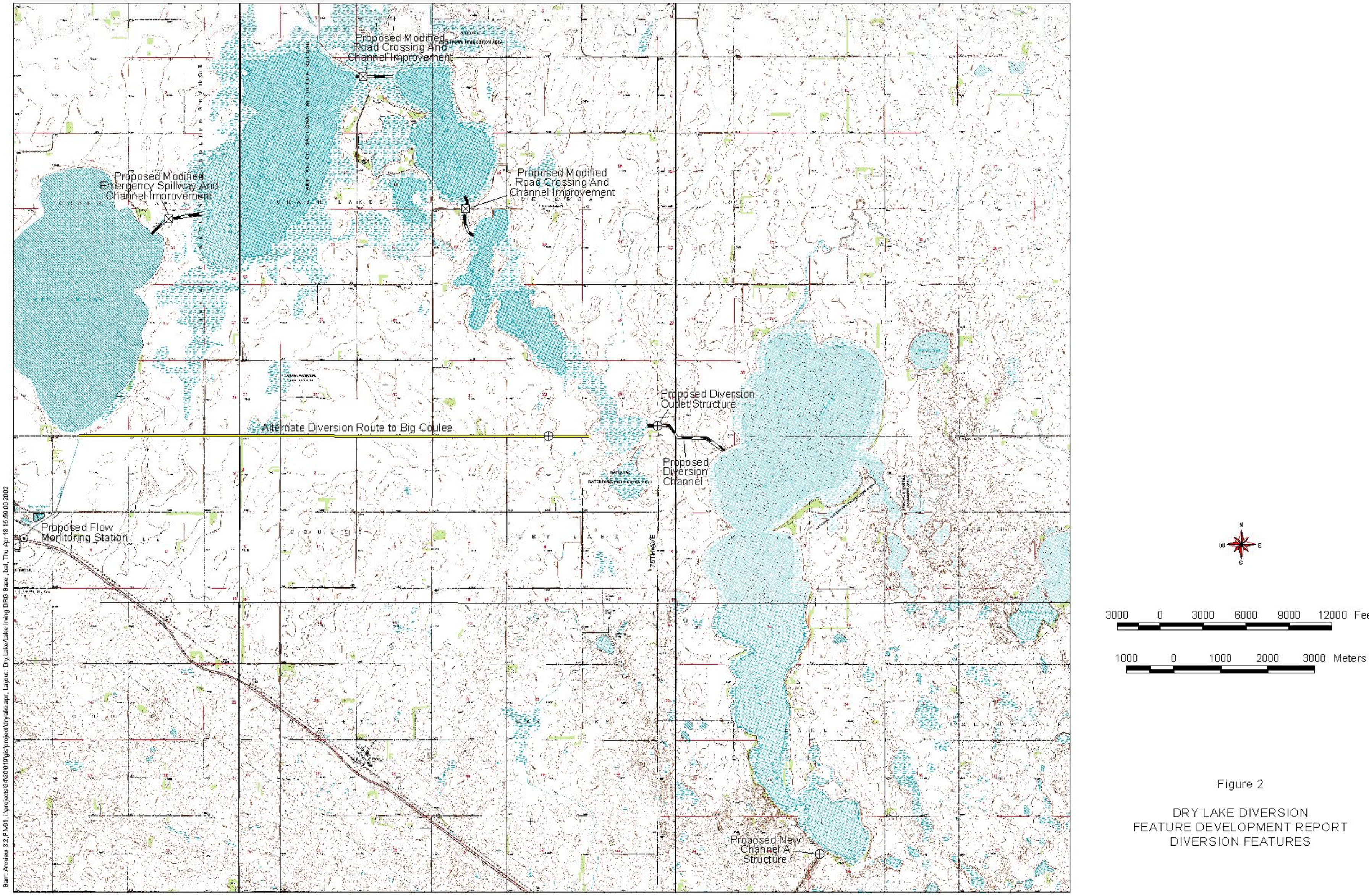

Figure 2

DRY LAKE DIVERSION
FEATURE DEVELOPMENT REPORT
DIVERSION FEATURES

TABLE A12-2.
Average Sulfate Concentration of Pelican Lake
During the First 10 Years of Pumping (2005-2014)
(all results are for a 300 cubic-foot-per-second Pelican Lake Outlet)

Scenario	Sulfate Constraint (mg/l)	Dry Lake Diversion (Y/N)	Pelican Lake Sulfate Concentration (mg/l)
Wet	350	No	347
Wet	350	Yes	246
Wet	450	No	352
Wet	450	Yes	246
Mod55	350	No	443
Mod55	350	Yes	336
Mod55	450	No	463
Mod55	450	Yes	364

For the moderate scenario and no diversion, the sulfate concentration in Pelican Lake is about 450 mg/l. Thus, the pump output is essentially unconstrained by the 450 mg/l sulfate constraint but becomes highly constrained by the 350 mg/l sulfate constraint. For the moderate scenario with the Dry Lake Diversion, the sulfate concentration in Pelican Lake is about 350 mg/l. Therefore, the pump output is essentially unconstrained by either the 350 or 450 mg/l sulfate constraint.

For the wet scenario, the differences between the with- and without-diversion simulations become more evident after the first 10 years of pumping. **Table A12-3** shows the average sulfate concentration of Pelican Lake during the second 10 years of pumping (2015-2014) for the WET scenario. With no Dry Lake Diversion, the sulfate concentration in Pelican Lake averages about 385 mg/l, which is higher than the 350 mg/l constraint on the Sheyenne River but still well below the 450 mg/l constraint. Therefore, the outlet discharge becomes constrained by the 350 mg/l sulfate constraint, particularly during the latter part of the 10-year period (when the sulfate concentration in Pelican Lake is over 400 mg/l). With the diversion, the sulfate concentration in Pelican Lake averages 290 mg/l and thus the outlet discharge is unconstrained by either the 350 mg/l or 450 mg/l sulfate constraints. Even though the sulfate concentration in Pelican Lake without the diversion only exceeds 350 mg/l by a small amount, it is enough to make a significant difference in the volume the outlet can discharge. This analysis suggests that the Dry Lake Diversion has the maximum effectiveness during periods of low to moderate precipitation and runoff.

TABLE A12-3.
Average Sulfate Concentration of Pelican Lake
During the Second 10 Years of Pumping (2015-2024)
(all results are for a 300 cubic-foot-per-second Pelican Lake Outlet)

Scenario	Sulfate Constraint (mg/l)	Dry Lake Diversion (Y/N)	Pelican Lake Sulfate Concentration (mg/l)
Wet	350	No	384
Wet	350	Yes	290
Wet	450	No	386
Wet	450	Yes	290

The amount of volume that could be diverted from Dry Lake if the diversion channel was limited in size was also analyzed. For the period of record for the model runs, 742,662 acre-feet are diverted from Dry Lake to Big Coulee. This amounts to an average of 43,868 acre-feet per year. **Table A12-4** shows the amount of diversion volume computed by the model for different maximum diversion discharges. This shows that 80 percent of the volume is conveyed to Big Coulee with only a 500 cfs diversion. A diversion with larger capacity would not appear to justify the increase in costs and environmental impacts for the effectiveness that is gained.

TABLE A12-4
Dry Lake Diversion Size vs. Effectiveness

Dry Lake Diversion Maximum Discharge (cfs)	Portion of Total Volume Diverted[a] (%)
100	31
200	48
300	62
400	72
500	80
1,000	97
1,500	100

[a] Volume is the total of 742,662 acre-feet diverted from Dry Lake to Big Coulee for the period of record from 1983–1999 as determined in the USGS Pelican Lake-Devils Lake Outlet Model.

Sensitivity Simulations

Based on the above analysis, the Corps requested the USGS to make some additional sensitivity simulations using a maximum diversion discharge of 500 cfs (the diversion features were eventually designed for a 400 cfs capacity). Flows up to 500 cfs were diverted through the Dry Lake Diversion regardless of the flow rate in Big Coulee. Flows in excess of 500 cfs were then diverted through the Channel A diversion. The sensitivity runs were made for a 300 cfs pumping capacity, a range of sulfate constraint values, three hydrologic scenarios, and for with- and without- the diversion feature. **Figure A12-2** shows the results of these runs. The adopted plan is the Pelican Lake 300 cfs pumping capacity, constrained for 300 mg/l SO4. Without a diversion the reduction for the WET future is only 0.5 foot but with the diversion the reduction is 3.1 feet in stage on Devils Lake. The diversion cost is estimated at approximately $10 million. If no diversion were adopted, the equivalent stage reduction could be achieved only by increasing the water quality constraint to 450 mg/l SO4. However, this option would increase water quality exceedences downstream. Therefore, the $10 million diversion feature not only improves the hydrologic effectiveness of this alternative, but also helps to minimize downstream water quality exceedences.

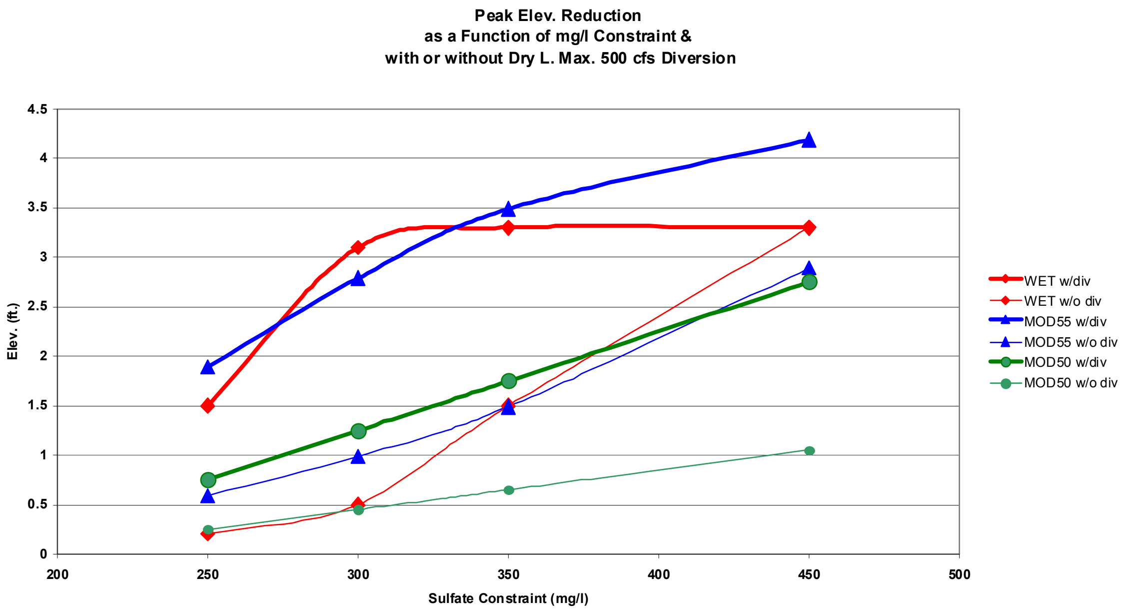

FIGURE A12-2

Table A12-5 shows the economic results of the incremental analysis of including the Dry Lake Diversion with the Pelican Lake outlet. The associated Pelican Lake outlet is a pumping capacity of 300 cfs, constrained for 300 mg/l SO4 (PL300/300). For the stochastic analysis and three future scenarios, the benefit-cost ratio is above unity, ranging from 1.02 to 12.31. The analysis shows that the diversion is an economically justified feature of the outlet alternative.

TABLE A12-5.

Dry Lake Diversion Economic Analysis						
Analysis Type or Future Scenario	Total Cost	Lake Level Without Diversion	Lake Level With Diversion	Total Annual Benefits	Total Annual Net Benefits	BCR
Stochastic	$9,068	1456.9[1]	1455.85[1]	$704	$15	1.02
Wet Future	$9,068	1460.1	1457.5	$12,050	$11,071	12.31
Moderate 1455 Future	$9,068	1453.9	1452.1	$1,917	$1,131	2.44
Moderate 1450 Future	$9,068	1449.6	1448.9	$1,225	$516	1.73

Note: All Costs are in Thousands of Dollars

[1] Elevation based on 10 % probability of reaching or exceeding given lake level in 50-years.

REFERENCES

1. Barr Engineering Company, Dry Lake Diversion Feature Development Report (FDR) Final Report, Mpls MN, April 19, 2002.