Red River Valley Water Supply Project
Environmental Impact Statement

Existing Water Quality Conditions, Impact Assessment Methods and Environmental Consequences

This document is intended to satisfy all or part of the following portions of the Task Order (as indicated by italic text):

WQ 1 – Existing Water Quality Conditions
WQ 2 – ***Modeling Water Quality***
WQ 3 – Water Quality Impact Assessment
WQ 4 – Meetings and Coordination with USGS and Reclamation

Task: This task combines the following work under one task order:

1) Existing Water Quality
2) Modeling Water Quality
3) Water Quality Impact Assessment
4) Meetings and Coordination with USGS and Reclamation

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EXECUTIVE SUMMARY
SURFACE WATER QUALITY

EXISTING WATER QUALITY

In general, the waters of the Sheyenne River, the Red River of the North, and the Missouri River are suitable for or mostly supporting designated uses. At most locations exceedences of water quality standards are fairly rare, and when they occur, are often naturally caused.

The water quality within lakes, reservoirs, streams and rivers is determined largely by interaction of water with the landscape, as modified by human activities. Water moving across the landscape is exposed to different minerals comprising soils and rocks within different geomorphic regions as well as different living and dead plant and animal material within different ecoregions. Human activities that alter the land surface (e.g., conversion to agriculture) or that consume and use water (e.g., for the assimilation of waste from a town) further modify water quality; therefore, it is typical to find differences in surface water quality across a large region like the Red River Basin.

Several local, state, provincial, and federal agencies are responsible for evaluating, describing, and ensuring that the quality of surface waters is sufficient to meet the beneficial uses of society. North Dakota Department of Health, Minnesota Pollution Control Agency, and Province of Manitoba (Water Quality Management Section) generally monitor and assess the condition of surface waters within their borders. Some oversight of their efforts is provided by the EPA (Environmental Protection Agency) in the United States. The USGS (U.S. Geological Survey) is also an active participant in assessing water quality within the Red River Basin.

Surface waters within North Dakota and Minnesota are categorized according to their anticipated and desired beneficial uses. Beneficial use designations consider the use and value of water for public water supplies, protection and propagation of aquatic life, recreation, agriculture, industry and other purposes. There may be more than one use designation assigned to a water body.

Not all surface waters can be used for their intended purposes, usually because of poorer than expected water quality, some physical modification of the habitat, or a biological problem. The stressors within the Red River Basin which cause use

impairment are most often associated with the following: ammonia concentrations, materials that consume oxygen (e.g., biochemical oxygen demand), dissolved solids, bacteria from mammals, and trace metals like mercury. Dissolved oxygen, a necessity for healthy aquatic plants and animals, declines when there is too much oxygen consuming material. The oxygen consuming material comes from both indirect sources like runoff from the land surface (i.e., nonpoint) and direct sources like pipes conveying storm water runoff and wastewater to the river (i.e., point sources).

There are three types of standards used to establish a regulatory limit that supports a designated use: 1) numeric, 2) narrative, and 3) anti-degradation. A numeric standard is the allowable concentration of a specific pollutant in a water body. It represents a "safe" concentration for a particular contaminant intended to protect a designated use. A narrative standard prohibits unacceptable conditions, such as floating solids, scums, visible oil film, or nuisance algal blooms. A narrative standard may also be interpreted as the physical condition necessary to achieve a designated use. The anti-degradation standard pertains to waters that currently have water quality better than the applicable numeric standards. The anti-degradation standard generally requires that these waterbodies should be maintained at that existing high quality, and not allowed to degrade to the level of applicable standards.

In North Dakota and Minnesota, lakes and stream reaches are evaluated according to the "degree" that each beneficial use (e.g., water supply, aquatic life, etc.) is achieved by placing them in one of three categories: 1) fully supporting, 2) fully supporting but threatened (termed "partially supporting" in Minnesota), or 3) not supporting. Generally, a water body is considered "threatened" or "partially supporting" if water quality and/or watershed trends are expected to continue to degrade the current condition into the future. A *threatened* use typically means there is some (small) proportion of the time that monitoring data shows the numeric water

Water Quality Sampling

quality standard is exceeded. *Not supporting* typically means the frequency and severity of the problem is greater than threatened and a documented problem exists (e.g., observed fish kill means not supporting aquatic life).

The determination of whether a surface water body meets its intended uses is often based upon whether a numeric water quality standard is exceeded. A numeric water quality standard is a number that represents the maximum (or minimum in the case of dissolved oxygen) allowable concentration in a surface water. Numeric standards sometimes differ between Minnesota and North Dakota for the same parameter. Within the Red River Basin in North Dakota and Minnesota, the percentage of samples collected that have exceeded the numeric water quality standard for some of the more common parameters is less than (see Appendix C):

- 3% of the sulfate samples (general indicator of drinking water quality);
- 12% of the fecal coliform bacteria samples collected during the recreation season (indicator of contamination by warm blooded animals);
- 15% of the TDS (total dissolved solids) samples, which is a general indicator of quality for Minnesota only; and
- 4% of the dissolved oxygen samples (indicator of aquatic biology health).

No water quality standard exists for phosphorus. Both Minnesota and North Dakota however, recognize "recommended maximum levels." The total phosphorus concentration exceeds the recommended levels more than 50% of the time within the Red River Basin. Existing water quality is described by stream reaches in the following discussion.

Sheyenne River

The USGS, in cooperation with the Bureau of Reclamation, evaluated the existing water quality of streams in the U.S. portion in the Red River basin (Tornes 2005). Data collected between 1970 and 2001 were retrieved from NWISWeb, a USGS internet-based data server. The following discussion is summarized from that report.

The physical and chemical data for the Sheyenne River indicate the water is suitable for most currently designated uses. The pH values rarely exceeded the criterion of 9.0 standard units established by the EPA (2005) for the protection of aquatic life and generally were less than 8.0 standard units.

The water chemistry of the Sheyenne River contains a mixture of calcium, sodium, bicarbonate, and sulfate ions. At many sites, the sulfate concentrations occasionally exceeds the established secondary (non-enforceable) drinking water standard of 250 milligrams per liter.

Chromium, lead, mercury, nickel, and zinc are infrequently detected, and concentrations have decreased over time, indicating better controls on wastewater discharges and/or improved sample collection and processing techniques that reduced unintended sample contamination. Trace elements that are detected more commonly included arsenic, copper, and nickel. Arsenic concentrations have occasionally exceeded the 10-µg/L EPA drinking water standard that is scheduled to take effect in 2006. All constituent concentrations for the Sheyenne River below Baldhill Dam, North Dakota, site were within established guidelines, standards, and criteria.

Sheyenne River

Water Quality Measurements

µg/L is micrograms per liter, which roughly translates to parts per billion.

mg/L is milligrams per liter or roughly parts per million.

µS/cm means microsiemens per centimeter is a measure of electrical conductivity, which is related to the number and type of ions in the water. When low conductivity is measured it may be expressed as resistively in micromhos per centimeter (umhos/cm).

Several reaches of the free flowing portions of the Sheyenne River are classified as threatened (North Dakota Department of Health 2004). In all cases, the identified impairment is caused by sedimentation/siltation or total fecal coliform bacteria. Excessive sedimentation is caused by bank erosion or runoff from agricultural fields. Fecal coliform bacteria is an indicator of the potential contamination of surface waters by warm blooded animals, including contamination from domestic and livestock wastes.

Lake Ashtabula

Except for nutrients, concentrations of most constituents in Lake Ashtabula are similar to those in the Sheyenne River upstream of the reservoir. Lake Ashtabula acts as a nutrient and sediment trap causing eutrophication that is manifested in excessive growth of algae and submerged vascular plants. As a result, Lake Ashtabula is classified as not supporting the recreation designated use (North Dakota Department of Health 2004).

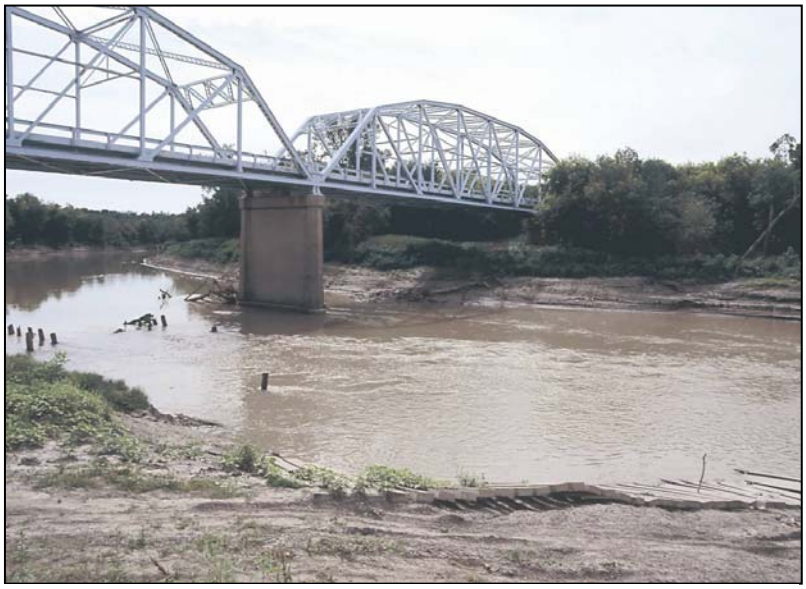
Red River

Red River at Emerson

The Red River at Emerson, Manitoba, site provides data on water quality entering Canada. It integrates flow from all of the streams that drain the United States portion of the Red River Basin except for the Roseau River. The Roseau River joins the Red River north of Emerson and annually contributes an additional 10% to the amount of streamflow carried by the Red River at Emerson (Tornes 2005). The Red River at Emerson also assimilates all of the point and nonpoint inputs to the system in the United States, including industrial and wastewater discharges and agricultural runoff. Because the Red River at Emerson integrates water from many streams, the constituent concentrations at the Emerson site generally are less variable than those at upstream sites. The following discussion is summarized from Tornes (2005).

The pH at the Emerson site ranges from 7.2 to 8.9 standard units, with a median of 8.1 standard units. All values reported by Tornes (2005) were within the range of 6. 5 to 9.0 standard units established by the EPA (2005b) and Environment Canada (2002) for the protection of aquatic life. Except for the late summer 1993 period when streamflow in the basin was unusually high, the dissolved oxygen concentration exceeds the EPA (1986) minimum dissolved oxygen criterion of 3.0 mg/ L and the Environment Canada (2002) guideline of 5.5 mg/L.

The concentration of TDS at the Emerson site ranges from 245 to 1,100 mg/L, with a median concentration of 438 mg/L. These concentrations are relatively high, and probably originate primarily from tributaries in the western part of the Red River Basin. Western tributaries generally have less precipitation and runoff than eastern tributaries, and the salts in the lakes and reservoirs become concentrated as a result of evaporation (Strobel and Haffield 1995). The dissolved solids concentrations in groundwater



Overview of the Red River

discharge from aquifers in the western part of the basin also tend to be large (Strobel and Haffield 1995).

Nutrient concentrations for the Red River at Emerson are generally lower than for smaller streams that drain agricultural areas, possibly because of the integrating effect of the stream system at Emerson. Ammonia concentrations have decreased substantially since more stringent water quality standards were enacted in the 1970s. Thus, the aquatic habitat in the Red River has improved. Data collected at the Emerson site as part of the National Aquatic Water Quality Assessment Program indicate the maximum ammonia concentration for that site during 1993-95 was 0.37 mg/L (Tornes et. al. 1997).

Water Quality objectives are levels of water quality established by the governments of the U.S. and Canada. They are intended as a general index of river conditions.

Based upon the most recent monitoring information available from the IJC (International Joint Commission), exceedances of the water quality objectives occur infrequently at the Emerson, Manitoba monitoring location. The chloride and sulfate objectives were not exceeded from 1999 through 2002. An exceedance of the dissolved oxygen objective occurred once, during July of 2000. The TDS objective has been exceeded each year, generally once or twice during the winter months. The bacteriological objective has been exceeded once annually, generally during the summer months.

Red River Upstream from Emerson

The following discussion is summarized from Tornes (2005). The pH criterion of 9.0 standard units established by the EPA (2005) and Environment Canada (2002) for the

protection of aquatic life is rarely exceeded in the Red River. The EPA (1986) minimum dissolved oxygen criterion of 3.0 mg/L was exceeded during the 1970s when the concentration reached 0.6 mg/L at the Hickson site and 1.4 mg/L at the site below Fargo. On occasion during the same period, the concentration reached 3.0 mg/L as far downstream as Halstad. Since more stringent water quality standards were enacted, dissolved oxygen concentrations in the Red River have improved. However, during July 1993, the criterion was exceeded at the Halstad site when high flows apparently washed oxygen demanding substances into the Red River.

Many constituent concentrations for the site below Fargo have exceeded water quality guidelines, standards, and criteria. The maximum sulfate concentration of 330 mg/L was greater than the 250 mg/L EPA (2005) drinking water standard. Other exceedances, including cadmium, copper, lead, and selenium concentrations, generally occurred during the 1970s or earlier and could be natural or could be related to pollution or sample contamination.

Dissolved mercury has been detected at some sites in the Red River, but the source or cause of the mercury is uncertain. The largest concentration (11 µg/L) was measured at the Hickson site. Because no other trace elements or other indicators were evident, the concentrations probably were an artifact of sample collection, processing, handling, or analysis (Windom et. al.1991).

The Red River is classified as not supporting the fish consumption designated use due to high methyl-mercury concentrations in fish (North Dakota Department of Health 2004). The sources of methyl-mercury in fish are largely unknown. Several reaches of the Red River upstream of the confluence with the Sheyenne River are classified as threatened due to high fecal coliform bacteria (North Dakota Department of Health 2004).

Missouri River and Reservoirs

Lake Sakakawea

Water in Lake Sakakawea generally meets North Dakota water quality standards. Algal blooms occur at times when the lake level is low. Decaying organic materials contribute to the biological oxygen demand and sometimes cause reduced dissolved oxygen levels in the deeper portions of the lake (Corps 2004). Dissolved oxygen and

arsenic concentrations at times exceed water quality standards. Reservoir levels have a significant influence on water quality, with higher concentrations of many constituents during droughts when water levels are low (Corps 2004).

Lake Sakakawea is classified as not supporting the fish consumption beneficial use due to high concentrations of methyl-mercury in fish tissue (North Dakota Department of Health 2004). The source of the methyl-mercury is unknown. Additionally, the lake is classified as threatened for the fish and other aquatic biota designated use due to low dissolved oxygen and temperatures to high for the coldwater fishery (North Dakota Department of Health 2004).

Missouri River below Garrison Dam and Lake Oahe

The Missouri River reach from Garrison Dam to Bismarck is dominated by releases of cold, clear water from Lake Sakakawea. TDS (estimated from specific conductance) average about 430 mg/L. Concentrations of nitrogen and phosphorus are low.

Water quality in Lake Oahe generally meets standards in North Dakota and South Dakota. Constituents of concern in Lake Oahe include arsenic, dissolved oxygen, pH, iron, lead, manganese, and copper (Corps 2004a). At times, dissolved oxygen is depleted during the summer in the deeper portions of the lake, particularly at low water levels (Corps 2004a).

Fishing on Chain of Lakes

Audubon Lake, McClusky Canal, and Chain of Lakes

The water chemistry in Audubon Lake is similar to Lake Sakakawea, but concentrations of most constituents are higher. Most of the water in Audubon Lake is supplied by the Snake Creek Pumping Plant, with relatively little runoff from the contributing drainage. Thus, higher concentrations in Audubon Lake result from

evaporation of the water supplied to the lake. Reclamation operates a freshening program to maintain water quality in Audubon Lake. Up to 100 cfs is released down the McClusky Canal during the open water season and replaced with water from Lake Sakakawea as needed to maintain the target elevation of 1847.2 feet msl (mean sea level). Additionally, the lake is lowered two feet each fall by releasing water to Lake Sakakawea through a conduit in the Snake Creek Embankment. Audubon Lake is then refilled in the spring with fresher water from Lake Sakakawea.

Concentrations of most constituents increase downstream from Audubon Lake to the end of the McClusky Canal. The median TDS concentration is 583 mg/L near the entrance to the McClusky Canal (in Audubon Lake) and exceeds 1100 mg/L near the end of the Canal. The median sulfate concentration is 263 mg/L near the entrance to the McClusky Canal (in Audubon Lake) and exceeds 500 mg/L near the end of the canal. Current flow rates in the canal tend to be low (i.e., less than 100 cfs), which explains the higher concentrations near the lower end of the canal. In particular, there is very little flow in the McClusky Canal downstream of New Johns Lake.

Lake of the Woods

In general terms, the water quality of Lake of the Woods is suitable for most designated uses including meeting drinking water standards with basic treatment operations. Given the size of the lake and the seasonal variability, it is difficult to characterize the overall water quality. The most recent assessment of the lake classifies it as eutrophic in relation to the Carlson Trophic State Index (MPCA 2005). These lakes have persistent algae and aquatic plant problems. The Carlson TSI uses three parameters for its assessment as follows: 1) Total Phosphorus, which is the nutrient that usually determines how much aquatic plant and algal growth there will be in a lake, 2) Chlorophyll a, the amount of chlorophyll a in a lake is a measure of how much algae is in the water, and 3) Secchi Disk, a measure of the transparency or clarity of the water.

The typical pH value for the lake is 7.7 which is within the range of 6.5 to 9.00 established by the EPA (2005b) for the protection of aquatic life.

Aquifer – A geologic unit that can store and transmit water at rates fast enough to provide reasonable amounts of water to wells.

Confined Aquifer – An aquifer found below a layer of material with very low permeability. Often referred to as an artesian aquifer, recharge is often negligible or from adjacent unconfined aquifers.

Unconfined Aquifer – An aquifer where the geologic materials above the water table are permeable enough to allow infiltration of water to the aquifer. Rainwater can seep into unconfined aquifers which make them more subject to pollution than confined aquifers.

ENVIRONMENTAL CONSEQUENCES OF THE ALTERNATIVES

Sheyenne River

Lake Ashtabula

The GDU to Sheyenne River Import Alternative delivers water directly to Lake Ashtabula. Two other alternatives deliver water to Lake Ashtabula but use Ashtabula primarily for the re-regulation of water; i.e., the Missouri to Red River Valley Import Alternative and the North Dakota In-Basin Alternative. Re-regulation means water is temporarily stored in the lake for later use. Because the demand for water is satisfied from other locations, typically more water remains within the reservoir.

The BATHTUB modeling results suggest that some small increase in total nitrogen (TN) concentration may occur during a dry year for the North Dakota In-Basin Alternative, presumably because of the return of water from Grand Forks to Lake Ashtabula. However, the total phosphorus concentration declines or remains unchanged for each alternative either directly delivering water to Lake Ashtabula or using the lake for re-regulation compared to the No Action Alternative. Both the Missouri to Red River Valley Import Alternative and the GDU Import to Sheyenne River decrease total phosphorus (TP) concentrations within Lake Ashtabula slightly. The model estimates essentially no change in the chlorophyll-a concentrations or secchi disk visibility because of the small changes in nutrient concentrations. The remaining alternatives cause no limnological change in Lake Ashtabula compared to the No Action Alternative. Because nutrient concentrations within Lake Ashtabula show little change, no change in the long-term average trophic state number of numeric standard exceedances or the beneficial uses of the lake is expected.

Sheyenne River below Lake Ashtabula to the Confluence with the Red River

The annual TP and TN nutrient loads compared to the mouth of the Sheyenne River for the ND In-Basin Alternative are < 5%, which is substantially less than the variability in daily discharge. No measurable change in beneficial uses within the River is anticipated as a result of the change in nutrient load.

Modeled conservative concentrations of chloride, sulfate and TDS (for September 2003 hydrologic conditions) on the lower Sheyenne River suggest little relative change in the long-term levels (< ± 15%) compared to the No Action Alternative. Considering modeling uncertainty, the normal variation in water quality and discharge, and the anticipated frequency of operation for the action alternatives, the percentage change is not considered as being measurable. Therefore, no long-term change in average water quality is anticipated for the conservative substances modeled and beneficial uses are expected to remain unchanged.

Red River

The annual TN and TP loads for the alternatives were compared to the annual loads at Fargo, ND and Grand Forks, ND, to gain some sense for potential eutrophication. The additional estimated nutrient loads from the Missouri River system entering the Red River system are generally less than 0.1% above existing loads at both Fargo, ND and Grand Forks, ND. In general, the estimated change in load for the action alternatives is a small fraction of the variation in annual loads.

Modeled conservative concentrations for September 2003 hydrologic conditions on the lower Red River suggest little relative change in long-term concentrations (< ± 15%) compared to the No Action Alternative based on the USGS model. Given the uncertainty associated with the model compared to the actual conditions for the operation of the alternatives, no long-term change in average water quality is anticipated for the conservative substances modeled and beneficial uses are expected to remain unchanged.

As flows decrease during drought conditions, the water quality of the Red River will become return flow dominated, taking on the chemical characteristics of return flow

for the build Alternatives. By contrast, the Red River will essentially become dry for the No Action Alternative.

Based upon the most recent monitoring information available from the IJC, exceedances of the water quality objectives occur infrequently at the Emerson, Manitoba monitoring location. Modeled concentrations differing from existing concentrations by more than ± 15% were considered to have the potential to cause additional or reduce the number of exceedances of the IJC objectives. With probable project operation occurring one-half the time at most, the actual change in the long term average concentration is expected to be less than 10%. No additional exceedances of these objectives are anticipated.

Missouri River System

Audubon Lake and Principal Supply Works

Four alternatives remove water from the Missouri River system, thereby changing current loads. These alternatives are the:

- GDU Import Pipeline Alternative;
- GDU Water Supply Replacement Alternative;
- GDU Import to Sheyenne River Alternative; and
- Missouri River to Red River Valley Import Alternative.

Based upon the amount of nutrient load removed from the Missouri River, the probable change in water quality is expected to be small and immeasurable. The reduction in annual nutrient load leaving the Missouri River system is less than 0.5%. No changes in beneficial uses within the Missouri River are expected.

Audubon Lake and Principal Supply Works

Three alternatives use portions of the existing Garrison Diversion Unit (GDU) infrastructure to deliver water to either the Sheyenne River system (i.e., Lake Ashtabula) or directly to a pipeline for distribution to users within the Red River Valley. These alternatives are the:

- GDU Import Pipeline Alternative (return flow is to the Red River);

- GDU Water Supply Replacement Alternative (return flow is to the Red River); and
- GDU Import to Sheyenne River Alternative (water is delivered to Lake Ashtabula prior to use).

Discharges at the headworks of the McClusky Canal are expected to range from 7 to 190 cfs for the various alternatives and differing hydrologic and climatic conditions. An improvement in water quality (i.e., lower concentrations) is expected within the principal supply works for the GDU to Sheyenne River Import Alternative, for each hydrologic condition. Concentrations decrease for each alternative compared to the No Action Alternative through the supply works (including New John's Lake) although concentrations are generally similar within Audubon Lake.

The concentrations within the canal approach those within Audubon Lake as the duration of operation increases. Water quality concentrations within the principal supply works are expected to be lower than currently occur (i.e., the No Action Alternative). Lower concentrations are generally considered favorable. No changes in beneficial uses within Audubon Lake or New John's Lake are expected. The McClusky Canal is not regulated as Waters of the State by North Dakota.

Lake of the Woods

The Lake of the Woods alternative removes water from the lake for municipal, rural and industrial use. Because water is removed from the lake and the volume removed is small compared to the volume of the lake, no adverse impacts are expected.

Cumulative Impacts

No cumulative water quality impacts are anticipated. Operation of the Devils Lake outlet is the most likely reasonably foreseeable activity, which could lead to potential cumulative impacts. Operation of the project is restricted by the National Pollutant Discharge Elimination System (NPDES) permit. Operation of the Devils Lake outlet is restricted to: 1) May through November; 2) periods of time when the discharge within the Sheyenne River is less than 600 cfs; and 3) periods of time when the sulfate concentration is less than 300 mg/L. The analysis presented shows that the likelihood of concurrent operation is low. The outlet is unlikely to operate at the fully discharge of 200 cfs during certain periods. Concurrent operation during the early portion of a drought may occur but as the duration of drought increases continued concurrent operation will decline. Should concurrent operation occur, water released from Devils Lake could be used to satisfy water supply demand. This further reduces the need for the operation of a project alternative.

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1.0 INTRODUCTION

1.1 SETTING

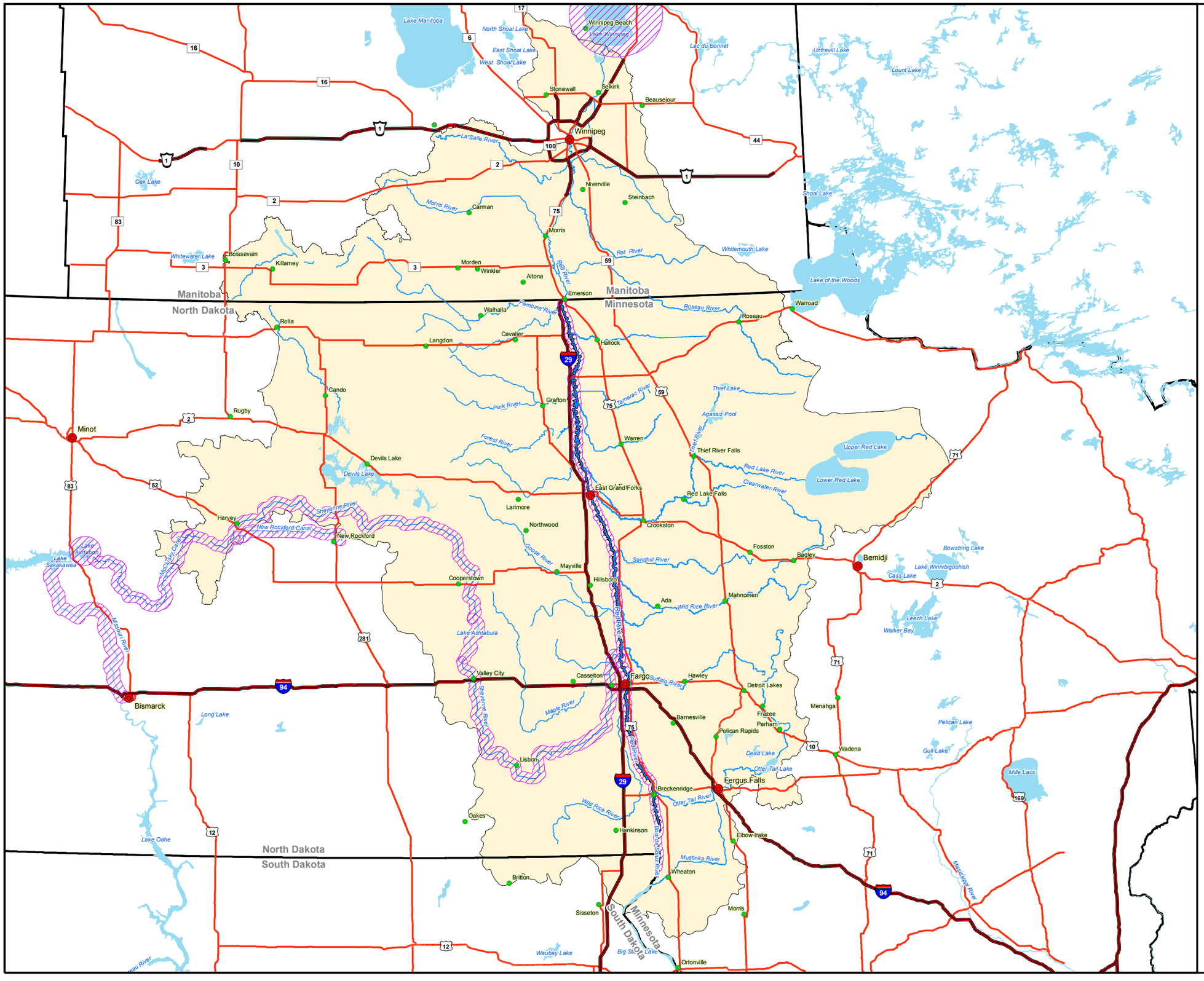
The United States Department of Interior, Bureau of Reclamation (Reclamation), in cooperation with the State of North Dakota, is evaluating the environmental impacts of several alternatives[1] to meet the future municipal, rural, and industrial (MR & I) water supply needs within select counties and cites within 13 eastern North Dakota Counties within Red River of the North Basin (Red River Basin). The Red River Basin stretches from south of the confluence of the Bois de Sioux and Otter Tail Rivers near Wahpeton, North Dakota north into southern Manitoba. The Red River Basin extends from Sheridan County and the upper portion of the Sheyenne River within North Dakota, to the east into Beltrami and Clearwater Counties and the headwaters of Upper and Lower Red Lake, in Minnesota. The Red River Basin comprises an area of 39,199 mi^2 within the United States and includes the major cities of Fargo and Grand Forks, North Dakota, Moorhead, Minnesota and Winnipeg, Manitoba. The Red River flows north along the border between North Dakota and Minnesota from northeastern South Dakota and west-central Minnesota into southern Manitoba (Figure 1-1). The mouth of the Red River occurs at the southern end of Lake Winnipeg.

Reclamation and the State of North Dakota are in the process of preparing an Environmental Impact Statement (EIS) to evaluate the potential adverse and beneficial impacts associated with the MR & I water supply alternatives. The purpose of this Technical Memorandum (TM) is to provide supporting information for preparation of the water quality portion of the EIS[2]. This TM specifically presents a description of the Red River Basin, describes various regulatory issues related to surface water quality, presents the methods used to describe existing conditions and evaluate the consequences of the alternatives. (A detailed discussion of the water supply alternatives is presented in the previously published Needs and Options Report.)

1 The alternatives consist of proposed options identified within the Needs and Options Report. The counties include 13 eastern North Dakota counties plus Breckenridge, Moorhead and East Grand Forks, Minnesota.

2 This TM is intended to satisfy all aspects of the Water Quality Task Order dated March 12, 2004.

Red River Valley Water Supply Project



Legend

- Major Watershed Boundary
- Provincial/State Boundaries
- General Impact Assessment Area
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal

Transportation

- Interstate
- US Highway
- Divided Highway (Canada)
- Main Road (Canada)

N W E S

0 15 30 60 90 Miles

Location Map

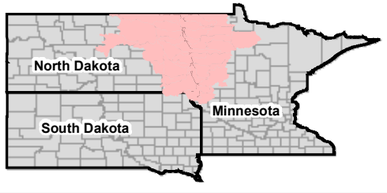


Figure 1-1: Geographic Location - Red River Basin of the North		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

1.2 PHYSICAL DESCRIPTION[3] OF THE RED RIVER BASIN

The terrain of the Red River Basin is diverse, a consequence of glacial activity occurring 10,000 years ago. Glaciation resulted in the deposition of 150 to 300 feet of unconsolidated material across portions of the Red River Basin forming three distinct landforms; i.e., the drift prairie, flat plains, and moraine (see Figure 1-2). The drift prairie is located along the western portion of the Red River Basin and is characterized by rolling uplands with short to medium grasses, shallow pothole lakes and streams flowing generally in an easterly direction toward the Red River. The flat plains comprise the central portion of the Red River Basin. This area, formerly the bed of glacial Lake Agassiz, is now predominantly farmed. The plains generally have poor drainage and were historically characterized by a mix of scattered boreal forest, marsh, and periodic peat deposits. The moraine, located on the eastern edge of the Basin, is a broad plateau with steep local relief with mixed hardwood and coniferous forests. Streams generally flow west toward the Red River of the North.

The Red River drains to the north through the valley and a poorly defined floodplain. Relief moving northerly in the basin is small; i.e., only 1 to 1.6 ft/mile slope along the Red River across the United States portion of the Basin (a straight line distance of 186 miles). The lack of relief generally requires drainage to improve agricultural yields. The vast majority of the land in the Red River Basin is currently in agricultural use (77%). The primary agricultural crops are spring wheat, sugar beets, barley, sunflowers, potatoes, corn and soybeans. Some land is also in pasture or used as range by livestock.

Climate is subhumid to humid. Annual mean temperature is 40 degrees Fahrenheit (^{o}F) with a summer temperature commonly ranging from 85 to 95 ^{o}F and a winter temperature minimum of -35 ^{o}F. Most precipitation occurs during the months of May, June and July. Average annual precipitation ranges from 17 inches in the western portion to 24 inches in the southeast portion of the Red River Basin. November and February are the months with the lowest amount of precipitation.

[3] This discussion modified from "A River Runs North".

Red River Valley Water Supply Project

Legend

- Major Watershed Boundary
- Provincial/State Boundaries
- Major City
- Intermediate City

Transportation
- Interstate
- US Highway
- Divided Highway (Canada)
- Main Road (Canada)

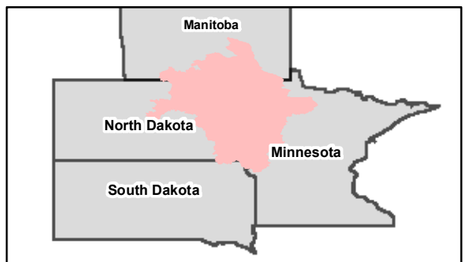
Water Features
- Lake or Resevoir
- Stream or River
- Major Canal

Ecoregion (Level III)
- Lake Agassiz Plain
- North Central Hardwood Forests
- Northern Glaciated Plains
- Northern Lakes and Forests
- Northern Minnesota Wetlands
- Northwestern Glaciated Plains

Geomorphic Region
- Drift Prairie
- Flat Plains
- Moraine

N W E S

0 12.5 25 50 75 Miles



Location Map

Figure 1-2: Level III Ecoregions and Geomorphic Regions of the Red River Basin within the U.S.

Notes:

Scale: As Shown	Project No: 3750-059	Date: 03/14/05

1.3 WATER RESOURCES IN THE BASIN

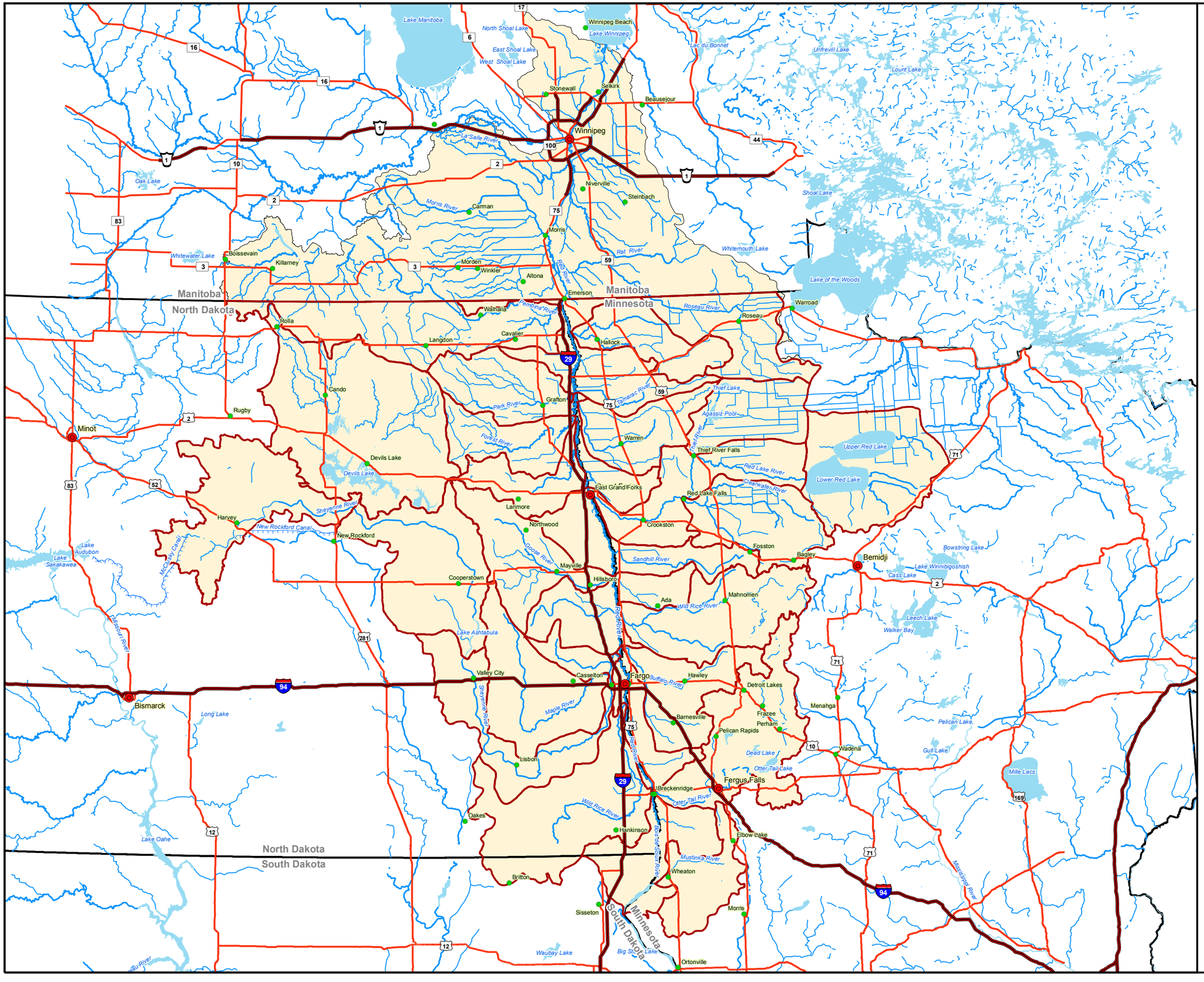
Several river systems, reservoirs, and lakes are prominent water features[4] within and near the Red River Basin. The Sheyenne River is the major North Dakota tributary to the Red River (Figure 1-3), draining a large portion of North Dakota to the west of the Red River. The confluence of the Sheyenne River and the Red River is immediately downstream from Fargo. Lake Ashtabula is a U.S. Army Corps of Engineers operated reservoir on the Sheyenne River. Numerous smaller tributaries drain portions of the North Dakota basin moving northerly along the Red River. These include the Wild Rice, Maple, Goose, Forest, Park and Pembina Rivers.

Orwell Dam and Reservoir (located on the Otter Tail River), Lake Traverse (on the Red River), Upper and Lower Red Lakes (in western Minnesota), and Lake Ashtabula (on the Sheyenne River) tends to "stabilize" flows on the Red River; i.e., provides baseflow during low flow conditions. The Otter Tail and Boise de Sioux Rivers form the headwaters of the Red River of the North. The Red Lake River, which drains a considerable area within the northwestern portion of the Red River Basin, also provides reasonably stable flows because of the presence of Upper and Lower Red Lakes. The Red River terminates at Lake Winnipeg within southern Manitoba.

The drainage divide between the Hudson Bay Drainage (i.e., of which the Red River is a part) and the Missouri River drainage occurs downstream from Audubon Lake, along the McClusky Canal. Lake Sakakawea, located to the west of Audubon Lake and the McClusky Canal, is one the mainstem Missouri River reservoirs.

[4] The purpose of this section is to generally identify the location of streams and lakes comprising a portion of one of the alternatives. This section is not intended to represent an exhaustive description of water resources within the Red River Basin.

Red River Valley Water Supply Project



Legend

- Major City
- Intermediate City
- Major Watershed Boundary
- USGS HUC Boundary

Transportation

- Interstate
- US Highway
- Divided Highway (Canada)
- Main Road (Canada)

Water Features

- Lake or Resevoir
- Major River
- Stream
- Major Canal

Location Map

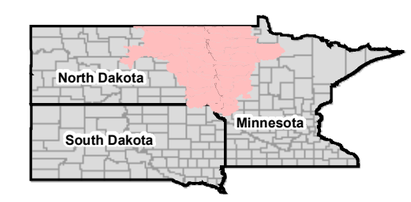


Figure 1-3: Water Resource Features - Red River Basin of the North		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

2.0 WATER QUALITY REGULATORY CONCEPTS AND DEFINITIONS

Concepts and definitions specific to understanding water quality, existing water quality with the Red River Basin and evaluating water quality impacts are presented within this section. Reference to specific statute, rule or policy is provided[5].

2.1 NORTH DAKOTA AND MINNESOTA

2.1.1 Beneficial Uses and Use Class Designations

Each state determines which beneficial uses are appropriate for their waters. The uses specify the value of a particular water body in the sense of how society will utilize them and their societal benefits. The best uses for a water body are those determined to be most consistent with the present and potential uses, while considering the economic and social development within an area. The level of water quality improvement or degree of protection necessary to achieve the uses occurs through the establishment and enforcement of water quality standards. Whether a use is being attained is evaluated based upon the physical, chemical and biological characteristics of the water body.

Minnesota and North Dakota have established many of the same beneficial uses (see Table 2-1) and both states associate a "class" with each beneficial use. Classes are essentially used for the purpose of establishing water quality standards. Several classes can apply to the same water body (because most water bodies have multiple beneficial uses). The most stringent water quality standard applies when there are multiple classes.

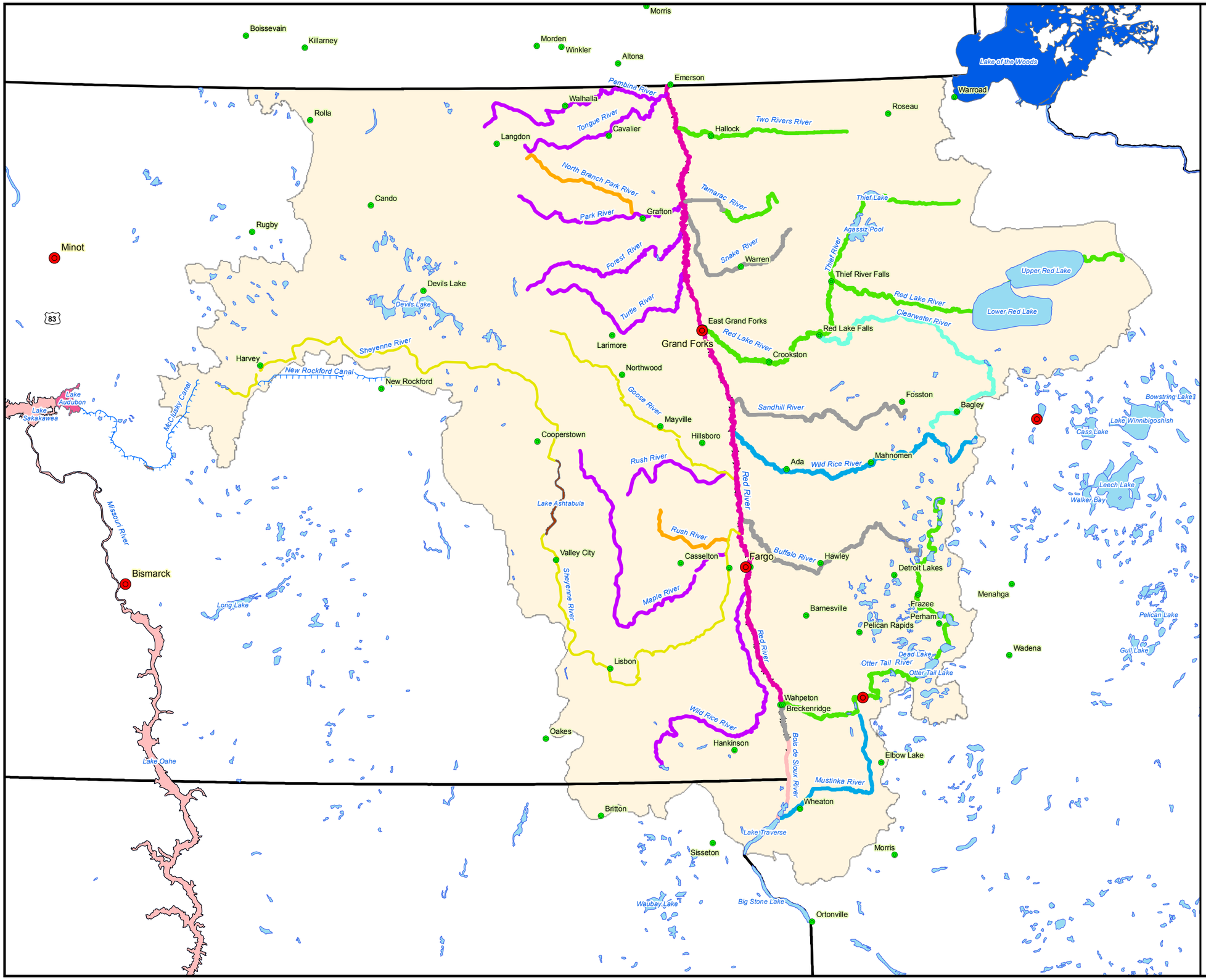
The Minnesota beneficial uses along with the corresponding classes are defined in Minnesota rules Chapter 7050.0200, "Water Use Classifications for Waters of the State" (http://www.pca.state.mn.us/water/standards/). Most of the streams and rivers within the Minnesota portion of the Red River Basin protect for aquatic life uses through a Class 2 designation (Figure 2-1). Minnesota Rules Chapter 7050.0200 Subpart 3, defines Class 2 waters as "all waters of the state which do or may support fish, or other

[5] The reader is encouraged to obtain and review the original source material. Only a summary is presented here.

Table 2-1. Beneficial Uses and Use Classification for Minnesota and North Dakota.

Beneficial Use	**Minnesota Use Classification**	**North Dakota Use Classification**
Drinking water and municipal	Class 1	Class I, Class IA, Class II
Aquatic life and recreation	Class 2	Class I
Industrial use and cooling	Class 3	Class III
Agricultural use, irrigation	Class 4A	Class I
Agricultural use, livestock and Wildlife watering	Class 4B	Class II
Aesthetics and navigation	Class 5	Does not apply
Other uses	Class 6	Does not apply
Limited resource value waters	Class 7	Does not apply
Fish consumption	Applies to multiple classes	Class I, Class IA, Class II

Red River Valley Water Supply Project



Major City

Intermediate City

Major Canal

Lake Classes

- 1
- 2
- 3
- 1B, 2Bd, 3A, 3C, 4A, 5, 6

Stream Class

- I
- II
- III
- IA
- I (ND) and 1C, 2Bd, 3B, 3C, 4A, 4B, 5, 6 (MN) (Red River)
- 1B, 2A, 3B, 3C, 4A, 4B, 5, 6
- 1C, 2Bd, 3B, 3C, 4A, 4B, 5, 6
- 2C, 3C, 4A, 4B, 5, 6
- Unlisted (2B, 3B, 4A, 4B, 5, 6)

N W E S

0 12.5 25 50 75 Miles

Location Map

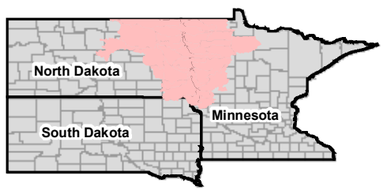


Figure 2-1: Stream and Lake Classes within North Dakota and Minnesota		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

aquatic life, bathing, boating, or other recreational purposes, and where quality control is or may be necessary to protect aquatic or terrestrial life or their habitats, or the public health, safety, or welfare." Some of the classes defined in Minnesota Rule are further defined using subclasses. For example, Class 2 has five different subclasses. Most Class 2 waters are defined using the subclass designation 2Bd. The 2Bd subclass is defined as "cool- and warm-water fisheries, also protected as a source of drinking water."

Most streams within the North Dakota portion of the Red River Basin are classified as IA or II (see Figure 2-1). Within North Dakota Class I, IA, and II streams must be suitable for the propagation and / or protection of the resident fish species and other aquatic biota and for swimming, boating and other water recreation (see North Dakota Century Code Chapter 33-16-02.1). These waters must be suitable for irrigation, stock watering and wildlife without causing injury. Municipal and domestic use of these waters must meet the bacteriological, physical and chemical requirements following treatment. Class III streams have limited seasonal value for immersion recreation, but fish life and aquatic biota are to be protected. Class III streams are intended to be suitable for agricultural and industrial uses such as stock watering, irrigation, washing and cooling.

Fish consumption is protected through both narrative and numerical human health criteria specified in the state's water quality standards. Fish consumption is assigned to all Class I, IA, and II streams and to those Class III streams known to provide a sport fishery. Fish consumption within Minnesota streams and rivers is protected by a description of Class I, Class IA or Class II.

Lakes within North Dakota have a separate classification and are placed within classes ranging from Class 1 to Class 5. The classes designate the type of fishery for which protection is required. Lake Ashtabula is an important resource within the State. Lake Ashtabula is designated as a Class 3 lake, meaning protection as a warm water fishery. The waters of Lake Ashtabula must be capable of supporting the growth and propagation of nonsalmonid fishes and associated aquatic biota.

2.1.2 Existing and Designated Beneficial Uses

According to the Clean Water Act (www.epa.gov/region5/water/cwa.htm#links), designated uses are "those uses specified in water quality standards for each water body or segment whether or not they are being attained." Existing uses are defined as "those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards." These definitions are important because a designated use can be altered in some cases if it can be shown that the designated use is not an existing use; i.e., the use as of November 28, 1975 cannot be attained or was inappropriately designated.

Waters failing to attain their designated use are defined as impaired. Each state determines the cause for impairment. The cause is typically associated with an excessive amount of some type of substance and/or exceedances of the water quality numeric standard. However, impairment can also result from a lack of habitat or a highly modified hydrologic regime, which no longer supports aquatic species. Impaired waters are placed on a list by each state and subject to completion of a Total Maximum Daily Load analysis. A Total Maximum Daily Load consists of many steps, but the process is intended to restore impaired waters to their full beneficial uses.

2.1.3 Water Quality Standards

There are three types of standards used to establish a regulatory limit that supports a designated use[6]; i.e., 1) a numeric standard; 2) a narrative standard; and 3) anti-degradation. A numeric standard represents a "safe" concentration for a particular contaminant intended to protect a designated use. The use will be adversely affected if the pollutant concentration exceeds the numeric standard too frequently. Numeric criteria, which form the basis for standards adopted by many states, are defined in federal rules as a recommended minimum water quality standard. A state can establish a more restrictive standard than the numeric criteria. Table 2-2 shows select numeric water quality

[6] The lakes along McClusky Canal (e.g. New Johns) are regulated by the state of North Dakota. The canal however is not "regulated" (conversation with M.Ell, NDDH).

Table 2-2. Select Numeric Water Quality Standards for Minnesota and North Dakota

Category / Parameter	Indicative of Primary Water Use	Minnesota	North Dakota
Physical			
Total dissolved solids	Drinking water	No standard	No standard
Dissolved oxygen	Aquatic life	5 mg/L	5 mg/L
Biochemical oxygen demand		not listed	not listed
Total suspended solids		not listed	not listed
Nutrients			
Ammonia Nitrogen	Aquatic life and recreation	varies with pH and temperature	varies with pH and temperature
Nitrate Nitrogen	Aquatic life and recreation	not listed	1 mg/L
Nitrate Nitrogen	Drinking water	not listed	not listed
Total Phosphorus	Aquatic life and recreation	No standard	0.1 mg/L
Ions			
Calcium (dissolved)	General indicator	not listed	not listed
Calcium (dissolved)	Live stock	not listed	not listed
Magnesium (dissolved)	General indicator	not listed	not listed
Chloride	Aquatic life and recreation	250 mg/L	175 mg/L
Sulfate	Aquatic life and recreation	250 mg/L	250 mg/L
Metals			
Iron (dissolved)	Human health and aquatic life	300 µg/L	not listed
Manganese (dissolved)	Human health and aquatic life	50 µg/L	not listed
Biological			
Fecal coliform bacteria	Human health (drinking water)	0 colonies/100 ml	0 colonies/100 ml
Fecal coliform bacteria	Human health (recreation)*	200 colonies/100 ml	200 colonies/100 ml

* Standard only applies April 1 - October 30 for MN and May 1 - September 30 for ND

standards for Minnesota and North Dakota. The parameters identified in Table 2-2 are those primarily used to describe existing conditions and assess environmental consequences.

The second type of standard is the narrative standard. The narrative standard is usually not as easily defined as a numeric standard. Narrative standards involve keeping waters free of unwanted conditions such as oil sheens, floating solids, or algae blooms. The narrative standard may also be interpreted as the physical condition necessary to achieve the designated use. For example, if the designated use is "cold water fish habitat" the surface water temperature and dissolved oxygen levels must remain within a range that can support cold water fish species.

The anti-degradation standard pertains to waters that currently have water quality better than the applicable numeric or narrative standards, for the designated use. The anti-degradation standard does not allow further degradation of the resource to the numeric standard. It essentially does not allow the polluting of a better quality resource from its current condition "back" to the level of the numeric standard for the designated use.

2.2 PROVINCE OF MANITOBA

Water quality protection within the Province of Manitoba differs from that in the U.S. Water quality protection measures are implemented in Tiers (see Final Draft, Manitoba Water Quality Standards, Objectives and Guidelines, November 22, 2002). Tier I standards essentially consist of minimum treatment requirements for various types of dischargers. Effluent quality standards are established by the type of discharger.

Tier II standards consists of water quality objectives defined for a limited number of common pollutants routinely controlled through licensing under the Manitoba Environment Act (www.gov.mb.ca/waterstewardship/waterstrategy/quality) (see Table 2-3). The objectives established under Tier II form the basis for defining water quality, similar to the numeric standards established within the U.S. One primary difference is that the objectives are non-binding; i.e., not enforceable through regulation unless incorporated into provincial legislation. The objectives are in part based upon the criteria established by the U.S. EPA.

Table 2-3. Tier II Water Quality Objectives and Guidelines for Manitoba

Category / Parameter	**Indicative of Primary Water Use**	**Manitoba**
Physical		
Total dissolved solids	Greenhouse Irrigation	700 mg/L
Total dissolved solids	Field, Park, and Garden Irrigation	1000 mg/L
Total dissolved solids	Drinking Water	≤500,000 μg/L*
Dissolved oxygen	Cool Water Aquatic Life and Wildlife	5.5 mg/L (varies with life stage and water temperature)
Biochemical oxygen demand		not listed
Total suspended solids	Aquatic Life and Wildlife	5 mg/L induced change from background
Nutrients		
Ammonia Nitrogen	Cool Water Aquatic Life and Wildlife	varies with temperature and pH
Nitrate Nitrogen	Drinking water	10 mg/L
Total Phosphorus	Aquatic life	no enforcable standard
Ions		
Calcium (dissolved)	Live stock	1000000 μg/L*
Magnesium (dissolved)		not listed
Chloride	Human health and general indicator	≤250,000 μg/L*
Sulfate	Human health and general indicator	≤500,000 μg/L*
Metals		
Iron (dissolved)	Human health and aquatic life	≤300 μg/L*
Manganese (dissolved)	Drinking Water	≤50 μg/L*
Biological		
Fecal coliform bacteria	Primary Recreation (May 1 - Sept 30)	200 mg/L
Fecal coliform bacteria	Drinking water	0 mg/L

* Tier III Guidelines

Most waters within Manitoba are afforded a routine level of protection. Under Tier II, waters are categorized according to the desired level of protection: i.e., routine protection of uses; high quality waters; or exceptional value waters. The routine level of protection ensures that all pollutants are reduced or eliminated through the use of standard treatment technologies commonly available to each type of discharger. Additional protection may be afforded based upon the Tier II water quality objectives. This level is intended to provide reasonable protection from unacceptable impacts to all but a small percentage of aquatic species for most of the time and reflects the principle advanced by the U.S. EPA that healthy aquatic communities can tolerate some stress and can recover.

Tier III water quality guidelines include three types of general guidance. The first guidance type established by Tier III includes numeric standards for a large number of parameters derived by the Canadian Council of Ministers of the Environment (CCME) for general application across Canada. These standards are intended to be used as a benchmark for trend analysis and interpreting water quality data. The CCME guidelines pertain to water bodies, lake and river bottom sediments, and residues in fish or the tissue of other aquatic life. The second guidance type within Tier III is the tissue residue guidelines derived by Health Canada to protect human consumers of fish or the tissue of other aquatic organisms. This information is intended to be used to assess whether specific uses are being achieved. The third guidance type within Tier III is narrative water quality guidelines. The narrative water quality guidelines establish minimum conditions at all times. They are intended to reasonably ensure that surface and ground water are free of constituents attributable to sewage, industrial, agricultural and other land-use practices or other man-induced point and non-point sources which impair water quality.

Manitoba has also developed a nutrient management strategy for surface waters in the southern portion of the Province. The effort is aimed at better understanding the nutrient status of lakes within southern Manitoba, developing and interpreting new information about lake nutrient status, and establishing guidelines, objectives and criteria for these lakes. An initial focus of this effort is Lake Winnipeg (see Development of a Nutrient Management Strategy for Surface Waters in Southern Manitoba, April 20,

2000). The intent is to develop a nutrient management plan specific to Lake Winnipeg to reduce nitrogen and phosphorus levels within Lake Winnipeg to pre-1970 levels. The Province estimates that achieving pre-1970 concentrations in Lake Winnipeg will require reducing nitrogen loading by 13% (8,200 tonnes per year) and total phosphorus loading by 10% (580 tonnes per year).

2.3 BOUNDARY WATERS TREATY BETWEEN THE UNITED STATES AND CANADA

Responsibilities pursuant to the Boundary Waters Treaty of 1909 were conferred to the International Joint Commission (IJC) under a 1948 reference from the governments of Canada and the United States. The Reference pertains to the use and apportionment of the waters along, across or in the vicinity of the international boundary from the eastern boundary of the Milk River drainage basin on the west (in Montana), up to and including the drainage basin of the Red River on the east (in Minnesota). Under a May 1969 authorization from the two governments, the IJC is to provide oversight over the quality of the waters crossing the boundary within the Red River. This oversight is currently provided through the International Red River Board (IRRB) of the IJC.

The IJC established Water Quality Objectives and Water Quality Alert Levels in 1969 to restore and maintain the chemical, physical and biological integrity of the Red River. Five specific Water Quality Objectives were adopted in 1969 (see Table 2-4). Water Quality Objectives are used (when necessary) to secure a government's commitment to pollution abatement action. The Water Quality Objectives are also the primary means by which the IRRB identifies major water quality issues to the IJC. This is accomplished by identifying how frequently an Objective is exceeded based upon monitoring data.

Alert Levels are intended to compliment the IJC Water Quality Objectives. Alert Levels were approved by the former Red River Pollution Board in 1984 for a variety of pesticides and herbicides (see Appendix C).

Table 2-4. International Joint Commissions Red River Board Water Quality Objectives.

Parameter	**Concentration Level**
Fecal Coliform	> 200 colonies/100 ml
Chloride	> 100 mg/l
Sulfate	> 250 mg/l
Total Dissolved Solids	> 500 mg/l
Dissolved Oxygen	< 5 mg/l

An exceedance occurs if an instantaneous grab sample exceeds the concentration. An exceedance does not have the same status as in the U.S.; i.e. they are advisory in nature.

3.0 METHODS USED TO ESTABLISH EXISTING CONDITIONS AND ASSESS ENVIRONEMNTAL CONSEQUENCES

3.1 EXISTING CONDITIONS METHODS

3.1.1 Process for Defining Existing Conditions

Water quality monitoring data from a variety of sources were assembled to establish the existing water quality conditions. The process of establishing existing conditions consisted of:

- Establishing the geographic limits for the general impact assessment area (i.e., study area) (see Figure 1-1);
- Identifying and selecting the specific stream reaches and lakes, within the Red River Basin;
- Identifying current and historic water quality monitoring locations of these stream reaches and lakes;
- Defining the water quality parameters, which would be used to describe existing conditions;
- Evaluating the period of record for each water quality monitoring location and the number of samples available (i.e., evaluate data quality);
- Characterizing the hydrologic regime for these data;
- Using descriptive statistics to define existing conditions; and
- Identifying currently impaired water bodies, the reason for impairment and describing the frequency of water quality standards exceedances.

3.1.2 Hydrologic Conditions

Existing water quality can vary with the amount of flow in a stream or river. Therefore, some understanding of the hydrologic conditions when data were collected is useful and should ideally represent the water quality in streams and lakes, corresponding to the hydrologic condition anticipated during operation of the proposed alternatives. Four factors are potentially involved in establishing the hydrologic conditions

corresponding with existing water quality. These factors are related to: 1) the timing (i.e., what time of year) of operation; 2) the volume and rate of water delivered; 3) the native volume and discharge within the streams; and 4) the duration of operation. The discharges associated with operation need to be superimposed upon the timing, duration and frequency of existing water quality problems. Reclamation has determined that the greatest stress on the river system is likely to occur when 2050 demands are superimposed on the native flows of a 1930's type drought. Therefore, the discharge between 1931 and 1940 could potentially be used to characterize the baseline hydrologic conditions (see Table 3-1).

The timing of project operation (i.e., when water is delivered), the volume and rate of water delivered, the native volume and discharge within the streams and the duration of operation is a concern, only if water quality varies with discharge in the stream. If the concentration for a parameter does not vary with discharge, then the existing water quality need not be stratified by discharge.

Simple scatter plots were made showing the relationship between discharge and select water quality parameters; i.e., total dissolved solids, sulfate, total phosphorus, arsenic, dissolved oxygen, and fecal coliform bacteria. These parameters were selected as indicators of stressors for different beneficial uses. All data for the Red River Basin were used to create the plots. Based upon this analysis, the period of record concentration data were used to compute descriptive statistics and describe the existing water quality within the Red River Basin. The reason is most parameters showed little obvious relationship to discharge. Therefore, stratifying the water quality data by discharge provides little additional information of central tendency.

3.1.3 Geographic Extent of the Study Area

Existing water quality is described for those waters potentially affected by the alternatives; i.e., perennial and intermittent streams and lakes within portions of North Dakota, Minnesota and at the Manitoba border.

Table 3-1. Discharges representing hydrologic baseline conditions within the Red River Basin (values are median monthly discharges 1931-1940 from STATEMOD model)

Station	January	Febuary	March	April	May	June	July	August	September	October	November	December
Red River at Drayton	25.5	38.5	251	1648	715.5	367	185.5	84.5	101.5	88	162.5	53
Red River at Emerson	19	29.5	381	3167	1526	487	187	97.5	82.5	49.5	147.5	58.5
Red River at Fargo	0	1	32	131	0.5	0	0	3	2	1	1	1
Red River at Grand Forks	22	33	233	1441.5	651.5	267	138	57.5	78.5	56.5	115	42
Red River at Halstad	25	22.5	103	929	471	167	89	51.5	75.5	39	79	46.5
Red River at Wahpeton	28.5	16.5	84.5	162.5	93	49	40.5	31	28	31.5	21	21
Sheyenne River above Harvey	1	1	6	14	4.5	3	1	1	0.5	1	1	1
Sheyenne River above Cooperstown	5.5	6.5	42.5	95.5	39	24.5	11	6	4.5	5	8	5
Sheyenne River at Kindred	30	27.5	46	80	53.5	79.5	96.5	80	18.5	14	17	14
Sheyenne River at Lisbon	27.5	26	31.5	48.5	27.5	70	91.5	79.5	17	10	10	10
Sheyenne River at Valley City	26	24.5	18	24	17.5	59	90.5	78	16	7.5	7.5	7.5
Sheyenne River at Warwick	3.5	4	27.5	61.5	24.5	14.5	6.5	4.5	3.5	3	3	3

The focus for describing existing conditions is perennial river systems within North Dakota, Minnesota and Manitoba, including the Missouri River, the Sheyenne River[7] and the Red River of the North. A portion of the Missouri River System including downstream from Garrison Dam, the portion of Lake Sakakawea from a north-south line bisecting Garrison dam east to the Snake Creek Pump Station, Audubon Lake, and the McClusky canal and the associated lakes east to the continental divide between the Missouri River and Sheyenne Rivers is included.

Existing water quality conditions for the Sheyenne River are described from near Harvey and Warwick, North Dakota, downstream to the confluence with the Red River of the North. The portion of the McClusky Canal from the drainage divide between the Missouri River and Sheyenne River to the Sheyenne River was also included.

Within the Red River of the North system existing conditions are described for the Red River from the confluence of the Ottertail and Bois de Sioux Rivers downstream to Lake Winnipeg, Manitoba.

Three lakes were of primary concern for describing existing water quality; i.e., Lake Ashtabula, Lake of the Woods and Lake Winnipeg (see Figure 1-3). These lakes were selected as surrogates for the remaining lakes, because of their high quality and sensitivity to impacts, as well as their value as a recreational resource. Lake Ashtabula is a component of three of the proposed alternatives, while Lake of the Woods is a feature of one of the alternatives. Nutrient loads at the Canadian – U.S. border were used to represent the potential conditions at Lake Winnipeg.

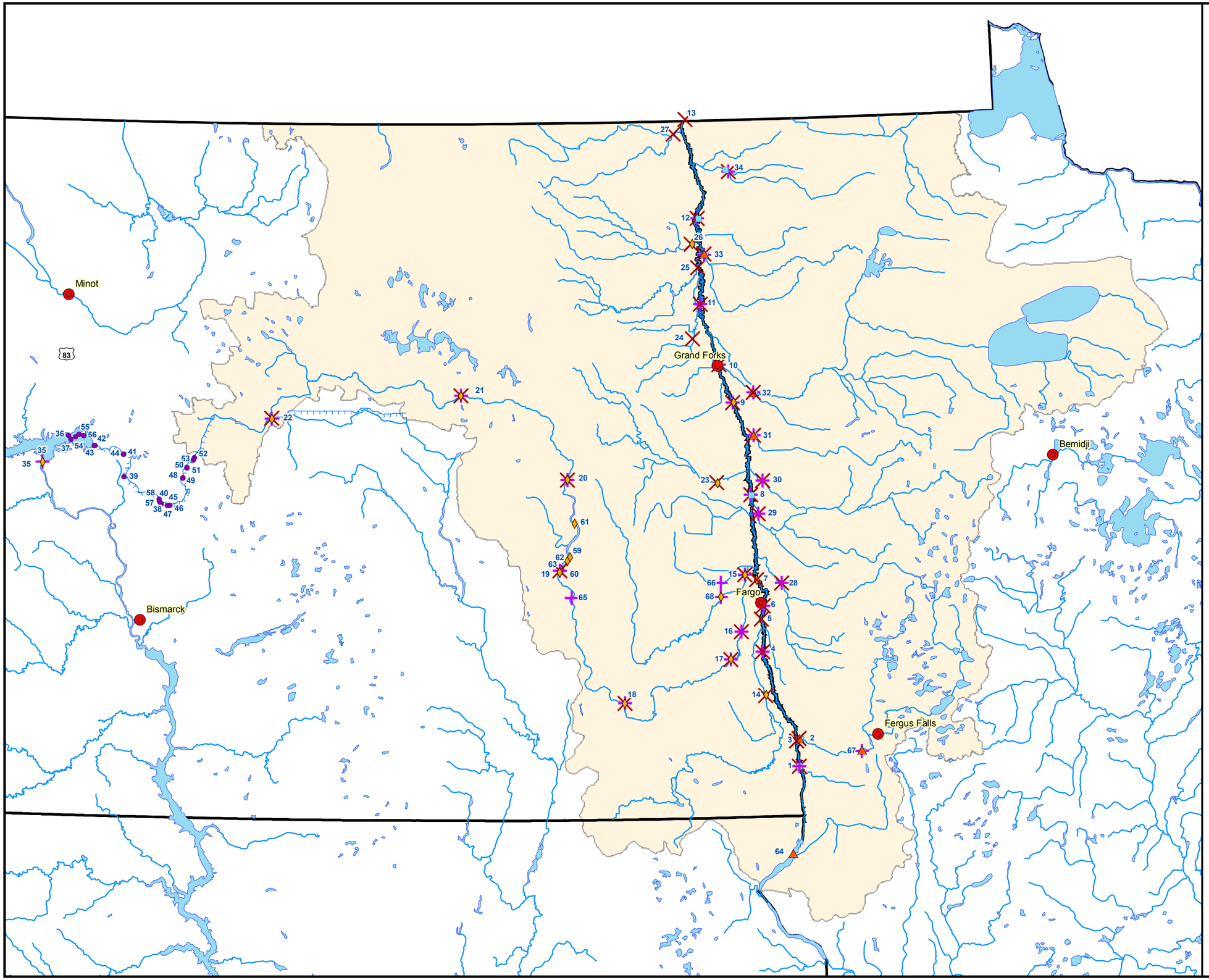
3.1.4 Use and Analysis of Existing Monitoring Data

3.1.4.1 Monitoring Locations Selected

Historic and existing water quality monitoring locations were identified and the data from those locations scrutinized, to determine which locations were best suited to describing existing conditions (see Figure 3-2). The best suited locations were generally those with a combination of the longest period of record, data collected for the parameters needed to assess impact and the largest sample size.

[7] The Sheyenne River, which is tributary to the Red River of the North, is considered a separate river system for the purpose of describing baseline conditions and assessing impacts.

Red River Valley Water Supply Project



Legend

- Major City

Water Quality Monitoring Locations

- USGS SYNOPTIC
- NWIS
- MCCLUSKY CANAL
- MN STORET
- ND STORET
- RIVERWATCH

- Lake or Resevoir
- Stream or River
- Major Canal

N W E S

0 10 20 40 60 Miles

Location Map

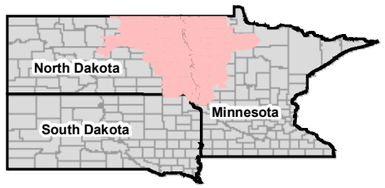


Figure 3-2: Water quality monitoring locations, responsible agency & LOCCODE assignment

Scale: As Shown	Project No: 3750-059	Date: 03/14/05

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GARRISON DIVERSION

The water quality data came from multiple sources including the North Dakota Department of Health (NDDH), the Minnesota Pollution Control Agency (MPCA), the U.S. Geological Survey (USGS), the Bureau of Reclamation (Reclamation) and the River Watch program. The NDDH and the MPCA were specifically contacted to reasonably ensure obtaining data for the period of record. Data from legacy and modern STORET were also obtained. Data obtain from the USGS included the data from the National Water Information System (NWIS) and studies contracted to the USGS by Reclamation specifically for the Red River Valley Water Supply Study.

Seventy locations were initially identified as having historic or current water quality data. However, not all of the locations were used to describe existing water quality or for assessing impacts. Locations were preferentially selected to ensure representation of certain features:

- Impaired water bodies as identified by the NDDH or the MPCA on their respective 303(d) lists;
- A location (node) in the USGS water quality model developed to assess the affects of the alternatives;
- The location of drinking water facilities; and
- Probable return flow locations.

Monitoring locations were also selected on specific stream reaches or lakes that are part of one of the alternatives.

The data from monitoring locations within close proximity of each other, with partial period of record or having only select parameters were sometimes combined. These locations were then given a new location code (i.e., LOCCODE) and considered representative of one of the features described previously. Simple descriptive statistics computed for one or two parameters (usually the parameter with the largest sample size) were used to ensure combining data from the different locations was “defensible.” Both the NDDH and the USGS had considerable data for Lake Ashtabula. Analysis of the NDDH data showed robust spatial and temporal characterization of water quality within the lake. Therefore, only the NDDH data were used.

Over 12,000 water quality records collected at 70 stations between 1951 and 2004 were compiled into the database, which has been included on a CD enclosed with this TM. This 53-year period was the longest period of record for which water quality data were available at a station (i.e., not all stations have a 53-year period of record). In order to populate the database all water quality data sources were integrated, providing a consistent naming convention for stations, sampling dates and parameters.

3.1.4.2 Parameters Used to Describe Existing Conditions

Several water quality parameters were selected to describe existing water quality. Each parameter can be placed into a general category intended to represent some aspect of water quality; i.e., a physical characteristic, the extent of nutrients and probable biological productivity, suitability for drinking water and relative ease of treatment, risk to human health, and risk to aquatic life (Table 3-2). These categories essentially represent different potential water and / or beneficial uses and relate to both narrative and numeric standards used by the NDDH and the MPCA. Appendix B shows the sample size by location and parameter. Appendix C shows sample size by LOCCODE and parameter. Generally, a minimum of 20 to 30 samples is considered necessary for adequately characterizing the water quality at a LOCCODE.

3.1.4.3 Treatment of Data

The data were stored in a Microsoft Access™ database. Values less than the minimum detection limit (mdl) were assigned a value of ½ the mdl. a common and accepted censoring technique. Sample sizes by location for each parameter were then generated to evaluate the amount of information available to establish baseline conditions. Water quality data within the Basin were summarized by location code (i.e., LOCCODE), which roughly correspond to the unit assessment identifications used by the NDDH and the MPCA. Each LOCCODE represents data collected as one or more locations within close proximity (see Figure 3-3). Data from the water quality monitoring locations were reviewed to resolve duplicate sampling dates from the database. When sample collection occurred at multiple locations on the same date for locations representing the same LOCCODE, the average concentration was computed and used as the data value.

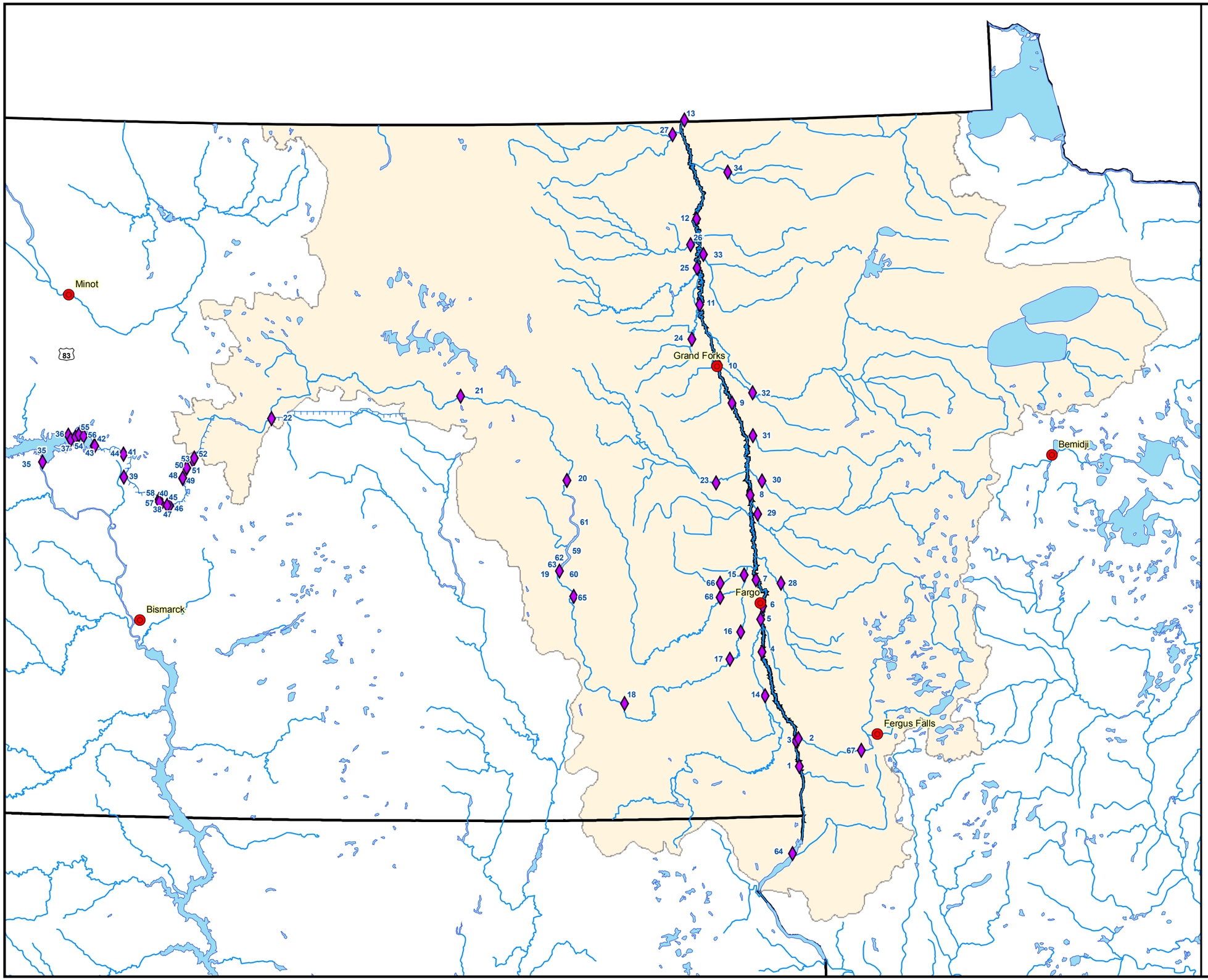
Table 3-2. Water quality parameters by category and the primary water use represented by the parameter.

Category / Parameter	Indicative of Primary Water Use
Physical	
Turbidity	Drinking water
Specific conductance	Drinking water
Total dissolved solids	Drinking water
Dissolved oxygen	Aquatic life
pH	Drinking water & aquatic life
Total alkalinity	Drinking water
Bicarbonate alkalinity	Drinking water
Carbonate alkalinity	Drinking water
Nutrients	
Total Nitrogen	Aquatic life
Ammonia Nitrogen	Aquatic life
Nitrate Nitrogen	Aquatic life
Nitrite Nirogen	Aquatic life
Total Kjeldahl Nitrogen	Aquatic life
Nitrite plus Nitrate Nitrogen	Aquatic life
Total Phosphorus	Aquatic life
Dissolved Phosphorus	Aquatic life
Ions	
Calcium (dissolved)	General indicator
Magnesium (dissolved)	General indicator
Sodium (dissolved)	General indicator
Potassium (dissolved)	General indicator
Chloride	Human health and general indicator
Sulfate	Human health and general indicator

Table 3-2 (cont). Water quality parameters by category and the primary water use represented by the parameter.

Category / Parameter	Indicative of Primary Water Use
Metals	
Arsenic (dissolved and total recoverable)	Human health and aquatic life
Iron (dissolved)	Human health and aquatic life
Manganese (dissolved)	Human health and aquatic life
Mercury (total)	Human health and aquatic life
Selenium (dissolved)	Human health and aquatic life
Biological	
Fecal coliform bacteria	Human health

Red River Valley Water Supply Project



Legend

- Major City
- Lake or Resevoir
- Stream or River
- Major Canal
- Location Code

N W E S

0 10 20 40 60 Miles

Location Map

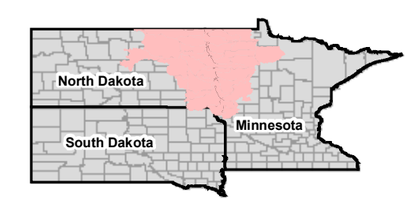


Figure 3-3: Location codes (LOCCODES) used to define the water quality of streams and lakes.

Scale: As Shown	Project No: 3750-059	Date: 03/14/05

3.2 IMPACT ANALYSES METHODS

The assessment of environmental consequences required making several assumptions. These assumptions include:

- Existing water quality described by descriptive statistics and how often numeric standard are exceeded adequately characterizes the future without project condition (i.e., the No Action Alternative);
- The water quality concentrations determined using different analytical methods for the same parameter could be combined, without loss of information or biasing data interpretation (this is necessary in some cases to increase sample size or to resolve duplicate sampling dates);
- The potential affects of individual return flows can be physically represented in aggregate at select locations along a river or stream; and
- Potential impacts at key locations can be described by characterizing conditions at the point of diversion (e.g., the relative change in water quality at Bismarck, North Dakota on the Missouri River can be described by assessing impacts immediately downstream from Garrison Dam).

The key to whether these assumptions are valid, is whether each alternative is equally affected by the assumptions; i.e., the assumption does not introduce bias.

3.2.1 U.S. Geological Survey HEC-5Q Modeling

3.2.1.1 General Modeling Approach

The USGS completed a HEC-5Q model of the Red River Basin. Details of the modeling are described elsewhere. Only information provided to the USGS by HEI for use in their modeling effort is described here.

3.2.1.2 McClusky Canal Boundary Conditions

The HEC-5Q water quality model requires information about the quality of water delivered from the Snake Creek Pump Station downstream through Audubon Lake and

the McClusky Canal to the Sheyenne River (for the GDU Import to Sheyenne River and the GDU Import Pipeline Alternatives). The water delivered from the Snake Creek Pump Station to the Sheyenne River was generally assumed to be the existing quality of Audubon Lake at the McClusky Canal headgates following treatment. Only total suspended solids, biological agents (e.g., bacteria, viruses), and total organic carbon are considered modified by the treatment plant. Table 3-3 shows the water quality delivered from the McClusky Canal to the water treatment plant and ultimately to the Sheyenne River following treatment.

Two methods were used to evaluate the reasonableness of assuming that the water quality delivered to the Sheyenne River during project operation would be similar to the quality within Audubon Lake. The first method consisted of developing an unsteady water quality model for the McClusky Canal from Audubon Lake downstream past New John's Lake to the point of diversion. The model divided the McClusky Canal system into four components; i.e., Audubon Lake, the canal between Audubon Lake and New John's Lake, New John's Lake and the canal downstream from New John's Lake to the point of diversion.

The model hydrology included terms for direct precipitation to and evaporation from the surface of the lakes, surface water runoff entering along the length of the canal in proportion to the direct drainage area, and diversions from the canal and lakes (e.g., from New John's Lake to Painted Woods Creek). The volume and quality of surface water entering the canal from surface water runoff was assumed to be represented by the NWIS gage at Harvey, North Dakota. Non-conservative substances like total phosphorus, nitrate-nitrogen and ammonia-nitrogen were assumed to react following a simple first-order loss rate.

Limited water quality data were available for model "calibration." Data were available for May 18 to August 19, 1999; April 16, 2001 to October 1, 2001; April 30 to September 11, 2002; and May 12 to September 23, 2003. The initial water quality within the canal was based upon measured data collected by Reclamation. Measured discharges at the headworks to the McClusky Canal were also known. Surface water runoff entering

Table 3-3. McClusky Canal Water Quality (values are median concentrations in mg/l unless noted)

River Mile	Description	Conductance (umhos/cm)	Sulfate	Chloride	Alkalinity	Calcium	Magnesium	Nitrate	Ammonia	Orthophosphate (ug/l)	Total Dissolved Solids
-5	Lake Sakakawea at Snake Creek Pumping Plant off west side of structure	680.0	176.4	10.3	163.2	51.8	21.6	0.050	0.100	5.0	417.4
-2.5	Lake Audubon Refuge Line 1/2mile South of #17 Buoy	835.0	246.0	14.4	194.9	46.6	33.9	0.050	0.140	7.5	546.9
0	McClusky Canal Headworks at Lake Audubon Inlet to canal	890.0	256.2	15.3	201.2	42.5	34.8	0.050	0.070	5.0	582.5
0.2	McClusky Canal Headworks Downstream side of Gates	885.0	263.4	15.2	205.6	43.1	35.1	0.050	0.115	5.0	583.7
11.1	McClusky Canal at Lake Brekken Turnout HW 41 N of Turtle Lake	920.0	263.0	15.4	204.5	44.6	35.1	0.050	0.185	7.5	585.1
19.9	McClusky Canal at Radial Gate (R1 & R2) Upstream	920.0	278.7	15.6	210.6	42.6	36.8	0.100	0.210	5.0	577.4
20	McClusky Canal Bridge South of Radial Gate (R1 & R2) D.Stream	950.0	263.3	14.9	193.1	47.0	34.6	0.050	0.130	7.5	594.7
34.2	Hecker's Lake Out From Canal	1270.0	421.8	17.9	225.2	59.0	61.1	0.050	0.120	5.0	860.0
35	New John's Lake West End	1150.0	362.9	17.9	230.6	53.9	53.9	0.050	0.150	10.0	766.3
36	Painted Woods Creek Outlet Channel from New Johns Lake (at structure)	1435.0	572.0	18.4	234.7	81.0	77.7	0.050	0.090	5.0	1047.6
37.8	East End of New John's Lake 1/4 mile west of canal 400' SE of boat ramp	1250.0	407.9	18.4	249.6	54.9	59.4	0.050	0.150	5.0	831.3
38.1	McClusky Canal Radial Gate at Mile 38 West Side	1185.0	428.7	17.9	250.0	62.9	59.1	0.050	0.140	7.5	851.1
38.4	McClusky Canal Bridge at Mile 38 Downstream of Radial Gate	1340.0	553.1	18.3	253.2	82.3	76.5	0.050	0.200	5.0	1056.2
51.2	McClusky Canal Plug @ mile 52 upstream	1490.0	596.9	17.3	274.2	87.9	85.1	0.050	0.195	10.0	1117.9
51.3	McClusky Canal Plug @ mile 52 downstream	1850.0	840.3	20.8	250.7	82.0	104.0	0.050	0.200	10.0	1413.2
54.9	McClusky Canal Gate at Highway 200 (mile 55) UpStream	2330.0	1026.8	29.2	314.4	80.0	132.6	0.050	0.230	10.0	1768.7
55	McClusky Canal Gate at Highway 200 (mile 55) DownStream	2605.0	1108.0	31.3	353.7	80.0	158.0	0.050	0.430	20.0	1923.8
58	McClusky Canal at Hoffer Lake Southeast of mile 58 plug at boat dock.	2555.0	1108.9	31.6	341.4	76.0	149.3	0.050	0.160	5.0	1857.8
58.8	McClusky Canal Plug at Mile 59 UpStream	8340.0	4622.8	169.7	618.3	105.6	588.5	0.050	0.760	50.0	7215.2

Notes: 1) Fecal Coliform bacteria and amount of oxygen demanding substances assumed equal to zero as a result of treatment.
2) Quality delivered to the Sheyenne River based in River Mile 0, McClusky Canal Headworks at Lake Audubon Inlet to canal

the canal for the calibration periods was estimated using an empirical relationship developed using the Harvey, ND gage. The calibration process for conservative substances (e.g., TDS) consisted of evaluating the reasonableness of model behavior; i.e., no model boundary conditions or surface water runoff assumptions were modified (Figure 3-4 and Appendix A). Calibration for non-conservative substances consisted of adjusting the first order rate constant.

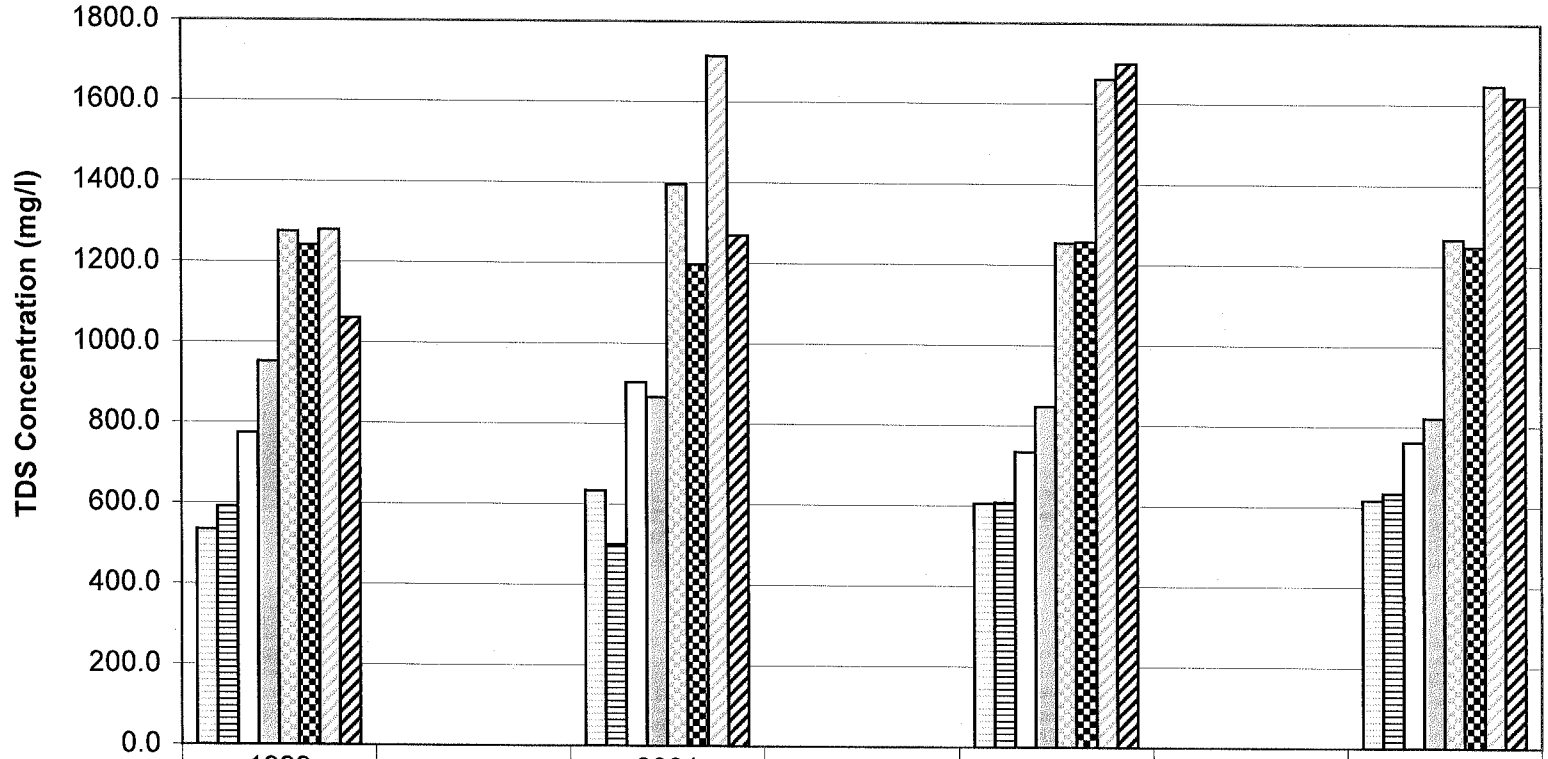
The need to assume the initial water quality within the McClusky Canal, even though based upon measurements completed for the calibration period, proved to be a primary limitation of the unsteady model. Although model behavior relative to the current conditions appeared reasonable, the predicted concentrations demonstrated levels above expected values. The predicted concentrations were largely based upon this assumption. Currently measured water quality does not reflect the greater flows which will occur during project operation. Therefore, a second method not based upon these assumptions was used to evaluate the reasonableness of assuming that the water quality delivered to the Sheyenne River during project operation would be similar to the quality within Lake Audubon.

The second method consisted of applying a set of mathematical equations representing a cells in series steady-state finite element network, as generally described by Thomann and Mueller (1987; see Section 3.6). This approach eliminated the need for an assumption about the initial water quality within the canal system. The result of this approach was estimated concentrations assuming continuous operation (i.e., steady-state) within the four portions of the system as previously described.

3.2.1.3 Lake of the Woods Boundary Conditions

The HEC-5Q water quality model requires information about the quality of water delivered from Lake of the Woods downstream to Grand Forks, Fargo and Wahpeton, North Dakota, for the Lake of the Woods Alternative. Table 3-4 shows the water quality of delivered from the Lake of the Woods to an interconnect near Grand Forks. The data are the median values within Traverse Bay on Lake of the Woods for the period of record.

Figure 3-4
Calibration of McClusky Canal Mass Balance Model for Total Dissolved Solids



	1999	2001	2002	2003
Observed Lake Audubon	534.1	633.7	605.6	616.1
Computed Lake Audubon	589.9	499.3	608.7	634.4
Observed M Canal to New Johns	774.2	903.0	734.4	762.2
Computed M Canal to New Johns	952.1	866.1	846.8	821.4
Observed New John's Lake	1275.1	1395.1	1254.0	1266.0
Computed New John's Lake	1241.3	1196.5	1256.8	1248.0
Observed M Canal to Diversion	1278.6	1714.2	1660.7	1647.0
Computed M Canal to Diversion	1060.0	1268.6	1699.9	1618.7

Time Period

Table 3-4. Lake of the Woods (Traverse Bay) Water Quality Data Used for the Grand Forks to Lake of the Woods Alternative

Parameter	n	Mean	SD	SE	95% CI of Mean			Median	IQR	95% CI of Median		
Total Alkalinity (mg/l)	19	53.5	8.7	2.0	49.3	to	57.67	50.0	9.0	48.0	to	58.0
TDS (uhmos/cm) computed from Conductance		53.6	9.3	1.5	50.6	to	56.7	49.7	3.8	49.4	to	52.7
Chloride (mg/l)	19	2.1	0.6	0.1	1.8	to	2.33	2.2	0.3	2.0	to	2.3
Dissolved Oxygen (mg/l)	152	8.9	1.7	0.1	8.7	to	9.20	8.3	0.8	8.3	to	8.4
Kjeldahl Nitrogen (mg/l)	12	0.6	0.2	0.0	0.54	to	0.76	0.6	0.2	0.54	to	0.8
Organic Nitrogen (mg/l)	7	1.6	2.3	0.9	-0.53	to	3.72	0.7	0.3	0.54	to	6.8
pH	44	7.7	0.3	0.0	7.65	to	7.82	7.7	0.4	7.67	to	7.8
Phosphorus (mg/l)	28	0.039	0.023	0.004	0.030	to	0.05	0.030	0.017	0.030	to	0.040
Specific Conductance (umhos/cm)	38	82.5	14.3	2.3	77.77	to	87.17	76.5	5.8	76.00	to	81.0
Total Suspended Solids (mg/l)	8	4.8	0.8	0.3	4.1	to	5.52	4.6	1.7	4.0	to	6.0

Total dissolved soilds can be computed from specific conductance by applying a ratio generally ranging from 0.6-0.7.

3.2.1.4 Missouri River Boundary Conditions

The HEC-5Q water quality model requires information about the quality of water delivered from the Missouri River to an interconnect west of Fargo, North Dakota for the Missouri River to Red River Valley Import Alternative. Table 3-5 shows the water quality of delivered by this alternative. The data are the median values on the Missouri River at Bismarck, North Dakota for the period of record.

3.2.1.5 Water Quality of Return Flows

The HEC-5Q model requires information about the volume and water quality of return flows. The volume of return flows for the various alternatives was established by Reclamation using the STATEMOD model. Because the greatest proportion of the MR & I water is being used for domestic purposes, typical wastewater discharge quality was used to characterize return flows (where available). Table 3-6 and Table 3-7 show return flow quality. The data were gathered and summarized for wastewater treatment plants at East Grand Forks and Moorhead, Minnesota and Fargo and Grand Forks, North Dakota.

Wastewater effluents are not routinely monitored for many of the parameters needed for operation of the HEC-5Q model. Therefore, for some parameters (chloride, sulfate, iron, calcium, manganese and TDS) return flow quality was "constructed" using the source water characteristics and some assumptions about the proportion of water derived from the various sources and how water quality changes during water treatment, use and wastewater treatment.

Table 3-5. Water quality delivered from the Missouri River to the Fargo Interconnect for the Missouri River to Red River Valley Impor
Alernative. (Missouri River at Bismarck, ND Station # 6342500)

		Descriptive Statistics								
Parameter	**n**	**Mean**	**SD**	**SE**	**95% CI of Mean**		**Median**	**IQR**	**95% CI of Median**	
					Low	**High**			**Low**	**High**
Specific Conductance (µhos/cm at 25 degrees C)	274	667.5	53.9	3.3	661.1	673.9	660.0	55.0	650.0	670.0
TDS (uhmos/ cm)		433.9	35.0	2.1	429.7	438.0	429.0	35.8	422.5	435.5
Dissolved Oxygen (mg/l)	150	10.8	1.6	0.1	10.5	11.0	10.6	2.9	10.0	11.3
Biochemical Oxygen Demand (mg/l)	10	0.60	0.40	0.13	0.31	0.89	0.50	0.40	0.20	1.20
Total Nitrogen (unfiltered, mg/l)	150	0.477	0.223	0.018	0.441	0.513	0.440	0.210	0.410	0.470
Ammonia as Nitrogen (mg/l)	38	0.097	0.120	0.019	0.058	0.136	0.045	0.080	0.020	0.090
Ammonia plus Organic N (mg/l)	164	0.328	0.209	0.016	0.296	0.360	0.285	0.220	0.250	0.310
Orthophosphate (mg/l)	10	0.021	0.025	0.008	0.003	0.039	0.010	0.003	0.010	0.030
Calcium (mg/l)	115	52.9	4.0	0.4	52.2	53.6	53.0	4.3	52.0	54.0
Magnesium (mg/l)	116	21.5	2.0	0.2	21.1	21.8	21.0	3.0	21.0	22.0
Chloride (mg/l)	117	9.8	1.7	0.2	9.5	10.1	9.5	1.2	9.2	9.8
Total Iron (µg/l)	60	1051.0	723.9	93.5	864.0	1238.0	850.0	1107.5	570.0	1200.0
Dissolved Iron (µg/l)	27	37.0	77.2	14.8	6.5	67.6	20.0	10.0	10.0	20.0
Fecal Coliform (colonies per 100 ml)	6	76.8	47.1	19.2	27.4	126.2	64.0	32.5	35.0	160.0
Sulfate (mg/l)	118	181.924	26.7803	2.4653	177.041	to 186.806	172.000	24.000	170.000	to 180.000

TDS is computed from specific conductance using a ration of 0.65.

t

Table 3-6. Wastewater Effluent Quality 2004. Values used as Characteristic of Return Flow Quality (Source: Respective Treatment Plants)

Parameter	Location			
Dissolved Oxygen	**Grand Forks**	**Fargo**	**Moorhead**	**East Grand**
Sample Size	NA	149.00	156.00	6.00
Mean	NA	9.65	5.16	6.33
Standard Deviation	NA	5.14	1.70	4.03
Minimum	NA	2.20	2.40	3.00
Maximum	NA	32.00	9.20	14.00
25% percentile	NA	6.30	3.70	3.75
Median	NA	8.10	4.90	6.00
75% percentile	NA	11.40	6.53	6.00
Biochemical Oxygen Demand - 5 day (mg/l)				
Sample Size	18.00	150.00	157.00	6.00
Mean	7.87	9.63	5.17	6.33
Standard Deviation	5.55	5.13	1.70	4.03
Minimum	3.00	2.20	2.40	3.00
Maximum	20.00	32.00	9.20	14.00
25% percentile	3.38	6.30	3.70	3.75
Median	6.00	8.10	4.90	6.00
75% percentile	10.28	11.38	6.60	6.00
Chemical Oxygen Demand (mg/l)				
Sample Size	NA	NA	52.00	NA
Mean	NA	NA	57.96	NA
Standard Deviation	NA	NA	20.35	NA
Minimum	NA	NA	22.10	NA
Maximum	NA	NA	165.00	NA
25% percentile	NA	NA	45.40	NA
Median	NA	NA	57.50	NA
75% percentile	NA	NA	65.28	NA
Ammonia (mg/l)				
Sample Size	16.00	130.00	157.00	NA
Mean	1.36	0.36	5.57	NA
Standard Deviation	0.71	0.53	4.03	NA
Minimum	0.27	0.05	0.60	NA
Maximum	2.54	4.10	16.00	NA
25% percentile	0.84	0.05	2.10	NA
Median	1.26	0.11	4.10	NA
75% percentile	1.83	0.49	8.50	NA
Total Kjeldahl Nitrogen (mg/l)				
Sample Size	NA	NA	13.00	NA
Mean	NA	NA	7.77	NA
Standard Deviation	NA	NA	4.20	NA
Minimum	NA	NA	3.00	NA
Maximum	NA	NA	14.90	NA
25% percentile	NA	NA	4.40	NA
Median	NA	NA	5.70	NA
75% percentile	NA	NA	11.10	NA

Table 3-6. Wastewater Effluent Quality 2004. Values used as Characteristic of Return Flow Quality (Source: Respective Treatment Plants)

Parameter	Location			
Dissolved Oxygen	**Grand Forks**	**Fargo**	**Moorhead**	**East Grand**
Sample Size	NA	149.00	156.00	6.00
Mean	NA	9.65	5.16	6.33
Standard Deviation	NA	5.14	1.70	4.03
Minimum	NA	2.20	2.40	3.00
Maximum	NA	32.00	9.20	14.00
25% percentile	NA	6.30	3.70	3.75
Median	NA	8.10	4.90	6.00
75% percentile	NA	11.40	6.53	6.00
Biochemical Oxygen Demand - 5 day (mg/l)				
Sample Size	18.00	150.00	157.00	6.00
Mean	7.87	9.63	5.17	6.33
Standard Deviation	5.55	5.13	1.70	4.03
Minimum	3.00	2.20	2.40	3.00
Maximum	20.00	32.00	9.20	14.00
25% percentile	3.38	6.30	3.70	3.75
Median	6.00	8.10	4.90	6.00
75% percentile	10.28	11.38	6.60	6.00
Chemical Oxygen Demand (mg/l)				
Sample Size	NA	NA	52.00	NA
Mean	NA	NA	57.96	NA
Standard Deviation	NA	NA	20.35	NA
Minimum	NA	NA	22.10	NA
Maximum	NA	NA	165.00	NA
25% percentile	NA	NA	45.40	NA
Median	NA	NA	57.50	NA
75% percentile	NA	NA	65.28	NA
Ammonia (mg/l)				
Sample Size	16.00	130.00	157.00	NA
Mean	1.36	0.36	5.57	NA
Standard Deviation	0.71	0.53	4.03	NA
Minimum	0.27	0.05	0.60	NA
Maximum	2.54	4.10	16.00	NA
25% percentile	0.84	0.05	2.10	NA
Median	1.26	0.11	4.10	NA
75% percentile	1.83	0.49	8.50	NA
Total Kjeldahl Nitrogen (mg/l)				
Sample Size	NA	NA	13.00	NA
Mean	NA	NA	7.77	NA
Standard Deviation	NA	NA	4.20	NA
Minimum	NA	NA	3.00	NA
Maximum	NA	NA	14.90	NA
25% percentile	NA	NA	4.40	NA
Median	NA	NA	5.70	NA
75% percentile	NA	NA	11.10	NA

Table 3-7. Water Quality in the Discharge from the Fargo/Moorhead Wastewater Treatment Facilities

Parameters (mg/l)	ND - In Basin	Red River Valley	Lake of the Woods	GDU to Sheyenne River	GUD Import	Missouri River to Red River Valley	GUD Replacement	No Action
Chloride	72.3	84.4	90.1	81.8	75.5	90.7	58.0	59.7
Sulfate	111.7	109.3	95.0	143.4	191.0	94.3	270.0	110.0
Calcium	54.7	60.9	41.1	47.1	45.0	48.0	40.0	53.0
Iron	0.60	0.75	0.53	0.50	0.67	0.36	0.97	0.35
Manganese	0.35	0.37	0.33	0.34	0.34	0.34	37.30	0.34
TDS	1053.1	1113.4	1001.1	1055.6	1037.2	1023.9	980.0	1008.5
Nitrate	15.2	15.3	15.2	15.2	15.2	15.2	15.2	15.2

Assumes 391 cfs (253mgd) Total Maximum demand

3.2.2 Audubon Lake Impacts

The potential water quality impacts within Audubon Lake were assessed by using the unsteady model for the McClusky Canal described previously.

3.2.3 Missouri River Impacts

Assessing the potential impacts to the Missouri River consisted of applying a mass balance approach (Table 3-8). The existing annual load from Lake Sakakawea and Garrison Dam to the Missouri River (Missouri River South of Garrison - STORET Location 380056) was estimated using the product of the mean concentration and mean annual discharge for the period of record. The load for the alternative delivering water through the Snake Creek Pump Station or withdrawing water for the Missouri River were then compared to the Missouri River.

3.3 Lake Ashtabula Eutrophication Modeling

The potential eutrophication impacts within Lake Ashtabula were evaluated using the U.S. Army Corps of Engineer's BATHTUB water quality model (see Walker, 1986). The BATHTUB model, which divides the lake into 4 longitudinal segments for predicting water quality, was obtained from the St. Paul District. The St. Paul District, U.S. Army Corps of Engineers previously developed and calibrated (for 1981 conditions) a model of Lake Ashtabula. The St. Paul District developed several models for annual conditions through 1999. The BATHTUB model predicts nutrient concentrations, water clarity expressed as secchi disc visibility and chlorophyll-a concentrations.

The BATHTUB model was modified to reflect the annual hydrologic and water quality conditions of the alternatives for four hydrologic periods; i.e., dry (1963), normal (1941), wet (1994) and long-term average (STATEMOD results for the 71-year period). Dry, normal and wet hydrologic conditions were operationally defined as the 90% exceedance, median and 10% exceedance values for annual runoff volume at the Cooperstown USGS gage. Water quality characteristics entering Lake Ashtabula from Baldhill Creek and upstream on the Sheyenne River were assumed to remain constant for the various hydrologic conditions.

The method used to develop information about the quality of water delivered by a project to Lake Ashtabula varied, depending upon the alternative. The quality of water

downstream of Grand Forks was assumed to represent the water quality delivered to Lake Ashtabula for the North Dakota In-Basin Alternative. Similarly, the quality of water at Bismarck was assumed to represent the water quality delivered to Lake Ashtabula for the Missouri to Red River Valley Import Alternative. Steady-state concentrations modeled through the McClusky Canal system were used for the GDU to Sheyenne Import Alternative. The models for the various alternatives are included on the CD with this TM.

3.4 CRITERIA FOR DETERMINING "SIGNIFICANCE" OF WATER QUALITY IMPACTS

The NEPA requires a determination of the magnitude of the impacts, whether beneficial or adverse, and whether the impacts are significant. The meaning of the term "significant" is determined by considering the context[8] in which it will occur and the intensity of the action. *Context* refers to the significance of the action and must be analyzed based on society as a whole, the affected interests, the affected region and the locality in which it would occur. Therefore, significance will vary depending on the setting and location of the proposed action. *Intensity* refers to the severity of the impact. Determining intensity is based upon:

- Beneficial effects;
- Public health;
- Unique characteristics of the area;
- Degree of controversy;
- Degree of unique or unknown risk;
- Precedent-setting action;
- Cumulative effect;
- Cultural or historical resources;
- Special status species (i.e., threatened & endangered species); and
- Violation of federal, state or local environmental law.

[8] See Mastering NEPA: A Step-by-Step Approach by Ronald E. Bass and Albert I Herson. 1993.

Table 3-8. Water Quality Data for Missouri River at Garrison.

	Descriptive Statistics									
Parameter	**n**	**Mean**	**SD**	**SE**	**95% CI of Mean**		**Median**	**IQR**	**95% CI of Median**	
					Low	**High**			**Low**	**High**
Specific Conductance (umhos/cm at 25 degrees C)	419	659.1	46.2	2.3	654.7	663.5	651.00	45.50	650.0	655.0
TDS (mg/l) (Computed from Conductance)		428.4	30.0	1.5	425.5	431.3	423.2	29.6	422.5	425.8
Dissolved Oxygen (mg/l)	358	10.7	2.0	0.1	10.5	10.9	10.90	3.20	10.5	11.2
Total Nitrogen (mg/l)	89	0.530	0.326	0.035	0.461	0.599	0.460	0.260	0.400	0.550
Dissolved Nitrogen (mg/l)	25	0.564	0.194	0.039	0.484	0.644	0.510	0.280	0.430	0.660
Dissolved Ammonia as Nitrogen (mg/l)	144	0.031	0.035	0.003	0.025	0.037	0.020	0.033	0.012	0.030
Total Ammonia as Nitrogen (mg/l)	137	0.026	0.043	0.004	0.019	0.034	0.010	0.025	0.010	0.020
Nitrite Nitrogen (mg/l)	106	0.004	0.003	0.000	0.003	0.004	0.005	0.003	0.003	0.005
Total Kjeldahl Nitrogen (mg/l)	212	0.349	0.281	0.019	0.311	0.387	0.270	0.250	0.220	0.300
Nitrite plus Nitrate (mg/l)	109	0.139	0.139	0.013	0.113	0.165	0.130	0.090	0.110	0.150
Total Phosphorus (mg/l)	213	0.017	0.028	0.002	0.013	0.021	0.010	0.015	0.010	0.010
Dissolved Phosphorus (mg/l)	241	0.012	0.017	0.001	0.010	0.015	0.005	0.015	0.005	0.010
Orthophosphate (mg/l)	117	0.008	0.011	0.001	0.006	0.010	0.005	0.002	0.005	0.005
Calcium (mg/l)	267	52.2	4.2	0.3	51.7	52.7	52.0	5.0	51.0	52.4
Magnesium (mg/l)	267	21.0	2.2	0.1	20.7	21.2	21.0	2.6	20.0	21.0
Sodium (mg/l)	267	59.6	7.3	0.4	58.7	60.5	58.0	8.0	58.0	59.0
Potassium (mg/l)	267	4.0	0.4	0.0	4.0	4.1	4.0	0.4	3.9	4.0
Chloride (mg/l)	243	9.5	1.5	0.1	9.4	9.7	9.5	1.4	9.2	9.7
Sulfate (mg/l)	243	179.5	26.2	1.7	176.2	182.9	170.0	30.0	170.0	180.0
Arsenic (µg/l)	145	2.1	0.9	0.1	1.9	2.2	2.0	0.0	2.0	2.0
Dissolved Iron (µg/l)	134	10.6	15.4	1.3	8.0	13.2	5.0	4.3	5.0	5.0
Dissolved Manganese (µg/l)	63	5.1	8.9	1.1	2.9	7.3	5.0	3.0	3.0	5.0
Dissolved Selenium (µg/l)	132	0.932	0.949	0.083	0.769	1.096	1.000	0.500	0.600	1.000
Suspended Selenium (µg/l)	31	0.065	0.250	0.045	-0.027	0.156	0.000	0.000	0.000	0.000
Total Mercury (µg/l)	55	0.154	0.097	0.013	0.128	0.180	0.100	0.200	0.050	0.250
Fecal Coliform Bacteria (colonies per 100 ml)	139	3.3	15.4	1.3	0.7	5.8	0.5	0.5	0.5	0.5

Total dissolved soilds can be computed by applying a ratio generally ranging from 0.6 - 0.7.

An impact to water quality will be considered significant *as a result of the Proposed Action if*:

- A water quality numeric standard is exceeded a sufficient number of times to change the impairment status; or
- A change in the beneficial uses. A positive impact occurs if the likelihood of achieving a beneficial use increases. Conversely, a negative impact occurs if the likelihood of achieving a current beneficial use is reduced; or
- The narrative portion of the standard is "violated"; or
- Degradation or improvement to water quality occurs.

Water quality degradation is defined as a change (deterioration) of $\pm$15% in the long-term (median) chemical concentration.

4.0 EXISTING WATER QUALITY WITHIN THE RED RIVER BASIN

The existing water quality within the Red River of the North Basin has recently or previously been described (e.g., Tornes, 2005; Stoner et al., 1998) primarily by using descriptive statistics to identify typical concentrations. Stoner et al. (1998) determined that:

> *Stream quality and basic water quality (as defined by concentrations of major ions) in surficial aquifers are not uniform in the Red River of the North Basin Study Unit. The differences in water quality generally can be related to differences in geology, soils, and hydrology in four subregions in the basin. Saline seeps from deep ground-water sources affect streams in the northwestern portion of the Study Unit during times of extremely low streamflow. Water in the Red River of the North Basin, when unaffected by human activities, generally is safe to drink according to U.S. Environmental Protection Agency (USEPA) standards for dissolved solids, major ions, and radionuclides. Natural differences in water quality are important factors for water and land management.*

Stoner et al. (1998) further indicated that:

> *Streams draining areas containing the largest percentage of cropland (central and southern parts of the Red River of the North Basin Study Unit) had the highest concentrations of nutrients (dissolved phosphorus, nitrate, and organic nitrogen). Wastewater from urban areas along the Red River of the North has a minimal effect on the river's quality. The median concentration of ammonia, commonly associated with wastewater, was not higher in the river than in the tributaries,but ammonia concentration was slightly higher in the river downstream from the Fargo-Moorhead area. Compared to historical data for the river, concentrations of ammonia have decreased and nitrate have increased slightly downstream from the Fargo-Moorhead area. These trends likely reflect improved aeration of wastewater effluent over time.*

This portion of the Technical Memorandum presents a summary of the existing water quality using additional data sources and a longer period of record (for NWIS locations) than utilized by Stoner et al. (1998) and Tornes (2005). The additional sources of information include data collected by the North Dakota Department of Health and

EPA's STORET system. The available data have been summarized in a manner intended to represent larger portions of stream and rivers within the Red River of the North Basin, rather than specific locations. The data are also summarized in a manner believed to be more applicable for assessing the environmental consequences of the alternatives.

4.1 DESCRIPTION OF CURRENT USE IMPAIRMENT AND STRESSORS – NORTH DAKOTA AND MINNESOTA

Most states collect water quality monitoring data for a representative subset of their streams and lakes. Therefore, only a portion of all the streams and lakes are actually "assessed" relative to meeting beneficial uses. Whether a stream or lake is able to achieve the current beneficial uses is based upon the analysis of the data collected.

This section presents and describes current use impairments within the Study Area. The states of North Dakota and Minnesota submit a report to the U.S. EPA and Congress, called the 305(b) report, every two years. The 305(b) report provides a state-wide perspective of water quality. The reports identify the status of streams and lakes relative to achieving beneficial uses. The methods used to conclude whether a stream or lake meets its beneficial uses can differ from state to state. A stream in North Dakota for example, is considered as partially supporting beneficial uses if 25% of the fecal coliform bacteria samples collected exceed 400 organism/100 ml. A stream in Minnesota however, is considered as partially supporting beneficial uses if 10% of the fecal coliform bacteria samples collected exceed 200 organism/100 ml.

4.1.1 North Dakota

Figure 4-1 shows the status of streams and lakes relative to their intended beneficial uses within North Dakota. Lakes and portions of streams are evaluated according to the "degree" that each beneficial use (e.g., water supply, aquatic life, etc.) is achieved, by placing them in one of three categories: 1) fully supporting; 2) fully supporting but threatened; or 3) not supporting. Generally, a water body is considered "threatened" if water quality and /or watershed trends are expected to continue to degrade the current condition into the future. A threatened use typically means there is some (small) proportion of the time that monitoring data shows the numeric water quality

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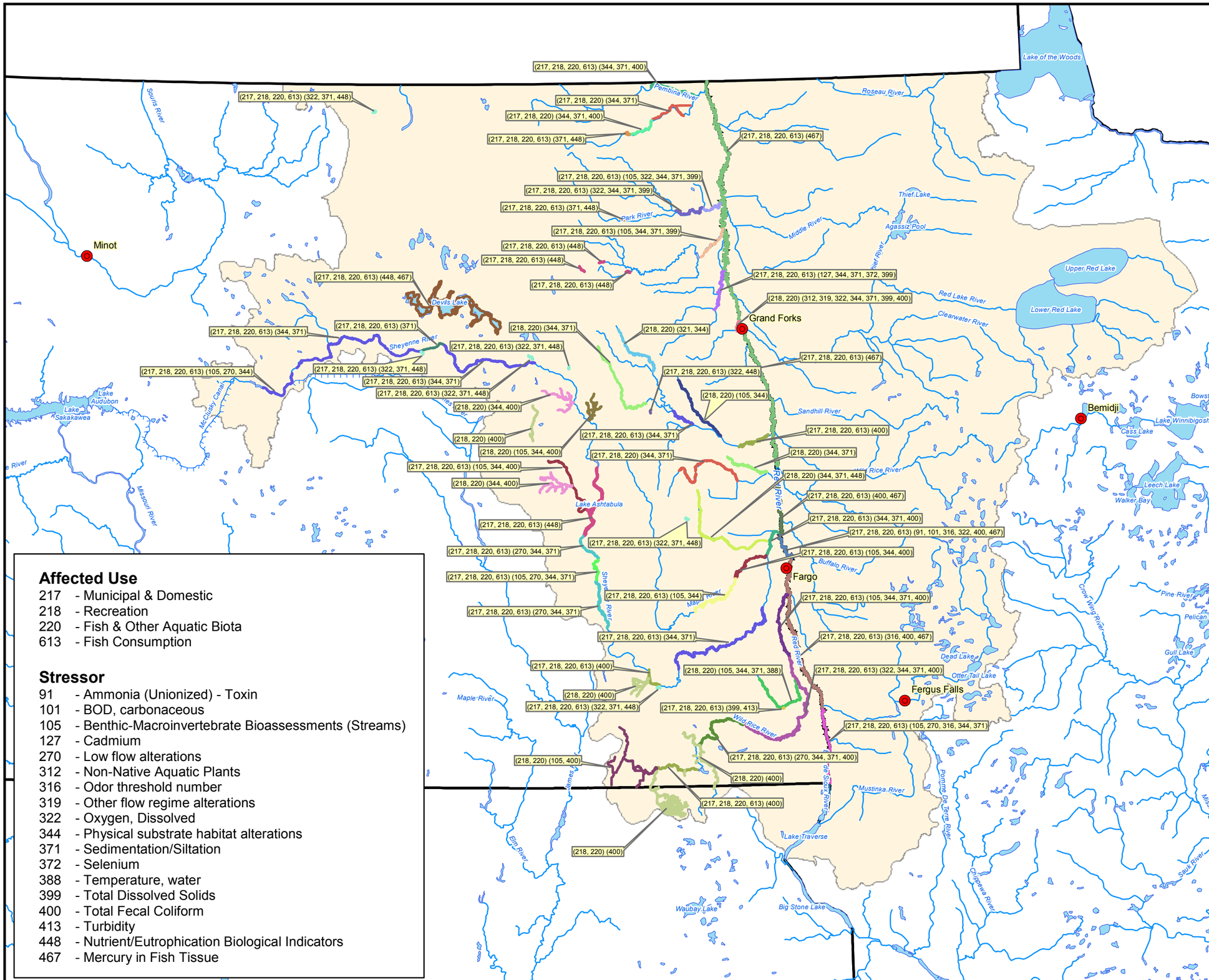


Affected Use

217 - Municipal & Domestic
218 - Recreation
220 - Fish & Other Aquatic Biota
613 - Fish Consumption

Stressor

91 - Ammonia (Unionized) - Toxin
101 - BOD, carbonaceous
105 - Benthic-Macroinvertebrate Bioassessments (Streams)
127 - Cadmium
270 - Low flow alterations
312 - Non-Native Aquatic Plants
316 - Odor threshold number
319 - Other flow regime alterations
322 - Oxygen, Dissolved
344 - Physical substrate habitat alterations
371 - Sedimentation/Siltation
372 - Selenium
388 - Temperature, water
399 - Total Dissolved Solids
400 - Total Fecal Coliform
413 - Turbidity
448 - Nutrient/Eutrophication Biological Indicators
467 - Mercury in Fish Tissue

(Affected use) (Stressor)

- (217, 218, 220, 613) (105, 270, 316, 344, 371)
- (217, 218, 220, 613) (105, 270, 344, 371)
- (217, 218, 220, 613) (105, 322, 344, 371, 399)
- (217, 218, 220, 613) (105, 344, 371, 399)
- (217, 218, 220, 613) (105, 344, 371, 400)
- (217, 218, 220, 613) (105, 344, 400)
- (217, 218, 220, 613) (105, 344)
- (217, 218, 220, 613) (127, 344, 371, 372, 399)
- (217, 218, 220, 613) (270, 344, 371, 400)
- (217, 218, 220, 613) (270, 344, 371)
- (217, 218, 220, 613) (316, 400, 467)
- (217, 218, 220, 613) (322, 344, 371, 399)
- (217, 218, 220, 613) (322, 344, 371, 400)
- (217, 218, 220, 613) (322, 371, 448)
- (217, 218, 220, 613) (322, 448)
- (217, 218, 220, 613) (344, 371, 400)
- (217, 218, 220, 613) (344, 371)
- (217, 218, 220, 613) (371, 448)
- (217, 218, 220, 613) (371)
- (217, 218, 220, 613) (399, 413)
- (217, 218, 220, 613) (400, 467)
- (217, 218, 220, 613) (400)
- (217, 218, 220, 613) (448, 467)
- (217, 218, 220, 613) (448)
- (217, 218, 220, 613) (467)
- (217, 218, 220, 613) (91, 101, 316, 322, 400, 467)
- (217, 218, 220) (344, 371, 400)
- (217, 218, 220) (344, 371)
- (218, 220) (312, 319, 322, 344, 371, 399, 400)
- (218, 220) (105, 344, 371, 388)
- (218, 220) (105, 344, 400)
- (218, 220) (105, 344)
- (218, 220) (105, 400)
- (218, 220) (321, 344)
- (218, 220) (344, 371, 448)
- (218, 220) (344, 371)
- (218, 220) (344, 400)
- (218, 220) (400)

N W E S

0 12.5 25 50 75 Miles

Location Map

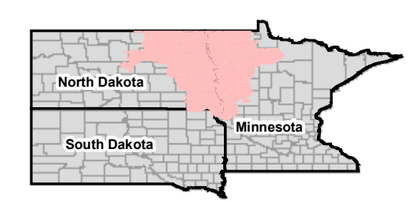


Figure 4-1: North Dakota Impaired Reaches & Stressors Causing Impairment

Source: 2004 305(b) Report

Scale: As Shown	Project No: 3750-059	Date: 03/14/05

standard is exceeded. Not supporting typically means the frequency and severity of the problem is greater than threatened and a documented problem exists (e.g., observed fish kill means not supporting aquatic life use).

North Dakota identifies the specific reasons or causes (i.e., stressors) for a stream or lake not meeting a beneficial use. Figure 4-1 shows the reasons or specific stressors for threatened and not supporting streams and lakes, within the North Dakota portion of the Study Area.

4.1.2 Minnesota

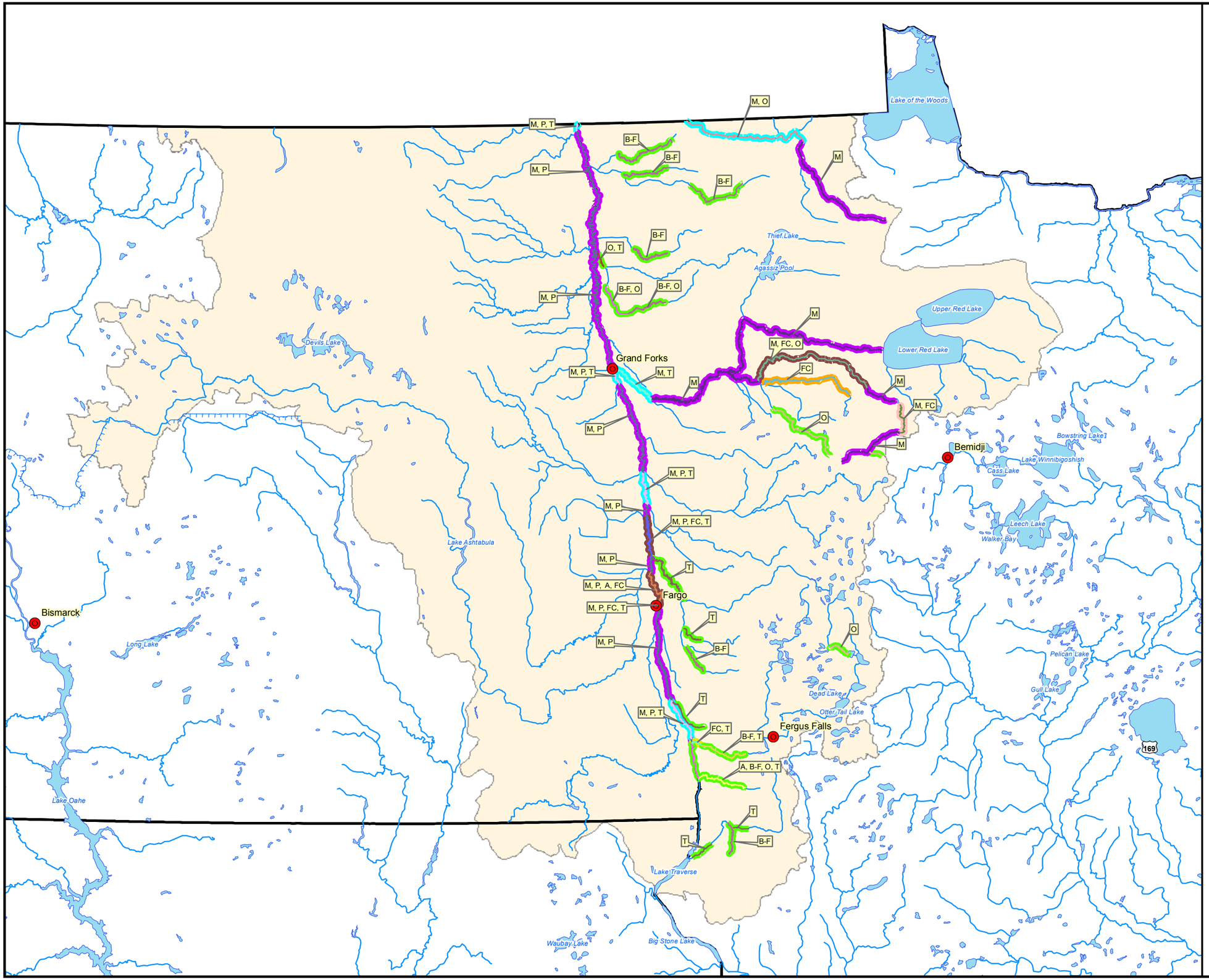
Figure 4-2 shows the status of streams and lakes relative to their intended beneficial uses within Minnesota. Lakes and portions of streams are evaluated according to the "degree" that each beneficial use (e.g., water supply, aquatic life, etc.). is achieved, by placing them in one of three categories: 1) fully supporting; 2) partially supporting; or 3) not supporting. Generally, a water body is considered partially supporting if water quality and /or watershed trends are expected to continue to degrade the current condition, into the future. A partially supporting use typically means there is some (small) proportion of the time that monitoring data shows the numeric water quality standard is exceeded. Not supporting typically means the frequency and severity of the problem is greater than threatened and a documented problem exists (e.g., observed fish kill means not supporting aquatic life use). Figure 4-2 shows the reasons or specific stressors for partially supporting and not supporting streams and lakes, within the Minnesota portion of the Study Area.

4.1.3 Missouri River

4.1.3.1 Lake Sakakawea

The beneficial uses for Lake Sakakawea for aquatic life are identified as fully supporting but threatened. The aquatic life threatened status is based on periodic problems with low dissolved oxygen concentrations and elevated water temperature, which can impair the cold water fishery within the lake. The lake is deemed as not supporting the fish consumption use because of mercury levels in fish tissue, an impact typically associated with atmospheric deposition.

Red River Valley Water Supply Project
Minnesota Portion



Affected Use - Rivers

- Aquatic Consumption
- Aquatic Life
- Aquatic Life and Aquatic Consumption
- Aquatic Life and Aquatic Recreation
- Aquatic Life, Aquatic Recreation, Aquatic Consumption
- Aquatic Recreation
- Aquatic Recreation and Aquatic Consumption

Affected Use - Lakes

- Aquatic Consumption
- Aquatic Rec and Consumption
- Aquatic Recreation

Stressor

- A, B-F, O, T
- B-F
- B-F, O
- B-F, T
- FC
- FC, T
- M
- M, FC
- M, FC, O
- M, O
- M, P
- M, P, A, FC
- M, P, FC, T
- M, P, T
- M, T
- O
- O, T
- T

Key:

A	- Ammonia
B-F	- Fish Biota
C	- Chloride
FC	- Fecal Coliform
M	- Mercury
O	- Low oxygen
P	- pH
T	- Turbidity
Tm	- Temperature

N W E S

0 12.5 25 50 75 Miles

Location Map

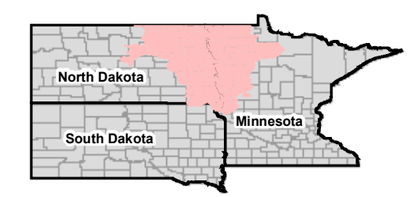


Figure 4-2: Minnesota Impaired Reaches & Stressors Causing Impairment

Source: 2004 305(b) Report

Scale: As Shown	Project No: 3750-059	Date: 03/14/05

4.1.3.2 Missouri River to Bismarck

The Missouri River is fully supporting all beneficial uses downstream from Garrison Dam to Bismarck, North Dakota.

4.1.4 Province of Manitoba

The Province of Manitoba does not identify impaired waters in the same manner as States within the U.S. However, the level of concern about a particular water body can perhaps be gauged in part from past and current water quality initiatives within the Province. The Red River of the North within Manitoba is classified as a routine protection of uses water.

Other than maintaining the water quality objectives established by the IJC and the proposed Provincial standards, objectives and guidelines, the Lake Winnipeg Nutrient Management Strategy is the most prominent current initiative. The Strategy establishes an action plan, intended to reduce nutrient loads to Lake Winnipeg. Data collected at Emerson, Manitoba suggest an increase in the median TP concentration has occurred within the lake since the late 1970's. An estimated 43% of the total nitrogen load (roughly 29,000 tons per year) and 66% of the total phosphorus load (roughly 4,200 tons per year) entering Lake Winnipeg originates within the Red River Basin. The Province has further estimated that 65% and 59% of the total nitrogen and total phosphorus loads respectively (from within the Basin) originates in the U.S.

4.2 EXCEEDANCES OF SELECT NUMERIC WATER QUALITY STANDARDS

An analysis of the frequency that numeric water quality standards are exceeded is presented within this section. The analysis is based upon the data compiled as described in *Section 3.1.4, Use and Analysis of Existing Monitoring Data.* The water quality parameters selected for the analysis are intended to be representative of the most common stressors affecting beneficial uses (see Table 4-1). The analysis is presented by LOCCODE and intended to provide basic information about the occurrence of water quality standards exceedances on an annual basis over the period of record for a LOCCODE (which differs by LOCCODE). Each LOCCODE essentially represents a portion or segment of the river. Standards differ depending upon the specific state and stream classification. Table 4-2 shows the standards by State and stream.

Table 4-1. Water quality parameters used to evaluate existing numeric standards exceedances.

Parameter	**Beneficial Use**
Dissolved Oxygen	Aquatic Life
Total Phosphorus	Nutrients
Sulfate	Drinking Water
Total Dissolved Solids / Turbidity	Drinking Water
Fecal Coliform Bacteria	Recreation
Arsenic	Human Health

Table 4-2. Numeric Water Quality Standards by Tributary/River Reach

Loccode	Tributary	DO (mg/l)	Total P (mg/l)*	Sulfate (mg/l)	Total Dissolved Soilds (mg/l)	Turbidity (NTU)	Fecal Coliform Bacteria (organisms)ml	Arsenic (ug/l)
1	Bois de Sioux River (MN)	5		1000	700	25	200	53
64	Bois de Sioux River (MN)	5		1000	700	25	200	53
28	Buffalo River (MN)	5		1000	700	25	200	53
30	Marsh River (MN)	5		1000	700	25	200	50
2	Otter Tail River (MN)	5		250	650	25	200	2
67	Otter Tail River (MN)	5		250	650	25	200	2
32	Red Lake River (MN)	5		250	650	25	200	2
3	Red River of the North (MN)	5		250	650	25	200	2
4	Red River of the North (MN)	5		250	650	25	200	2
5	Red River of the North (MN)	5		250	650	25	200	2
6	Red River of the North (MN)	5		250	650	25	200	2
7	Red River of the North (MN)	5		250	650	25	200	2
8	Red River of the North (MN)	5		250	650	25	200	2
9	Red River of the North (MN)	5		250	650	25	200	2
10	Red River of the North (MN)	5		250	650	25	200	2
11	Red River of the North (MN)	5		250	650	25	200	2
12	Red River of the North (MN)	5		250	650	25	200	2
13	Red River of the North (MN)	5		250	650	25	200	2
31	Sand Hill River (MN)	5		1000	700	25	200	53
33	Snake River (MN)	5		1000	700	25	200	53
34	Two Rivers (MN)	5		250	650	25	200	2
29	Wild Rice River (MN)	5		1000	700	25	200	53
101	Bois de Sioux (ND)	5	0.1	250			200	50
25	Forest River (ND)	5	0.1	450			200	50
23	Goose River (ND)	5	0.1	450			200	50
59	Lake Ashtabula (ND)	5	0.02	750			200	50
60	Lake Ashtabula (ND)	5	0.02	750			200	50
61	Lake Ashtabula (ND)	5	0.02	750			200	50
62	Lake Ashtabula (ND)	5	0.02	750			200	50
63	Lake Ashtabula (ND)	5	0.02	750			200	50
37	Lake Audobon (ND)	5	0.02	450			200	50
54	Lake Audobon (ND)	5	0.02	450			200	50
55	Lake Audobon (ND)	5	0.02	450			200	50
56	Lake Audobon (ND)	5	0.02	450			200	50
36	Lake Sakakawea (ND)	5	0.02	250			200	50

Table 4-2. Numeric Water Quality Standards by Tributary/River Reach

Loccode	Tributary	DO (mg/l)	Total P (mg/l)*	Sulfate (mg/l)	Total Dissolved Soilds (mg/l)	Turbidity (NTU)	Fecal Coliform Bacteria (organisms)ml	Arsenic (ug/l)
1	Bois de Sioux River (MN)	5		1000	700	25	200	53
64	Bois de Sioux River (MN)	5		1000	700	25	200	53
28	Buffalo River (MN)	5		1000	700	25	200	53
30	Marsh River (MN)	5		1000	700	25	200	50
2	Otter Tail River (MN)	5		250	650	25	200	2
67	Otter Tail River (MN)	5		250	650	25	200	2
32	Red Lake River (MN)	5		250	650	25	200	2
3	Red River of the North (MN)	5		250	650	25	200	2
4	Red River of the North (MN)	5		250	650	25	200	2
5	Red River of the North (MN)	5		250	650	25	200	2
6	Red River of the North (MN)	5		250	650	25	200	2
7	Red River of the North (MN)	5		250	650	25	200	2
8	Red River of the North (MN)	5		250	650	25	200	2
9	Red River of the North (MN)	5		250	650	25	200	2
10	Red River of the North (MN)	5		250	650	25	200	2
11	Red River of the North (MN)	5		250	650	25	200	2
12	Red River of the North (MN)	5		250	650	25	200	2
13	Red River of the North (MN)	5		250	650	25	200	2
31	Sand Hill River (MN)	5		1000	700	25	200	53
33	Snake River (MN)	5		1000	700	25	200	53
34	Two Rivers (MN)	5		250	650	25	200	2
29	Wild Rice River (MN)	5		1000	700	25	200	53
101	Bois de Sioux (ND)	5	0.1	250			200	50
25	Forest River (ND)	5	0.1	450			200	50
23	Goose River (ND)	5	0.1	450			200	50
59	Lake Ashtabula (ND)	5	0.02	750			200	50
60	Lake Ashtabula (ND)	5	0.02	750			200	50
61	Lake Ashtabula (ND)	5	0.02	750			200	50
62	Lake Ashtabula (ND)	5	0.02	750			200	50
63	Lake Ashtabula (ND)	5	0.02	750			200	50
37	Lake Audobon (ND)	5	0.02	450			200	50
54	Lake Audobon (ND)	5	0.02	450			200	50
55	Lake Audobon (ND)	5	0.02	450			200	50
56	Lake Audobon (ND)	5	0.02	450			200	50
36	Lake Sakakawea (ND)	5	0.02	250			200	50

4.2.1 Sheyenne River

4.2.1.1 Total Phosphorus Recommendation

The amount of phosphorus present in a water body is generally indicative of the capacity to grow algae within lakes and the biological productivity in streams and rivers. North Dakota advocates an upper limit of 100 μg/L as a "recommendation" for the maximum concentration of total phosphorus within surface waters (Note: this is not a numeric standard and does not have regulatory standing). Figure 4-9 shows the total phosphorus recommendation for the Sheyenne River is exceeded more than 50% of the time based upon the samples collected. The level is exceeded more than 80% of the time upstream from Lake Ashtabula and less below Lake Ashtabula. The recommendation is generally exceeded most frequently during the summer months (Figure 4-3).

4.2.1.2 Sulfate

Elevated amounts of sulfate within domestic drinking water can cause a laxative affect. Therefore, sulfate is used to indicate suitability as a domestic water supply. The sulfate numeric standard varies depending upon the water body, within North Dakota (see Table 4-2). This standard is only exceeded within the upper portion of the Sheyenne River at Harvey, North Dakota. An estimated 3% of the samples collected exceed the sulfate standard (Figure 4-9). The remaining portion of the Sheyenne River does not show exceedances of the sulfate standard based upon the existing information. From a basin-wide perspective the number of exceedances is greatest in June and February (Figure 4-4).

4.2.1.3 Total Dissolved Solids (and Salts) and Turbidity

Total dissolved solids and salts are used to represent the general health or condition of a water body. When dissolved salts comprise the greatest proportion of the dissolved material in water, total dissolved salts and total dissolved solids are nearly equal. Turbidity is a measurement of the light scattering properties of water. Turbid waters appear murky and indicate a stress to aquatic life or recreation. Only Minnesota

Figure 4-3. Exceedance of the total phosphorus recommendation within North Dakota based upon historical data.

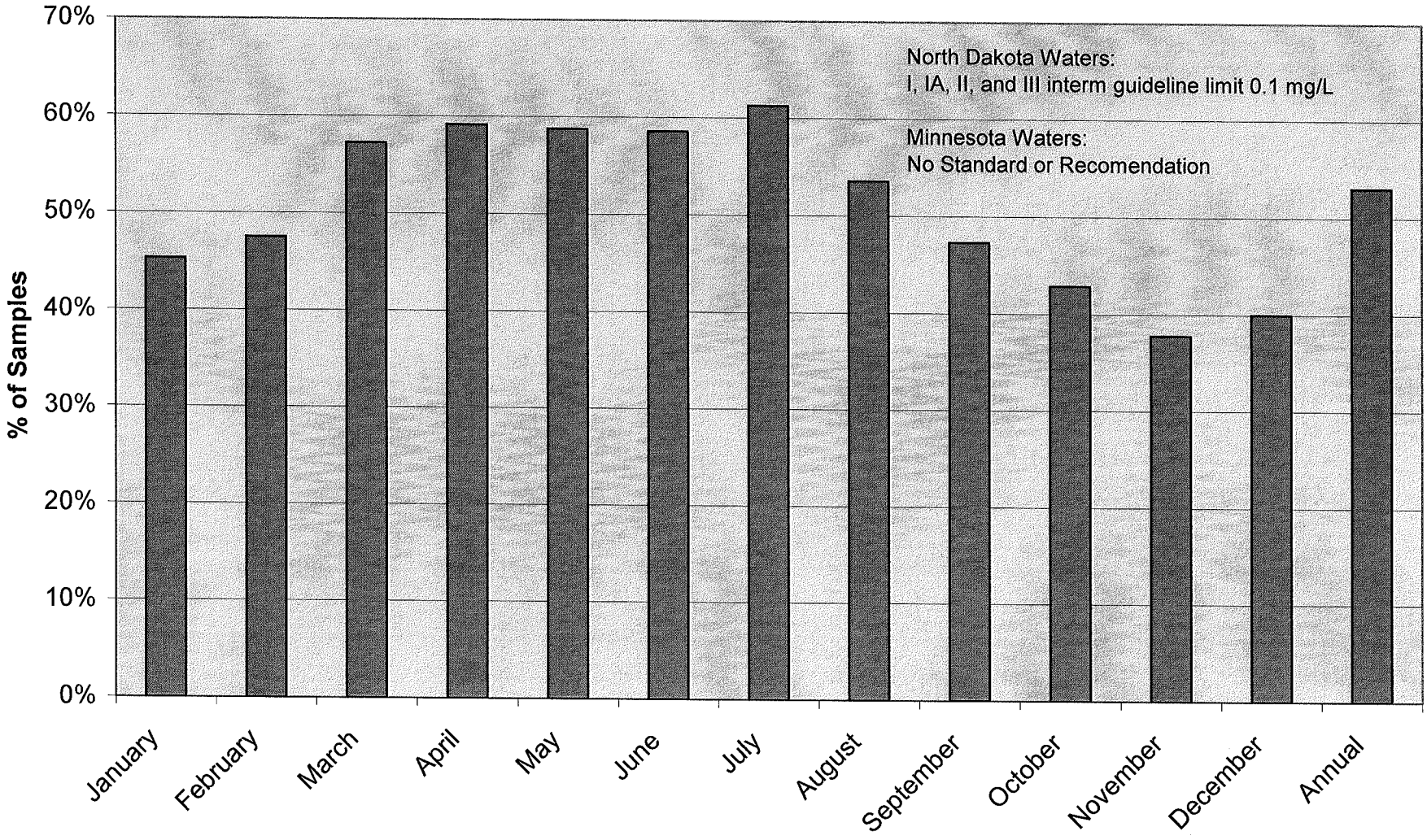
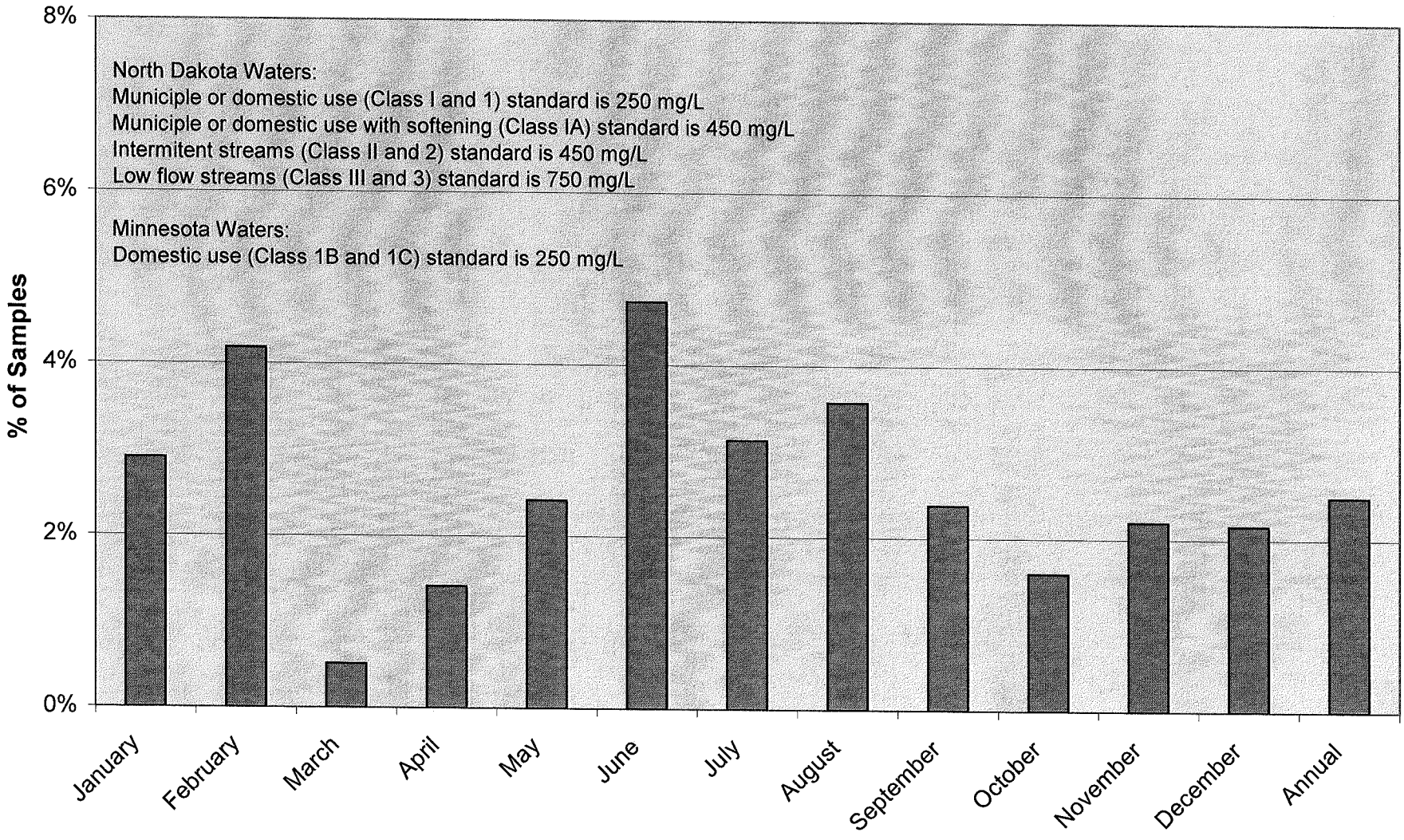


Figure 4-4. Exceedance of the sulfate standard within North Dakota and Minnesota based upon historical data.



has total dissolved solids and turbidity numeric standards. These standards are generally exceeded all months, most often during low flow conditions in late winter (Figure 4-5).

4.2.1.4 Dissolved Oxygen

Sufficient dissolved oxygen is necessary to maintain a healthy and viable aquatic community. Figure 4-9 shows that the dissolved oxygen standard within the Sheyenne River is periodically exceeded. Approximately 10% of the samples exceed the dissolved oxygen standard of 5 mg/L within portions of the Sheyenne River upstream from Lake Ashtabula. Immediately downstream from Lake Ashtabula the standard is not exceeded, while the standard is exceeded approximately 10% of the time near the mouth of the Sheyenne River. From a basin-wide perspective, the number of exceedances is greatest during the months of January, February and March (Figure 4-6).

4.2.1.5 Fecal Coliform Bacteria

Fecal coliform bacteria is an indicator of the potential contamination of surface waters by warm blooded animals, including contamination from domestic and livestock wastes. The recreational use of a river, stream or lake is limited when fecal coliform bacteria levels become excessive. The fecal coliform standard is only applicable to the summer months, when surface waters are used for full immersion recreation (e.g., swimming). Figure 4-9 shows that based upon the available data, the fecal coliform bacteria standard is not exceeded within the Sheyenne River upstream from Lake Ashtabula. The standard is exceeded on the Sheyenne River between Lisbon and Kindred less than 10% of the time for the samples collected. The number of exceedances within the Red River Basin in general, is greatest during the months of April and July (Figure 4-7).

4.2.1.6 Arsenic

Arsenic is a naturally occurring substance in the environment, but can pose a long-term human health risk, when present in excessive amounts within surface waters. Arsenic naturally occurs in soils and is present in many forms. The chronic arsenic standard of 50 μg/L is generally not exceeded within the Sheyenne River (Figure 4-8).

Figure 4-5. Exceedance of the total dissolved solids (calculated from specific conductance) standard within RRV in Minnesota based on historical data.

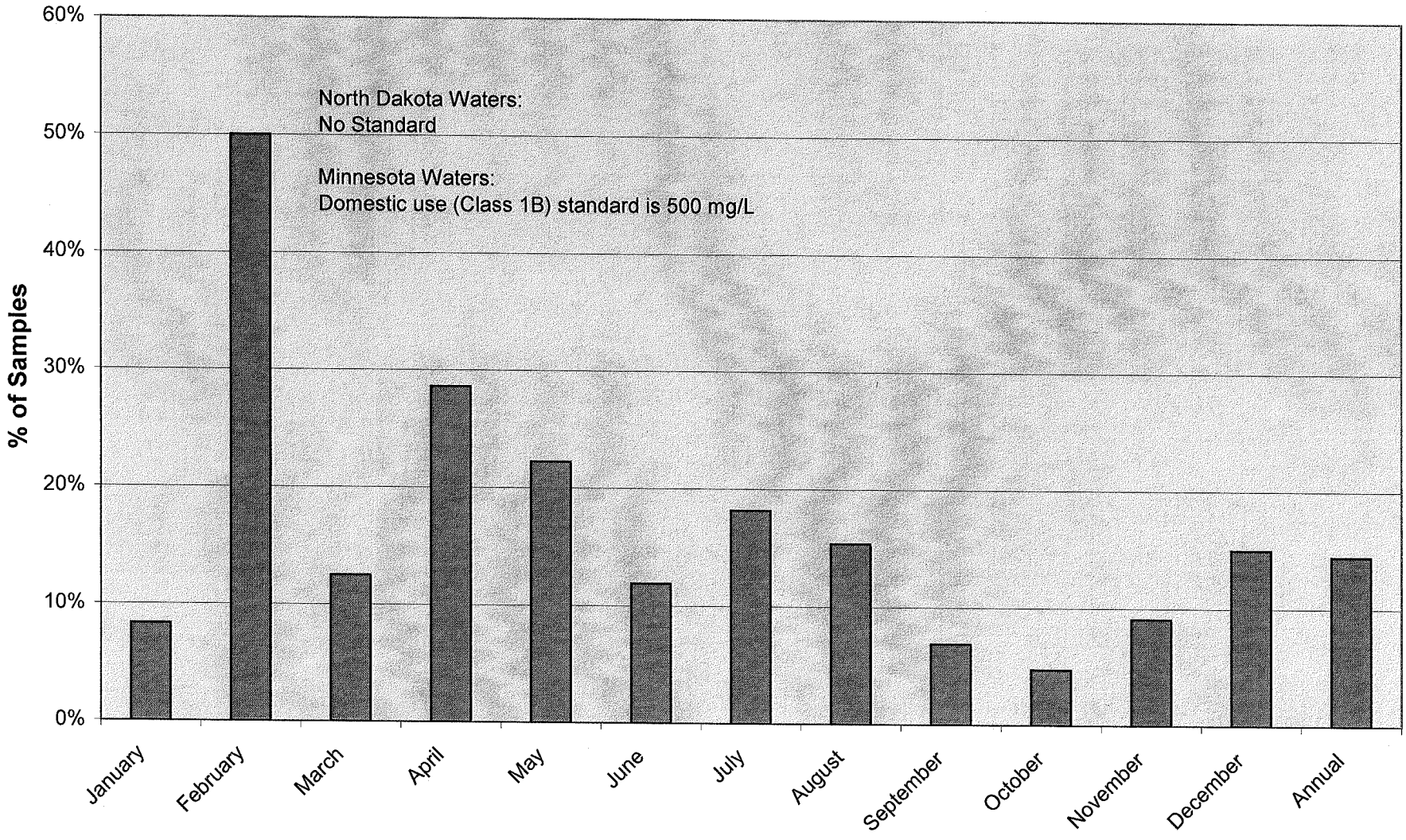


Figure 4-6. Exceedance of the dissolved oxygen standard within North Dakota and Minnesota based on historical data.

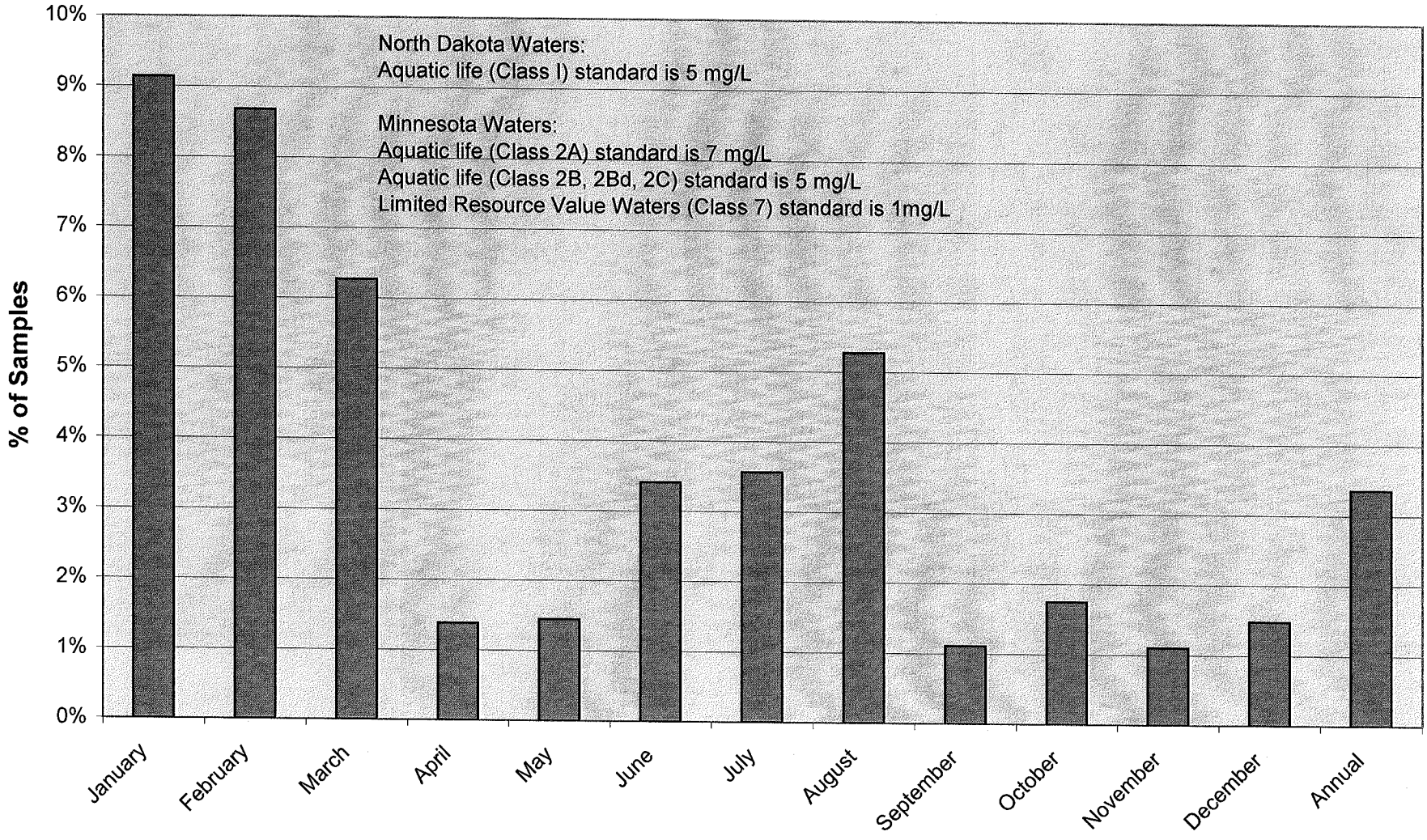
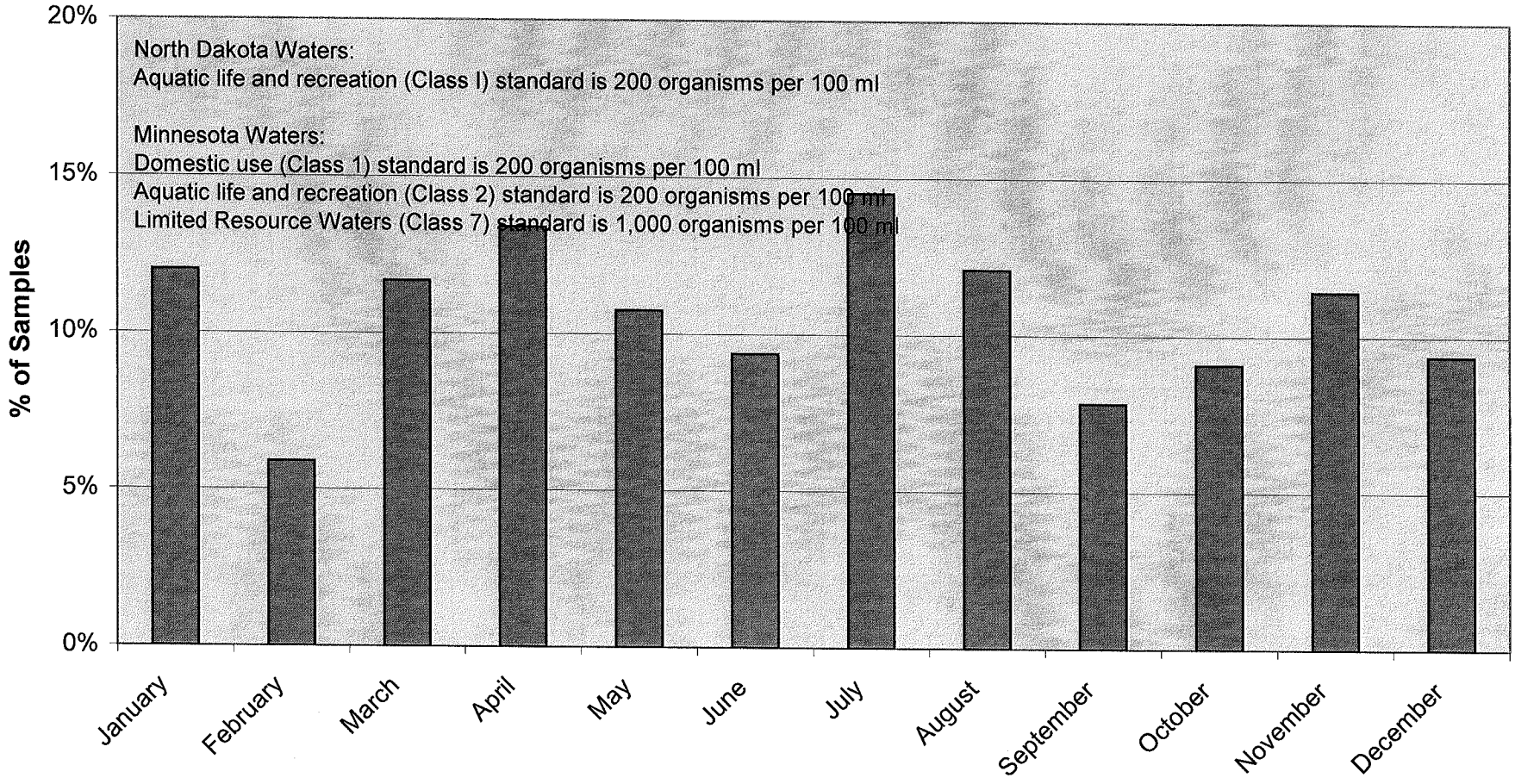
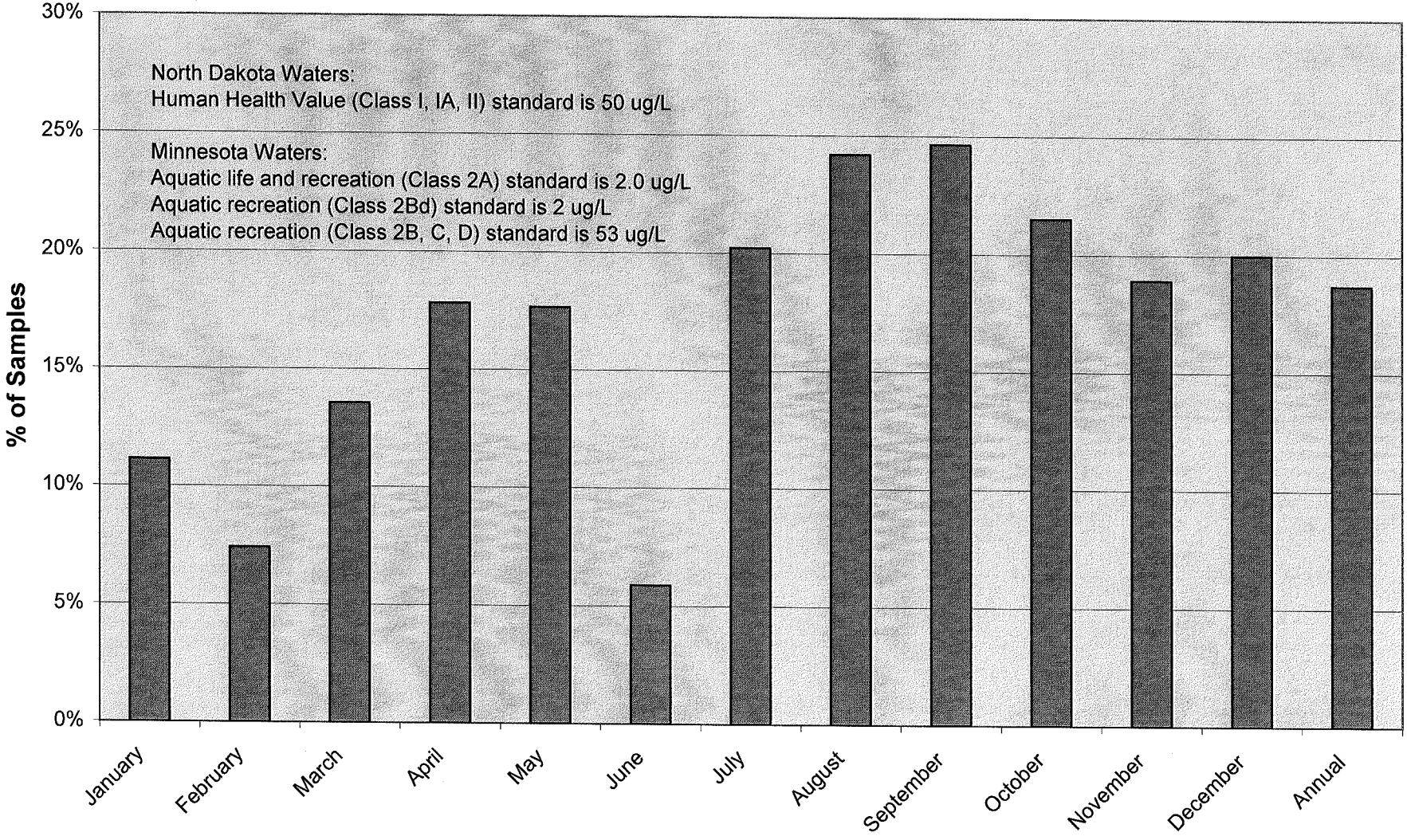


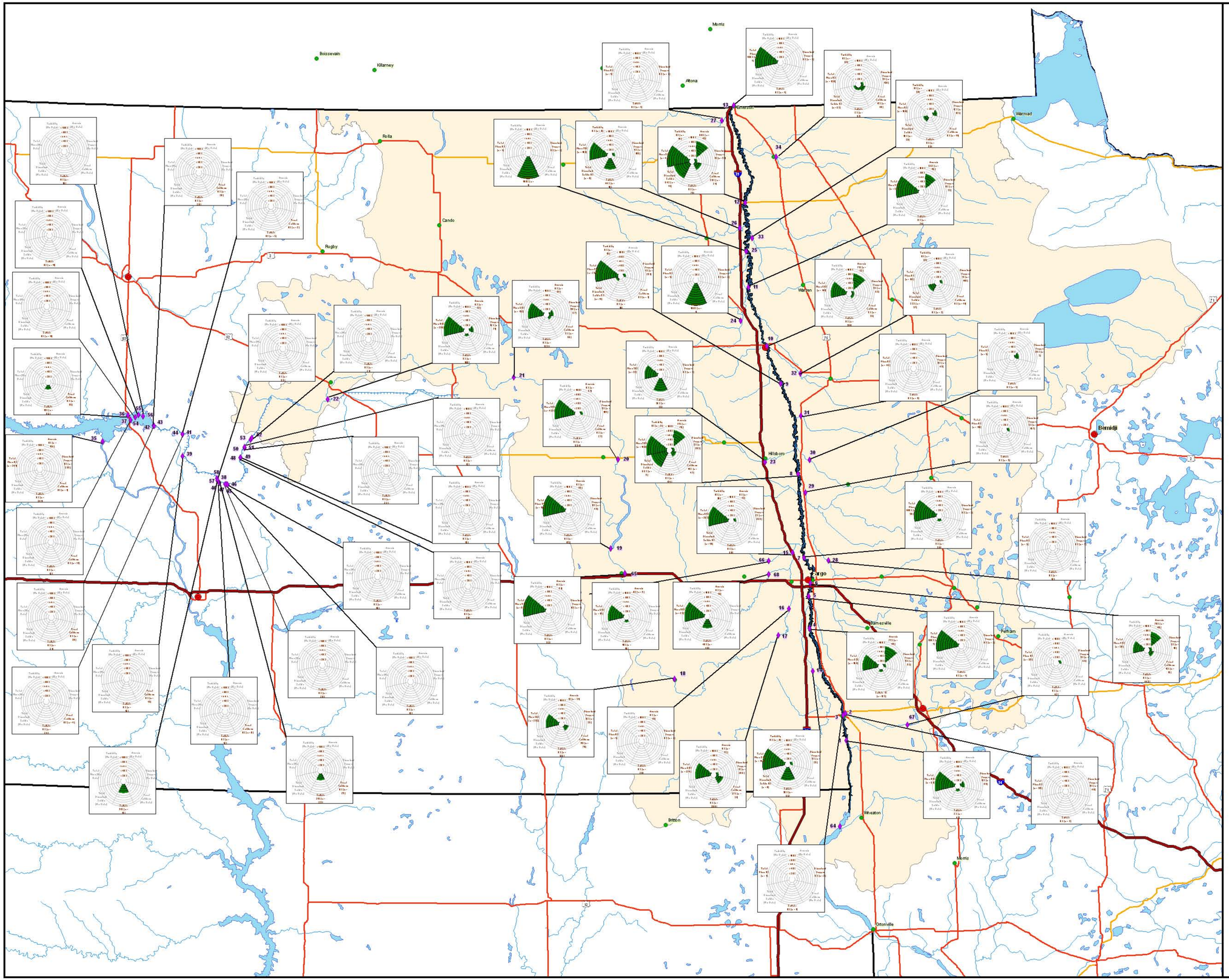
Figure 4-7. Exceedance of the fecal coliform standard within North Dakota and Minnesota based on historical data



(Note: Aquatic life and recreation standards apply from April 1 - October 31 in Minnesota and from May 1 - September 30 in North Dakota.)

Figure 4-8. Exceedance of the chronic arsenic standard within North Dakota and Minnesota based upon historical data.



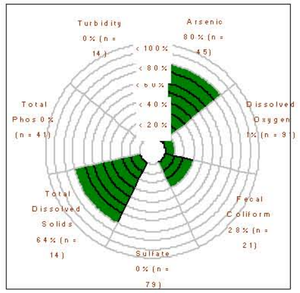


Red River Valley Water Supply Project

Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Percent of Samples Exceeding Numeric Criteria or Objective



Data by LOCCODES

N
W E
S

0 12.5 25 50 75 Miles

Location Map

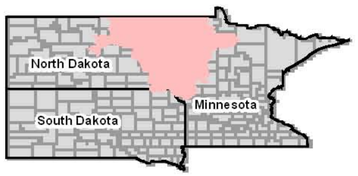


Figure 4-9: Exceedences by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 07/21/05

4.2.2 Red River

4.2.2.1 Total Phosphorus Recommendation

Figure 4-9 shows the recommended total phosphorus level within for the Red River is exceeded in excess of 50% of the time for the samples collected. This is generally consistent along the Red River moving from upstream to downstream.

4.2.2.2 Sulfate

This standard is exceeded infrequently on the Red River; i.e., generally less than 3% of the measured samples. Some exceedances do occur immediately downstream from Lake Traverse within the upper portion of the Red River and upstream of Fargo (Figure 4-9).

4.2.2.3 Total Dissolved Solids (and Salts) and Turbidity

Only Minnesota has numeric standards for total dissolved solids and turbidity and few data are available for the Red River (i.e., 3 locations). Based upon these locations, the turbidity standard is not exceeded on the Red River (Figure 4-9). However, the total dissolved solids standard is exceeded between 9% and 66% of the time, depending upon the portion of the river.

4.2.2.4 Dissolved Oxygen

The dissolved oxygen standard based upon the samples collected is exceeded relatively infrequently along the Red River (Figure 4-9). Generally, less than 3% of the samples at most locations are lower than the dissolved oxygen standard of 5 mg/L. Some locations show dissolved oxygen consistently above (i.e., better than) the numeric standard.

4.2.2.5 Fecal Coliform Bacteria

Many locations along the Red River lack information about fecal coliform levels (see Figure 4-9). Data are generally available only within close proximity to urban areas like Fargo and Grand Forks. Those locations with data show the fecal coliform bacteria standard is generally exceeded between 9% and 15% of the time for the samples collected.

4.2.2.6 Arsenic

The chronic arsenic standard differs between North Dakota (i.e., 50 μg/L) and Minnesota (i.e., 2 μg/L). The more restrictive Minnesota standard has been used for this analysis and consequently indicates considerable exceedances. The analysis shows that the using the 2 μg/L standard, aresenic exceedances are in excess of 60% for many LOCCODES along the Red River (Figure 4-9). The standard is generally exceeded during the months of August and September (Figure 4-8).

4.2.3 Missouri River

Only data at Garrison Dam were used for the analysis. These data generally show no exceedances of the numeric standards at Garrison Dam and generally within Lake Sakakawea and Lake Audubon.

4.3 CHARACTERIZATION OF EXISTING WATER QUALITY

Modified notched box and whisker plots were used to describe the existing water quality within the project area for select parameters. Notched box and whisker plots were determined by LOCCODE[9] for the purposes of completing the analysis. A simple graphical method can be used to conclude whether the water quality between LOCCODES differs. The water quality between two locations is considered different if the interquartile range (i.e., the difference between the upper and lower quartiles) for two LOCCODES does not overlap. Figures 4-10 through 4-15 show notched box and whisker plots using the data for the period of record (independent of discharge) for the monitoring locations: (a minimum of 10 samples was deemed necessary for completing this analysis).

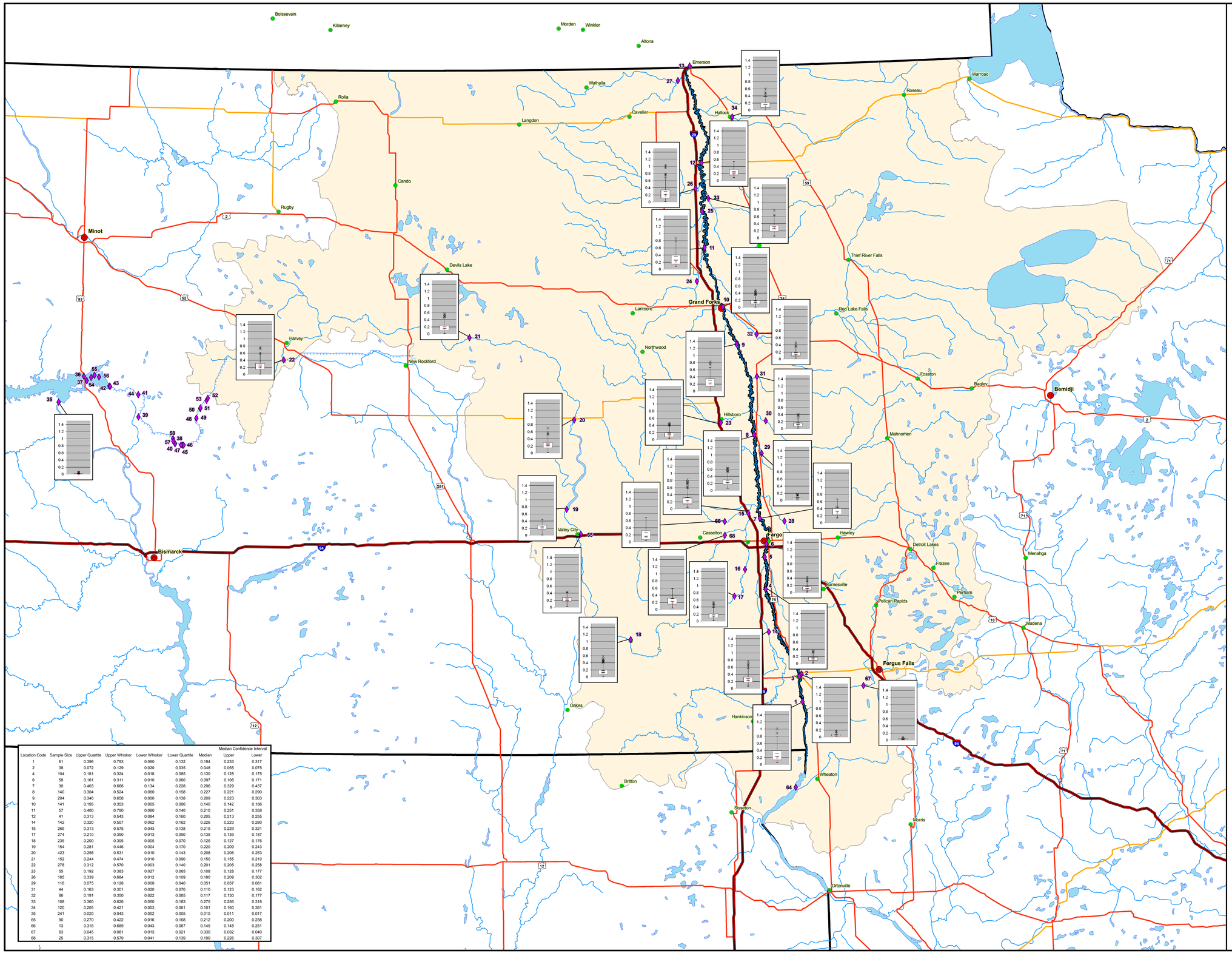
4.3.1 Sheyenne River

4.3.1.1 Total Phosphorus (TP)

The total phosphorus (TP) recommendation for North Dakota streams and rivers is 100 μg/L. Median concentrations within the Sheyenne River consistently exceed this level (Figure 4-10). Median TP concentrations within the Sheyenne River upstream from

[9] The "LOCCODE" is a combination of data from multiple locations (see Methods section).

Red River Valley Water Supply Project

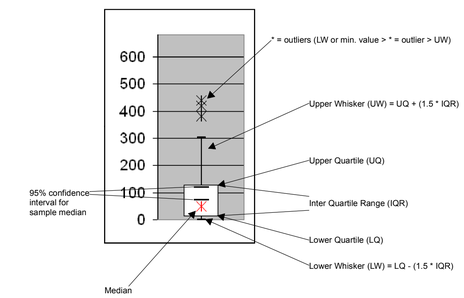


Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
1	61	0.396	0.793	0.060	0.132	0.194	0.233	0.317
2	38	0.072	0.129	0.020	0.035	0.048	0.055	0.075
4	104	0.181	0.324	0.018	0.085	0.130	0.128	0.175
6	58	0.161	0.311	0.010	0.060	0.097	0.106	0.171
7	30	0.403	0.666	0.134	0.228	0.296	0.329	0.437
8	140	0.304	0.524	0.060	0.158	0.227	0.221	0.290
9	204	0.346	0.658	0.000	0.138	0.209	0.223	0.303
10	141	0.195	0.353	0.005	0.090	0.140	0.142	0.186
11	57	0.400	0.790	0.080	0.140	0.210	0.251	0.358
12	41	0.313	0.543	0.084	0.160	0.205	0.213	0.255
14	142	0.320	0.557	0.062	0.162	0.226	0.223	0.280
15	265	0.313	0.575	0.043	0.138	0.215	0.229	0.321
17	274	0.210	0.390	0.013	0.090	0.135	0.139	0.187
18	235	0.200	0.395	0.005	0.070	0.125	0.127	0.176
19	154	0.281	0.446	0.004	0.170	0.220	0.209	0.243
20	423	0.298	0.531	0.010	0.143	0.208	0.206	0.253
21	152	0.244	0.474	0.010	0.090	0.150	0.155	0.210
22	278	0.312	0.570	0.003	0.140	0.201	0.205	0.258
23	55	0.192	0.383	0.027	0.065	0.108	0.128	0.177
26	185	0.339	0.684	0.012	0.109	0.190	0.209	0.302
29	116	0.075	0.128	0.008	0.040	0.051	0.057	0.081
31	44	0.163	0.301	0.020	0.070	0.110	0.123	0.162
32	86	0.191	0.350	0.022	0.085	0.117	0.130	0.177
33	108	0.360	0.626	0.050	0.183	0.275	0.256	0.318
34	120	0.205	0.421	0.003	0.061	0.101	0.160	0.381
35	241	0.020	0.043	0.002	0.005	0.010	0.011	0.017
65	90	0.270	0.422	0.016	0.168	0.212	0.200	0.238
66	13	0.316	0.689	0.043	0.067	0.145	0.148	0.251
67	63	0.045	0.081	0.013	0.021	0.030	0.032	0.040
68	25	0.315	0.579	0.041	0.139	0.190	0.226	0.307

Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Notched Box Plot for Total Phosphorus (mg/L)



Note: Location codes with less than 10 data points not charted

Data are for LOCCODES;
i.e. may be from 2 or more stations

N W E S

0 12.5 25 50 75 Miles

Location Map

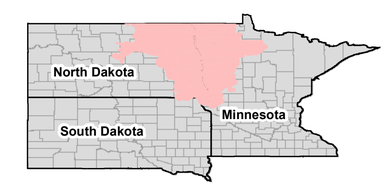


Figure 4-10: Total phosphorus modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

Lake Ashtabula range from 150 μg/L to 220 μg/L. Median concentrations below Lake Asthabula are similar to those upstream of the lake, ranging from 125 μg/L to 212 μg/L. Median concentrations do appear to decline downstream from the confluence with the Maple River. The variability in measured concentrations, as represented by the interquartile range, is similar from upstream to downstream within the Sheyenne River.

4.3.1.2 Sulfate

One point of reference for evaluating sulfate concentrations is the 450 mg/L standard for the river. The median sulfate concentration on the Sheyenne River ranges from 100 mg/L to 210 mg/L (Figure 4-11). There is no readily apparent increase or decrease in the sulfate concentration from upstream to downstream within the Sheyenne River. The interquartile ranges typically overlap between LOCCODES on the Sheyenne River. The variability in measured concentrations, as represented by the interquartile range, is generally similar from upstream to downstream within the Sheyenne River.

4.3.1.3 Total Dissolved Solids (TDS)

The State of North Dakota lacks a TDS numeric standard. However, the 500 mg/L IJC objective at the U.S.- Canadian border can serve as a point of reference when evaluating TDS concentrations. The median TDS concentration on the Sheyenne River ranges from 839 mg/L at the most upstream location to 585 mg/L at the most downstream location. There is no readily apparent trend with regard to increasing or decreasing median TDS concentrations within the Sheyenne River (i.e., the interquartile ranges tend to overlap between LOCCODES) (Figure 4-12). The range in median TDS concentrations for the Sheyenne River LOCCODES is 497 mg/L to 839 mg/L. The variability in measured concentrations, as represented by the interquartile range, is generally similar from upstream to downstream within the Sheyenne River.

4.3.1.4 Dissolved Oxygen (DO)

Measured median DO concentrations within the Sheyenne River are generally above the requirements necessary to support aquatic life (Figure 4-13); i.e., from 4 to 5 mg/L. Low concentrations (< 2 mg/L) do occur within the Sheyenne River (Figure 4-13) as

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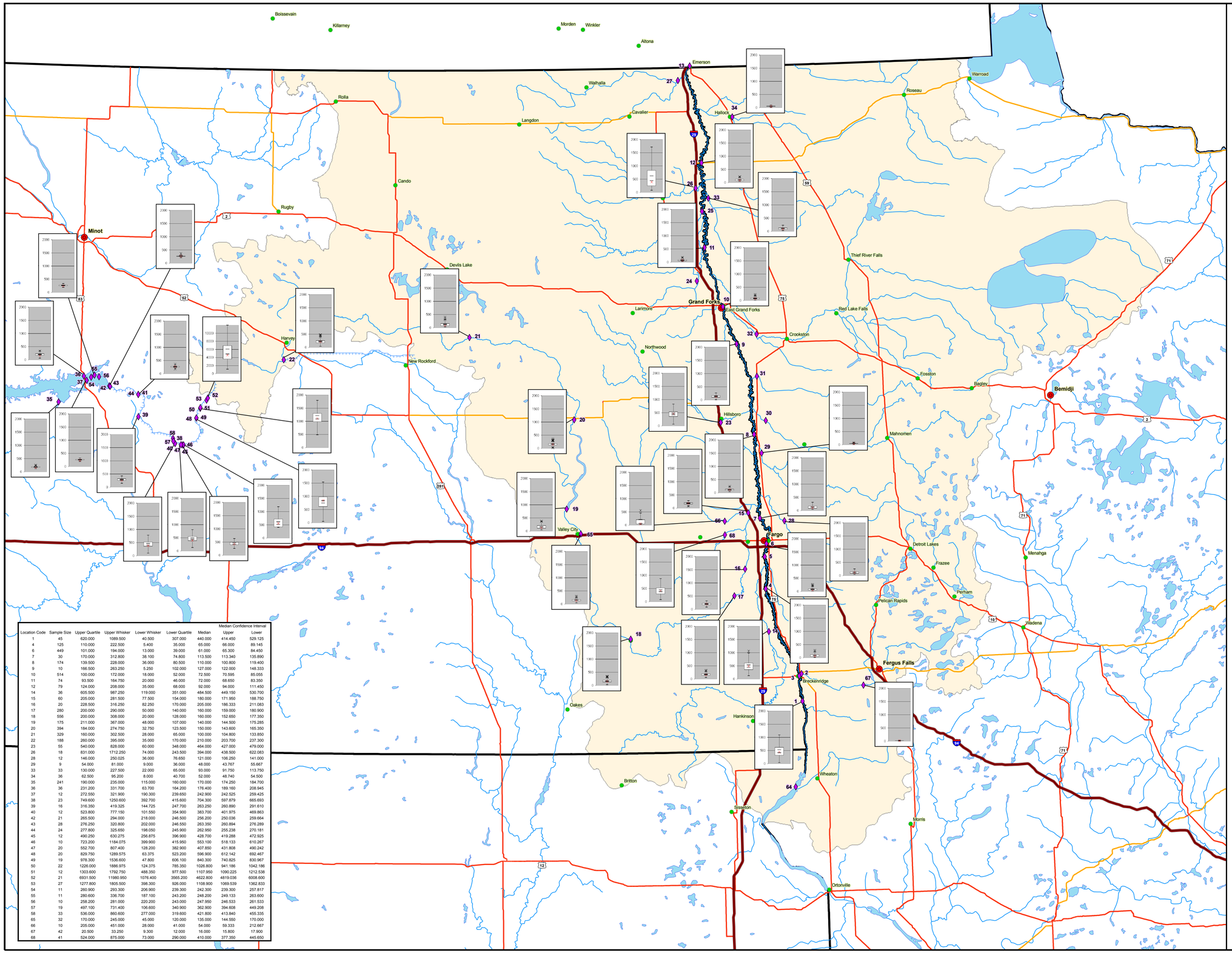
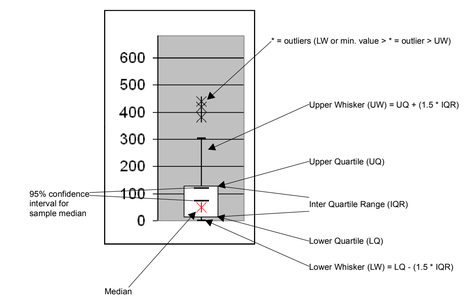


Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
1	45	620.000	1089.500	40.500	307.000	440.000	414.450	529.125
4	125	110.000	222.500	5.400	35.000	65.000	66.000	89.145
6	449	101.000	194.000	13.000	39.000	61.000	65.300	84.450
7	30	170.000	312.800	38.100	74.800	113.500	113.340	135.890
8	174	139.500	228.000	36.000	80.500	110.000	100.800	119.400
9	10	166.500	263.250	5.250	102.000	127.000	122.000	148.333
10	514	100.000	172.000	18.000	52.000	72.500	70.595	85.055
11	74	93.500	164.750	20.000	46.000	72.000	68.650	83.350
12	79	124.000	208.000	35.000	68.000	92.000	94.000	111.450
14	36	605.500	987.250	119.000	351.000	484.500	449.150	530.700
15	60	205.000	281.500	77.500	154.000	180.000	171.950	188.750
16	20	228.500	316.250	82.250	170.000	205.000	186.333	211.083
17	280	200.000	290.000	50.000	140.000	160.000	159.000	180.900
18	556	200.000	308.000	20.000	128.000	160.000	152.650	177.350
19	175	211.000	367.000	48.000	107.000	140.000	144.500	175.285
20	394	184.000	274.750	32.750	123.500	150.000	143.600	165.350
21	329	160.000	302.500	28.000	65.000	100.000	104.800	133.850
22	188	260.000	395.000	35.000	170.000	210.000	203.700	237.300
23	55	540.000	828.000	60.000	348.000	464.000	427.000	479.000
26	18	831.000	1712.250	74.000	243.500	394.000	438.500	622.083
28	12	146.000	250.025	36.000	76.650	121.000	106.250	141.000
29	9	54.000	81.000	9.000	36.000	48.000	43.767	55.667
33	33	130.000	227.500	22.000	65.000	93.000	91.750	113.750
34	36	62.500	95.200	8.000	40.700	52.000	48.740	54.500
35	241	190.000	235.000	115.000	160.000	170.000	174.250	184.700
36	36	231.200	331.700	63.700	164.200	176.400	189.160	208.945
37	12	272.550	321.900	190.300	239.650	242.900	242.525	259.425
38	23	749.600	1250.600	392.700	415.600	704.300	597.879	665.693
39	16	316.350	419.325	144.725	247.700	263.250	260.890	291.610
40	12	523.800	777.150	101.550	354.900	383.700	401.975	469.863
42	21	265.500	294.000	218.000	246.500	256.200	250.036	259.664
43	28	276.250	320.800	202.000	246.550	263.350	260.894	276.289
44	24	277.800	325.650	198.050	245.900	262.950	255.238	270.181
45	12	490.250	630.275	256.875	396.900	428.700	419.288	472.925
46	10	723.200	1184.075	399.900	415.950	553.100	518.133	610.267
47	20	552.700	807.400	128.200	382.900	407.850	431.808	490.242
48	20	829.750	1289.575	63.375	523.200	596.900	612.142	692.467
49	19	978.300	1536.600	47.800	606.100	840.300	740.825	830.967
50	22	1226.000	1886.975	124.375	785.350	1026.800	941.186	1042.186
51	12	1303.600	1792.750	488.350	977.500	1107.950	1090.225	1212.538
52	21	6931.500	11980.950	1076.400	3565.200	4622.800	4819.036	6008.600
53	27	1277.800	1805.500	398.300	926.000	1108.900	1069.539	1362.833
54	11	260.900	293.300	206.900	239.300	242.300	239.300	257.817
55	11	280.600	336.700	187.100	243.200	248.200	249.133	263.600
56	10	258.200	281.000	220.200	243.000	247.950	246.533	261.533
57	19	497.100	731.400	106.600	340.900	362.900	394.608	449.208
58	33	536.000	860.600	277.000	319.600	421.800	413.840	455.335
65	32	170.000	245.000	45.000	120.000	135.000	144.550	170.000
66	10	205.000	451.000	28.000	41.000	54.000	59.333	212.667
67	42	20.500	33.250	9.300	12.000	16.000	15.800	17.900
68	41	524.000	875.000	73.000	290.000	410.000	377.350	445.650

Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Notched Box Plot for Sulfate (mg/L)



Note: Location codes with less than 10 data points not charted

Data are for LOCCODES;
i.e. may be from 2 or more stations

N
W E
S

0 12.5 25 50 75 Miles

Location Map

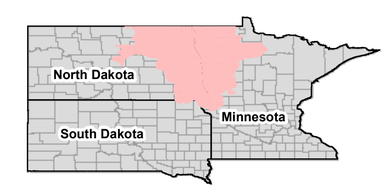


Figure 4-11: Sulfate modified box plots by LOCCODE

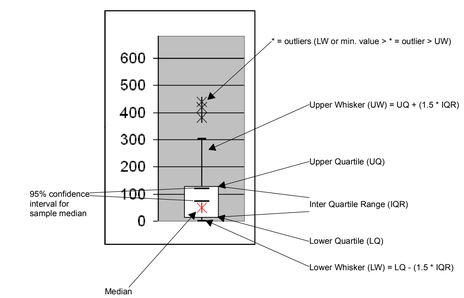
Scale: As Shown	Project No: 3750-059	Date: 04/25/05

Red River Valley Water Supply Project

Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Notched Box Plot for Total Dissolved Solids (mg/L)



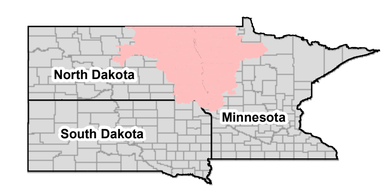
Note: Location codes with less than 10 data points not charted

Data are for LOCCODES;
i.e. may be from 2 or more stations

N
W E
S

0 12.5 25 50 75 Miles

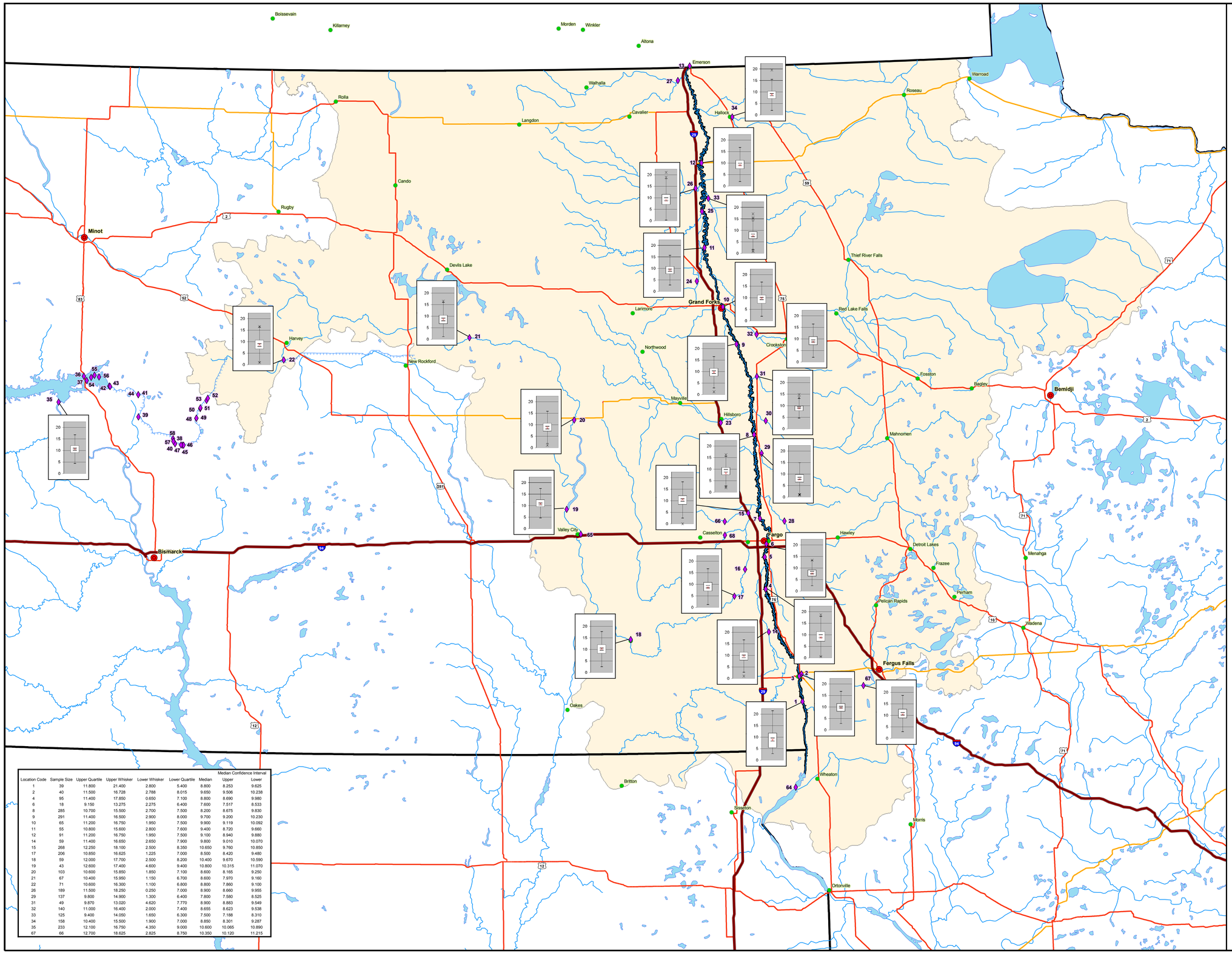
Location Map



Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
1	60	1004.250	1604.850	3.250	603.850	849.875	762.483	885.430
2	41	312.000	370.500	214.500	273.000	285.350	285.220	293.930
4	305	403.000	539.500	175.500	312.000	351.000	347.068	382.980
6	810	401.375	545.675	160.875	305.175	345.800	337.448	375.375
7	30	520.650	696.150	228.150	403.650	454.675	442.033	473.980
8	554	496.600	685.750	181.350	370.500	428.350	407.193	453.603
9	171	482.950	709.150	105.950	332.150	403.000	393.673	452.595
10	993	397.150	536.575	164.775	304.200	351.000	334.653	371.313
11	79	419.250	619.125	86.125	286.000	337.350	337.480	379.178
12	423	500.500	734.500	110.500	344.500	410.800	402.155	461.630
14	93	929.500	1580.800	166.400	495.300	756.600	696.670	850.850
15	230	682.825	941.688	251.388	510.250	585.000	567.320	632.158
16	155	682.500	1009.125	138.125	464.750	611.000	551.428	614.120
17	474	638.300	893.750	212.550	468.000	552.500	518.928	581.133
18	775	650.000	952.250	146.250	448.500	545.350	517.075	579.605
19	448	623.350	934.375	104.975	416.000	507.000	495.820	553.670
20	688	689.000	990.275	186.875	488.150	605.475	550.843	620.750
21	764	631.150	994.338	25.838	389.025	497.250	480.805	559.650
22	312	968.500	1459.413	150.313	641.225	838.500	728.000	842.270
23	56	994.500	1316.250	458.250	780.000	916.500	864.435	935.513
26	170	6568.250	15546.050	16.250	583.050	1612.000	3482.733	6681.350
28	119	487.500	663.000	195.000	370.500	406.250	395.655	432.055
29	142	384.475	493.188	203.288	312.000	351.000	338.943	399.588
31	55	446.550	571.350	238.550	363.350	410.150	389.188	418.535
32	89	305.500	412.750	126.750	234.000	260.000	256.523	280.638
33	128	558.025	847.600	75.400	364.975	468.000	444.405	510.770
34	112	412.750	583.375	128.375	299.000	367.900	340.568	384.963
35	292	452.725	507.813	360.913	416.000	429.000	428.903	442.098
65	106	569.400	826.313	141.213	398.125	471.250	464.718	533.975
66	31	728.000	1483.625	126.750	224.250	441.350	454.968	558.155
67	73	298.350	356.850	200.850	259.350	271.700	273.000	281.678
68	133	1027.000	1573.000	117.000	663.000	858.000	773.565	919.165

Figure 4-12: Total dissolved solids modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05



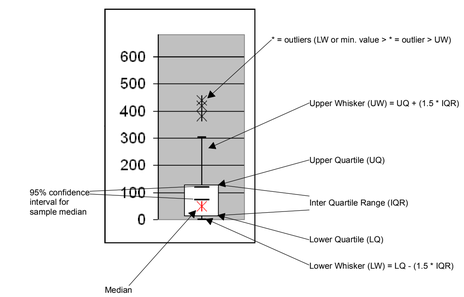
Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
1	39	11.800	21.400	2.800	5.400	8.800	8.253	9.625
2	40	11.500	16.728	2.788	8.015	9.650	9.506	10.238
4	95	11.400	17.850	0.650	7.100	8.800	8.690	9.980
6	18	9.150	13.275	2.275	6.400	7.600	7.517	8.533
8	285	10.700	15.500	2.700	7.500	8.200	8.675	9.830
9	291	11.400	16.500	2.900	8.000	9.700	9.200	10.230
10	65	11.200	16.750	1.950	7.500	9.900	9.119	10.092
11	55	10.800	15.600	2.800	7.600	9.400	8.720	9.660
12	91	11.200	16.750	1.950	7.500	9.100	8.940	9.880
14	59	11.400	16.650	2.650	7.900	9.800	9.010	10.070
15	268	12.250	18.100	2.500	8.350	10.650	9.760	10.850
17	206	10.850	16.625	1.225	7.000	8.500	8.420	9.480
18	59	12.000	17.700	2.500	8.200	10.400	9.670	10.590
19	43	12.600	17.400	4.600	9.400	10.800	10.315	11.070
20	103	10.600	15.850	1.850	7.100	8.600	8.165	9.250
21	67	10.400	15.950	1.150	6.700	8.600	7.970	9.160
22	71	10.600	16.300	1.100	6.800	8.800	7.860	9.100
26	189	11.500	18.250	0.250	7.000	8.900	8.660	9.955
29	137	9.800	14.900	1.300	6.400	7.800	7.580	8.525
31	49	9.870	13.020	4.620	7.770	8.900	8.883	9.549
32	140	11.000	16.400	2.000	7.400	8.655	8.623	9.538
33	125	9.400	14.050	1.650	6.300	7.500	7.188	8.310
34	158	10.400	15.500	1.900	7.000	8.850	8.301	9.287
35	233	12.100	16.750	4.350	9.000	10.600	10.065	10.890
67	66	12.700	18.625	2.825	8.750	10.350	10.120	11.215

Red River Valley Water Supply Project

Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Notched Box Plot for Dissolved Oxygen (mg/L)



Note: Location codes with less than 10 data points not charted

Data are for LOCCODES;
i.e. may be from 2 or more stations

N
W E
S

0 12.5 25 50 75 Miles

Location Map

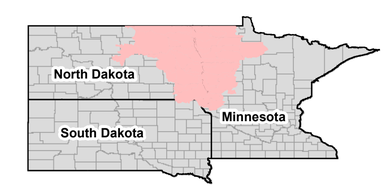


Figure 4-13: Dissolved oxygen modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

well as supersaturation, which is typical for most streams and rivers. The median DO concentration on the Sheyenne River ranges from 8.8 mg/L at the most upstream location to 10.1 mg/L at the most downstream location, but there is no readily apparent trend with regard to increasing or decreasing median DO concentrations (i.e., the interquartile ranges tend to overlap between LOCCODES). The range in median DO concentrations for the Sheyenne River LOCCODES is 8.6 mg/L to 10.8 mg/L. The variability in measured concentrations, as represented by the interquartile range, is generally similar from upstream to downstream within the Sheyenne River.

4.3.1.5 Fecal Coliform Bacteria (FCB)

Only four LOCCODES have sufficient measured FCB concentrations (i.e., more than 10 measurements per LOCCODE) within the Sheyenne River. The FCB standard of 200 most probable number per ml (MPN/ml) (May 1 to September 30) for the Sheyenne River provides a frame of reference for evaluating the median concentrations. The median FCB concentration on the Sheyenne River ranges from 29 MPN/ml at the most upstream location to 110 MPN/ml at the most downstream location. There is no readily apparent trend with regard to increasing or decreasing median FCB concentrations within the Sheyenne River (i.e., the interquartile ranges tend to overlap between LOCCODES) (Figure 4-14). The range in median FCB concentrations for the Sheyenne River LOCCODES is 2 MPN/ml to 110 MPN/ml.

4.3.1.6 Arsenic

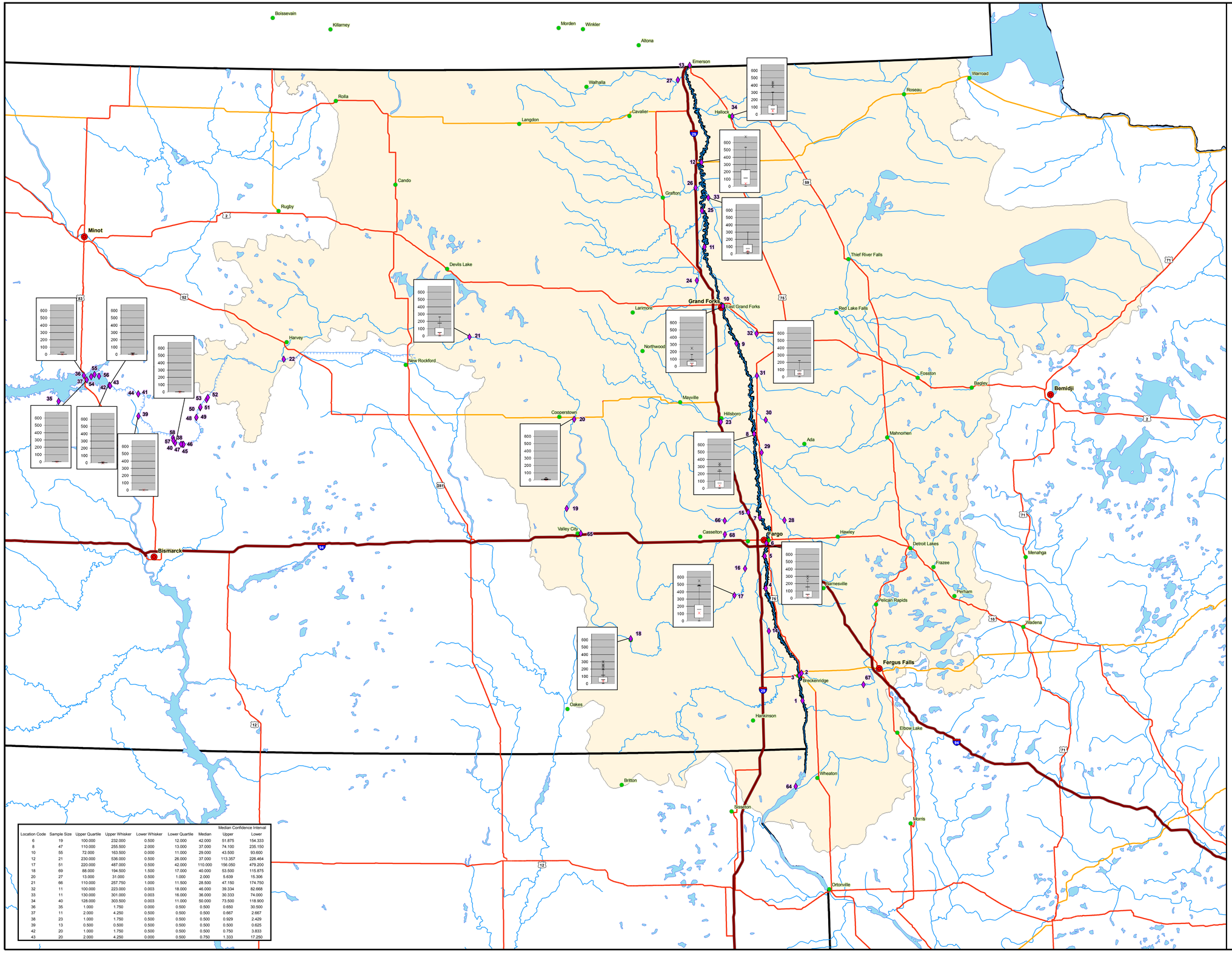
Arsenic concentrations along the Sheyenne are generally less than 5 μg/L, which is considerably lower than the safe drinking water act standard of 50 μg/L. There is little spatial variability in arsenic concentrations within the Sheyenne River Basin (Figure 4-15).

4.3.2 Red River

4.3.2.1 Total Phosphorus (TP)

The most downstream monitoring location on the Red River can be used to describe and infer the quality of surface waters within the basin compared to other basins. As the Red River flows north the observed water quality reflects an integration of the

Red River Valley Water Supply Project

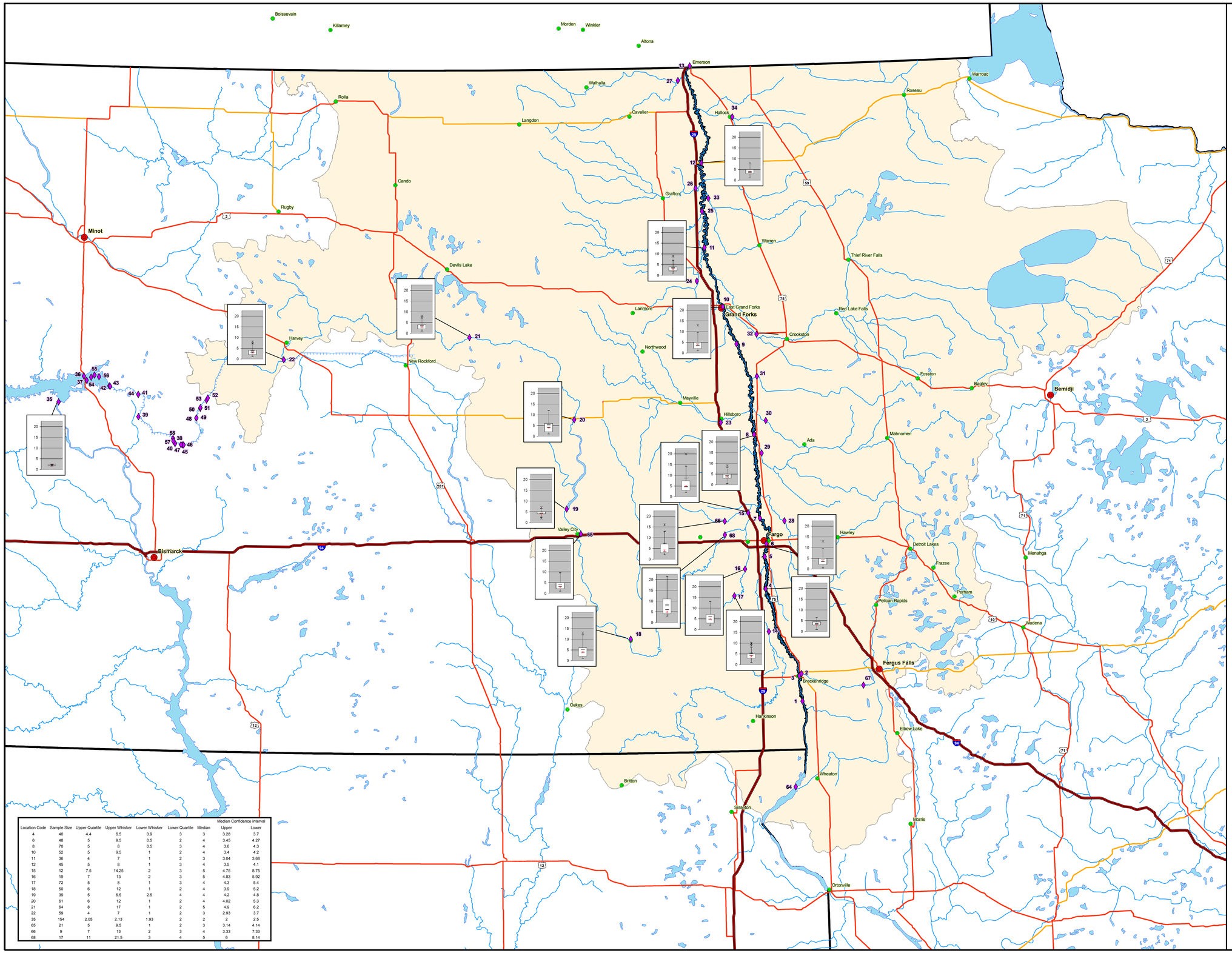


Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
6	19	100.000	232.000	0.500	12.000	42.000	51.875	154.333
8	47	110.000	255.500	2.000	13.000	37.000	74.100	235.150
10	55	72.000	163.500	0.000	11.000	29.000	43.500	93.600
12	21	230.000	536.000	0.500	26.000	37.000	113.357	226.464
17	51	220.000	487.000	0.500	42.000	110.000	156.050	479.200
18	69	88.000	194.500	1.500	17.000	40.000	53.500	115.875
20	27	13.000	31.000	0.500	1.000	2.000	5.639	15.306
21	66	110.000	257.750	1.000	11.500	28.500	47.150	174.750
32	11	100.000	223.000	0.003	18.000	46.000	39.334	82.668
33	11	130.000	301.000	0.003	16.000	36.000	30.333	74.000
34	40	128.000	303.500	0.003	11.000	50.000	73.500	118.900
36	35	1.000	1.750	0.000	0.500	0.500	0.650	30.500
37	11	2.000	4.250	0.500	0.500	0.500	0.667	2.667
38	23	1.000	1.750	0.500	0.500	0.500	0.929	2.429
39	13	0.500	0.500	0.500	0.500	0.500	0.500	0.625
42	20	1.000	1.750	0.500	0.500	0.500	0.750	3.833
43	20	2.000	4.250	0.000	0.500	0.750	1.333	17.250

Figure 4-14: Fecal coliform modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

Red River Valley Water Supply Project



Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
4	40	4.4	6.5	0.9	3	3	3.28	3.7
6	48	5	9.5	0.5	2	4	3.45	4.27
8	70	5	8	0.5	3	4	3.6	4.3
10	52	5	9.5	1	2	4	3.4	4.2
11	36	4	7	1	2	3	3.04	3.68
12	45	5	8	1	3	4	3.5	4.1
15	12	7.5	14.25	2	3	5	4.75	8.75
16	19	7	13	2	3	5	4.83	5.92
17	72	5	8	1	3	4	4.3	5.4
18	50	6	12	1	2	4	3.9	5.2
19	39	5	6.5	2.5	4	4	4.2	4.8
20	61	6	12	1	2	4	4.02	5.3
21	64	8	17	1	2	5	4.9	6.2
22	59	4	7	1	2	3	2.93	3.7
35	154	2.05	2.13	1.93	2	2	2	2.5
65	21	5	9.5	1	2	3	3.14	4.14
66	9	7	13	2	3	4	3.33	7.33
68	17	11	21.5	3	4	5	6	8.14

Figure 4-15: Arsenic modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

upstream conditions and factors determining water quality characteristics; e.g., land use, waste assimilation, soils. The median concentration of the Red River north of Grand Forks, North Dakota is 205 μg/L. This compares to a median concentration of 226 μg/L at the most downstream location on the Sheyenne River.

The TP recommendation for North Dakota streams and rivers is 100 μg/L. Median concentrations within the Red River consistently exceed this level (Figure 4-10). Median TP concentrations within the Red River upstream from Fargo range from 97 μg/L to 194 μg/L. Median concentrations below Grand Forks tend to increase compared to the upstream portion of the Red River ranging from 140 μg/L to 210 μg/L.

The TP concentrations within Minnesota tributaries to the Red River are generally less than for tributaries within North Dakota. Minnesota tributaries are characterized by median TP concentrations on the order of 100 μg/L to 150 μg/L compared to median concentrations exceeding 200 μg/L for many North Dakota tributaries (Figure 4-10).

4.3.2.2 Sulfate

One point of reference for evaluating sulfate concentrations is the 250 mg/L standard for the Red River. The median sulfate concentration on the Red River ranges from 61 mg/L to 440 mg/L (Figure 4-11). The greatest median values on the Red River are immediately downstream of Lake Traverse and Mud Lake where the median concentration is 440 mg/L. Moving downstream toward Fargo the median sulfate concentration declines because of the addition of low sulfate water from the Otter Tail River. Median concentrations downstream from Grand Forks North Dakota range from 72 mg/L to 92 mg/L.

The most downstream monitoring location on the Red River can be used to describe and infer the quality of surface waters within the basin compared to other basins. The median concentration within the Red River north of Grand Forks, North Dakota is 92 mg/L. This compares to a median concentration of 180 mg/L at the most downstream location on the Sheyenne River. The concentration within the Red River increases moving toward the Canadian border because of the addition of water with naturally occurring high sulfates from the Park River (LOCODE 26).

Sulfate concentrations within Minnesota tributaries are less than for tributaries within North Dakota. Minnesota tributaries are characterized by median sulfate concentrations on the order of 100 mg/L compared to median concentrations exceeding 200 mg/L for some North Dakota tributaries (Figure 4-11).

4.3.2.3 Total Dissolved Solids (TDS)

The IJC TDS objective at the border of 500 mg/L is more stringent than the Minnesota standard of 650 mg/L for the Red River. These numeric values provide some frame of reference for evaluate TDS concentrations on the Red River. The median TDS concentration within the most upstream portion of the Red River ranges from 346 mg/L to 850 mg/L (Figure 4-12). The greatest median value within the upper portion of the the Red River is immediately downstream of Lake Traverse and Mud Lake, as is the case with sulfates. The median TDS concentration declines considerably below the confluence with the Otter Tail River.

The median concentration within the Red River north of Grand Forks, North Dakota is 410 mg/L. This reflects the addition of water with naturally occurring high TDS from the Park River (LOCODE 26). TDS concentrations within the Park River could be characterized as "extreme." The median concentration at Grand Forks compares to a median concentration of 585 mg/L at the most downstream location on the Sheyenne River.

TDS concentrations within Minnesota tributaries are less than for tributaries within North Dakota. Minnesota tributaries are characterized by median TDS concentrations on the order of 250 mg/L to 500 mg/L compared to median concentrations exceeding 600 mg/L for North Dakota tributaries (Figure 4-12).

4.3.2.4 Dissolved Oxygen (DO)

Measured median DO concentrations within the Red River are generally above the requirements necessary to support aquatic life (Figure 4-13); i.e., from 4 to 5 mg/L. Low concentrations (< 2 mg l) do occur within the Red River (Figure 4-13). The median DO concentration on the Red River generally exceeds 8 mg/L at most locations. These concentrations are similar to those on the Sheyenne River.

4.3.2.5 Fecal Coliform Bacteria (FCB)

Only two LOCCODES have more than 10 measured FCB concentrations within the Red River. The FCB standard of 200 most probable number per ml (MPN/ml) (May 1 to September 30) for the Red River provides a frame of reference for evaluating the median concentrations. The median FCB concentration on the Red River ranges from 42 MPN/ml near Fargo to 37 MPN/ml downstream from Grand Forks. The range in median FCB concentrations for the Sheyenne River LOCCODES is 2 MPN/ml to 110 MPN/ml.

4.3.2.6 Arsenic

Arsenic concentrations along the Red are generally less than 5 μg/L, considerably lower than the safe drinking water act standard of 50 μg/L. The concentrations are at or near the Minnesota standard of 2 μg/L. There tends to be little spatial variability in arsenic concentrations within the Red River Basin (Figure 4-14).

4.3.3 Missouri River

4.3.3.1 Total Phosphorus (TP)

The TP concentration within the Missouri River system, as characterized by the the Garrison Dam location, is considerably lower than the Sheyenne and Red Rivers. The median concentration at Garrison Dam is less than 5 μg/L. The TP recommendation for North Dakota lakes is 20 μg/L.

4.3.3.2 Sulfate

Sulfate concentrations generally increase moving in a downstream direction from Audubon Lake to the end of the McClusky Canal. The median concentration is 263 mg/L near the entrance to the McClusky Canal (in Audubon Lake) and exceeds 500 mg/L near the end of the canal (Figure 4-11). Current flow rates in the canal tend to be low (i.e., less than 100 cfs and often near 10 cfs) and explain the higher concentrations near the lower end of the canal; i.e., there is currently no flow through the end of the canal. The median sulfate concentration at the most downstream location on the Sheyenne River is lower than the concentration near the end of the McClusky Canal but similar to that within Audubon Lake. The median sulfate concentration near the mouth of the Sheyenne River is 180 mg/L.

4.3.3.3 Total Dissolved Solids (TDS)

TDS concentrations increase moving in a downstream direction from Audubon Lake to the end of the McClusky Canal. The median concentration is 583 mg/L near the entrance to the McClusky Canal (in Lake Audubon) and exceeds 1100 mg/L near the end of the Canal (Figure 4-12). The TDS concentration at the most downstream location on the Sheyenne River is considerably less than the concentration near the end of the McClusky Canal. The greater current concentrations near the end of the McClusky canal can be explained by the lack of flow within this portion of the canal. The median TDS concentration near the mouth of the Sheyenne River is 585 mg/L.

4.3.3.4 Dissolved Oxygen (DO)

The median DO concentration within the Missouri River system as characterized by the concentration at Garrison Dam is excellent, exceeding 10 mg/L.

4.3.3.5 Fecal Coliform Bacteria (FCB)

Fecal coliform bacteria concentrations within the basin are generally less than 50 most probable number (MPN) per 100 ml. Concentrations tend to be lowest downstream from Audubon Lake through the McClusky Canal and increase slightly moving in a downstream direction (Figure 4-14). These concentrations are lower than those on the Sheyenne River or the Red River.

4.3.3.6 Arsenic

The arsenic concentration within the Missouri River system, as characterized by the concentration at Garrison Dam, is similar to the Sheyenne and Red Rivers. The median concentration at Garrison Dam is 2 μg/L.

4.4 IJC WATER QUALITY OBJECTIVES

Based upon the most recent monitoring information available from the IJC, exceedances of the water quality objectives occur infrequently at the Emerson, Manitoba monitoring location (Table 4-3). The chloride and sulfate objectives were not exceeded from 1999 through 2002. An exceedance of the dissolved oxygen objective occurred

once, during July of 2000. The TDS objective has been exceeded each year, generally once or twice during the winter months. The bacteriological objective has been exceeded annually, generally during the summer months.

Table 4-3. Number of exceedances of the IJC water quality objective by year.

Parameter	Objective	No. of Exceedances (Month)			
		1999	2000	2001	2002
Dissolved Oxygen	5 mg/l	0	1 (Jul)	0	0
Total Dissolved Solids	500 mg/l	3 (Nov. 98, Dec. 99, & Jan. 99)	1 (Apr.)	2 (Dec.)	1 (Jan.)
Chloride	100 mg/l	0	0	0	0
Sulfate	250 mg/l	0	0	0	0
Bacteriological (fecal coliform bacteria)	200 colonies/ml	1 (Aug.)	1 (Sep)	1 (Nov)	1 (Jul)

The objectives are not regulatory standards but values jointly established by the U.S. and Canada.

5.0 Environmental Consequences of the Alternatives

5.1 Missouri River System

5.1.1 Missouri River Nutrient Loads

Potential riverine impacts can be inferred by evaluating the gain or loss in the amount of nutrients within the Missouri, Sheyenne and Red River systems. The amount of nutrients can be expressed as concentration or load. Concentration is defined as the amount or mass of a substance per volume of water and typically has units of milligrams per liter (mg/L) or micrograms per liter (μg/L). Load is defined as the total mass of a substance (e.g., kilograms) passing a stream or river location within a period of time (e.g., one year). The load is expressed in units of mass per time (e.g., kilograms per year). Expressing the amount of nutrients as a load incorporates not only the nutrient concentration in water but the volume of water passing a specific location during some period of time. Evaluating the amount of nutrients in a riverine system through the context of total load is preferred, because it integrates the volume of water.

Four alternatives remove water from the Missouri River system, thereby changing current loads. These alternatives are the:

- GDU Import Pipeline Alternative;
- GDU Water Supply Replacement Alternative;
- GDU Import to Sheyenne River Alternative; and
- Missouri River Import to Red River Valley Alternative.

Based upon the amount of nutrient load removed from the Missouri River, the probable change in water quality is expected to be small and immeasurable. The reduction in annual nutrient load leaving the Missouri River system is less than 0.5% (see Table 5-1).

Table 5-1
Analysis of Nutrient Loads Resulting From Select Red River Valley Water Supply Alternatives
Estimated Annual Nutrient Loads[1] in Metric Tons (1,000 kilograms)

River System & Location [4,5]	Daily Discharge (cfs)	Total Nitrogen	Ammonia Nitrogen	Nitrite + Nitrate Nitrogen	Total Kjeldahl Nitrogen	Total Phosphorus[2]	Dissolved Phosphorus
Missouri River System							
Garrison Dam (ND Storet ID 06338490)	22680	9648.6	609.7	2748.9	6899.7	333.9	245.9
Missouri River at Bismarck (NWIS ID 6342500)	33750	14255.7	301.4	4068.8	9885.6	1537.1	632.9
Sheyenne River System							
Sheyenne River near Cooperstown, ND (NWIS ID 5057000)	140	237.3	21.6	21.4	193.8	30.2	21.3
Sheyenne River near Kindred, ND NWIS ID 5059000	328	433.8	24.6	75.6	358.2	60.0	24.3
Sheyenne River near Mouth, ND Hwy 81 (NWIS ID 5060600)	207	ND	43.2	ND	ND	67.1	40.8
Red River System							
Red River of the North at Fargo, ND ND Storet ID 385040	1120	ND	ND	896.0	ND	495.3	ND
Red River of the North at Grand Forks, ND (NWIS ID 5082500, ND Storet ID 384156, Synoptic ID 5082500)	4461	3689.3	278.7	656.7	3032.6	626.4	356.0
Missouri River Import to Red River Valley Alternative (Pipe to Ashtabula)	6	2.7	0.1	0.8	1.9	0.3	0.1
Percentage of Missouri River at Bismarck Load		0.02%	0.02%	0.02%	0.02%	0.02%	0.02%
Percentage of Sheyenne River near Mouth, ND Hwy 81			0.13%			0.44%	0.30%
Percentage of Sheyenne River near Kindred, ND		0.62%	0.24%	1.04%	0.53%	0.49%	0.50%
Percentage of Red River of the North at Grand Forks, ND Load		0.07%	0.02%	0.12%	0.06%	0.05%	0.03%
Missouri River Import to Red River Valley Alternative (Leaving River)	31	13.5	0.3	3.8	9.2	1.4	0.6
Percentage of Missouri River at Bismarck Load		0.09%	0.09%	0.09%	0.09%	0.09%	0.09%
Percentage of Red River of the North at Fargo, ND Load				0.42%		0.29%	
Percentage of Red River of the North at Grand Forks, ND Load		0.37%	0.10%	0.58%	0.30%	0.23%	0.17%
Missouri River Import to Red River Valley Alternative (to Red River)	25	10.8	0.2	3.0	7.3	1.1	0.5
Percentage of Red River of the North at Fargo, ND Load				0.34%		0.23%	
Percentage of Red River of the North at Grand Forks, ND Load		0.29%	0.08%	0.46%	0.24%	0.18%	0.13%

Table 5-1
Analysis of Nutrient Loads Resulting From Select Red River Valley Water Supply Alternatives
Estimated Annual Nutrient Loads[1] in Metric Tons (1,000 kilograms)

River System & Location [4,5]	Daily Discharge (cfs)	Total Nitrogen	Ammonia Nitrogen	Nitrite + Nitrate Nitrogen	Total Kjeldahl Nitrogen	Total Phosphorus[2]	Dissolved Phosphorus
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Garrison Dam (ND Storet ID 06338490)	22680	9648.6	609.7	2748.9	6899.7	333.9	245.9
Missouri River at Bismarck (NWIS ID 6342500)	33750	14255.7	301.4	4068.8	9885.6	1537.1	632.9
Sheyenne River System							
Sheyenne River near Cooperstown, ND (NWIS ID 5057000)	140	237.3	21.6	21.4	193.8	30.2	21.3
Sheyenne River near Kindred, ND NWIS ID 5059000	328	433.8	24.6	75.6	358.2	60.0	24.3
Sheyenne River near Mouth, ND Hwy 81 (NWIS ID 5060600)	207	ND	43.2	ND	ND	67.1	40.8
Red River System							
Red River of the North at Fargo, ND ND Storet ID 385040	1120	ND	ND	896.0	ND	495.3	ND
Red River of the North at Grand Forks, ND (NWIS ID 5082500, ND Storet ID 384156, Synoptic ID 5082500)	4461	3689.3	278.7	656.7	3032.6	626.4	356.0
Missouri River Import to Red River Valley Alternative (Pipe to Ashtabula)	6	2.7	0.1	0.8	1.9	0.3	0.1
Percentage of Missouri River at Bismarck Load		0.02%	0.02%	0.02%	0.02%	0.02%	0.02%
Percentage of Sheyenne River near Mouth, ND Hwy 81			0.13%			0.44%	0.30%
Percentage of Sheyenne River near Kindred, ND		0.62%	0.24%	1.04%	0.53%	0.49%	0.50%
Percentage of Red River of the North at Grand Forks, ND Load		0.07%	0.02%	0.12%	0.06%	0.05%	0.03%
Missouri River Import to Red River Valley Alternative (Leaving River)	31	13.5	0.3	3.8	9.2	1.4	0.6
Percentage of Missouri River at Bismarck Load		0.09%	0.09%	0.09%	0.09%	0.09%	0.09%
Percentage of Red River of the North at Fargo, ND Load				0.42%		0.29%	
Percentage of Red River of the North at Grand Forks, ND Load		0.37%	0.10%	0.58%	0.30%	0.23%	0.17%
Missouri River Import to Red River Valley Alternative (to Red River)	25	10.8	0.2	3.0	7.3	1.1	0.5
Percentage of Red River of the North at Fargo, ND Load				0.34%		0.23%	
Percentage of Red River of the North at Grand Forks, ND Load		0.29%	0.08%	0.46%	0.24%	0.18%	0.13%

5.1.2 Audubon Lake and Principal Supply Works (McClusky Canal)

Three alternatives use portions of the existing Garrison Diversion Unit (GDU) infrastructure to deliver water to either the Sheyenne River system (i.e., Lake Ashtabula) or directly to a pipeline for distribution to users within the Red River Valley. These alternatives are the:

- GDU Import Pipeline Alternative (return flow is to the Red River);
- GDU Water Supply Replacement Alternative (return flow is to the Red River); and
- GDU Import to Sheyenne River Alternative (water is delivered to Lake Ashtabula prior to use).

Both unsteady and steady state analyses were completed to assess the potential affect of these alternatives.

5.1.2.1 Unsteady Analysis

Several hydrologic conditions were evaluated for the GDU Import to Sheyenne River Alternative using a model capable of estimating time varying concentrations. The modeling analysis focused on the GDU Import to Sheyenne River Alternative because this alternative delivers water directly to Lake Ashtabula (the other alternatives bypass the reservoir and deliver water to a pipeline distribution system) and has potential impacts on the Sheyenne River. The hydrologic conditions simulated for the GDU Import to Sheyenne River Alternative included dry, normal, wet and long-term average (period of record) hydrologic conditions (Table 5-2). The discharges for this alternative are less than those for the GDU Import Pipeline Alternative and the GDU Water Supply Replacement Alternative. Higher discharges are expected to result in lower concentrations within the system. The results presented represent predicted water quality concentrations at the end of one calendar year, assuming operation begins at the beginning of the calendar year.

Table 5-2. Hydrologic Conditions Simulated for the GDU Import to Sheyenne River Alternative at McClusky Canal Headworks.

Hydrologic Condition	Average Discharge Leaving Lake Audubon (cfs)
Dry	32.2
Normal	51.5
Wet	7
Average (Period of Record)	31.7
GDU Water Supply Replacement Alternative	189.5
GDU Import to Sheyenne River Alternative	167.0

An improvement in water quality (i.e., lower concentrations) is expected within the principal supply works for the GDU Import to Sheyenne River Alternative, for each hydrologic condition. Concentrations decrease for this alternative compared to the No Action Alternative although concentrations are generally similar within Audubon Lake. The reason is that the water quality of Audubon Lake is more affected by runoff adjacent to the lake than the operation of a proposed project.

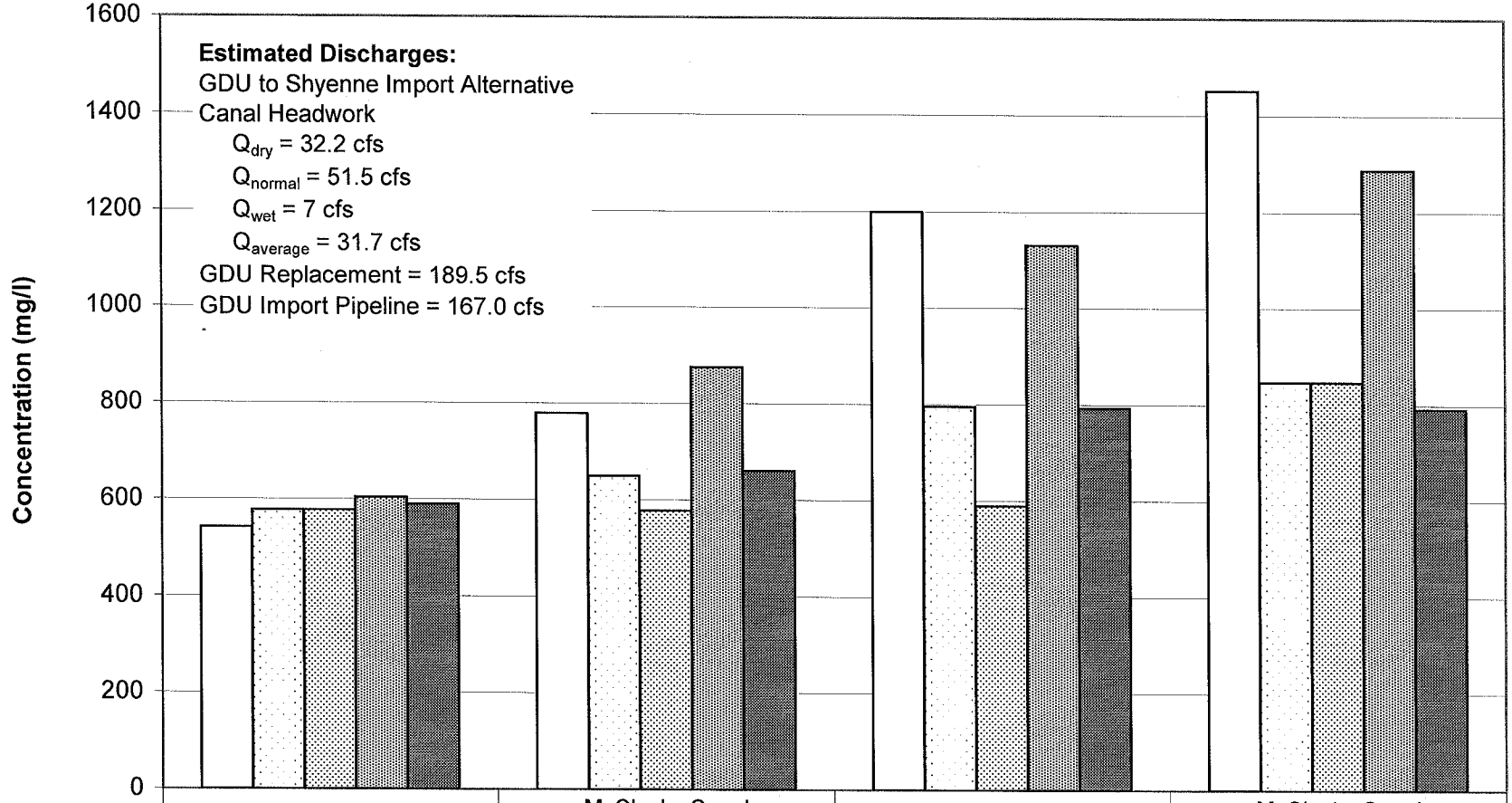
The estimated Total Dissolved Solids (TDS)[10] concentration within Audubon Lake is similar (Figure 5-1), while the concentration is less within New John's Lake and the McClusky Canal compared to the No Action Alternative[11] (Figure 5-1). Chloride and sulfate concentrations also generally decline moving downstream through the McClusky Canal system compared to the No Action alternative (see Figure 5-2 and Figure 5-3).

Nutrient concentrations, which are indicators of the trophic state and level of productivity, were also modeled within the McClusky Canal system. An increase in nutrient concentrations generally results in an increase in the amount of algae, especially

[10] TDS is defined as the amount (i.e., weight) of dissolved material (generally ions like sulfate and chloride) within water.

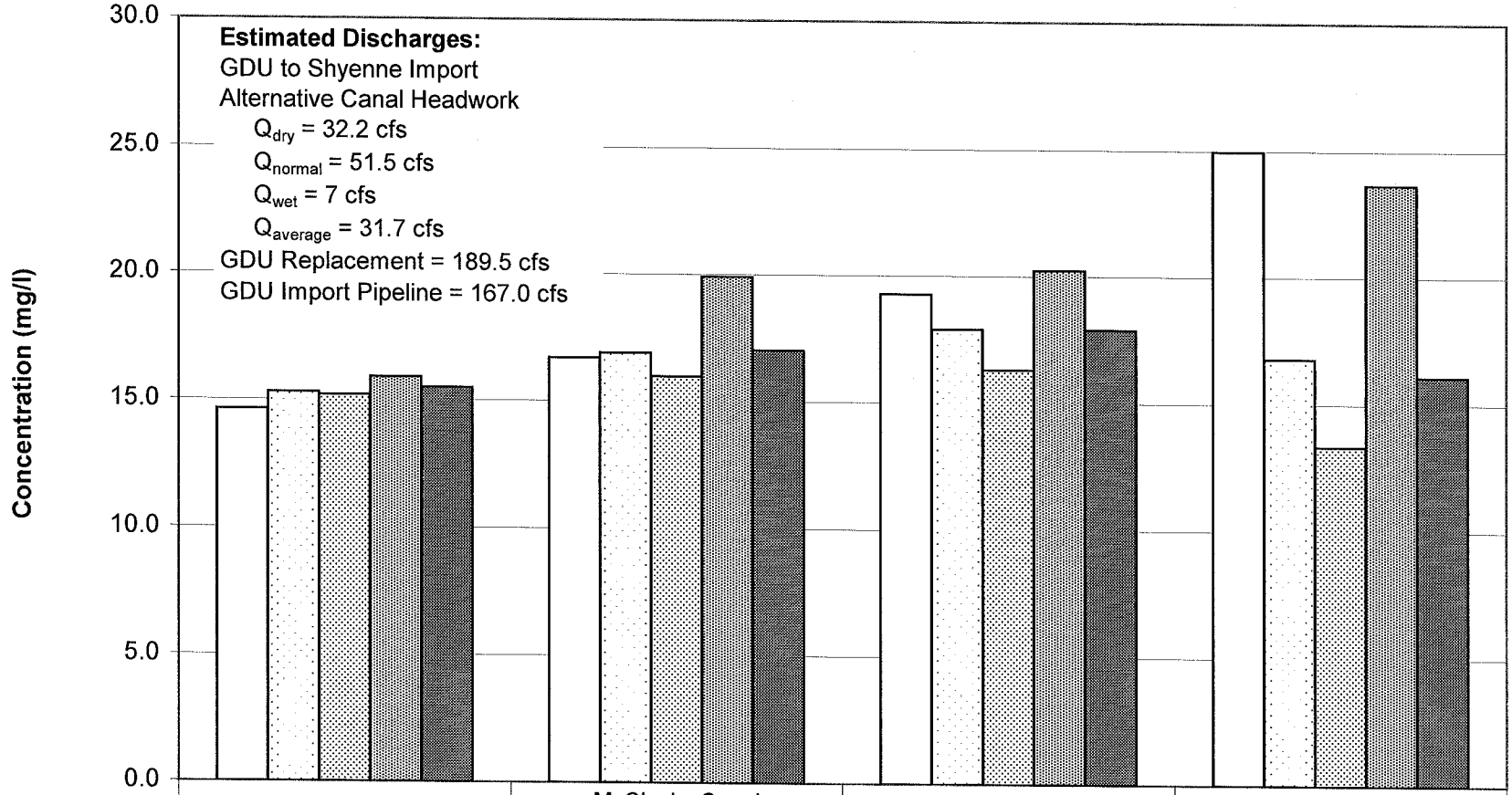
[11] The concentration for the No Action Alternative reflects the measured concentrations for the 4-year period used to calibrate the mass balance model. This concentration was used to established the water quality within the canal at the start of the simulation period.

Figure 5-1
Estimated Concentrations for Total Dissolved Solids
Garrison Diversion Unit Import to Sheyenne Alternative



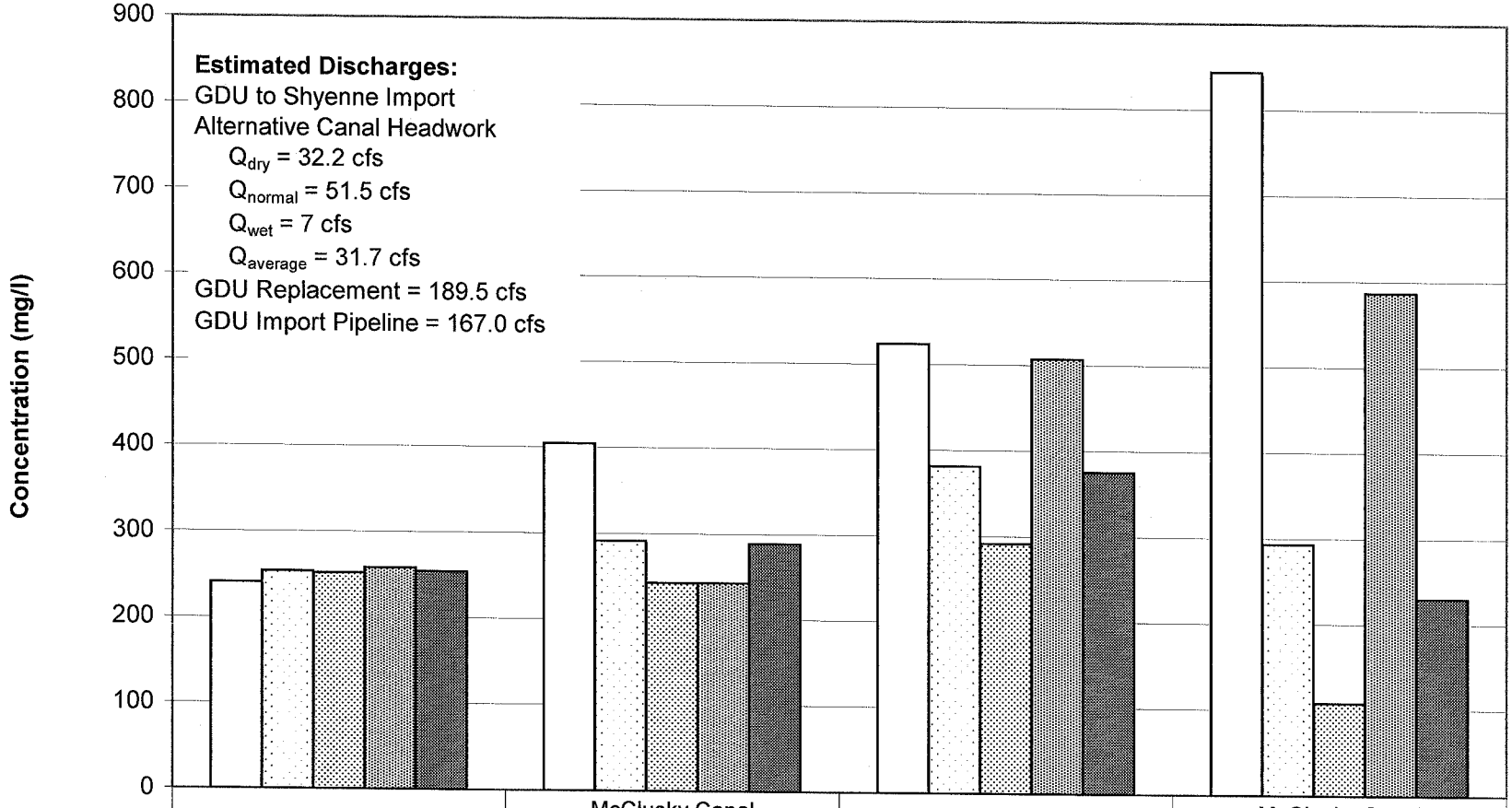
	Lake Audubon	McClusky Canal to New John's Lake	New John's Lake	McClusky Canal to Diversion Location
No Action (measured)	542	779	1200	1451
Dry Year - 1963	578	649	795	847
Normal Year - 1941	578	578	590	847
Wet Year - 1994	604	875	1131	1288
Period of Record Average	590	661	793	792

Figure 5-2
Estimated Concentrations for Chloride
Garrison Diversion Unit Import to Sheyenne Alternative



	Lake Audubon	McClusky Canal to New John's Lake	New John's Lake	McClusky Canal to Diversion Location
No Action (measured)	14.6	16.7	19.3	25.0
Dry Year - 1963	15.3	16.9	17.9	16.8
Normal Year - 1941	15.2	16.0	16.3	13.3
Wet Year - 1994	15.9	19.9	20.2	23.7
Period of Record Average	15.5	17.0	17.9	16.1

Figure 5-3
Estimated Concentrations for Sulfate
Garrison Diversion Unit Import to Sheyenne Alternative



	Lake Audubon	McClusky Canal to New John's Lake	New John's Lake	McClusky Canal to Diversion Location
No Action (measured)	241	405	524	844
Dry Year - 1963	254	291	382	293
Normal Year - 1941	252	242	291	108
Wet Year - 1994	258	242	507	587
Period of Record Average	254	289	375	230

in lakes and reservoirs. This is considered undesirable. The GDU Import to Sheyenne River Alternative shows lower inorganic nitrogen concentration (a combination of nitrite, nitrate and ammonia nitrogen) compared to the No Action Alternative (Figure 5-4), except during a wet hydrologic year. Local runoff bringing additional inorganic nitrogen into the canal, during wet hydrologic conditions, is the reason for the greater inorganic nitrogen concentration.

Compared to the No Action Alternative, orthophosphate concentrations also decline for the GDU Import to Sheyenne River Alternative (Figure 5-5). Within New John's Lake the decline is relative small. Water is currently circulated through New John's Lake in accordance with a "freshening program" established by Reclamation to maintain water quality.

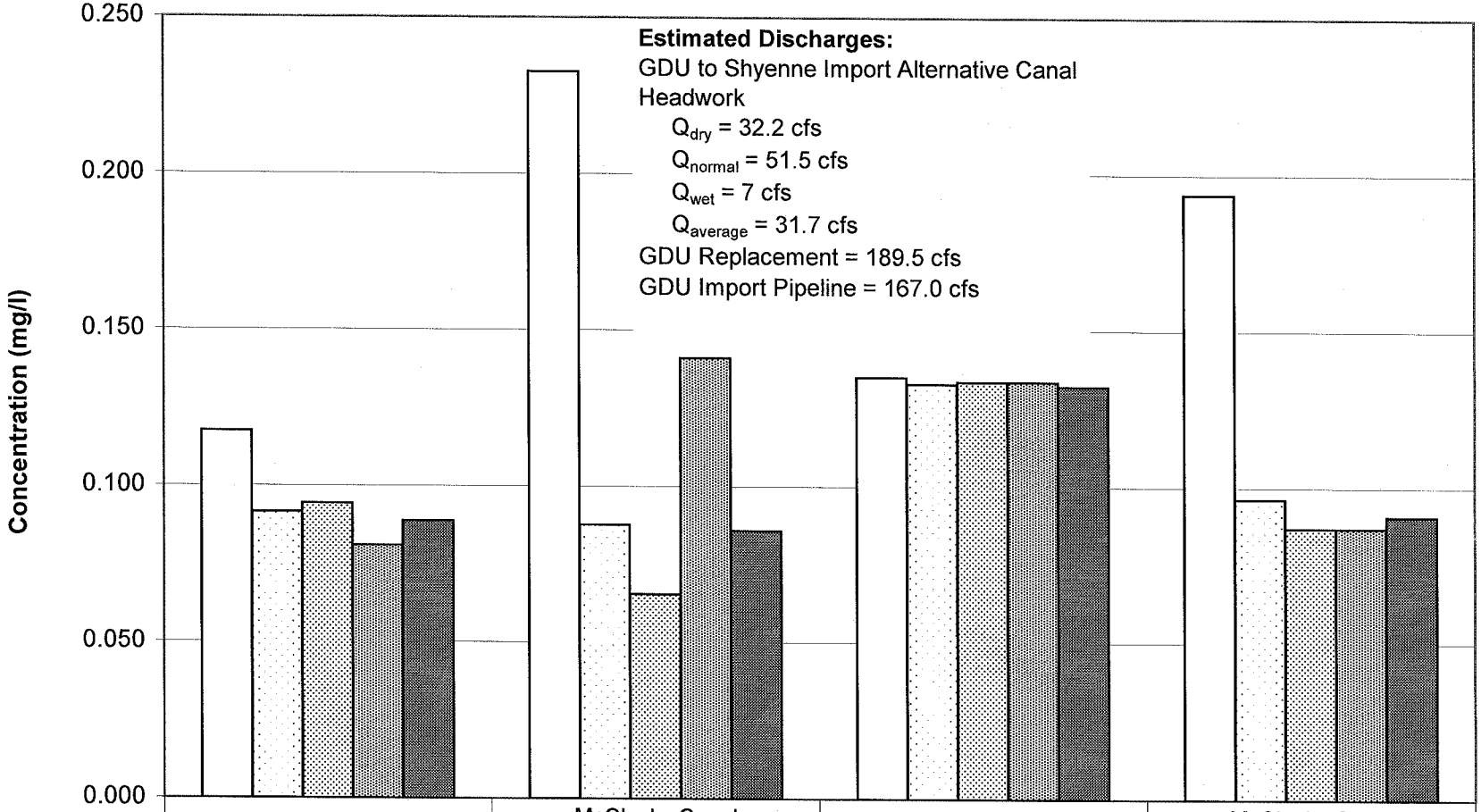
The unsteady analysis is useful for assessing the *relative* change in water quality for an alternative compared to the No Action. The analysis is also useful for estimating and describing how concentrations change moving in a downstream direction through the principal supply works. However, the unsteady analysis requires an assumption about the initial water quality concentrations within the canal. Existing concentrations as measured by Reclamation were used for this analysis. The existing concentrations are expected to be greater than those after implementation of one of the alternatives. An additional method was therefore used to estimate *absolute* concentrations within the principal supply works.

5.1.2.2 Steady State Analysis

The steady state analysis does not require an assumption about the initial concentrations within the principal supply works. All other assumptions about the amount of water and contaminant concentrations within water entering the canal are the same as for the unsteady analysis. The steady state condition reflects the concentrations within the canal that will be approached, and perhaps attained, as the duration of project operation increases.

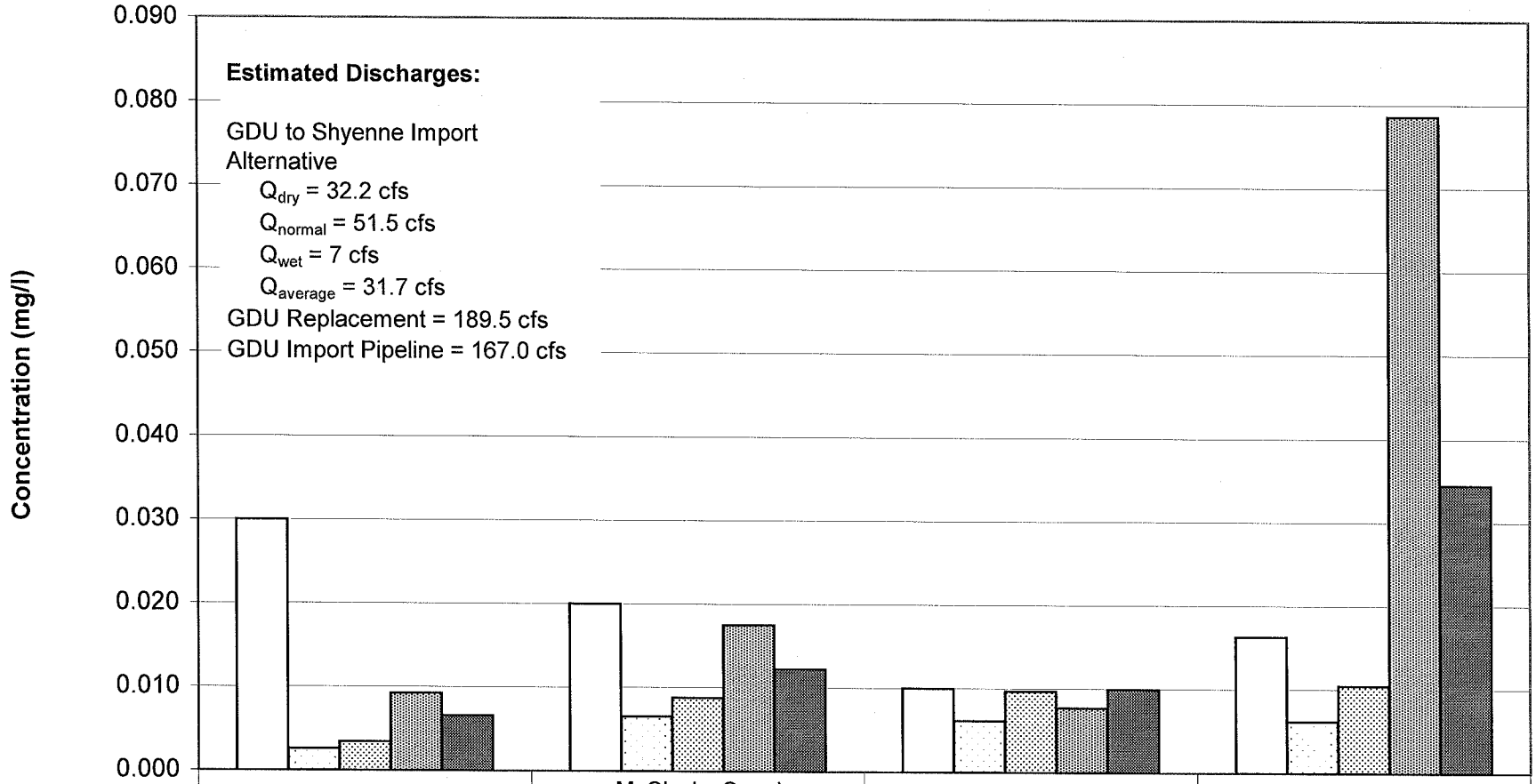
The concentrations within the canal approach those within Audubon Lake for the steady state condition (Table 5-3). Water quality concentrations within the principal

Figure 5-4
Estimated Concentrations for Inorganic Nitrogen
Garrison Diversion Unit Import to Sheyenne Alternative



	Lake Audubon	McClusky Canal to New John's Lake	New John's Lake	McClusky Canal to Diversion Location
No Action (measured)	0.118	0.233	0.135	0.194
Dry Year - 1963	0.092	0.088	0.133	0.096
Normal Year - 1941	0.094	0.065	0.134	0.087
Wet Year - 1994	0.081	0.141	0.134	0.087
Period of Record Average	0.089	0.086	0.132	0.091

Figure 5-5
Estimated Concentrations for Orthophosphate
Garrison Diversion Unit Import to Sheyenne Alternative



	Lake Audubon	McClusky Canal to New John's Lake	New John's Lake	McClusky Canal to Diversion Location
No Action (measured)	0.030	0.020	0.010	0.016
Dry Year - 1963	0.003	0.007	0.006	0.006
Normal Year - 1941	0.003	0.009	0.010	0.010
Wet Year - 1994	0.009	0.017	0.008	0.079
Period of Record Average	0.007	0.012	0.010	0.034

Table 5-3
Steady State Water Quality Model Results
Audubon Lake and Principal Supply Works

Hydrologic Year	Lake / Canal Reach	TDS	Sulfate	Chloride	Inorganic Nitrogen	Orthophosphate
Dry	Audubon Lake	753	195	13.4	0.072	0.027
	McClusky Canal from Lake Audubon to New John's Lake	755	196	13.5	0.074	0.027
	New John's Lake	756	196	13.6	0.074	0.019
	McClusky Canal from New John's Lake to Diversion	762	197	13.8	0.077	0.032
Normal	Audubon Lake	743	194	13.0	0.068	0.027
	McClusky Canal from Lake Audubon to New John's Lake	746	194	13.1	0.069	0.026
	New John's Lake	747	194	13.2	0.070	0.019
	McClusky Canal from New John's Lake to Diversion	753	195	13.4	0.072	0.031
Wet	Lake Audubon	823	207	16.3	0.104	0.029
	McClusky Canal from Lake Audubon to New John's Lake	824	207	16.4	0.104	0.028
	New John's Lake	824	208	16.4	0.105	0.016
	McClusky Canal from New John's Lake to Diversion	826	208	16.5	0.105	0.040
Average	Audubon Lake	766	198	14.0	0.078	0.028
	McClusky Canal from Lake Audubon to New John's Lake	768	198	14.1	0.079	0.027
	New John's Lake	769	198	14.1	0.080	0.018
	McClusky Canal from New John's Lake to Diversion	775	199	14.3	0.082	0.034

Values are mg/l unless indicated.

supply works are predicted to be lower than currently occur (i.e., the No Action Alternative). Lower concentrations are generally considered favorable.

5.1.3 Numeric Standards and Beneficial Uses

The amount of variation in environmental data can be expressed as the coefficient of variation (CV). The CV is expressed as a percent and is defined as the standard deviation divided by the mean times 100. The CV can be thought of as the percentage difference about or from the average value. Measured discharge in a stream or river can provide a frame of reference for understanding the amount of variability with environmental data.

Discharge below a dam should have a relatively low CV, as the rate of outflow is controlled. The CV for daily discharge at the Bismarck USGS gage (1960-current to reflect post dam construction) is 36.6%. This compares to a CV of 182% for the Grand Forks gage, where the Red River is no longer "controlled" by upstream storage. The variability in daily discharge is considerably greater than at Bismarck, based upon the CVs.

Assuming that the variability in nutrient load is similar to daily discharge CV (which is used to compute load) the estimated loads diverted from the Missouri River and entering the Sheyenne and Red Rivers for the three alternatives is expected to be immeasurable and is considered negligible. The percentage change (Table 5-1) is small compared to the daily discharge CVs of 36.6% and 182%. The nutrient concentrations will remain unchanged compared to the No Action Alternative. Therefore, no change in the number of times the numeric standards are exceeded is expected. Beneficial uses will remain unchanged.

Periodic occurrences above a numeric standard are allowed without considering a water body as failing to fully meet the beneficial uses. Within North Dakota a fully supporting designation allows for up to a maximum of 10% of the samples collected to exceed the numeric standard within a 10 year period.

5.2 Sheyenne River System

5.2.1 Lake Ashtabula

5.2.1.1 Nutrient Loads

The GDU Import to Sheyenne River Alternative directly delivers[12] water to Lake Ashtabula. Two other alternatives use Lake Ashtabula for the re-regulation of water; i.e., the Missouri River Import to Red River Valley Alternative and the North Dakota In-Basin Alternative. Re-regulation means water is temporarily stored in the lake for later use. Most of the water for the Missouri River Import to Red River Valley Alternative is brought directly to a pipeline distribution system within the Red River Valley. However, a small amount will be brought to the reservoir by pipeline and stored for later use. The North Dakota In-Basin Alternative circulates water back to Lake Ashtabula from a location just downstream of Grand Forks for reuse. The other alternatives primarily affect the hydrology of the reservoir. Because the demand for water is satisfied from other locations, typically more water remains within the reservoir.

The annual TN and TP loads for the GDU Import to Sheyenne River Alternative are estimated at 7.0% and 6.5% respectively of the annual load at Cooperstown upstream from the Lake (Table 5-1). The annual TN and TP loads for the Missouri River Import to Red River Valley Alternative and the North Dakota In-Basin Alternative are a small (< 1%) portion of the Sheyenne River loads. To better understand the importance of the change in nutrient loads a computer model was used to evaluate the change in nutrients, the amount of algae and water clarity.

5.2.1.2 Eutrophication Modeling of Lake Ashtabula

The GDU Import to Sheyenne River Alternative, the Missouri River Import to Red River Valley Alternative, and the North Dakota In-Basin Alternatives discharge water directly into Lake Ashtabula. The primary hydrologic effect of the remaining alternatives is altering the storage within Lake Ashtabula. These alternatives alter storage because user demands are satisfied by water sources other than from Lake Ashtabula.

[12] Deliver occurs during dry and normal hydrologic years. Natural flows within the river during wet years are generally sufficient to satisfy user demand, so no additional project water is delivered during wet years.

Total nitrogen concentration, total phosphorus concentration, chlorophyll-a concentration and secchi disk visibility were used to assess the potential change in water quality within Lake Ashtabula. The amount (i.e., concentration) of chlorophyll-a within a lake is related to nutrient concentrations. The productivity and amount of chlorophyll-a increases as nutrient concentrations increase. An increase in productivity is considered undesirable. Secchi disk visibility is an indicator of water clarity. A decrease in secchi disk visibility and water clarity is also considered undesirable.

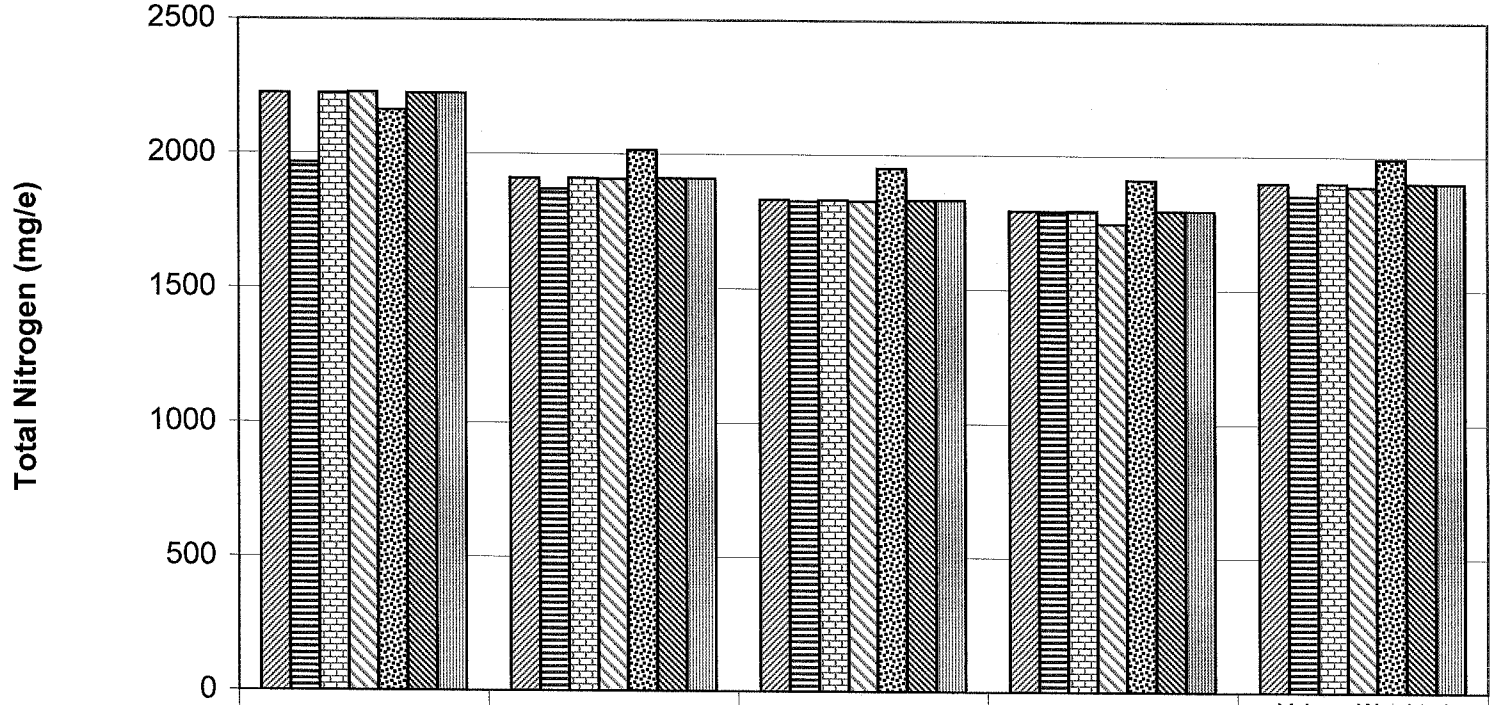
The environmental consequences of the alternatives were evaluated using four hydrologic conditions; i.e., a dry hydrologic year, a normal hydrologic year, a wet hydrologic year and the long-term average (period of record) hydrologic conditions. Annual runoff volumes at Cooperstown, ND based upon the STATEMOD results were used to define three of the four hydrologic conditions:

- Dry year (1963) – 90% exceedance annual runoff volume (i.e., 90% of the time the amount of annual runoff exceeds this value);
- Normal year (1941) – 50% exceedance annual runoff volume (i.e., 50% of the time the amount of annual runoff exceeds this value); and
- Wet year (1994) – 10% exceedance annual runoff volume (i.e., 10% of the time the amount of annual runoff exceeds this value)

Hydrologic data specific to these years from STATEMOD were used to simulate the hydrology of Lake Ashtabula for each of these hydrologic conditions. The average year reflects the hydrologic conditions based upon the STATEMOD model on average, for the 71-year period of record (i.e., total runoff volumes divided by the 71-year period).

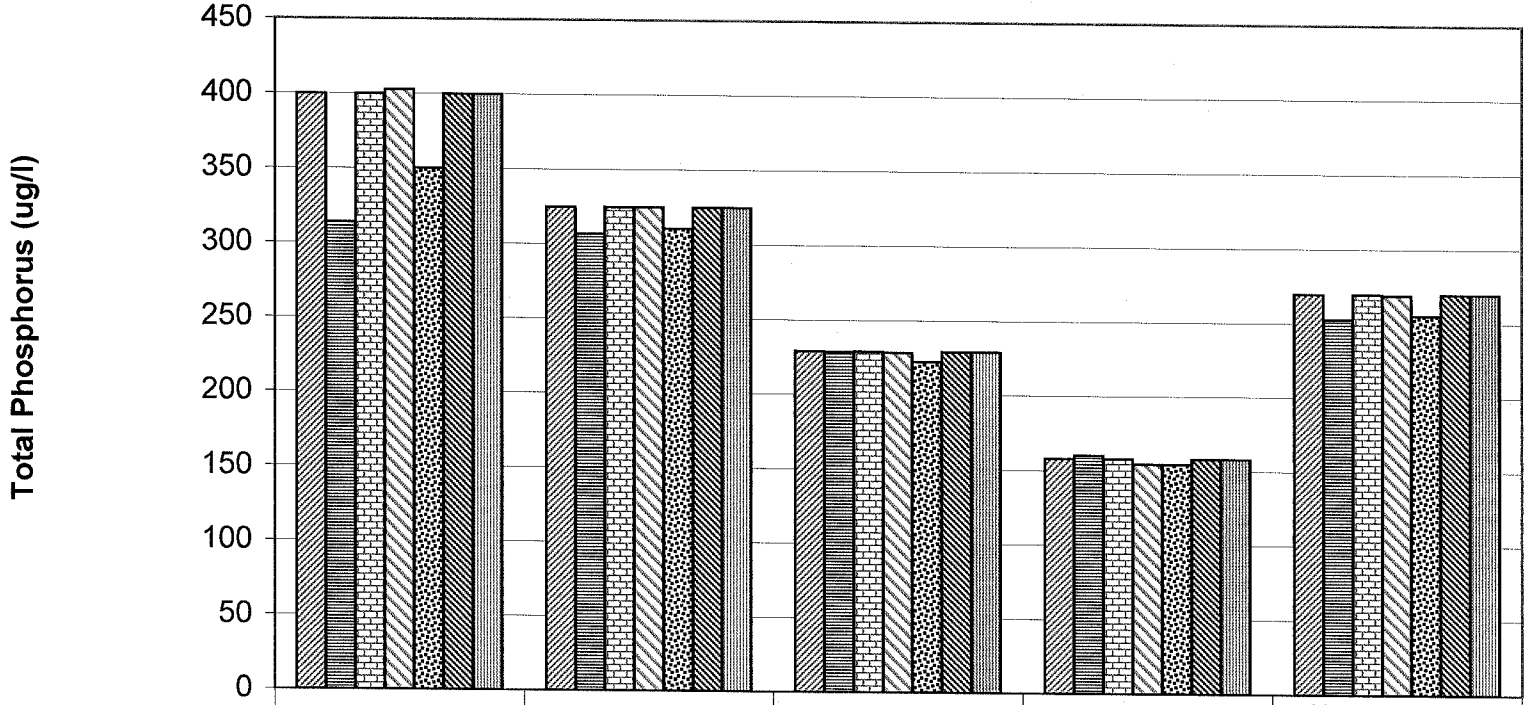
The modeling results suggest that some increase in TN concentration may occur during a dry year for the North Dakota In-Basin Alternative, presumably because of the return of water from Grand Forks to Lake Ashtabula (Figure 5-6). However, the total phosphorus concentration declines or remain unchanged for each alternative either directly delivering water to Lake Ashtabula or using the lake for re-regulation (Figure 5-7) compared to the No Action Alternative. Both the Missouri River Import to Red River Valley Alternative and the GDU Import to Sheyenne River decrease total phosphorus

Figure 5-6
Modeled Total Nitrogen in Lake Ashtabula by Alternative (Dry Year)



	Segment 1	Segment 2	Segment 3	Segment 4	Volume Weighted Average
No Action	2224.9	1911.1	1833.8	1795.0	1901.4
GDU Import to Sheyenne	1966.5	1869.9	1829.0	1794.4	1853.2
GDU Import to Red River Valley	2224.9	1911.1	1833.8	1795.0	1901.4
Missouri River Import to Red River Valley	2228.2	1908.9	1827.9	1747.7	1888.5
North Dakota in Basin	2162.7	2014.9	1951.4	1911.2	1991.7
Lake of the Woods	2224.9	1911.1	1833.8	1795.0	1901.4
Red River Basin	2224.9	1911.1	1833.8	1795.0	1901.4

Figure 5-7
Modeled Total Phosphorus in Lake Ashtabula by Alternative (Dry Year)



	Segment 1	Segment 2	Segment 3	Segment 4	Volume Weighted Average
No Action	399.7	324.6	229.1	158.1	269.6
GDU Import to Sheyenne	313.7	306.7	228.5	160.5	252.8
GDU Import to Red River Valley	399.7	324.6	229.1	158.1	269.6
Missouri River Import to Red River Valley	402.6	324.6	228.5	154.5	268.9
North Dakota in Basin	350.2	310.4	222.4	154.5	255.6
Lake of the Woods	399.7	324.6	229.1	158.1	269.6
Red River Basin	399.7	324.6	229.1	158.1	269.6

concentrations within Lake Ashtabula slightly. The model estimates however, essentially no change in the chlorophyll-a concentrations or secchi disk visibility because of the small changes in nutrient concentrations (Figures 5-8 and 5-9). The remaining alternatives cause no limnological change in Lake Ashtabula compared to the No Action Alternative.

During normal and average hydrologic years[13] nutrient concentrations decline for the Red River In-Basin Alternative and the GDU Import to Sheyenne River Alternative (Figures 5-10 and 5-11). The decline occurs even though loads increase. Concentrations decline because of the volume of low nutrient concentration water which dilutes higher nutrient concentration water coming from the Sheyenne River and Baldhill Creek. The change in nutrient concentrations results in little reduction in the chlorophyll-a concentration or increase in secchi depth (Figure 5-12 and 5-13).

During wet hydrologic years none of the alternatives alter nutrient concentrations within Lake Ashtabula (see Appendix A). Natural flows within the Sheyenne River and Bald Hill Creek drive the limnology of Lake Ashtabula.

5.2.1.3 Numeric Standards and Beneficial Uses

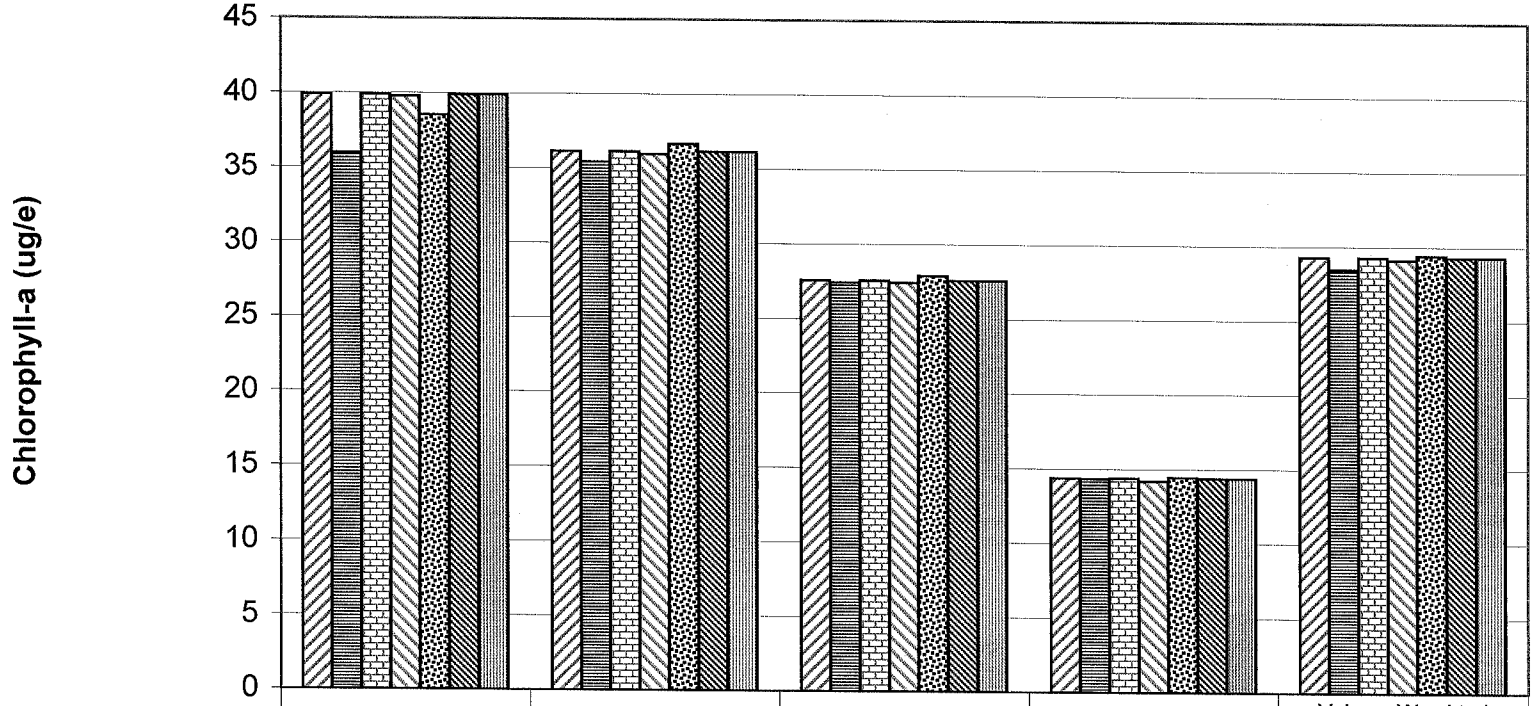
Because nutrient concentrations within Lake Ashtabula show little change, no change in the number of numeric standard exceedances or the beneficial uses of the lake is expected.

5.2.1.4 Cumulative Impacts

No cumulative water quality impacts are anticipated. Operation of the Devils Lake outlet is the most likely reasonably foreseeable activity, which could lead to potential cumulative impacts. Operation of the project is restricted by the National Pollutant Discharge Elimination System (NPDES) permit. Project operation is restricted to: 1) May through November; 2) periods of time when the discharge within the Sheyenne River is less than 600 cfs; and 3) periods of time when the sulfate concentration is less than 300 mg/L. Measurement of the discharge and sulfate

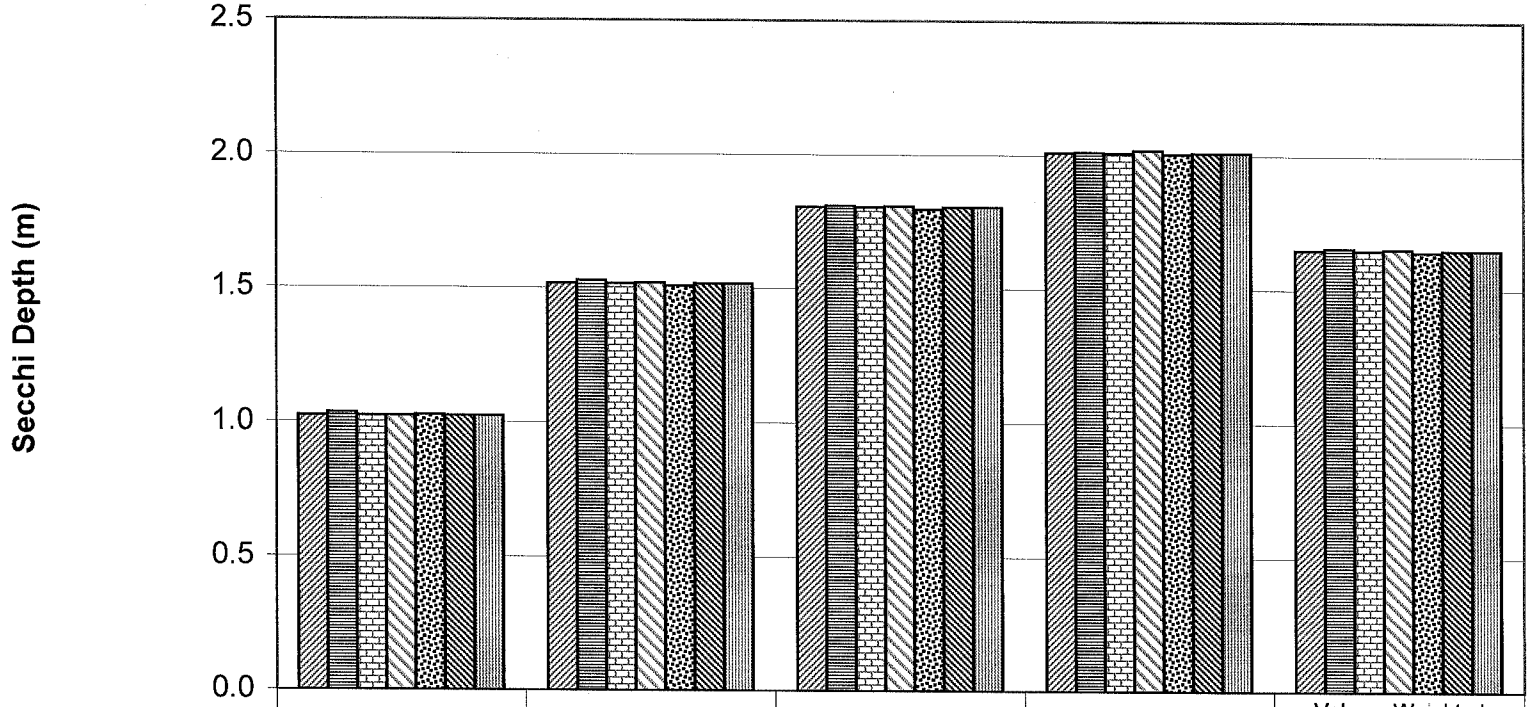
[13] Only results for the normal hydrologic year are presented within the text. The results for an average hydrologic year can be found in Appendix A.

Figure 5-8
Modeled Chlorophyll-a in Lake Ashtabula by Alternative (Dry Year)



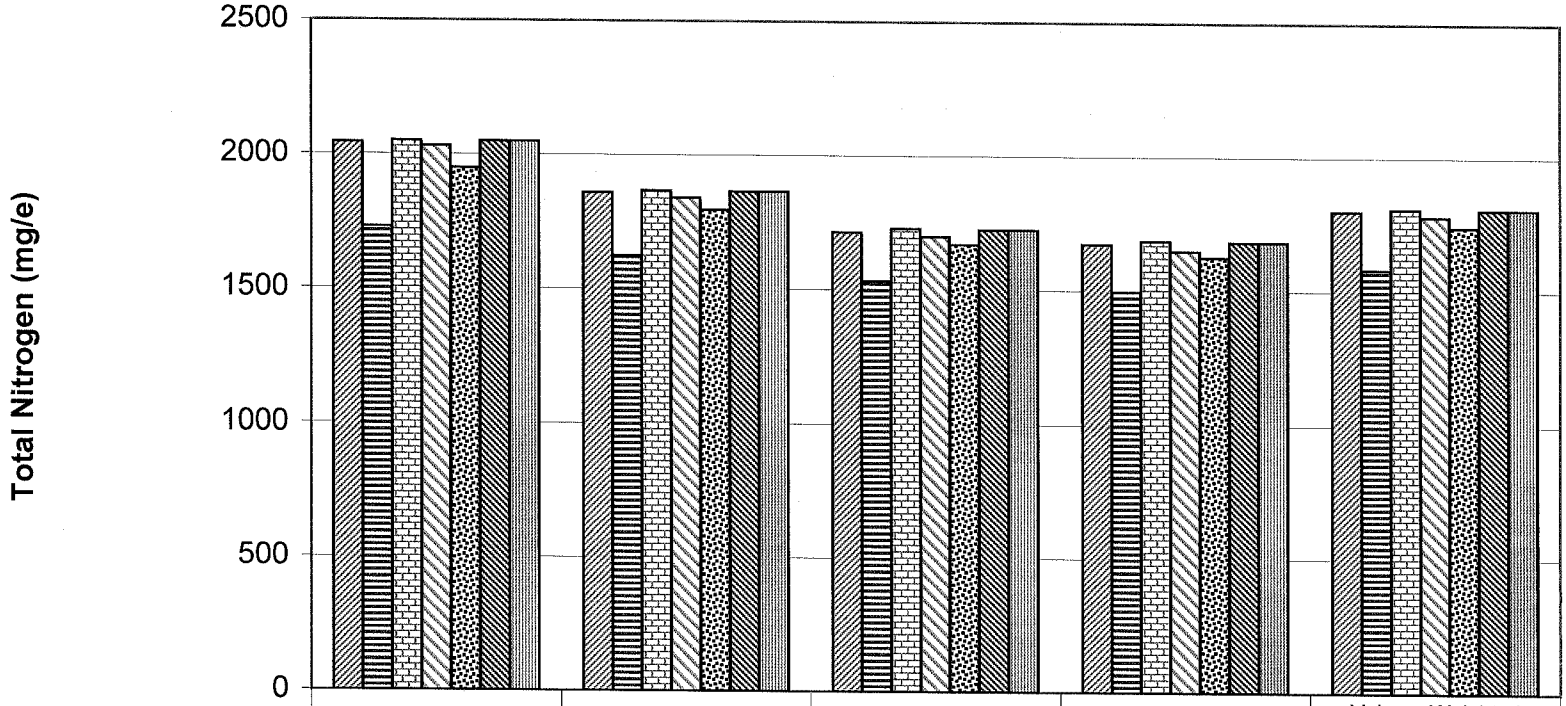
	Segment 1	Segment 2	Segment 3	Segment 4	Volume Weighted Average
No Action	39.9	36.1	27.6	14.4	29.3
GDU Import to Sheyenne	36.0	35.4	27.4	14.3	28.5
GDU Import to Red River Valley	39.9	36.1	27.6	14.4	29.3
Missouri River Import to Red River Valley	39.8	36.0	27.4	14.2	29.1
North Dakota in Basin	38.5	36.7	27.9	14.4	29.4
Lake of the Woods	39.9	36.1	27.6	14.4	29.3
Red River Basin	39.9	36.1	27.6	14.4	29.3

Figure 5-9
Modeled Secchi Depth in Lake Ashtabula by Alternative (Dry Year)



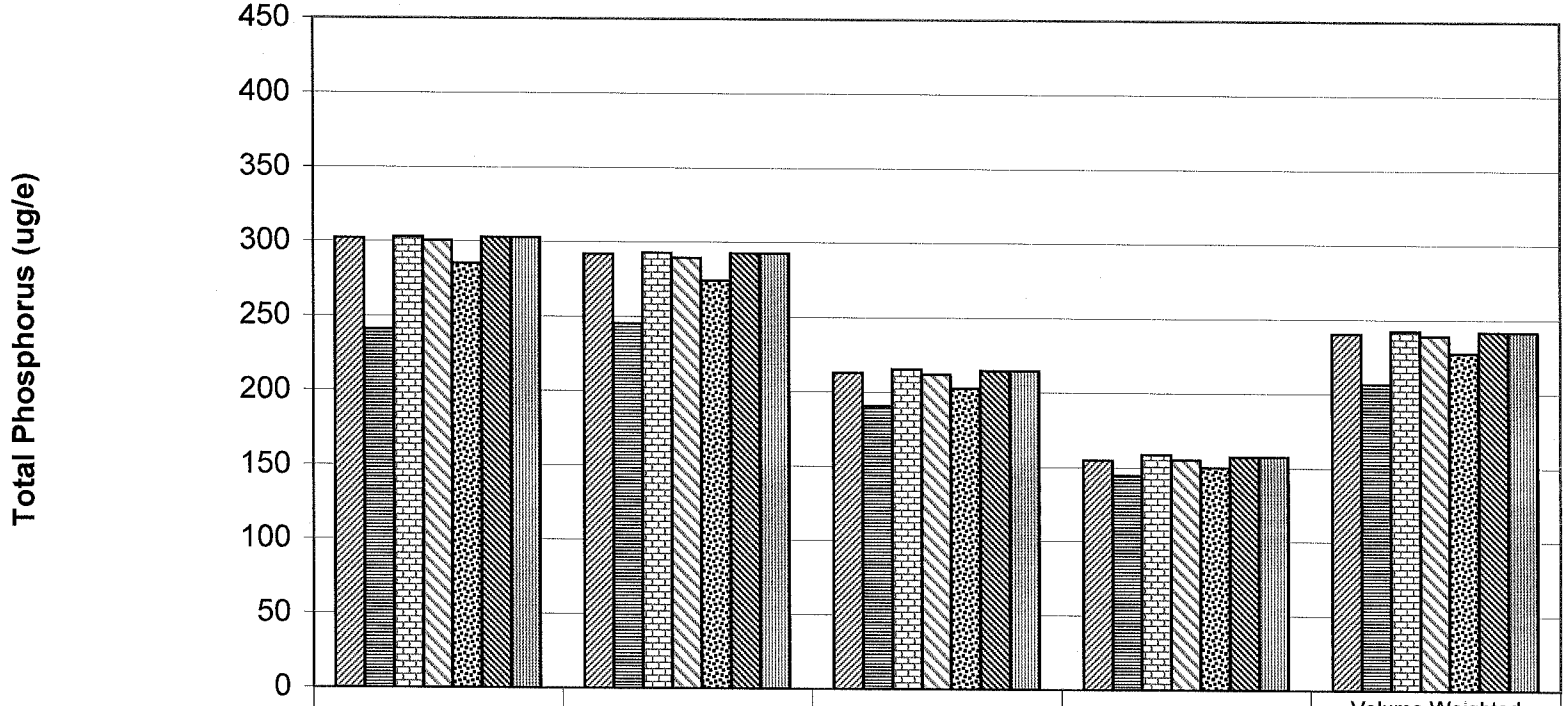
	Segment 1	Segment 2	Segment 3	Segment 4	Volume Weighted Average
No Action	1.0	1.5	1.8	2.0	1.6
GDU Import to Sheyenne	1.0	1.5	1.8	2.0	1.7
GDU Import to Red River Valley	1.0	1.5	1.8	2.0	1.6
Missouri River Import to Red River Valley	1.0	1.5	1.8	2.0	1.7
North Dakota in Basin	1.0	1.5	1.8	2.0	1.6
Lake of the Woods	1.0	1.5	1.8	2.0	1.6
Red River Basin	1.0	1.5	1.8	2.0	1.6

Figure 5-10
Modeled Total Nitrogen in Lake Ashtabula by Alternative (Normal Year)



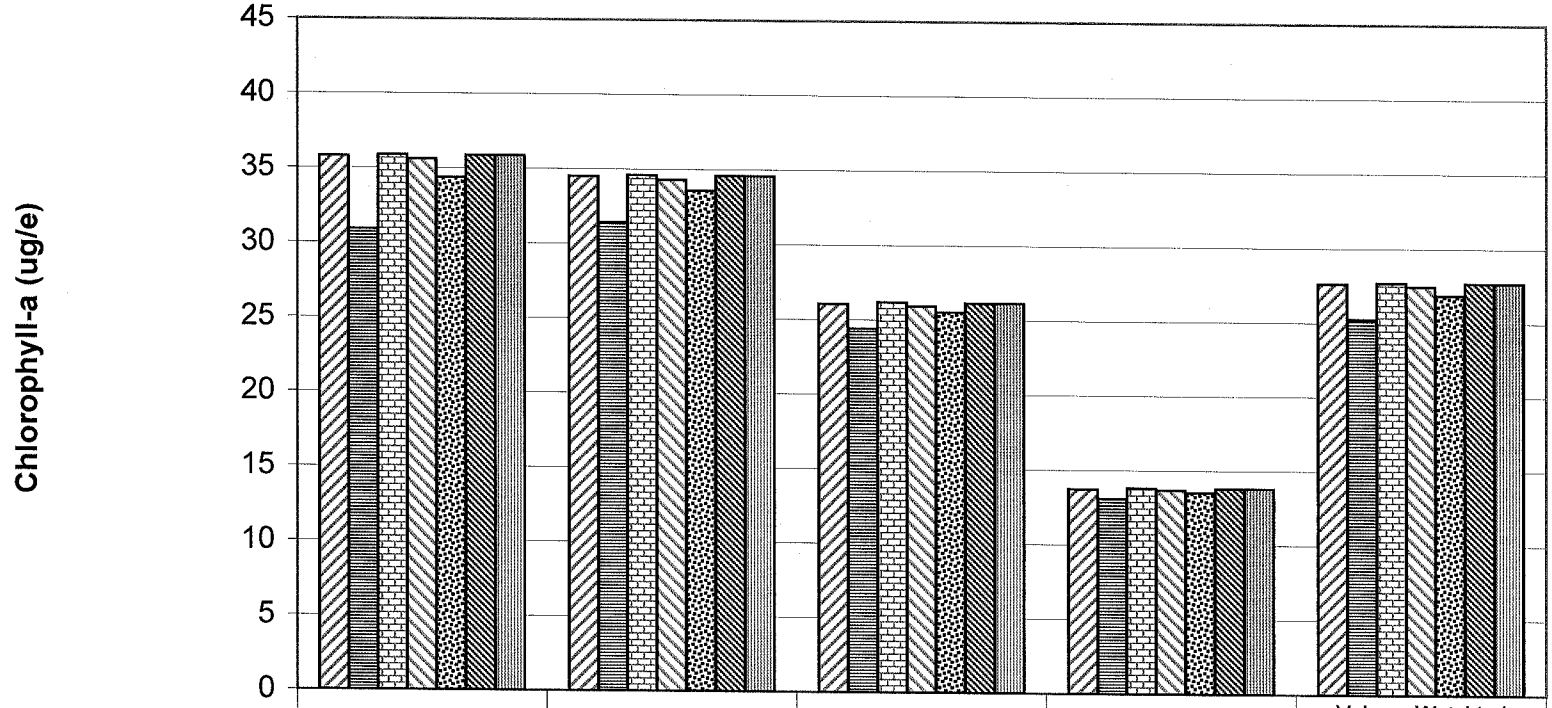
	Segment 1	Segment 2	Segment 3	Segment 4	Volume Weighted Average
No Action	2044.6	1858.1	1714.4	1673.9	1799.4
GDU Import to Sheyenne	1728.5	1622.4	1533.2	1497.5	1582.3
GDU Import to Red River Valley	2050.5	1866.1	1728.5	1686.1	1809.8
Missouri River Import to Red River Valley	2031.5	1840.3	1698.0	1648.6	1780.8
North Dakota in Basin	1949.5	1794.9	1669.9	1625.7	1740.9
Lake of the Woods	2049.0	1864.0	1724.3	1682.5	1806.8
Red River Basin	2049.0	1864.0	1724.3	1682.5	1806.8

Figure 5-11
Modeled Total Phosphorus in Lake Ashtabula by Alternative (Normal Year)



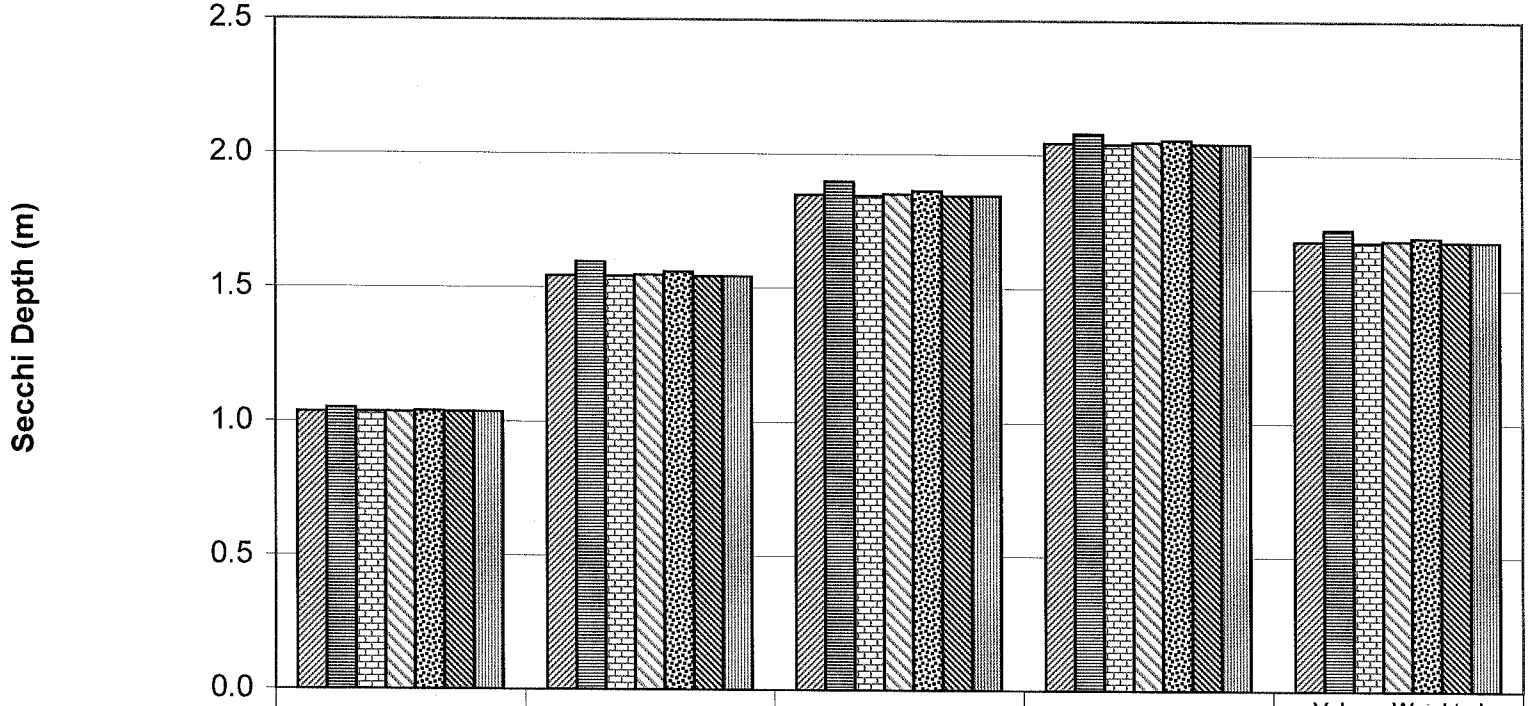
	Segment 1	Segment 2	Segment 3	Segment 4	Volume Weighted Average
No Action	302.0	291.8	213.1	154.7	240.2
GDU Import to Sheyenne	241.0	245.2	190.6	144.6	206.8
GDU Import to Red River Valley	302.8	292.8	215.5	158.7	242.3
Missouri River Import to Red River Valley	300.5	289.4	212.0	155.2	238.9
North Dakota in Basin	285.2	274.2	202.6	150.2	227.7
Lake of the Woods	302.6	292.6	214.7	157.3	241.6
Red River Basin	302.6	292.6	214.7	157.3	241.6

Figure 5-12
Modeled Chlorophyll-a in Lake Ashtabula by Alternative (Normal Year)



	Segment 1	Segment 2	Segment 3	Segment 4	Volume Weighted Average
No Action	35.8	34.5	26.1	13.7	27.6
GDU Import to Sheyenne	30.9	31.4	24.4	13.1	25.3
GDU Import to Red River Valley	35.9	34.6	26.2	13.8	27.7
Missouri River Import to Red River Valley	35.6	34.3	25.9	13.7	27.5
North Dakota in Basin	34.3	33.6	25.5	13.5	26.9
Lake of the Woods	35.9	34.6	26.2	13.8	27.7
Red River Basin	35.9	34.6	26.2	13.8	27.7

Figure 5-13
Modeled Secchi Depth in Lake Ashtabula by Alternative (Normal Year)



	Segment 1	Segment 2	Segment 3	Segment 4	Volume Weighted Average
No Action	1.0	1.5	1.8	2.0	1.7
GDU Import to Sheyenne	1.0	1.6	1.9	2.1	1.7
GDU Import to Red River Valley	1.0	1.5	1.8	2.0	1.7
Missouri River Import to Red River Valley	1.0	1.5	1.9	2.0	1.7
North Dakota in Basin	1.0	1.6	1.9	2.1	1.7
Lake of the Woods	1.0	1.5	1.8	2.0	1.7
Red River Basin	1.0	1.5	1.8	2.0	1.7

concentration will occur immediately downstream of the location where water enters the Sheyenne River.

Simultaneous operation of the Devils Lake Outlet and a RRVWS project seems unlikely and is the basis for concluding no cumulative impact. Of the alternatives, the GDU Import to Sheyenne River Alternative delivers the greatest volume of water to the Sheyenne River and therefore has the greatest potential for cumulative impacts. Based upon the STATEMOD analysis, the GDU Import to Sheyenne River Alternative delivers no water to Lake Ashtabula for one-half of the months from May through November (Figure 5-14). The average monthly discharge to Lake Ashtabula is less than 22 cfs for 75% of the months. This compares to a mean daily discharge of 16 cfs for the 60 year period of record at Cooperstown, just upstream of Lake Ashtabula.

Using the historic daily discharge data from the Cooperstown gage shows that from May through November the peak discharge of 600 cfs is exceeded 20% of the time, precluding operation of the Devils Lake outlet (Figure 5-15). Historic measured sulfate concentrations at Warwick exceed 300 mg/L 5% of the time (Figure 5-16). If these events occur independently then the probability of coincident operation of the projects is 0.5 times 0.2 times 0.95 or approximately 10% of the time.

Coincident operation of the two projects is unlikely for a second reason. The Devils Lake outlet is permitted to release up to 100 cfs. During a release the water from Devils Lake could be used to satisfy downstream demands and the need for delivery from an alternative could be reduced or curtailed.

5.2.2 Sheyenne River below Lake Ashtabula to the Confluence with the Red River

5.2.2.1 Nutrient Loads

Loads within the lower portion of the Sheyenne River can be altered by those alternatives which use Lake Ashtabula[14] for the re-regulation of water. These alternatives are the GDU Import to Sheyenne River Alternative, the North Dakota In-Basin Alternative and the Missouri River Import to Red River Valley Alternative. The annual TP and TN nutrient loads entering the Sheyenne River for the Missouri River Import to Red

[14] The response of Lake Ashtabula to these loads is evaluated within Section 5.2.3.2.

Figure 5-14
GDU Import to Sheyenne River Alternative
Percentage of Months with Discharge to Lake Ashtabula During Devils Lake Outlet Operation
(May to November)

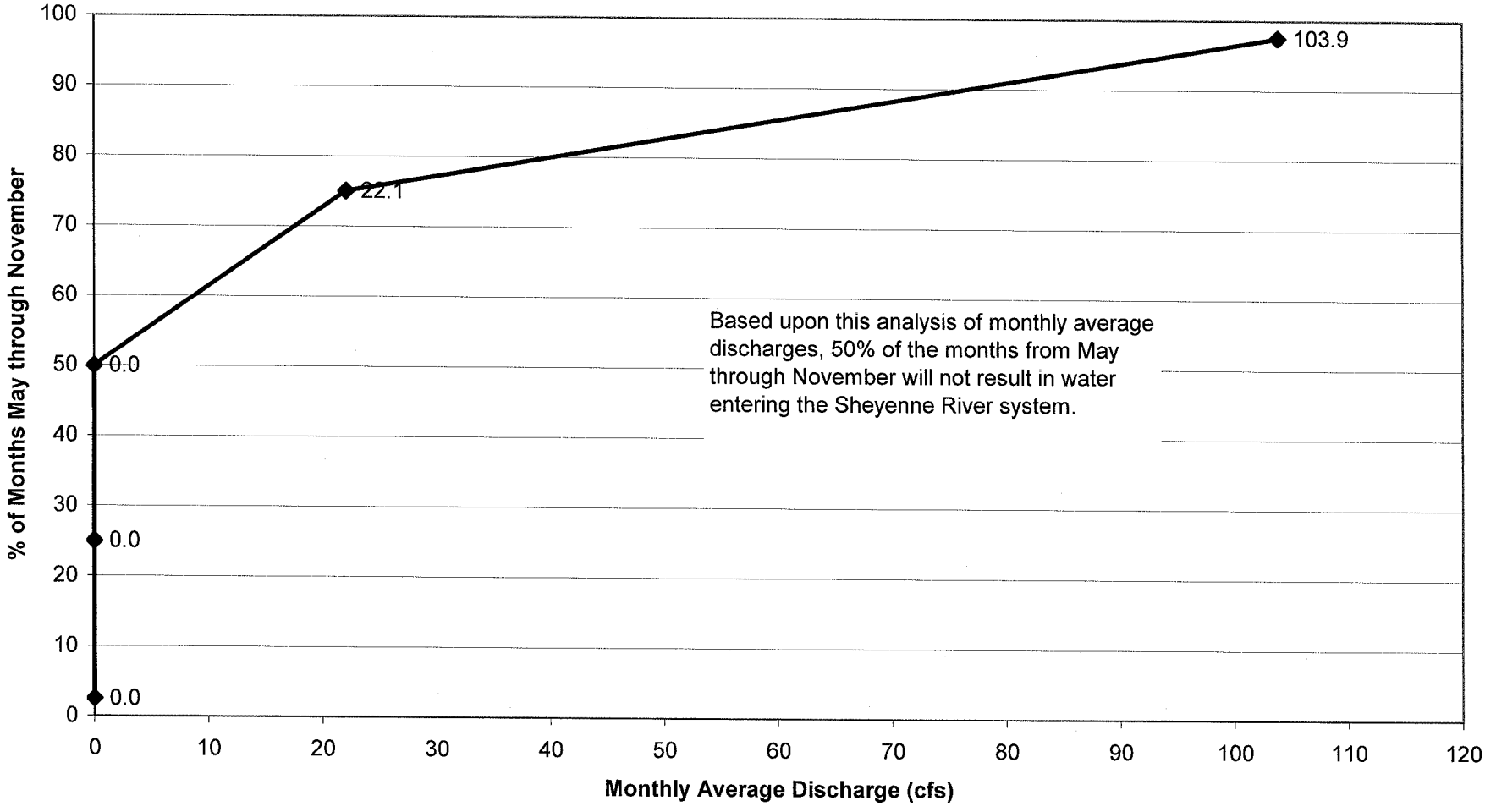


Figure 5-15
Daily Discharge @ Cooperstown, North Dakota Gage
Period of Record for Months May through November

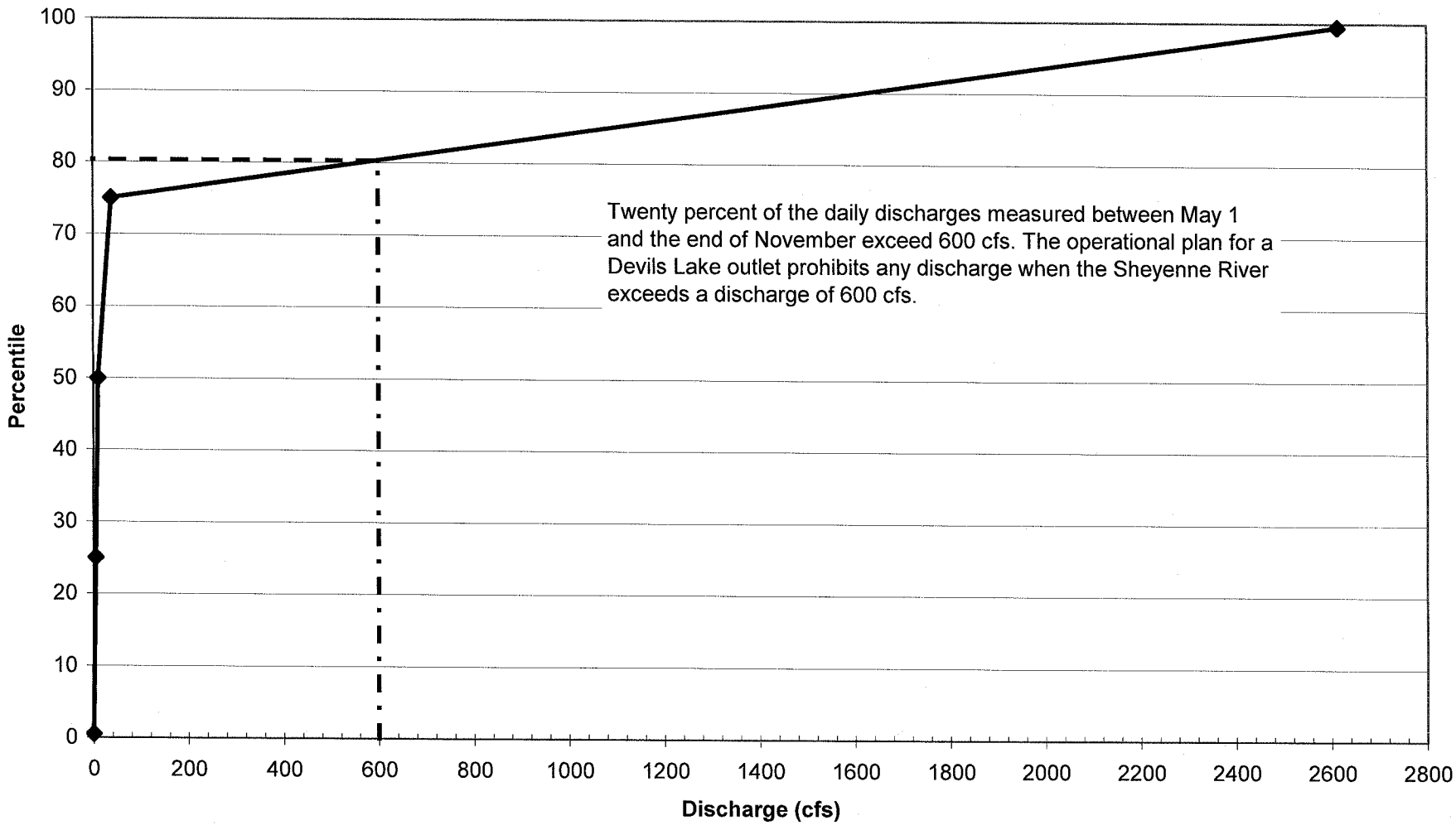
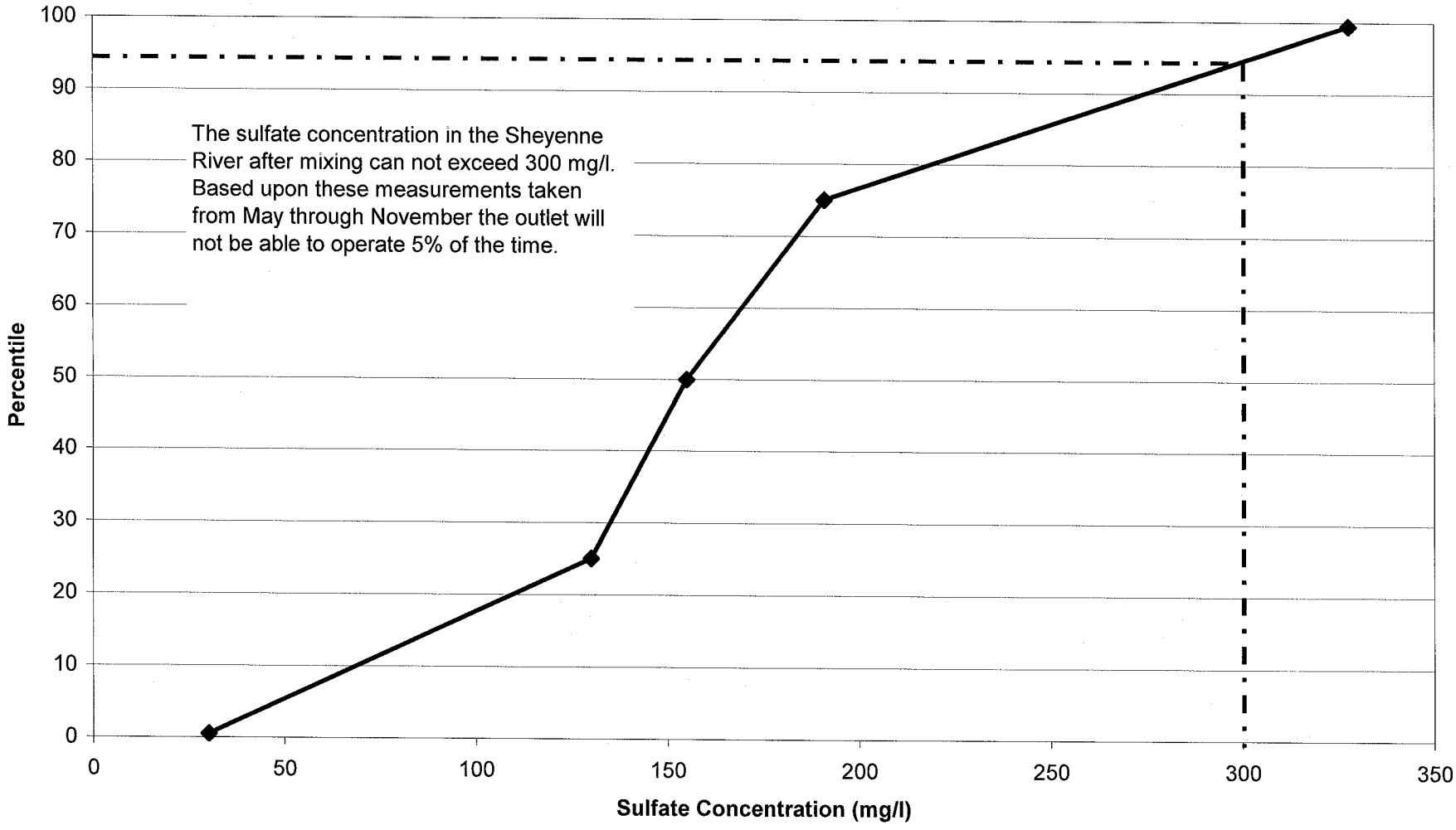


Figure 5-16
Period of Record Frequency Analysis
Warwick Sulfate Concentration (Period of Record May through November)



River Valley Alternative are < 2% of the annual nutrient load at the mouth of the Sheyenne River. Any increase in nutrient load associated with the ND In-Basin Alternative results from the use of additional groundwater for domestic and industrial use. The annual TP and TN nutrient loads compared to the mouth of the Sheyenne River for the ND In-Basin Alternative are < 5%, which are substantially less than the variability in daily discharge (see discussion within *Section 5.1.3, Numeric Standards and Beneficial Uses*). No measurable change in beneficial uses within the River is anticipated as a result of the change in nutrient load.

5.2.2.2 Modeled Concentrations – Conservative Substances

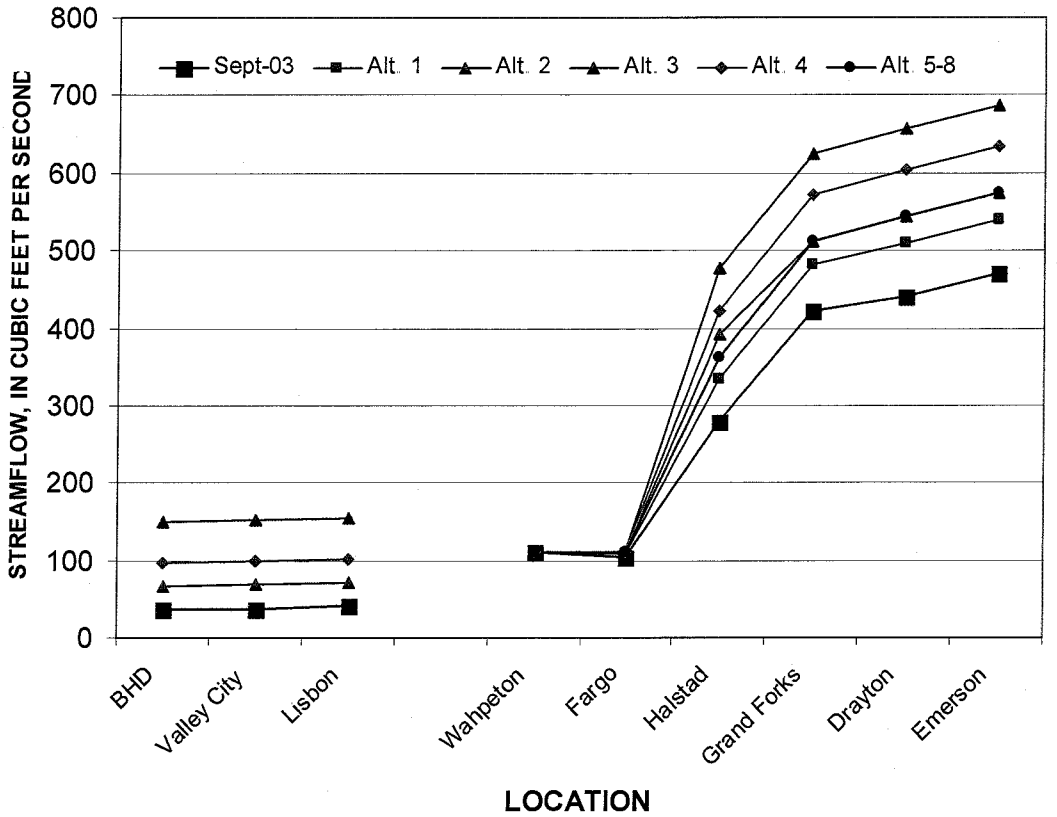
The USGS utilized the HEC-5Q model to predict conservative substances within the Sheyenne and Red Rivers. Essentially, the modeling results represent steady state conditions with hydrologic and water quality conditions similar to the fall of 2003. Hydrologic conditions during the fall of 2003 showed generally higher flows than would occur under drought conditions (see Table 5-4). Measured concentration used in the model came from data collected by the USGS during the fall of 2003. These concentrations were generally greater than the long term median concentrations (see Section 4). Although the HEC-5Q model is an unsteady model, constant discharge and water quality measured during the fall of 2003 were used as input; i.e., the results represent steady state. The 2050 demands and return flows were assumed to be superimposed on the fall 2003 conditions. The simulated discharge at Emerson, Manitoba for the alternatives ranged from in excess of 500 to less than 700 cfs (see Figure 5-17). (Note: results for a reduced discharge model can be found in Appendix G.)

The model results are useful for assessing the relative change in water quality for the alternatives. However, the results ***should not*** be interpreted as the long term average condition that would occur with the alternatives. For example, the GDU Import to Sheyenne River Alternative is expected to deliver water to Lake Ashtabula only 50% of the months (see *Section 5.2.2.5 Cumulative Impacts*). The discharge will be less than 20 cfs (less than 3% of that simulated at Emerson) for 70% of the months. Since no water would be delivered to the Sheyenne River for more than one-half the months, the concentrations estimated by the model will be the same as the No Action Alternative 50%

Table 5-4. Fall 2003 discharges used by the USGS in the HEC-5Q model.

Location	Streamflow (cfs)	Streamflow duration (percent exceedance)
Sheyenne River near Harvey, ND	2.5	
Sheyenne River near Warwick, ND	14	
Sheyenne River near Cooperstown, ND	21	
Sheyenne River below Baldhill Dam, ND	37	
Sheyenne River at Lisbon	41	
Sheyenne River near Kindred, ND	69	
Sheyenne River above Sheyenne River Diversion near Horace, ND	71	
Sheyenne River at Brooktree Park, ND	80	58.0
Bois de Sioux River near Doran, MN	0	
Otter Tail River at 11th Street in Breckenridge, MN	114	79.0
Red River at Wahpeton, ND	110	
Red River at Hickson, ND	119	
Wild Rice River near Abercrombie, ND	0.3	
Red River above Fargo, ND	114	
Red River at Fargo, ND	104	
Red River on Cass County Road 20 below Fargo, ND	118	
Buffalo River near Dilworth, MN	22	
Wild Rice River at Hendrum, MN	46	
Red River at Halstad, MN	278	
Goose River at Hillsboro, ND	19	
Marsh River near Shelly, MN	0.1	
Sand Hill River at Climax, MN	22	
Red River near Thompson, ND	325	
Red Lake River at Fisher, MN	159	87.1
Red River at Grand Forks	422	
Turtle River above Manvel, ND	2	
Red River at Oslo, MN	425	
Forest River near confluence with Red River, ND	10	
Snake River near Big Woods, MN	0	
Park River near Oakwood, ND	2	
Red River at Drayton	440	
Two Rivers at Hallock, MN	5	
Pembina River above Pembina, ND	20	
Red River at Emerson, Manitoba	470	83.8

Figure 5-17. Simulated discharges on the Sheyenne and Red Rivers for fall 2003 hydrologic conditions.



Alternative	Name
1	No Action
2	North Dakota In-Basin
3	GDU to Sheyenne River Import
4	Missouri River to Red River Valley Import
5	Red River Basin
6	Lake of the Woods
7	GDU Import
8	GDU Replacement

of the time. The long term average concentrations for this alternative will in fact reach a value somewhere between the No Action Alternative and that predicted by the model.

Only the GDU Import to Sheyenne River Alternative, the North Dakota In-Basin Alternative and the Missouri River Import to Red River Valley Alternative deliver water to the Sheyenne River. Results for the fall 2003 and reduced discharge hydrologic conditions were similar. Therefore, only results for the fall of 2003 are discussed[15] here.

Elevated TDS makes water less desirable for domestic use, can increase the cost of treatment, and is undesirable. TDS concentrations remain relatively unchanged compared to the No Action Alternative (Figure 5-18). The ND In-Basin Alternative and the Missouri River Import to Red River Valley Alternative reduce TDS (by approximately 15% at Horace) compared to the No Action Alternative on the lower portion of the Sheyenne River. This reduction however, is expected to be within the normal variation of TDS concentration within the river. Because the lower concentration will occur only during a drought[16], no measurable long-term change in TDS concentration is anticipated.

Chloride is a general indicator of the amount of salts present in surface water. Chloride is generally not harmful to humans, although the sodium associated with common table salt has been linked to heart and kidney disease. Fish and aquatic communities can be sensitive to high chloride levels. Chloride concentrations show a trend similar to TDS within the lower portion of the Sheyenne River (Figure 5-19). The ND In-Basin, the GDU Import to Sheyenne River and the Missouri River Import to Red River Valley Alternatives reduce chloride concentrations (by a maximum of 32% at Horace) compared to the No Action Alternative on the lower portion of the Sheyenne River. Again, no measurable change in long-term TDS concentration is anticipated.

Sulfate concentrations within the Missouri River System within Lake Sakakawea and Lake Audubon tend to be greater than within the upper portion of the Sheyenne River (see *Section 4, Existing Conditions*). One alternative increases sulfate concentrations within the

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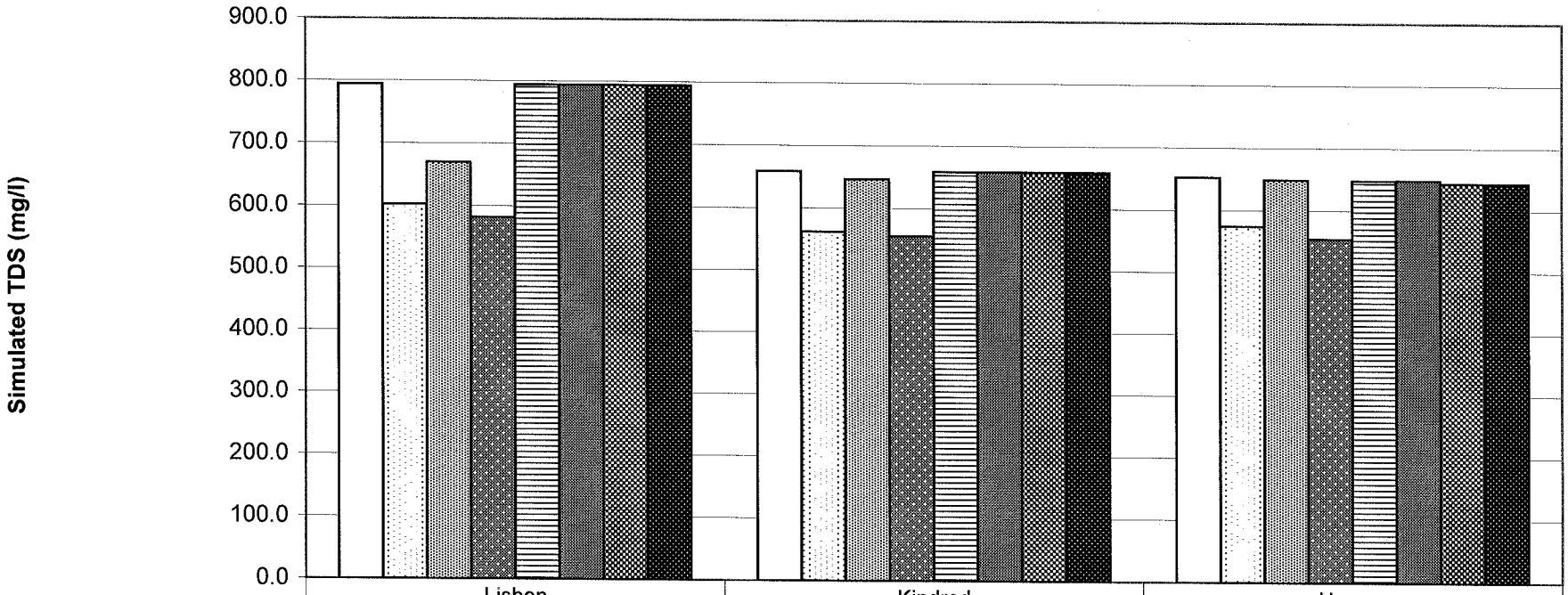
[15] Results for the 25% reduced discharges can be found in Appendix B.

16 The concentration is predicated to occur less than 50% of the time as a long-term average. Using TDS as an example the long-term average could be (0.5) (652.4) + (0.5) (554.1) = 603.3

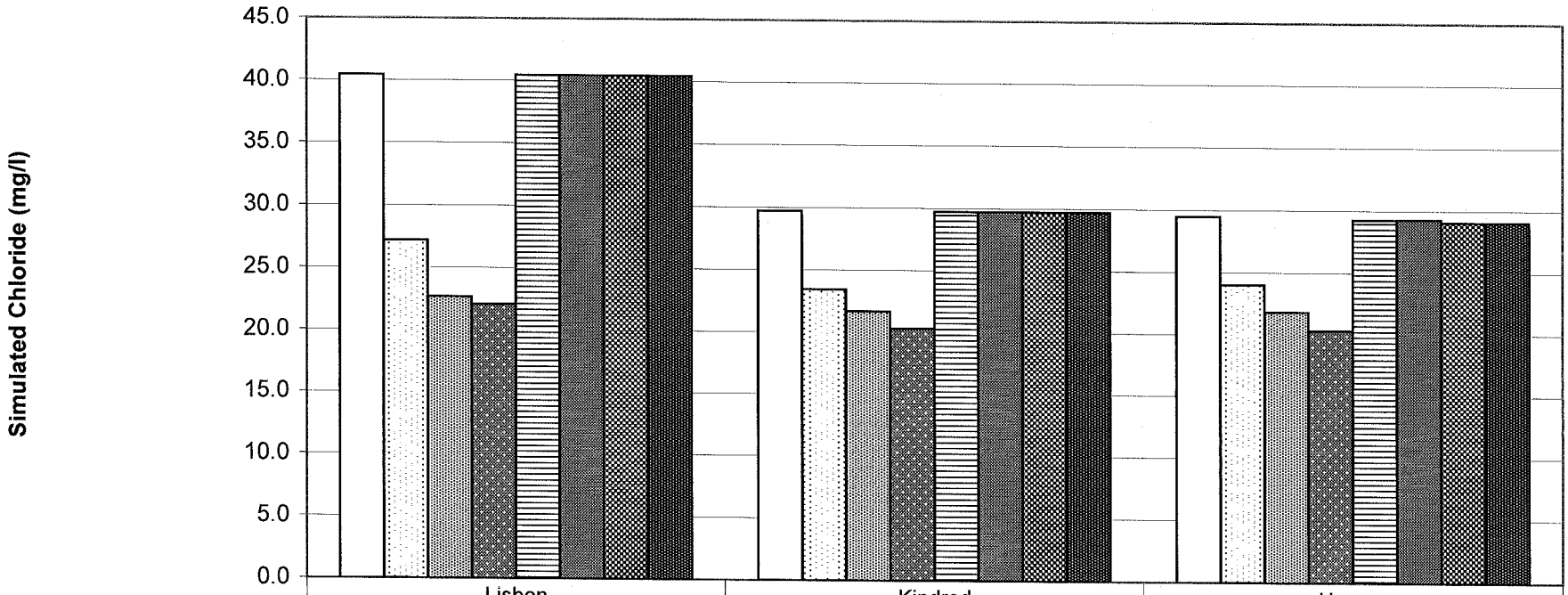
lower Sheyenne River compared to the No Action Alternative (Figure 5-20). The GDU Import to Sheyenne River Alternatives elevates

Figure 5-18
August - October 2003 Hydrologic Conditions
HEC-5Q Simulated Total Dissolved Solids on the Sheyenne River



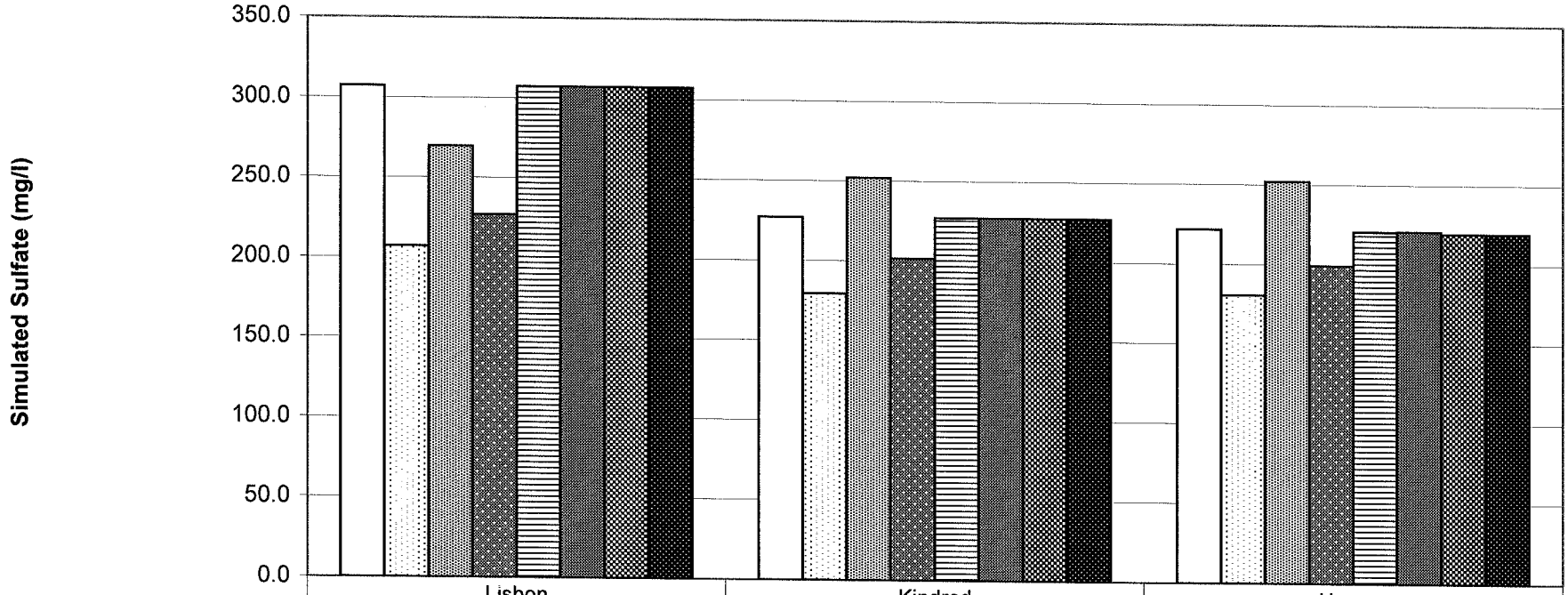
	Lisbon	Kindred	Horace
No Action	794.4	658.3	652.4
ND In-Basin	602.1	561.6	574.0
GDU Import to Sh. River	669.4	646.2	648.7
Mo. River Import to RRV	581.6	555.0	554.1
RRV Alternative	794.4	658.3	647.9
Lake of the Woods	794.4	658.3	648.6
GDU Import	794.4	658.3	643.7
GDU Replacement	794.4	658.3	643.7

Figure 5-19
August - October 2003 Hydrologic Conditions
HEC-5Q Simulated Chloride on the Sheyenne River



	Lisbon	Kindred	Horace
No Action	40.4	29.7	29.5
ND In-Basin	27.2	23.4	24.0
GDU Import to Sh. River	22.7	21.7	21.8
Mo. River Import to RRV	22.1	20.3	20.3
RRV Alternative	40.4	29.7	29.3
Lake of the Woods	40.4	29.7	29.3
GDU Import	40.4	29.7	29.1
GDU Replacement	40.4	29.7	29.1

Figure 5-20
August - October 2003 Hydrologic Conditions
HEC-5Q Simulated Sulfate on the Sheyenne River



	Lisbon	Kindred	Horace
No Action	307.2	227.0	221.7
ND In-Basin	207.0	179.5	180.7
GDU Import to Sh. River	269.7	252.0	251.9
Mo River Import to RRV	226.9	201.5	199.3
RRV Alternative	307.2	227.0	220.6
Lake of the Woods	307.2	227.0	220.8
GDU Import	307.2	227.0	219.6
GDU Replacement	307.2	227.0	219.6

sulfate concentrations (by roughly 18% or less at Horace) compared to the No Action Alternative. The ND In-Basin Missouri River Import to Red River Valley Alternative decreases sulfate concentration slightly Horace, compared to the No Action Alternative. No measurable change in water quality is anticipated.

5.2.2.3 Non-conservative Substances

Non-conservative substances include dissolved oxygen (DO) and fecal coliform bacteria. Water treatment will occur prior to the delivery of water to the point of use. The treatment will include oxidizing organic carbon and other oxygen demanding materials as well as disinfection and biota treatment. Because of treatment, none of the alternatives is expected to increase dissolved oxygen or bacterial levels compared to the No Action Alternative within the lower portion of the Sheyenne River. Some benefit may in fact be realized by the delivery of high DO, low oxygen-demanding water to the Sheyenne River, for the GDU to Sheyenne River Import Alternative.

5.2.2.4 Numeric Standards and Beneficial Uses

Modeled conservative concentrations for September 2003 on the lower Sheyenne River suggest little relative change[17] (< ± 15%) compared to the No Action Alternative. Considering modeling uncertainty, the normal variation in water quality and discharge, and the anticipated frequency of operation for the build alternatives, the percentage change is not considered as being measurable. Therefore, no additional exceedances of numeric standards are anticipated for the conservative substances modeled and beneficial uses are expected to remain unchanged.

As flows decrease during drought conditions, the water quality of the lower Sheyenne River and the Red River will become return flow dominated, taking on the quality characteristics of return flow for the build alternatives. By contrast, the Red River will essentially become dry for the No Action Alternative. Water with return flow quality for the build alternatives is considered better than no water for the No Action Alternative.

[17] The modeling is based on several assumptions with probable cumulative errors exceeding 15%.

5.2.2.5 Cumulative Impacts

No cumulative impacts are anticipated (*see Section 5.2.1.4*).

5.3 Red River

5.3.1 Nutrient Loads

The annual TN and TP loads for the alternatives were compared to the annual loads at Fargo, ND and Grand Forks, ND, to gain some sense[18] for potential eutrophication. The additional nutrient loads from the Missouri River system entering the Red River system are generally less than 0.1% at both Fargo, ND and Grand Forks, ND (Table 5-1). The estimated increase in nutrient load is considerably less than the variation in annual loads, assuming a coefficient of variation (CV - defined as the standard deviation divided by the mean concentration times 100) similar to that for daily discharge (see *5.1.3 Numeric Standards and Beneficial Uses*).

5.3.2 Modeled Concentrations – Conservative Substances

The modeled change in TDS at the U.S. – Canadian Border for the September 2003 period is an estimated 11% increase for the ND In-Basin Alternative and 5% for the GDU Import to Sheyenne Alternative (Figure 5-21). The remaining alternatives show little to no change compared to the No Action Alternative.

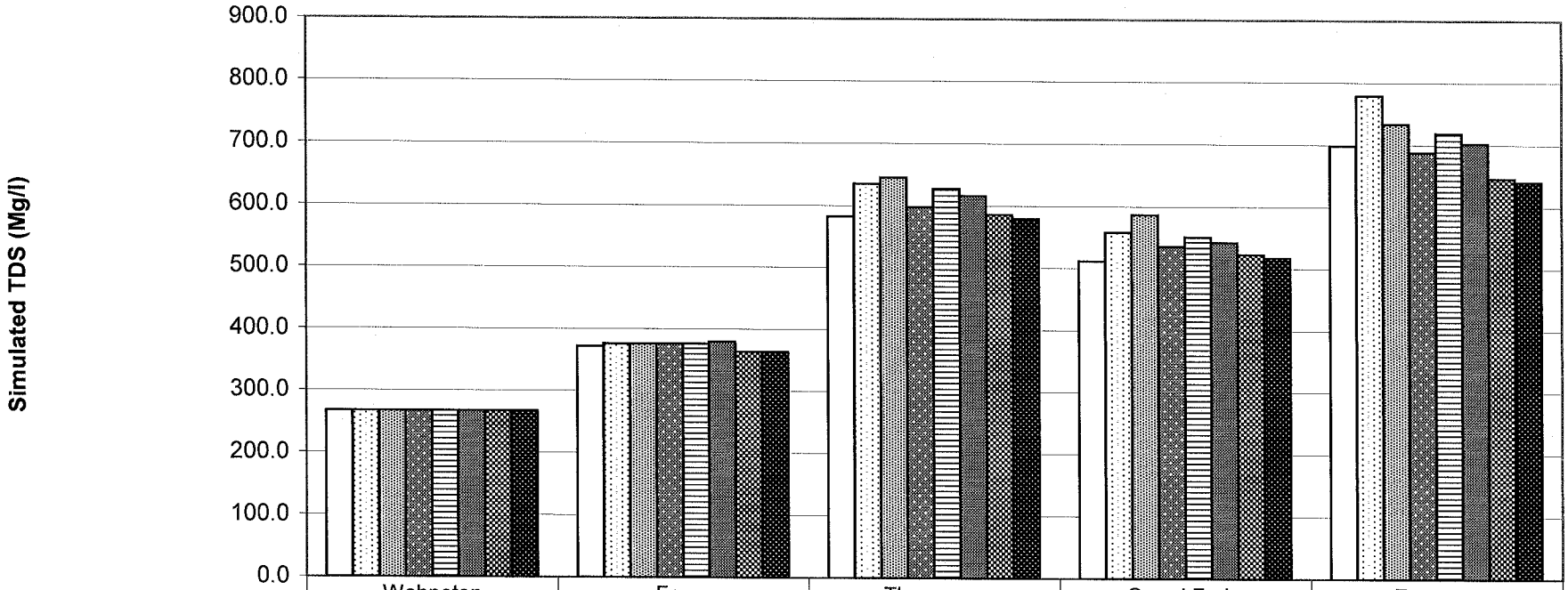
Chloride concentrations show a trend similar to TDS within the lower portion of the Red River (Figure 5-22). The ND In-Basin Alternative shows an increase in chloride concentration by up to 9% at Emerson, Manitoba. The GDU Import to Sheyenne River, GDU Import and GDU Replacement Alternatives show an up to 18% decline in concentrations.

The modeling analysis shows that the GDU Import to Sheyenne River Alternative increases sulfate concentrations within the lower Red River compared to the No Action Alternative (Figure 5-23). The GDU Import to Sheyenne River Import Alternative shows a potential increase of up to 18% in sulfate

Figure 5-21

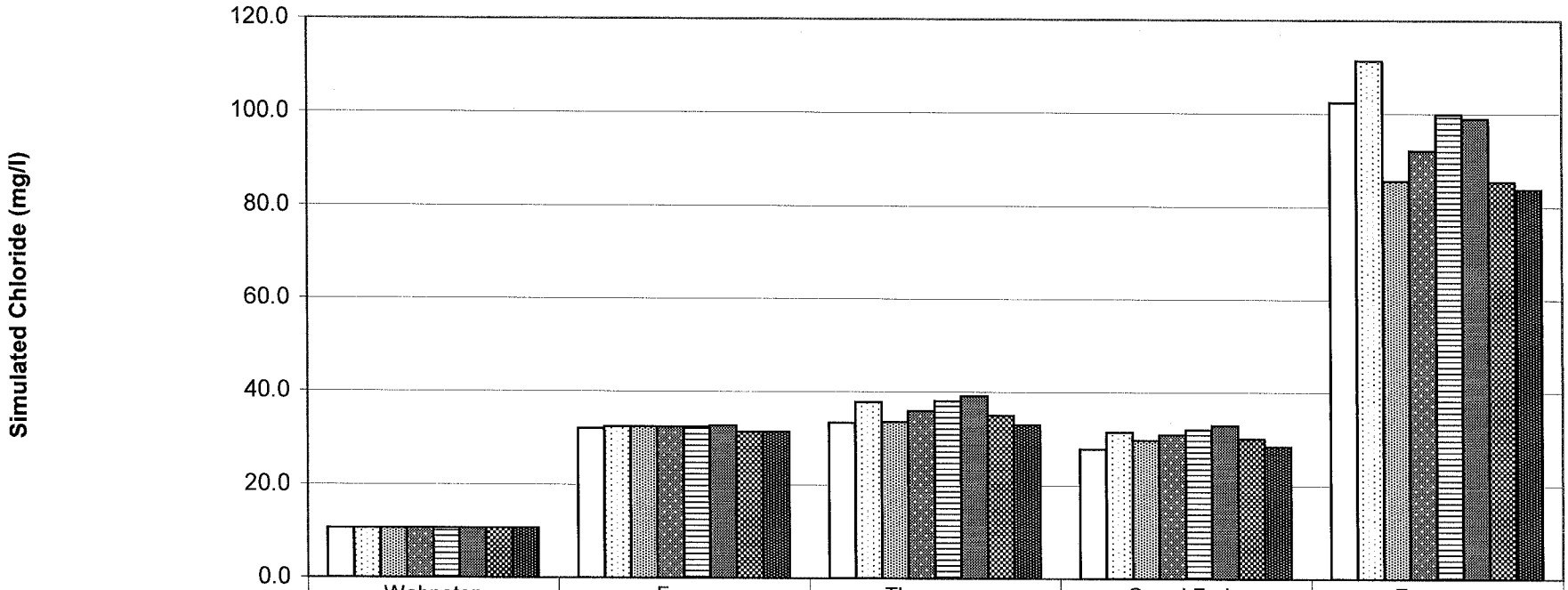
[18] The analysis assumes that these nutrients are not altered by biological processes like uptake by aquatic plans and algae.

Figure 5-21
August - October 2003 Hydrologic Conditions
HEC-5Q Simulated Total Dissolved Solids on the Red River



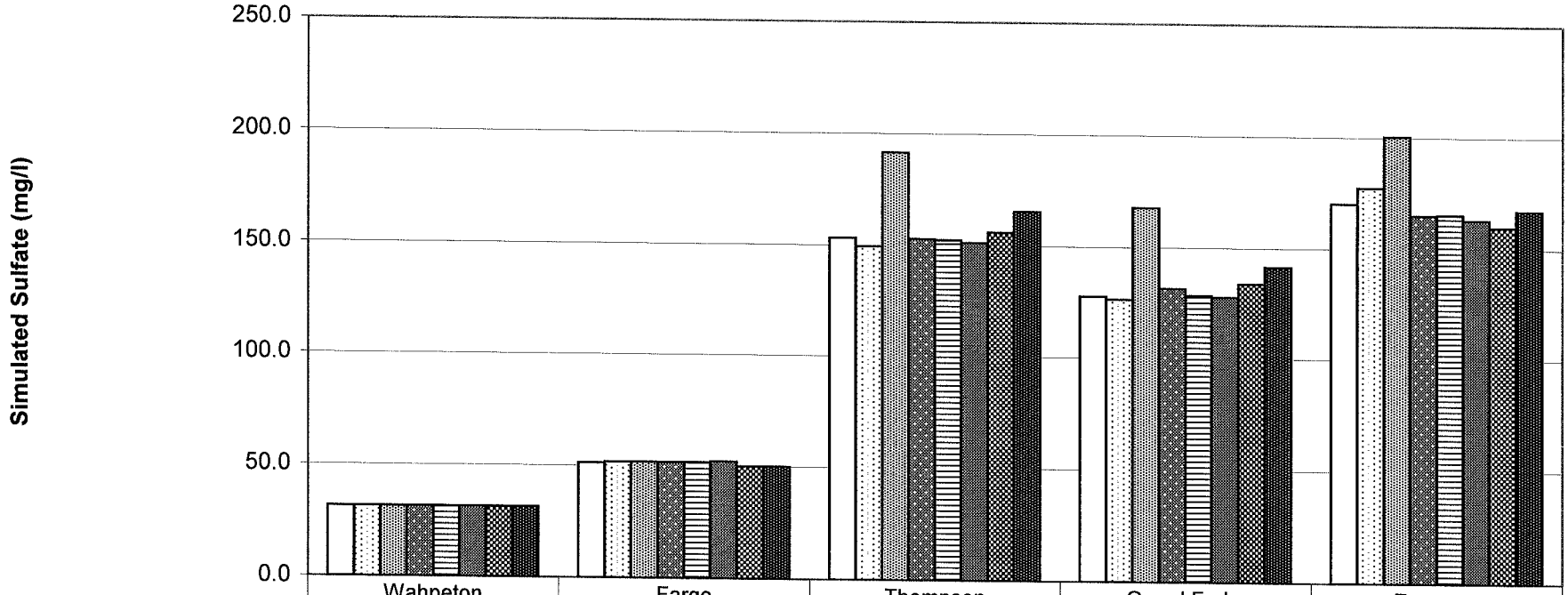
	Wahpeton	Fargo	Thompson	Grand Forks	Emerson
No Action	267.1	371.5	582.6	511.3	698.9
ND In-Basin	267.1	375.6	635.0	558.3	778.8
GDU Import to Sh. River	267.1	375.6	645.3	586.5	733.5
Mo. River Import to RRV	267.1	375.6	598.1	535.7	688.1
RRV Alternative	267.1	375.6	627.2	550.9	718.9
Lake of the Woods	267.1	378.8	615.8	542.0	702.6
GDU Import	267.1	363.4	586.1	522.9	645.9
GDU Replacement	267.1	363.4	579.3	517.4	640.5

Figure 5-22
August - October 2003 Hydrologic Conditions
HEC-5Q Simulated Chloride on the Red River



	Wahpeton	Fargo	Thompson	Grand Forks	Emerson
No Action	10.6	32.0	33.3	27.8	102.4
ND In-Basin	10.6	32.4	37.7	31.4	111.3
GDU Import to Sh. River	10.6	32.4	33.5	29.6	85.5
Mo. River Import to RRV	10.6	32.4	35.9	30.9	92.1
RRV Alternative	10.6	32.4	38.0	32.0	99.9
Lake of the Woods	10.6	32.6	39.1	32.9	98.9
GDU Import	10.6	31.3	34.9	30.0	85.4
GDU Replacement	10.6	31.3	32.9	28.4	83.8

Figure 5-23
August - October 2003 Hydrologic Conditions
HEC-5Q Simulated Sulfate on the Red River



	Wahpeton	Fargo	Thompson	Grand Forks	Emerson
No Action	31.4	51.2	153.2	127.8	170.3
ND In-Basin	31.4	51.8	149.5	126.5	177.4
GDU Import to Sh. River	31.4	51.8	191.5	167.8	200.5
Mo. River Import to RRV	31.4	51.8	152.8	131.7	165.3
RRV Alternative	31.4	51.8	152.5	128.5	165.5
Lake of the Woods	31.4	52.3	151.3	127.8	163.0
GDU Import	31.4	50.1	156.1	133.9	159.8
GDU Replacement	31.4	50.1	165.4	141.6	167.3

concentration at Emerson, Manitoba, compared to the No Action Alternative. The remaining alternatives show little change in concentration compared to the No Action Alternative.

The modeling results must be placed in proper context. Based upon the discussion presented in Section *5.2.2.2 Modeled Concentrations – Conservative Substances,* the change in concentrations are not expected to be measurable. The potential affects of each alternative is modified by the contributing drainage areas of both the Park and Forest Rivers. These drainage areas within North Dakota are known to be substantive sources of sulfate, chloride and TDS within the lower portion of the Red River. The affects of the various alternatives become reduced by this influence.

5.3.3 Non-conservative Substances

Non-conservative substances include dissolved oxygen and fecal coliform bacteria. Water treatment will occur prior to the delivery of water to the point of use. The treatment will include oxidizing organic carbon and other oxygen demanding materials as well as disinfection and biota treatment. Because of treatment, none of the alternatives is expected to increase or decrease dissolved oxygen or bacterial levels compared to the No Action Alternative within the Red River.

5.3.4 Numeric Standards and Beneficial Uses

Modeled conservative concentrations for September 2003 on the lower Red River suggest little relative change[19] ($< \pm$ 15%) compared to the No Action Alternative based on the USGS model. Giving the uncertainty associated with the model compared to the actual conditions for the operation of the alternatives, no additional exceedances of numeric standards are anticipated for the conservative substances modeled and beneficial uses are expected to remain unchanged.

5.3.5 IJC Objectives

Based upon the most recent monitoring information available from the IJC, exceedances of the water quality objectives occur infrequently at the Emerson, Manitoba

[19] The modeling is based on several assumptions with probable cumulative errors exceeding 10%.

monitoring location. The chloride and sulfate objectives were not exceeded from 1999 through 2002. An exceedance of the dissolved oxygen objective occurred once, during July of 2000. The TDS objective has been exceeded each year, generally once or twice during the winter months. The bacteriological objective has been exceeded once annually, generally during the summer months.

Although the changes in long-term concentrations are expected to be less than 10% for multiple locations and parameters for the action alternatives, the water quality of the Red River will become return flow dominated during conditions similar to the 1930's type drought (i.e., hydrologic baseline conditions). The water quality is expected to reflect the quality of the source water as modified by water and wastewater treatment (see Tables 3-6 and 3-7) and may fail to meet the numeric standard for ammonia near select cities since no to little dilution will be present within the river. The discharge from the City of Fargo may in fact achieve the standards because of the advanced treatment technology.

This contrasts to the No Action Alternative, where during hydrologic baseline conditions the discharge at Fargo is expected to be at or near zero and downstream water quality will reflect the influence of the Minnesota tributaries moving north toward the U.S. - Canadian border.

Whether water with the quality of effluent is more desirable than a lack of water quality because of little to no flow is a policy decision. The State of North Dakota may have to consider special NPDES permit conditions for the action alternatives.

5.4 Lake of the Woods

The Lake of the Woods alternative removes water from the lake for municipal, rural and industrial use. Because water is removed from the lake and the volume removed is small compared to the volume of the lake, no adverse impacts are expected.

6.0 CONCLUSIONS

6.1 Existing Conditions

In general, the waters of the Sheyenne River, the Red River of the North, and the Missouri River are suitable for most designated uses. At most locations exceedences of water quality standards are fairly rare, and when they occur, are often naturally caused.

The water quality within lakes, reservoirs, streams and rivers is determined largely by interaction of water with the landscape, as modified by human activities. Water moving across the landscape is exposed to different minerals comprising soils and rocks within different geomorphic regions as well as different living and dead plant and animal material within different ecoregions. Human activities that alter the land surface (e.g., conversion to agriculture) or that consume and use water (e.g., for the assimilation of waste from a town) further modify water quality. Therefore, it is typical to find inherent variability in surface water quality across a large region like the Red River Basin.

Several local, state, provincial, and federal agencies are responsible for evaluating, describing, and ensuring that the quality of surface waters is sufficient to meet the beneficial uses of society. The North Dakota Department of Health, the Minnesota Pollution Control Agency, and the Province of Manitoba monitor and assess the condition of surface waters within their borders.

Surface waters within North Dakota and Minnesota are categorized according to their anticipated and desired beneficial uses. Beneficial use designations consider the use and value of water for public water supplies, protection and propagation of aquatic life, recreation, agriculture, industry and other purposes. There may be more than one use designation assigned to a water body.

Not all surface waters can be used for their intended purposes, usually because of poorer than expected water quality, some physical modification of the habitat, or a biological problem. The stressors within the Red River Basin which cause use impairment are most often associated with the following: ammonia concentrations,

materials that consume oxygen (e.g., biochemical oxygen demand), dissolved solids, bacteria from mammals, and trace metals like mercury.

Within the Red River Basin in North Dakota and Minnesota, the percentage of samples collected that have exceeded the numeric water quality standard for some of the more common parameters is less than:

- 3% of the sulfate samples (general indicator of drinking water quality);
- 12% of the fecal coliform bacteria samples collected during the recreation season (indicator of contamination by warm blooded animals);
- 15% of the TDS (total dissolved solids) samples, which is a general indicator of quality for Minnesota only; and
- 4% of the dissolved oxygen samples (indicator of aquatic biology health).

Based upon the most recent monitoring information available from the IJC, exceedances of the water quality objectives occur infrequently at the Emerson, Manitoba monitoring location. The chloride and sulfate objectives were not exceeded from 1999 through 2002. An exceedance of the dissolved oxygen objective occurred once, during July of 2000. The TDS objective has been exceeded each year, generally once or twice during the winter months. The bacteriological objective has been exceeded annually, generally during the summer months.

6.2 Environmental Consequences of the Alternatives

6.2.1 Missouri River

Four alternatives remove water from the Missouri River system, thereby changing current loads. These alternatives are the:

- GDU Import Pipeline Alternative;
- GDU Water Supply Replacement Alternative;
- GDU Import to Sheyenne River Alternative; and
- Missouri River Import to Red River Valley Alternative.

Based upon the amount of nutrient load removed from the Missouri River, the probable change in water quality is expected to be small and immeasurable. The reduction in annual nutrient load leaving the Missouri River system is less than 0.5%. No changes in beneficial uses within the Missouri River are expected.

6.2.2 Audubon Lake and Principal Supply Works

Three alternatives use portions of the existing Garrison Diversion Unit (GDU) infrastructure to deliver water to either the Sheyenne River system (i.e., Lake Ashtabula) or directly to a pipeline for distribution to users within the Red River Valley. These alternatives are the:

- GDU Import Pipeline Alternative (return flow is to the Red River);
- GDU Water Supply Replacement Alternative (return flow is to the Red River); and
- GDU Import to Sheyenne River Alternative (water is delivered to Lake Ashtabula prior to use).

Discharges at the headworks of the McClusky Canal are expected to range from 7 to 190 cfs for the various alternatives and differing hydrologic and climatic conditions. An improvement in water quality (i.e., lower concentrations) is expected within the principal supply works for the GDU Import to Sheyenne River Alternative, for each hydrologic condition. Concentrations decrease for each alternative compared to the No Action Alternative through the supply works (including New John's Lake) although concentrations are generally similar within Audubon Lake. The reason for similar concentrations within Audubon Lake is that this lake is more affected by runoff from land adjacent to the lake than the operation of an alternative.

The concentrations within the canal approach those within Audubon Lake as the duration of operation increases. Water quality concentrations within the principal supply works are expected to be lower than currently occur (i.e., the No Action Alternative). Lower concentrations are generally considered favorable. No changes in beneficial uses within Lake Audubon or New John's Lake are expected. The McClusky Canal is not regulated as Waters of the State by North Dakota.

6.2.3 Sheyenne River

6.2.3.1 Lake Ashtabula

The GDU Import to Sheyenne River Alternative directly delivers water directly to Lake Ashtabula, while two other alternatives use Lake Ashtabula for the re-regulation of water; i.e., the Missouri River Import to Red River Valley Alternative and the North Dakota In-Basin Alternative. Re-regulation means water is temporarily stored in the lake for later use. Because the demand for water is satisfied from other locations, typically more water remains within the reservoir.

The BATHTUB modeling results suggest that some increase in total nitrogen (TN) concentration may occur during a dry year for the North Dakota In-Basin Alternative, presumably because of the return of water from Grand Forks to Lake Ashtabula. However, the total phosphorus concentration declines or remains unchanged for each alternative either directly delivering water to Lake Ashtabula or using the lake for re-regulation compared to the No Action Alternative. Both the Missouri River Import to Red River Valley Alternative and the GDU Import to Sheyenne River decrease total phosphorus (TP) concentrations within Lake Ashtabula slightly. The model estimates essentially no change in the chlorophyll-a concentrations or secchi disk visibility because of the small changes in nutrient concentrations. The remaining alternatives cause no limnological change in Lake Ashtabula compared to the No Action Alternative. Because nutrient concentrations within Lake Ashtabula show little change, no change in the number of numeric standard exceedances or the beneficial uses of the lake is expected.

6.2.3.2 Sheyenne River below Lake Ashtabula to the Confluence with the Red River

The annual TP and TN nutrient loads compared to the mouth of the Sheyenne River for the ND In-Basin Alternative are < 5%, which is substantially less than the variability in daily discharge. No measurable change in beneficial uses within the River is anticipated as a result of the change in nutrient load.

Modeled conservative concentrations of chloride, sulfate and TDS (for September 2003 hydrologic conditions) on the lower Sheyenne River suggest a relative change of < ± 15% compared to the No Action Alternative. Considering modeling uncertainty, the

normal variation in water quality and discharge, and the anticipated frequency of operation for the action alternatives, the percentage change is not considered as being measurable. Therefore, no changes in long-term concentration is anticipated for the conservative substances modeled and beneficial uses are expected to remain unchanged.

6.2.4 Red River

The annual TN and TP loads for the alternatives were compared to the annual loads at Fargo, ND and Grand Forks, ND, to gain some sense for potential eutrophication. The additional estimated nutrient loads from the Missouri River system entering the Red River system are generally less than 0.1% above existing loads at both Fargo, ND and Grand Forks, ND. In general, the estimated change in load for the alternatives is a small fraction of the variation in annual loads.

Modeled conservative concentrations for September 2003 hydrologic conditions on the lower Red River suggest a relative change in long-term concentrations $< \pm 15\%$ compared to the No Action Alternative based on the USGS model. Given the uncertainty associated with the model compared to the actual conditions for the operation of the alternatives, no additional exceedances of numeric standards is anticipated for the conservative substances modeled and beneficial uses are expected to remain unchanged.

Although the changes in long-term concentrations are expected to be less than 10% for multiple locations and parameters for the action alternatives, the water quality of the Red River will become return flow dominated during conditions similar to the 1930's type drought (i.e., hydrologic baseline conditions). The water quality is expected to reflect the quality of the source water as modified by water and wastewater treatment (see Tables 3-6 and 3-7) and may fail to meet the numeric standard for ammonia near select cities since no to little dilution will be present within the river. The discharge from the City of Fargo may in fact achieve the standards because of the advanced treatment technology.

This contrasts to the No Action Alternative, where during hydrologic baseline conditions the discharge at Fargo is expected to be at or near zero and downstream water

quality will reflect the influence of the Minnesota tributaries moving north toward the U.S. - Canadian border.

Whether water with the quality of effluent is more desirable than a lack of water quality because of little to no flow is a policy decision. The State of North Dakota may have to consider special NPDES permit conditions for the action alternatives.

As flows decrease during drought conditions, the water quality of the Red River will become return flow dominated, taking on the quality characteristics of return flow for the build Alternatives. By contrast, the Red River will essentially become dry or have very low flow for the No Action Alternative. Water with return flow quality for the action alternatives is considered better than no water for the No Action Alternative.

Based upon the most recent monitoring information available from the IJC, exceedances of the water quality objectives occur infrequently at the Emerson, Manitoba monitoring location. Modeled concentrations differing from existing concentrations by more than ± 15% were considered to have the potential to cause additional or reduce the number of exceedances of the IJC objectives. With probable project operation occurring one-half the time at most, the actual change in the long term average concentration is expected to be less than 10%.

6.2.5 Lake of the Woods

The Lake of the Woods alternative removes water from the lake for municipal, rural and industrial use. Because water is removed from the lake and the volume removed is small compared to the volume of the lake, no adverse impacts are expected.

6.2.6 Cumulative Impacts

No cumulative water quality impacts are anticipated. Operation of the Devils Lake outlet is the most likely reasonably foreseeable activity, which could lead to potential cumulative impacts. Operation of the project is restricted by the National Pollutant Discharge Elimination System (NPDES) permit. Operation of the Devils Lake outlet is restricted to: 1) May through November; 2) periods of time when the discharge within the Sheyenne River is less than 600 cfs; and 3) periods of time when the sulfate concentration is less than 300 mg/L. The analysis presented shows that the likelihood of

concurrent operation is low. Should concurrent operation occur, water released from Devils Lake could be used to satisfy water supply demand. This further reduces the need for operation of a RRVWS alternative.

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APPENDIX A

McCLUSKY CANAL
UNSTEADY WATER QUALITY

GDU IMPORT TO SHEYENNE - SCENARIO 2

			Monthly Evap. Rate			Precipitation	
		Month	(% of mean annual)	(in.)		Month	Bismarck Normals
		January	0.75	0.26		January	0.45
Mean Annual Evap =		February	0.95	0.32		February	0.51
34	in.	March	2.30	0.78		March	0.85
		April	5.85	1.99		April	1.46
		May	10.33	3.51		May	2.22
		June	13.57	4.61		June	2.59
		July	18.59	6.32		July	2.58
		August	20.16	6.85		August	2.15
		September	14.95	5.08		r	1.61
		October	8.53	2.90		October	1.28
		November	3.00	1.02		November	0.7
		December	1.02	0.35		December	0.44
		Sum	100.0	34.0		Total	16.84
Canal S.A. =	282.5	acres	Lakes S.A. =	671.0	acres	Bismarck Normals (1971-2000)	
Canal S.A. =	0.4	sq. mi.	Lakes S.A. =	1.0	sq. mi.		

GDU IMPORT TO SHEYENNE - SCENARIO 2

McClusky Canal and Lakes Volumes							Lake Audubon Area/Storage			
S:\3750-059WQEIS\Engineering\Canal & Lake volumes.xls							*Source: Engineering/Audubon Storage.xls,Storage Calc*			
Station	**Canal volume (a.f.)**			**Lake volume (a.f.)**			Elevation	Storage	Increment	Elevation
82 - 780		1,660					Elevation	Audubon Storage (ac-ft?)		Elevation
780 - 794				153	Lightning Lake		1844	283412		1844
794 - 1107		747					1845	300587	17175	1845
1107 - 1544		1,014					1846	318408	17821	1846
1544 - 1654				3,820	West Park Lake		1847	336871	18463	1847
1654 - 1680		61					1848	355967	19096	1848
1680 - 1739				1,820	East Park Lake		1849	375683	19716	1849
1739 - 1747		19								
1747 - 1786				380	East Park Lake		Ave area =	18454	acres	
1786 - 1802		38					Rounded	18500	acres	
1802 - 1885				2,820	Hecker's Lake		=	*28.9*	*sq. mi.*	
1885 - 1906		50					Average Volume =		327639.5	ac-ft
1906 - 2066									330000	ac-ft
Sum		3,589	ac-ft	8993	ac-ft					

GDU IMPORT TO SHEYENNE - SCENARIO 2

	Time Increment			Inflow									Outflow					Volume			
				Upstream Inflow		Local Drainage Inflow						Precipitation	Downstream Outflow		Local Outflow		Evaporation	Time 1	Time 2		
Year	T_1	T_2	dt	$Q_{in\ u/s}$	$V_{in\ u/s}$					$Q_{in\ local}$	$V_{in\ local}$	P_{in}	$Q_{out\ ds}$	$V_{out\ ds}$	Q_{local}	$V_{out\ local}$	$V_{out\ evap}$	V1	V2	dE	T_R
	Time 1	Time 2	dt (days)	Inflow from upstream (HW releases) (cfs)	Volume of upstream inflow (ac-ft)	Average local inflow over time period (NWIS-Harvey) (cfs)	Local Drainage Area to Harvey Station (sq.mi.)	Average local inflow over time period (NWIS-Harvey) (cfs/sq.mi.)	Local Contributing Drainage Area (sq. mi.)	Average inflow from local drainage area (cfs)	Volume of Local Inflow (ac-ft)	Volume of Precipitation (ac-ft.)	Average (T1&T2) outstream (HW releases) (cfs)	Volume of d/s ouflow (ac-ft)	Average local outflow (operations) (cfs)	Volume of Local Outflow (ac-ft)	Volume of Evaporation (ac-ft)	V1 (ac-ft)	**V2 (ac-ft)**	Elev. Change in Water Body (in.)	Residence Time (days)
															Ave. from Calibration						Ave. V1&V2
																					$Q_{in\ u/s}$ +$Q_{in\ local}$ (no precip)
									(Brent's estimate)				= inflow								
Lake Audubon																					
Dry - 1963	1/1/1963	12/31/1963	365	18.2	13141	1.9	154.0	0.012	246	3	2197.3	25962	18.2	13141.0	0.0	0.0	52416.7	330000	**305742**	-15.7	7564
Normal - 1941	1/1/1941	12/31/1941	365	38.2	27648	4.2	154.0	0.027	246	7	4868.7	25962	38.2	27648.0	0.0	0.0	52416.7	330000	**308414**	-14.0	3583
Wet - 1994	1/1/1994	12/31/1994	365	6.947	5030	17.8	154.0	0.116	246	28	20585.1	25962	6.9	5029.7	0.0	0.0	52416.7	330000	**324130**	-3.8	4661
Average	1/1/0000	12/31/0000	365	17.1	15169	11.9	154.0	0.077	246	19	13766.0	25962	17.1	12379.8	0.0	0.0	52416.7	330000	**320100**	-6.4	4538
																		s			
McClusky Canal																					
Dry - 1963	1/1/1963	12/31/1963	365	18.2	13141	1.9	154.0	0.0	14.7	0.2	131.0	0	18.2	13141.0	11.7	8434.2	2701.5	12582	**1577**	- -	195
Normal - 1941	1/1/1941	12/31/1941	365	38.2	27648	4.2	154.0	0.0	14.7	0.4	290.3	0	38.2	27648.0	11.7	8434.2	2701.5	12582	**1737**	- -	94
Wet - 1994	1/1/1994	12/31/1994	365	6.947	5030	17.8	154.0	0.1	14.7	1.7	1227.2	0	6.9	5029.7	11.7	8434.2	2701.5	12582	**2673**	- -	445
Average	1/1/0000	12/31/0000	365	17.1	15169	11.9	154.0	0.1	14.7	1.1	820.7	0	17.1	12379.8	11.7	8434.2	2701.5	12582	**5056**	- -	244
New John's Lake																					
Dry - 1963	1/1/1963	12/31/1963	365	18.2	13141	1.9	154.0	0.0	4.7	0.1	42.1	496	18.2	13141.0	9.4	6787.2	1866.6	9,740	**1624**	-5.3	157
Normal - 1941	1/1/1941	12/31/1941	365	38.2	27648	4.2	154.0	0.0	4.7	0.1	93.4	655	38.2	27648.0	9.4	6787.2	1866.6	9,740	**1834**	-5.1	76
Wet - 1994	1/1/1994	12/31/1994	365	6.947	5030	17.8	154.0	0.1	4.7	0.5	394.8	556	6.9	5029.7	9.4	6787.2	1866.6	9,740	**2037**	-5.0	396
Average	1/1/0000	12/31/0000	365	17.1	15169	11.9	154.0	0.1	4.7	0.4	264.0	544	17.1	12379.8	9.4	6787.2	1866.6	9,740	**4684**	-3.3	208
McClusky Canal																					
New John's Lake to Diversion																					
Dry - 1963	1/1/1963	12/31/1963	365	18.2	13141	1.9	154.0	0.0	30.5	0.4	272.4	0	18.2	13141.0	0	0.0	586.0	2401	**2087**	- -	61
Normal - 1941	1/1/1941	12/31/1941	365	38.2	27648	4.2	154.0	0.0	30.5	0.8	603.6	0	38.2	27648.0	0	0.0	586.0	2401	**2419**	- -	31
Wet - 1994	1/1/1994	12/31/1994	365	6.947	5030	17.8	154.0	0.1	30.5	3.5	2552.2	0	6.9	5029.7	0	0.0	586.0	2401	**4367**	- -	163
Average	1/1/0000	12/31/0000	365	17.1	15169	11.9	154.0	0.1	30.5	2.4	1706.8	0	17.1	12379.8	0	0.0	586.0	2401	**6311**	- -	113

GDU IMPORT TO SHEYENNE - SCENARIO 2

				TDS Loads												
Year	Time Increment			System at T1			Upstream Inflow			Local Drainage Inflow			Local Ouflow	Reaction	D/S Outflow	System T2
	T1	T2	dt	C1	V1	M1	$C_{in\ u/s}$	$V_{in\ u/s}$	$M_{in\ u/s}$	$C_{in\ local}$	$V_{in\ local}$	$M_{in\ local}$	$V_{out\ local}$	K	Vout ds	C2
	Time 1	Time 2	(days)	Concen-tration at Time 1 (mg/l)	Volume of System at Time 1 (ac-ft)	Mass of System at Time 1 (V1C1) (kg)	Average Conc. from upstream (mg/l)	Volume of upstream inflow (ac-ft)	Mass of upstream inflow (kg)	Median Conc. at Harvey (mg/l)	Volume of local inflow (ac-ft)	Mass in local inflow (kg)	Volume of local outflow (ac-ft)	Rate of Reaction (Day-1)	Volume of downstream ouflow (ac-ft)	Computed (mg/l)
				Average from						*Median at Harvey =*						
	Lake Audubon			*Calibration*			*Calibration*				*838.5*	*mg/l*				
				Years			*Average*									
Dry - 1963	1/1/1963	12/31/1963	365	542	330000	220664974	485	13141	**7857464**	838.5	2197	**2272594**	0	0	13141	**575**
Normal - 1941	1/1/1941	12/31/1941	365	542	330000	220664974	485	27648	**16531708**	838.5	4869	**5035590**	0	0	27648	**573**
Wet - 1994	1/1/1994	12/31/1994	365	542	330000	220664974	485	5030	**3007425**	838.5	20585	**21290616**	0	0	5030	**591**
Average	1/1/0000	12/31/0000	365	542	330000	220664974	485	15169	**9070196**	838.5	13766	**14237851**	0	0	12380	**583**
	McClusky Canal						*Average of*									
							C1 and C2									
							from upstream									
Dry - 1963	1/1/1963	12/31/1963	365	779	12582	12092068	558	13141	**9050079**	838.5	131	**135482**	8434	0	13141	**698**
Normal - 1941	1/1/1941	12/31/1941	365	779	12582	12092068	558	27648	**19021739**	838.5	290	**300200**	8434	0	27648	**566**
Wet - 1994	1/1/1994	12/31/1994	365	779	12582	12092068	567	5030	**3515654**	838.5	1227	**1269256**	8434	0	5030	**874**
Average	1/1/0000	12/31/0000	365	779	12582	12092068	563	15169	**10528856**	838.5	821	**848800**	8434	0	12380	**692**
	New John's Lake															
Dry - 1963	1/1/1963	12/31/1963	365	1200	9740	14414879	738	13141	**11970031**	838.5	42	**43583**	6787	0	13141	**795**
Normal - 1941	1/1/1941	12/31/1941	365	1200	9740	14414879	673	27648	**22937140**	838.5	93	**96570**	6787	0	27648	**496**
Wet - 1994	1/1/1994	12/31/1994	365	1200	9740	14414879	827	5030	**5128125**	838.5	395	**408300**	6787	0	5030	**1111**
Average	1/1/0000	12/31/0000	365	1200	9740	14414879	736	15169	**13764009**	838.5	264	**273046**	6787	0	12380	**793**
	McClusky Canal															
	New John's Lake to Diversion															
Dry - 1963	1/1/1963	12/31/1963	365	1451	2401	4298289	997	13141	**16167395**	838.5	272	**281765**	0	0	13141	**832**
Normal - 1941	1/1/1941	12/31/1941	365	1451	2401	4298289	848	27648	**28911384**	838.5	604	**624331**	0	0	27648	**449**
Wet - 1994	1/1/1994	12/31/1994	365	1451	2401	4298289	1155	5030	**7168276**	838.5	2552	**2639690**	0	0	5030	**1120**
Average	1/1/0000	12/31/0000	365	1451	2401	4298289	996	15169	**18641038**	838.5	1707	**1765262**	0	0	12380	**877**

GDU IMPORT TO SHEYENNE - SCENARIO 2

	Time Increment			SO4 Loads												
Year				System at T1			Upstream Inflow			Local Drainage Inflow			Local Ouflow	Reaction	D/S Outflow	System T2
			dt	C1	V1	M1	$C_{in\ u/s}$	$V_{in\ u/s}$	$M_{in\ u/s}$	$C_{in\ local}$	$V_{in\ local}$	$M_{in\ local}$	$V_{out\ local}$	K	Vout ds	C2
	Time 1	Time 2	(days)	Concen-tration at Time 1 (mg/l)	Volume of System at Time 1 (ac-ft)	Mass of System at Time 1 (V1C1) (kg)	Volume of upstream inflow (ac-ft)	Mass of upstream inflow (kg)	Mass of upstream inflow (kg)	Median Conc. at Harvey (mg/l)	Volume of local inflow (ac-ft)	Mass in local inflow (kg)	Volume of local outflow (ac-ft)	Rate of Reaction (Day-1)	Volume of downstream ouflow (ac-ft)	Computed (mg/l)
				Average from						*Median at Harvey =*						
	Lake Audubon			*Calibration*			*Calibration*				*210*	*mg/l*				
				Years			*Average*									
Dry - 1963	1/1/1963	12/31/1963	365	240.6	330000	97946006	201.0	13141	**3258041**	210	2197	**569165**	0	0	13141	**253**
Normal - 1941	1/1/1941	12/31/1941	365	240.6	330000	97946006	201.0	27648	**6854753**	210	4869	**1261149**	0	0	27648	**251**
Wet - 1994	1/1/1994	12/31/1994	365	240.6	330000	97946006	201.0	5030	**1247007**	210	20585	**5332176**	0	0	5030	**252**
Average	1/1/0000	12/31/0000	365	240.6	330000	97946006	201.0	15169	**3760891**	210	13766	**3565830**	0	0	12380	**251**
							Average of									
	McClusky Canal						*C1 and C2*									
							from upstream									
Dry - 1963	1/1/1963	12/31/1963	365	404.6	12582	6278860	247	13141	**4002957**	210	131	**33931**	8434	0	13141	**314**
Normal - 1941	1/1/1941	12/31/1941	365	404.6	12582	6278860	246	27648	**8380621**	210	290	**75184**	8434	0	27648	**229**
Wet - 1994	1/1/1994	12/31/1994	365	404.6	12582	6278860	246	5030	**1528103**	210	1227	**317882**	8434	0	5030	**399**
Average	1/1/0000	12/31/0000	365	404.6	12582	6278860	246	15169	**4603241**	210	821	**212580**	8434	0	12380	**302**
	New John's Lake															
Dry - 1963	1/1/1963	12/31/1963	365	523.8	9740	6292682	359	13141	**5826117**	210	42	**10915**	6787	0	13141	**389**
Normal - 1941	1/1/1941	12/31/1941	365	523.8	9740	6292682	317	27648	**10807795**	210	93	**24186**	6787	0	27648	**249**
Wet - 1994	1/1/1994	12/31/1994	365	523.8	9740	6292682	402	5030	**2492051**	210	395	**102258**	6787	0	5030	**503**
Average	1/1/0000	12/31/0000	365	523.8	9740	6292682	353	15169	**6611370**	210	264	**68384**	6787	0	12380	**377**
	McClusky Canal															
	New John's Lake to Diversion															
Dry - 1963	1/1/1963	12/31/1963	365	843.6	2401	2498430	456	13141	**7393733**	210	272	**70567**	0	0	13141	**287**
Normal - 1941	1/1/1941	12/31/1941	365	843.6	2401	2498430	387	27648	**13184656**	210	604	**156362**	0	0	27648	**70**
Wet - 1994	1/1/1994	12/31/1994	365	843.6	2401	2498430	513	5030	**3185404**	210	2552	**661103**	0	0	5030	**432**
Average	1/1/0000	12/31/0000	365	843.6	2401	2498430	451	15169	**8431021**	210	1707	**442105**	0	0	12380	**316**

GDU IMPORT TO SHEYENNE - SCENARIO 2

	Time Increment			CL Loads												
Year				System at T1			Upstream Inflow			Local Drainage Inflow			Local Ouflow	Reaction	D/S Ouflow	System T2
			dt	C1	V1	M1	$C_{in\ u/s}$	$V_{in\ u/s}$	$M_{in\ u/s}$	$C_{in\ local}$	$V_{in\ local}$	$M_{in\ local}$	$V_{out\ local}$	K	Vout ds	C2
	Time 1	Time 2	(days)	Concen-tration at Time 1 (mg/l)	Volume of System at Time 1 (ac-ft)	Mass of System at Time 1 (V1C1) (kg)	Volume of upstream inflow (ac-ft)	Mass of upstream inflow (kg)	Mass of upstream inflow (kg)	Median Conc. at Harvey (mg/l)	Volume of local inflow (ac-ft)	Mass in local inflow (kg)	Volume of local outflow (ac-ft)	Rate of Reaction (Day-1)	Volume of downstream ouflow (ac-ft)	Computed (mg/l)
				Average from						*Median at Harvey =*						
	Lake Audubon			*Calibration*			*Calibration*				*17*	*mg/l*				
				Years			*Average*									
Dry - 1963	1/1/1963	12/31/1963	365	14.61	330000	5947994	11.2	13141	**181684**	17	2197	**46075**	0	0	13141	**15.4**
Normal - 1941	1/1/1941	12/31/1941	365	14.61	330000	5947994	11.2	27648	**382255**	17	4869	**102093**	0	0	27648	**15.2**
Wet - 1994	1/1/1994	12/31/1994	365	14.61	330000	5947994	11.2	5030	**69539**	17	20585	**431652**	0	0	5030	**15.6**
Average	1/1/0000	12/31/0000	365	14.61	330000	5947994	11.2	15169	**209726**	17	13766	**288662**	0	0	12380	**15.4**
							Average of									
	McClusky Canal						*C1 and C2*									
							from upstream									
Dry - 1963	1/1/1963	12/31/1963	365	16.69	12582	258945	15	13141	**242991**	17	131	**2747**	8434	0	13141	**18.2**
Normal - 1941	1/1/1941	12/31/1941	365	16.69	12582	258945	15	27648	**508567**	17	290	**6086**	8434	0	27648	**16.3**
Wet - 1994	1/1/1994	12/31/1994	365	16.69	12582	258945	15	5030	**93580**	17	1227	**25733**	8434	0	5030	**20.2**
Average	1/1/0000	12/31/0000	365	16.69	12582	258945	15	15169	**280785**	17	821	**17209**	8434	0	12380	**17.7**
	New John's Lake															
Dry - 1963	1/1/1963	12/31/1963	365	19.28	9740	231572	17	13141	**282388**	17	42	**884**	6787	0	13141	**19.1**
Normal - 1941	1/1/1941	12/31/1941	365	19.28	9740	231572	16	27648	**561702**	17	93	**1958**	6787	0	27648	**16.2**
Wet - 1994	1/1/1994	12/31/1994	365	19.28	9740	231572	18	5030	**114321**	17	395	**8278**	6787	0	5030	**21.3**
Average	1/1/0000	12/31/0000	365	19.28	9740	231572	17	15169	**321406**	17	264	**5536**	6787	0	12380	**18.5**
	McClusky Canal															
	New John's Lake to Diversion															
Dry - 1963	1/1/1963	12/31/1963	365	24.97	2401	73951	19	13141	**310912**	17	272	**5713**	0	0	13141	**17.5**
Normal - 1941	1/1/1941	12/31/1941	365	24.97	2401	73951	18	27648	**604950**	17	604	**12658**	0	0	27648	**13.2**
Wet - 1994	1/1/1994	12/31/1994	365	24.97	2401	73951	20	5030	**125810**	17	2552	**53518**	0	0	5030	**20.5**
Average	1/1/0000	12/31/0000	365	24.97	2401	73951	19	15169	**353389**	17	1707	**35789**	0	0	12380	**17.6**

GDU IMPORT TO SHEYENNE - SCENARIO 2

	Time Increment			NO3 as N (1/2 MDL) + NH3 as N (1/2 MDL) Loads												
Year				System at T1			Upstream Inflow			Local Drainage Inflow			Local Ouflow	Reaction	D/S Outflow	System T2
			dt	C1	V1	M1	$C_{in\ u/s}$	$V_{in\ u/s}$	$M_{in\ u/s}$	$C_{in\ local}$	$V_{in\ local}$	$M_{in\ local}$	$V_{out\ local}$	K	Vout ds	C2
	Time 1	Time 2	(days)	Concen-tration at Time 1 (mg/l)	Volume of System at Time 1 (ac-ft)	Mass of System at Time 1 (V1C1) (kg)	Volume of upstream inflow (ac-ft)	Mass of upstream inflow (kg)	Mass of upstream inflow (kg)	Median Conc. at Harvey (mg/l)	Volume of local inflow (ac-ft)	Mass in local inflow (kg)	Volume of local outflow (ac-ft)	Rate of Reaction (Day-1)	Volume of downstream ouflow (ac-ft)	Computed (mg/l)
										Median at Harvey =						
	Lake Audubon										*0.111176*	*mg/l*				
							Lk Sakakawea at Snake Cr Pumping plant									
Dry - 1963	1/1/1963	12/31/1963	365	0.118	330000	47828	0.21	13141	**3404**	0.111176	2197	**301**	0	0.0000	13141	**0.13**
Normal - 1941	1/1/1941	12/31/1941	365	0.118	330000	47828	0.21	27648	**7162**	0.111176	4869	**668**	0	0.0000	27648	**0.13**
Wet - 1994	1/1/1994	12/31/1994	365	0.118	330000	47828	0.21	5030	**1303**	0.111176	20585	**2823**	0	0.0000	5030	**0.13**
Average	1/1/0000	12/31/0000	365	0.118	330000	47828	0.21	15169	**3929**	0.111176	13766	**1888**	0	0.0000	12380	**0.13**
	McClusky Canal															
							McClusky Canal Headworks									
Dry - 1963	1/1/1963	12/31/1963	365	0.233	12582	3608	0.128	13141	**2082**	0.111176	131	**18**	8434	0.0000	13141	**0.17**
Normal - 1941	1/1/1941	12/31/1941	365	0.233	12582	3608	0.132	27648	**4509**	0.111176	290	**40**	8434	0.0000	27648	**0.12**
Wet - 1994	1/1/1994	12/31/1994	365	0.233	12582	3608	0.125	5030	**777**	0.111176	1227	**168**	8434	0.0000	5030	**0.22**
Average	1/1/0000	12/31/0000	365	0.233	12582	3608	0.128	15169	**2401**	0.111176	821	**113**	8434	0.0000	12380	**0.16**
	New John's Lake															
							Hecker's Lake Out From Canal									
Dry - 1963	1/1/1963	12/31/1963	365	0.135	9740	1622	0.166	13141	**2694**	0.111176	42	**6**	6787	0.0000	13141	**0.18**
Normal - 1941	1/1/1941	12/31/1941	365	0.135	9740	1622	0.119	27648	**4059**	0.111176	93	**13**	6787	0.0000	27648	**0.12**
Wet - 1994	1/1/1994	12/31/1994	365	0.135	9740	1622	0.219	5030	**1360**	0.111176	395	**54**	6787	0.0000	5030	**0.21**
Average	1/1/0000	12/31/0000	365	0.135	9740	1622	0.160	15169	**3000**	0.111176	264	**36**	6787	0.0000	12380	**0.17**
	McClusky Canal															
	New John's Lake to Diversion						*Painted Woods Cr Outlet Chan from NJ Lk (Lakeside)*									
Dry - 1963	1/1/1963	12/31/1963	365	0.194	2401	574	0.184	13141	**2979**	0.111176	272	**37**	0	0.0000	13141	**0.19**
Normal - 1941	1/1/1941	12/31/1941	365	0.194	2401	574	0.119	27648	**4050**	0.111176	604	**83**	0	0.0000	27648	**0.07**
Wet - 1994	1/1/1994	12/31/1994	365	0.194	2401	574	0.206	5030	**1277**	0.111176	2552	**350**	0	0.0000	5030	**0.19**
Average	1/1/0000	12/31/0000	365	0.194	2401	574	0.172	15169	**3217**	0.111176	1707	**234**	0	0.0000	12380	**0.16**

GDU IMPORT TO SHEYENNE - SCENARIO 2

				PO4 as P (1/2 MDL) Loads												
Year	Time Increment			System at T1			Upstream Inflow			Local Drainage Inflow			Local Ouflow	Reaction	D/S Ouflow	System T2
	T1	T2	dt	C1	V1	M1	$C_{in\ u/s}$	$V_{in\ u/s}$	$M_{in\ u/s}$	$C_{in\ local}$	$V_{in\ local}$	$M_{in\ local}$	$V_{out\ local}$	K	Vout ds	C2
	Time 1	Time 2	(days)	Concen-tration at Time 1 (mg/l)	Volume of System at Time 1 (ac-ft)	Mass of System at Time 1 (V1C1) (kg)	Volume of upstream inflow (ac-ft)	Mass of upstream inflow (kg)	Mass of upstream inflow (kg)	Median Conc. at Harvey (mg/l)	Volume of local inflow (ac-ft)	Mass in local inflow (kg)	Volume of local outflow (ac-ft)	Rate of Reaction (Day-1)	Volume of downstream ouflow (ac-ft)	Computed (mg/l)
				Average from						*Median at Harvey =*						
	Lake Audubon			*Calibration*			*Calibration*				*0.201*	*mg/l*		*Calibration*		
				Years			*Average*							*Average*		
Dry - 1963	1/1/1963	12/31/1963	365	0.030	330000	12211	0.013	13141	**213**	0.234	2197	**634**	0	0.0000	13141	**0.033**
Normal - 1941	1/1/1941	12/31/1941	365	0.030	330000	12211	0.013	27648	**448**	0.234	4869	**1405**	0	0.0000	27648	**0.033**
Wet - 1994	1/1/1994	12/31/1994	365	0.030	330000	12211	0.013	5030	**81**	0.234	20585	**5942**	0	0.0000	2	**0.045**
Average	1/1/0000	12/31/0000	365	0.030	330000	12211	0.013	15169	**246**	0.234	13766	**3973**	0	0.0000	12380	**0.040**
	McClusky Canal						*Average of*									
							C1 and C2									
							from upstream									
Dry - 1963	1/1/1963	12/31/1963	365	0.020	12582	310	0.031	13141	**507**	0.234	131	**38**	8434	0.0000	13141	**0.038**
Normal - 1941	1/1/1941	12/31/1941	365	0.020	12582	310	0.032	27648	**1081**	0.234	290	**84**	8434	0.0000	27648	**0.042**
Wet - 1994	1/1/1994	12/31/1994	365	0.020	12582	310	0.037	5030	**232**	0.234	1227	**354**	8434	0.0000	5030	**0.062**
Average	1/1/0000	12/31/0000	365	0.020	12582	310	0.035	15169	**651**	0.234	821	**237**	8434	0.0000	12380	**0.049**
	New John's Lake															
Dry - 1963	1/1/1963	12/31/1963	365	0.010	9740	120	0.029	13141	**471**	0.234	42	**12**	6787	0.0000	13141	**0.033**
Normal - 1941	1/1/1941	12/31/1941	365	0.010	9740	120	0.031	27648	**1056**	0.234	93	**27**	6787	0.0000	27648	**0.042**
Wet - 1994	1/1/1994	12/31/1994	365	0.010	9740	120	0.041	5030	**256**	0.234	395	**114**	6787	0.0000	5030	**0.042**
Average	1/1/0000	12/31/0000	365	0.010	9740	120	0.034	15169	**645**	0.234	264	**76**	6787	0.0000	12380	**0.041**
	McClusky Canal															
	New John's Lake to Diversion															
Dry - 1963	1/1/1963	12/31/1963	365	0.016	2401	48	0.022	13141	**352**	0.234	272	**79**	0	0.0000	13141	**0.032**
Normal - 1941	1/1/1941	12/31/1941	365	0.016	2401	48	0.026	27648	**888**	0.234	604	**174**	0	0.0000	27648	**0.042**
Wet - 1994	1/1/1994	12/31/1994	365	0.016	2401	48	0.026	5030	**162**	0.234	2552	**737**	0	0.0000	5030	**0.105**
Average	1/1/0000	12/31/0000	365	0.016	2401	48	0.025	15169	**477**	0.234	1707	**493**	0	0.0000	12380	**0.058**

APPENDIX B

McCLUSKY CANAL STEADY-STATE MODEL CALCULATIONS

THEORY

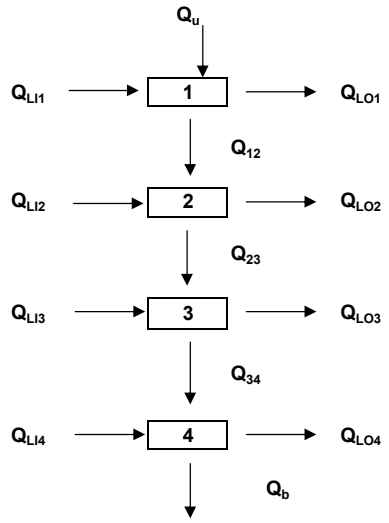
Steady State Model - McClusky Canal

(Advective Transport)

(Volume of segment does not change with time)

Cells

1	Lake Audubon
2	McClusky Canal from Lake Audubon to New John's Lake
3	New John's Lake
4	McClusky Canal from New John's Lake to Diversion



Key

Q_u	Flow from Lake Sakawea to Lake Audubon (Cell 1)
Q_{LI2}	Local Inflow to Cell 2
Q_{LO2}	Local Outflow from Cell 2
Q_{23}	Flow from Cell 2 to Cell 3
V_i	Volume in Cell i
S_{LIi}	Concentration of Local inflow to Cell i
S_{LOi}	Concentration of Local outflow to Cell i

Flows (cfs)

$Q_{12} = Q_u + Q_{LI1} - Q_{LO1}$

$Q_{23} = Q_{12} + Q_{LI2} - Q_{LO2}$

$Q_{34} = Q_{23} + Q_{LI3} - Q_{LO3}$

$Q_{4b} = Q_{34} + Q_{LI4} - Q_{LO4}$

Sources / Sinks (cfs * mg/l)

$W_i = Q_{LIi} * s_{LIi}$

$W_1' = W_1 + Q_u s_u$

$W_1' = Q_{LI1} S_{LI1} + Q_u s_u$

$W_2 = Q_{LI2} S_{LI2}$

$W_3 = Q_{LI3} S_{LI3}$

$W_4 = Q_{LI4} S_{LI4}$

Steady State Response Matrix

$$\begin{vmatrix} a_{11} & a_{12} & 0 & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & 0 & a_{43} & a_{44} \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} W_1' \\ W_2 \\ W_3 \\ W_4 \end{vmatrix}$$

Coefficients (E = 0 - no dispersion) (p. 130)

$a_{i,i-1} = -Q_{i-1,i}$

$a_{i,i} = -Q_{i,\,i+1} + V_i K_i + Q_{LOi}$

$a_{i,i+1} = 0$

		Substituting Q's into a's:	
$a_{11} =$	$-Q_{12} + V_1K_1 + Q_{LO1}$	$a_{11} =$	$Q_u + Q_{LI1} + V_1K_1$
$a_{12} =$	0	$a_{12} =$	0
$a_{21} =$	$-Q_{12}$	$a_{21} =$	$-Q_u - Q_{LI1} + Q_{LO1}$
$a_{22} =$	$-Q_{23} + V_2K_2 + Q_{LO2}$	$a_{22} =$	$Q_u + Q_{LI1} - Q_{LO1} + Q_{LI2} + V_{2K2}$
$a_{23} =$	0	$a_{23} =$	0
$a_{32} =$	$-Q_{23}$	$a_{32} =$	$-Q_u - Q_{LI1} + Q_{LO1} - Q_{LI2} + Q_{LO2}$
$a_{33} =$	$-Q_{34} + V_3K_3 + Q_{LO3}$	$a_{33} =$	$Q_u + Q_{LI1} - Q_{LO1} + Q_{LI2} - Q_{LO2} + Q_{LI3} + V_{3K3}$
$a_{34} =$	0	$a_{34} =$	0
$a_{43} =$	$-Q_{34}$	$a_{43} =$	$-Q_u - Q_{LI1} + Q_{LO1} - Q_{LI2} + Q_{LO2} - Q_{LI3} + Q_{LO3}$
$a_{44} =$	$-Q_{4b} + V_4K_4 + Q_{LO4}$	$a_{44} =$	$Q_u + Q_{LI1} - Q_{LO1} + Q_{LI2} - Q_{LO2} + Q_{LI3} - Q_{LO3} + Q_{LI4} + V_{3K3}$

CALCULATIONS

Steady State Model - McClusky Canal

Average Year

Discharges (cfs)	
Dry	65.7
Normal	81.3
Wet	6.9
Ave	49.3

Input Values

Q_u = *49.3* cfs

Cell	Volume V (ac-ft)	Local Inflow Q_{LI} (cfs)	Local Outflow Q_{LO} (cfs)
1	*330000*	*72*	*0*
2	*12582*	*4.3*	*13.8*
3	*9740*	*1.4*	*11.5*
4	*2401*	*8.9*	*0*

TDS

Upstream Concentration, s_u = *659.1* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
838.5	s_1	*0*
838.5	s_2	*0*
838.5	s_3	*0*
838.5	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**765.6**	542
s_2	**768.1**	779
s_3	**769.0**	1200
s_4	**774.5**	1451

Coefficients (cfs)

a_{11} = 121.3
a_{12} = 0
a_{21} = -121.3
a_{22} = 125.6
a_{23} = 0
a_{32} = -111.8
a_{33} = 113.2
a_{34} = 0
a_{43} = -101.7
a_{44} = 110.6

Sinks (cfs * mg/l)

W_1' = 92865.6
W_2 = 3605.6
W_3 = 1173.9
W_4 = 7462.7

Steady State Response Matrix

$$\begin{vmatrix} 121.3 & 0 & 0 & 0 \\ -121 & 125.6 & 0 & 0 \\ 0 & -111.8 & 113.2 & 0 \\ 0 & 0 & -101.7 & 110.6 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 92865.63 \\ 3605.6 \\ 1173.9 \\ 7462.7 \end{vmatrix}$$

SO_4

Upstream Concentration, s_u = *179.5* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
210	s_1	*0*
210	s_2	*0*
210	s_3	*0*
210	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**197.6**	241
s_2	**198.0**	405
s_3	**198.2**	524
s_4	**199.1**	844

Coefficients (cfs)

a_{11} = 121.3
a_{12} = 0
a_{21} = -121.3
a_{22} = 125.6
a_{23} = 0
a_{32} = -111.8
a_{33} = 113.2
a_{34} = 0
a_{43} = -101.7
a_{44} = 110.6

Sinks (cfs * mg/l)

W_1' = 23969
W_2 = 903
W_3 = 294
W_4 = 1869

Steady State Response Matrix

$$\begin{vmatrix} 121.3 & 0 & 0 & 0 \\ -121.3 & 125.6 & 0 & 0 \\ 0 & -111.8 & 113.2 & 0 \\ 0 & 0 & -101.7 & 110.6 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 23969 \\ 903 \\ 294 \\ 1869 \end{vmatrix}$$

NO3 as N (1/2 MDL) + NH3 as N (1/2 MDL)

Upstream Concentration, s_u = *0.030* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
0.11118	s_1	*0*
0.11118	s_2	*0*
0.11118	s_3	*0*
0.11118	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**0.0782**	0.118
s_2	**0.0793**	0.230
s_3	**0.0797**	0.135
s_4	**0.0822**	0.194

Coefficients (cfs)

a_{11} = 121.3
a_{12} = 0
a_{21} = -121.3
a_{22} = 125.6
a_{23} = 0
a_{32} = -111.8
a_{33} = 113.2
a_{34} = 0
a_{43} = -101.7
a_{44} = 110.6

Sinks (cfs * mg/l)

W_1' = 9.484
W_2 = 0.5
W_3 = 0.156
W_4 = 1.0

Steady State Response Matrix

$$\begin{vmatrix} 121.3 & 0 & 0 & 0 \\ -121 & 125.6 & 0 & 0 \\ 0 & -111.8 & 113.2 & 0 \\ 0 & 0 & -101.7 & 110.6 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 9.484 \\ 0.5 \\ 0.156 \\ 1.0 \end{vmatrix}$$

PO4 as P (1/2 MDL)

Upstream Concentration, s_u = *0.008* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
0.234	s_1	*0.0015*
0.234	s_2	*0.003*
0.234	s_3	*0.007*
0.234	s_4	*0.003*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**0.0280**	0.030
s_2	**0.0269**	0.020
s_3	**0.0184**	0.010
s_4	**0.0336**	0.016

0.00383333

Coefficients (cfs)

a_{11} = 616.3
a_{12} = 0
a_{21} = -121.3
a_{22} = 163.346
a_{23} = 0
a_{32} = -111.8
a_{33} = 181.38
a_{34} = 0
a_{43} = -101.7
a_{44} = 117.803

Sinks (cfs * mg/l)

W_1' = 17.242
W_2 = 1.0
W_3 = 0.328
W_4 = 2.1

Steady State Response Matrix

$$\begin{vmatrix} 616.3 & 0 & 0 & 0 \\ -121.3 & 163.35 & 0 & 0 \\ 0 & -111.8 & 181.38 & 0 \\ 0 & 0 & -101.7 & 117.8 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 17.242 \\ 1.0 \\ 0.328 \\ 2.1 \end{vmatrix}$$

CALCULATIONS

Steady State Model - McClusky Canal

Wet Year

Dry	65.7
Normal	81.3
Wet	6.9
Ave	49.3

Input Values

Q_u = *6.9* cfs

Cell	Volume V (ac-ft)	Local Inflow Q_{LI} (cfs)	Local Outflow Q_{LO} (cfs)
1	*330000*	*72*	*0*
2	*12582*	*4.3*	*13.8*
3	*9740*	*1.4*	*11.5*
4	*2401*	*8.9*	*0*

TDS

Upstream Concentration, s_u = *659.1* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
838.5	s_1	*0*
838.5	s_2	*0*
838.5	s_3	*0*
838.5	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**822.8**	542
s_2	**823.6**	779
s_3	**823.9**	1200
s_4	**825.8**	1451

Coefficients (cfs)

a_{11} = 78.9
a_{12} = 0
a_{21} = -78.9
a_{22} = 83.2
a_{23} = 0
a_{32} = -69.4
a_{33} = 70.8
a_{34} = 0
a_{43} = -59.3
a_{44} = 68.2

Sinks (cfs * mg/l)

W_1' = 64919.8
W_2 = 3605.6
W_3 = 1173.9
W_4 = 7462.7

Steady State Response Matrix

$$\begin{vmatrix} 78.9 & 0 & 0 & 0 \\ -78.9 & 83.2 & 0 & 0 \\ 0 & -69.4 & 70.8 & 0 \\ 0 & 0 & -59.3 & 68.2 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 64919.79 \\ 3605.6 \\ 1173.9 \\ 7462.7 \end{vmatrix}$$

SO_4

Upstream Concentration, s_u = *179.5* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
210	s_1	*0*
210	s_2	*0*
210	s_3	*0*
210	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**207.3**	241
s_2	**207.5**	405
s_3	**207.5**	524
s_4	**207.8**	844

Coefficients (cfs)

a_{11} = 78.9
a_{12} = 0
a_{21} = -78.9
a_{22} = 83.2
a_{23} = 0
a_{32} = -69.4
a_{33} = 70.8
a_{34} = 0
a_{43} = -59.3
a_{44} = 68.2

Sinks (cfs * mg/l)

W_1' = 16359
W_2 = 903
W_3 = 294
W_4 = 1869

Steady State Response Matrix

$$\begin{vmatrix} 78.9 & 0 & 0 & 0 \\ -78.9 & 83.2 & 0 & 0 \\ 0 & -69.4 & 70.8 & 0 \\ 0 & 0 & -59.3 & 68.2 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 16359 \\ 903 \\ 294 \\ 1869 \end{vmatrix}$$

NO3 as N (1/2 MDL) + NH3 as N (1/2 MDL)

Upstream Concentration, s_u = *0.030* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
0.11118	s_1	*0*
0.11118	s_2	*0*
0.11118	s_3	*0*
0.11118	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**0.1041**	0.118
s_2	**0.1044**	0.230
s_3	**0.1046**	0.135
s_4	**0.1054**	0.194

Coefficients (cfs)

a_{11} = 78.9
a_{12} = 0
a_{21} = -78.9
a_{22} = 83.2
a_{23} = 0
a_{32} = -69.4
a_{33} = 70.8
a_{34} = 0
a_{43} = -59.3
a_{44} = 68.2

Sinks (cfs * mg/l)

W_1' = 8.212
W_2 = 0.5
W_3 = 0.156
W_4 = 1.0

Steady State Response Matrix

$$\begin{vmatrix} 78.9 & 0 & 0 & 0 \\ -78.9 & 83.2 & 0 & 0 \\ 0 & -69.4 & 70.8 & 0 \\ 0 & 0 & -59.3 & 68.2 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 8.212 \\ 0.5 \\ 0.156 \\ 1.0 \end{vmatrix}$$

PO4 as P (1/2 MDL)

Upstream Concentration, s_u = *0.008* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
0.234	s_1	*0.0015*
0.234	s_2	*0.003*
0.234	s_3	*0.007*
0.234	s_4	*0.003*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**0.0295**	0.030
s_2	**0.0275**	0.020
s_3	**0.0161**	0.010
s_4	**0.0403**	0.016

0.00383333

Coefficients (cfs)

a_{11} = 573.9
a_{12} = 0
a_{21} = -78.9
a_{22} = 120.946
a_{23} = 0
a_{32} = -69.4
a_{33} = 138.98
a_{34} = 0
a_{43} = -59.3
a_{44} = 75.403

Sinks (cfs * mg/l)

W_1' = 16.903
W_2 = 1.0
W_3 = 0.328
W_4 = 2.1

Steady State Response Matrix

$$\begin{vmatrix} 573.9 & 0 & 0 & 0 \\ -78.9 & 120.95 & 0 & 0 \\ 0 & -69.4 & 138.98 & 0 \\ 0 & 0 & -59.3 & 75.4 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 16.903 \\ 1.0 \\ 0.328 \\ 2.1 \end{vmatrix}$$

CALCULATIONS

Steady State Model - McClusky Canal

Normal Year

Dry	65.7
Normal	81.3
Wet	6.9
Ave	49.3

Input Values

Q_u = *81.3* cfs

Cell	Volume V (ac-ft)	Local Inflow Q_{LI} (cfs)	Local Outflow Q_{LO} (cfs)
1	*330000*	*72*	*0*
2	*12582*	*4.3*	*13.8*
3	*9740*	*1.4*	*11.5*
4	*2401*	*8.9*	*0*

TDS

Upstream Concentration, s_u = *659.1* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
838.5	s_1	*0*
838.5	s_2	*0*
838.5	s_3	*0*
838.5	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**743.4**	542
s_2	**746.0**	779
s_3	**746.8**	1200
s_4	**752.6**	1451

Coefficients (cfs)

a_{11} = 153.3
a_{12} = 0
a_{21} = -153.3
a_{22} = 157.6
a_{23} = 0
a_{32} = -143.8
a_{33} = 145.2
a_{34} = 0
a_{43} = -133.7
a_{44} = 142.6

Sinks (cfs * mg/l)

W_1' = 113956.8
W_2 = 3605.6
W_3 = 1173.9
W_4 = 7462.7

Steady State Response Matrix

$$\begin{vmatrix} 153.3 & 0 & 0 & 0 \\ -153 & 157.6 & 0 & 0 \\ 0 & -143.8 & 145.2 & 0 \\ 0 & 0 & -133.7 & 142.6 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 113956.8 \\ 3605.6 \\ 1173.9 \\ 7462.7 \end{vmatrix}$$

SO_4

Upstream Concentration, s_u = *179.5* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
210	s_1	*0*
210	s_2	*0*
210	s_3	*0*
210	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**193.8**	241
s_2	**194.3**	405
s_3	**194.4**	524
s_4	**195.4**	844

Coefficients (cfs)

a_{11} = 153.3
a_{12} = 0
a_{21} = -153.3
a_{22} = 157.6
a_{23} = 0
a_{32} = -143.8
a_{33} = 145.2
a_{34} = 0
a_{43} = -133.7
a_{44} = 142.6

Sinks (cfs * mg/l)

W_1' = 29713
W_2 = 903
W_3 = 294
W_4 = 1869

Steady State Response Matrix

$$\begin{vmatrix} 153.3 & 0 & 0 & 0 \\ -153.3 & 157.6 & 0 & 0 \\ 0 & -143.8 & 145.2 & 0 \\ 0 & 0 & -133.7 & 142.6 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 29713 \\ 903 \\ 294 \\ 1869 \end{vmatrix}$$

NO3 as N (1/2 MDL) + NH3 as N (1/2 MDL)

Upstream Concentration, s_u = *0.030* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
0.11118	s_1	*0*
0.11118	s_2	*0*
0.11118	s_3	*0*
0.11118	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**0.0681**	0.118
s_2	**0.0693**	0.230
s_3	**0.0697**	0.135
s_4	**0.0723**	0.194

Coefficients (cfs)

a_{11} = 153.3
a_{12} = 0
a_{21} = -153.3
a_{22} = 157.6
a_{23} = 0
a_{32} = -143.8
a_{33} = 145.2
a_{34} = 0
a_{43} = -133.7
a_{44} = 142.6

Sinks (cfs * mg/l)

W_1' = 10.444
W_2 = 0.5
W_3 = 0.156
W_4 = 1.0

Steady State Response Matrix

$$\begin{vmatrix} 153.3 & 0 & 0 & 0 \\ -153 & 157.6 & 0 & 0 \\ 0 & -143.8 & 145.2 & 0 \\ 0 & 0 & -133.7 & 142.6 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 10.444 \\ 0.5 \\ 0.156 \\ 1.0 \end{vmatrix}$$

PO4 as P (1/2 MDL)

Upstream Concentration, s_u = *0.008* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
0.234	s_1	*0.0015*
0.234	s_2	*0.003*
0.234	s_3	*0.007*
0.234	s_4	*0.003*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**0.0270**	0.030
s_2	**0.0263**	0.020
s_3	**0.0193**	0.010
s_4	**0.0311**	0.016

0.00383333

Coefficients (cfs)

a_{11} = 648.3
a_{12} = 0
a_{21} = -153.3
a_{22} = 195.346
a_{23} = 0
a_{32} = -143.8
a_{33} = 213.38
a_{34} = 0
a_{43} = -133.7
a_{44} = 149.803

Sinks (cfs * mg/l)

W_1' = 17.498
W_2 = 1.0
W_3 = 0.328
W_4 = 2.1

Steady State Response Matrix

$$\begin{vmatrix} 648.3 & 0 & 0 & 0 \\ -153.3 & 195.35 & 0 & 0 \\ 0 & -143.8 & 213.38 & 0 \\ 0 & 0 & -133.7 & 149.8 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 17.498 \\ 1.0 \\ 0.328 \\ 2.1 \end{vmatrix}$$

CALCULATIONS

Steady State Model - McClusky Canal

Dry Year

Dry	65.7
Normal	81.3
Wet	6.9
Ave	49.3

Input Values

Q_u = *65.7* cfs

Cell	Volume V (ac-ft)	Local Inflow Q_{LI} (cfs)	Local Outflow Q_{LO} (cfs)
1	*330000*	*72*	*0*
2	*12582*	*4.3*	*13.8*
3	*9740*	*1.4*	*11.5*
4	*2401*	*8.9*	*0*

TDS

Upstream Concentration, s_u = *659.1* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
838.5	s_1	*0*
838.5	s_2	*0*
838.5	s_3	*0*
838.5	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**752.9**	542
s_2	**755.5**	779
s_3	**756.4**	1200
s_4	**762.1**	1451

Coefficients (cfs)		Sinks (cfs * mg/l)	
a_{11} =	137.7	W_1' =	103674.9
a_{12} =	0	W_2 =	3605.6
a_{21} =	-137.7	W_3 =	1173.9
a_{22} =	142	W_4 =	7462.7
a_{23} =	0		
a_{32} =	-128.2		
a_{33} =	129.6		
a_{34} =	0		
a_{43} =	-118.1		
a_{44} =	127		

Steady State Response Matrix

$$\begin{vmatrix} 137.7 & 0 & 0 & 0 \\ -138 & 142 & 0 & 0 \\ 0 & -128.2 & 129.6 & 0 \\ 0 & 0 & -118.1 & 127 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 103674.9 \\ 3605.6 \\ 1173.9 \\ 7462.7 \end{vmatrix}$$

SO_4

Upstream Concentration, s_u = *179.5* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
210	s_1	*0*
210	s_2	*0*
210	s_3	*0*
210	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**195.4**	241
s_2	**195.9**	405
s_3	**196.0**	524
s_4	**197.0**	844

Coefficients (cfs)		Sinks (cfs * mg/l)	
a_{11} =	137.7	W_1' =	26913
a_{12} =	0	W_2 =	903
a_{21} =	-137.7	W_3 =	294
a_{22} =	142	W_4 =	1869
a_{23} =	0		
a_{32} =	-128.2		
a_{33} =	129.6		
a_{34} =	0		
a_{43} =	-118.1		
a_{44} =	127		

Steady State Response Matrix

$$\begin{vmatrix} 137.7 & 0 & 0 & 0 \\ -137.7 & 142 & 0 & 0 \\ 0 & -128.2 & 129.6 & 0 \\ 0 & 0 & -118.1 & 127 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 26913 \\ 903 \\ 294 \\ 1869 \end{vmatrix}$$

NO3 as N (1/2 MDL) + NH3 as N (1/2 MDL)

Upstream Concentration, s_u = *0.030* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
0.11118	s_1	*0*
0.11118	s_2	*0*
0.11118	s_3	*0*
0.11118	s_4	*0*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**0.0724**	0.118
s_2	**0.0736**	0.230
s_3	**0.0740**	0.135
s_4	**0.0766**	0.194

Coefficients (cfs)		Sinks (cfs * mg/l)	
a_{11} =	137.7	W_1' =	9.976
a_{12} =	0	W_2 =	0.5
a_{21} =	-137.7	W_3 =	0.156
a_{22} =	142	W_4 =	1.0
a_{23} =	0		
a_{32} =	-128.2		
a_{33} =	129.6		
a_{34} =	0		
a_{43} =	-118.1		
a_{44} =	127		

Steady State Response Matrix

$$\begin{vmatrix} 137.7 & 0 & 0 & 0 \\ -138 & 142 & 0 & 0 \\ 0 & -128.2 & 129.6 & 0 \\ 0 & 0 & -118.1 & 127 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 9.976 \\ 0.5 \\ 0.156 \\ 1.0 \end{vmatrix}$$

PO4 as P (1/2 MDL)

Upstream Concentration, s_u = *0.008* mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
0.234	s_1	*0.0015*
0.234	s_2	*0.003*
0.234	s_3	*0.007*
0.234	s_4	*0.003*

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	**0.0275**	0.030
s_2	**0.0266**	0.020
s_3	**0.0189**	0.010
s_4	**0.0322**	0.016

0.00383333

Coefficients (cfs)		Sinks (cfs * mg/l)	
a_{11} =	632.7	W_1' =	17.374
a_{12} =	0	W_2 =	1.0
a_{21} =	-137.7	W_3 =	0.328
a_{22} =	179.746	W_4 =	2.1
a_{23} =	0		
a_{32} =	-128.2		
a_{33} =	197.78		
a_{34} =	0		
a_{43} =	-118.1		
a_{44} =	134.203		

Steady State Response Matrix

$$\begin{vmatrix} 632.7 & 0 & 0 & 0 \\ -137.7 & 179.75 & 0 & 0 \\ 0 & -128.2 & 197.78 & 0 \\ 0 & 0 & -118.1 & 134.2 \end{vmatrix} \begin{vmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{vmatrix} = \begin{vmatrix} 17.374 \\ 1.0 \\ 0.328 \\ 2.1 \end{vmatrix}$$

CALCULATIONS

Steady State Model - McClusky Canal

Calibration Year 1999

Input Values

Q_u =	2.7	cfs

Cell	Volume V (ac-ft)	Local Inflow Q_{LI} (cfs)	Local Outflow Q_{LO} (cfs)
1	330000	72	0
2	12582	4.3	13.8
3	9740	1.4	11.5
4	2401	8.9	0

TDS

Upstream Concentration, s_u = 659.1 mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
838.5	s_1	0
838.5	s_2	0
838.5	s_3	0
838.5	s_4	0

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	832.0	542
s_2	832.4	779
s_3	832.5	1200
s_4	833.3	1451

Coefficients (cfs)

a_{11} = 74.7
a_{12} = 0
a_{21} = -74.7
a_{22} = 79
a_{23} = 0
a_{32} = -65.2
a_{33} = 66.6
a_{34} = 0
a_{43} = -55.1
a_{44} = 64

Sinks (cfs * mg/l)

W_1' = 62151.6
W_2 = 3605.6
W_3 = 1173.9
W_4 = 7462.7

Steady State Response Matrix

$$\begin{bmatrix} 74.7 & 0 & 0 & 0 \\ -74.7 & 79 & 0 & 0 \\ 0 & -65.2 & 66.6 & 0 \\ 0 & 0 & -55.1 & 64 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} = \begin{bmatrix} 62151.57 \\ 3605.6 \\ 1173.9 \\ 7462.7 \end{bmatrix}$$

SO_4

Upstream Concentration, s_u = 179.5 mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
210	s_1	0
210	s_2	0
210	s_3	0
210	s_4	0

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	208.9	241
s_2	209.0	405
s_3	209.0	524
s_4	209.1	844

Coefficients (cfs)

a_{11} = 74.7
a_{12} = 0
a_{21} = -74.7
a_{22} = 79
a_{23} = 0
a_{32} = -65.2
a_{33} = 66.6
a_{34} = 0
a_{43} = -55.1
a_{44} = 64

Sinks (cfs * mg/l)

W_1' = 15605
W_2 = 903
W_3 = 294
W_4 = 1869

Steady State Response Matrix

$$\begin{bmatrix} 74.7 & 0 & 0 & 0 \\ -74.7 & 79 & 0 & 0 \\ 0 & -65.2 & 66.6 & 0 \\ 0 & 0 & -55.1 & 64 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} = \begin{bmatrix} 15605 \\ 903 \\ 294 \\ 1869 \end{bmatrix}$$

NO3 as N (1/2 MDL) + NH3 as N (1/2 MDL)

Upstream Concentration, s_u = 0.030 mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
0.11118	s_1	0
0.11118	s_2	0
0.11118	s_3	0
0.11118	s_4	0

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	0.1082	0.118
s_2	0.1084	0.230
s_3	0.1085	0.135
s_4	0.1088	0.194

Coefficients (cfs)

a_{11} = 74.7
a_{12} = 0
a_{21} = -74.7
a_{22} = 79
a_{23} = 0
a_{32} = -65.2
a_{33} = 66.6
a_{34} = 0
a_{43} = -55.1
a_{44} = 64

Sinks (cfs * mg/l)

W_1' = 8.086
W_2 = 0.5
W_3 = 0.156
W_4 = 1.0

Steady State Response Matrix

$$\begin{bmatrix} 74.7 & 0 & 0 & 0 \\ -74.7 & 79 & 0 & 0 \\ 0 & -65.2 & 66.6 & 0 \\ 0 & 0 & -55.1 & 64 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} = \begin{bmatrix} 8.086 \\ 0.5 \\ 0.156 \\ 1.0 \end{bmatrix}$$

PO4 as P (1/2 MDL)

Upstream Concentration, s_u = 0.008 mg/l

Concentration Local in s_{LI} (mg/l)	Concentration Local out s_{LO} (mg/l)	Reaction K (/day)
0.234	s_1	0.0015
0.234	s_2	0.003
0.234	s_3	0.007
0.234	s_4	0.0015

Resultant Concentration	(mg/l)	Measured Concentration (mg/l)
s_1	0.0296	0.030
s_2	0.0276	0.020
s_3	0.0158	0.010
s_4	0.0437	0.016

0.00383333

Coefficients (cfs)

a_{11} = 569.7
a_{12} = 0
a_{21} = -74.7
a_{22} = 116.746
a_{23} = 0
a_{32} = -65.2
a_{33} = 134.78
a_{34} = 0
a_{43} = -55.1
a_{44} = 67.6015

Sinks (cfs * mg/l)

W_1' = 16.870
W_2 = 1.0
W_3 = 0.328
W_4 = 2.1

Steady State Response Matrix

$$\begin{bmatrix} 569.7 & 0 & 0 & 0 \\ -74.7 & 116.75 & 0 & 0 \\ 0 & -65.2 & 134.78 & 0 \\ 0 & 0 & -55.1 & 67.6 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} = \begin{bmatrix} 16.870 \\ 1.0 \\ 0.328 \\ 2.1 \end{bmatrix}$$

APPENDIX C

INTERNATIONAL JOINT COMMISSION WATER QUALITY ALERT LEVELS

B.1 WATER QUALITY OBJECTIVES

The purpose of the water quality objectives and alert levels is to restore and maintain the chemical, physical, and biological integrity of the waters of the Red River. Five specific objectives were adopted for the Red River by the IJC in 1969.

Water quality objectives are used when necessary to secure government commitment to pollution abatement action. Compliance with the objectives is the primary means by which the Board identifies major water quality issues to the Commission.

The term "exceedence" is used to describe a situation where an objective is not met. A situation is classified as an exceedence if an individual instantaneous sample, obtained from the continuous auto-monitor, or through a grab sample, is equal to or greater than the corresponding water quality objective (except for dissolved oxygen, which must be observed to be equal to or less than the objective). The five specific parameters and corresponding objective are listed below.

Fecal Coliform	200 colonies/100 ml
Chloride	100 mg/L
Sulphate	250 mg/L
Total Dissolved Solids	500 mg/L
Dissolved Oxygen	5 mg/L

B.2 WATER QUALITY ALERT LEVELS

Water quality alert levels are used to complement water quality objectives. If exceeded, alert levels will trigger investigative action on the part of the Board or its representatives. The exceedence is addressed in terms of its magnitude, implications to water uses and possible resolutions. On the basis of alert level exceedences and subsequent investigations, the Board may advance proposals for additional objectives.

Water quality alert levels, for a wide range of parameters, in addition to the five specific parameters noted above, were developed by a working group in 1985. These alert levels were approved by the predecessor International Red River Pollution Board in January 1986. The alert levels that are currently in effect are listed in the following table. Further, the table provides a comparison of alert levels with the North Dakota and Minnesota Water Quality Standards, and with the Manitoba Water Quality Objectives as of 1990. The table has not been updated to reflect recent state or provincial revisions. The Aquatic Ecosystem Health Committee established by the Board in June 2001 will be reviewing the issue of objectives and alert levels with respect to monitoring requirements, analytical methodologies, and reporting protocols.

WATER QUALITY OBJECTIVES FOR THE RED RIVER OF THE NORTH

August 20, 1990

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Objectives	Origin/ Rational
Fecal Coliform	200/100 ml geometric mean 10% of samples not to exceed 2,000 based on a minimum of 5 samples in a 30 day period from Mar. 1 - Oct. 31. HH*	200 fecal coliforms per 100 ml. This standard shall apply only during the recreation season, May 1 to September 30. HH	100/100 ml. At least 90% of samples in any consecutive 30 day period should have a fecal coliform density of less than 100 per 100 ml. HH	200/100 ml geometric mean with 10% of samples not to exceed 400 based on on min. 5 samples - 30 day period - May 1 - Oct. 31 and for the balance of year not to exceed 1000/100 ml. Current IJC objective.	Minnesota and North Dakota based on primary body contact recreation.
Chloride	100 mg/l (total) ID	100 mg/l (total) ID	100 mg/l (soluble) ID	100 mg/l (dissolved) Current IJC Objective	All agencies based on industrial consumption.
Sulfate	250 mg/l (total) DW	250 mg/l (total) DW	250 mg/l (dissolved) DW	250 mg/l (total) Current IJC Objective	All agencies based on domestic consumption.
TDS	500 mg/l DW	None	500 mg/l DW	500 mg/l Current IJC Objective	All agencies, excluding North Dakota based on domestic consumption.
Dissolved Oxygen	5 mg/l (minimum)	5 mg/l (minimum)	47% saturation or more.	5 mg/l (minimum) Current IJC Objective	All agencies for the protection of aquatic life.

*DW - Drinking Water
HH - Human Health
AL - Aquatic Life
ID - Industrial Consumption
IR - Irrigation

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
			Chemical Characteristics		
Ph	6.5 - 9.0 AL	7.0 - 9.0 AL	6.5 - 9.0 AL	6.5 - 9.0	All agencies based on protection of aquatic life.
Temperature	5°F above natural in streams and 3°F above natural in lakes, based on monthly average of the maximum daily temperature, except in no case shall it exceed the daily average temperature of 86°F. AL	85°F. The maximum increase shall not be greater than 5°F above natural background conditions. AL	Site-specific objectives can be developed using procedures set out in the Manitoba Surface Water Quality Objectives. AL	None	All agencies based on protection of aquatic life.
			Dissolved Gas		
Ammonia-N	.04 mg/l as N unionized (warm water) AL	Unionized as N (dissolved). Calculation from standards. See page B-10. AL	Variable, ranging from 0.0184 to 0.050 mg/l ammonia as NH_3.*		Minnesota and North Dakota for the protection of aquatic life.
			Metals (Total)		
Aluminum	Total 125 $\mu g/l$ AL	None	None	None	Minnesota for the protection of aquatic life.

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
Cadmium	Total The chronic standard shall not exceed: e(0.7852 [ln (total hardness mg/l)]-3.49). For hardness values greater than 400 mg/l, 400 mg/l shall be used in the calculation of the standard. Cadmium standards in μg/l at various hardness values: 50 mg/l hardness = 0.66 μg/l, 100 mg/l hardness = 1.1 μg/l, 200 mg/l hardness = 2.0 μg/l AL	Total The one-hour average concentration in μg/l cannot exceed the numerical value given by $e^{(1.128[\ln(\text{hardness as mg/l})]-3.828)}$ more than once every 3 years on the average. AL The four day average concentration in μg/l cannot exceed the numerical value given by $e^{(.7852[\ln(\text{hardness as mg/l})]-3.490)}$ more than once every 3 years on the average. AL	e(0.7852 [ln (hardness)] -3.49), where hardness is expressed in mg/l $CaCO_3$ and the resultant objective is expressed in μg/l. (e.g.) 50 mg/l $CaCO_3$ = 0.66 μg/l, 100 mg/l $CaCO_3$ = 1.1 μg/l, 200 mg/l $CaCO_3$ = 2.0 μg/l. AL	Less than detection.	Minnesota and Manitoba for the protection of aquatic life and wildlife.
Chromium	None	Total 50 μg/l DW	e(0.8190[ln (hardness)] +1.561), where hardness is expressed in mg/l $CaCO_3$ and the resultant objective is expressed in μg/l. (e.g.) 50 mg/l $CaCO_3$ = 120 μg/l, 100 mg/l $CaCO_3$ = 210 μg/l, 200 mg/l $CaCO_3$ = 370 μg/l.	50 μg/l	North Dakota based on domestic consumption.

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
Chromium, Trivalent	Total The chronic standard shall not exceed: exp.(0.819[ln(total hardness mg/l]+1.561). For hardness values greater than 400 mg/l, 400 mg/l shall be used in the calculation of the standard. Chromium +3 standards in μg/l at various hardness values: 50 mg/l hardness = 117 μg/l, 100 mg/l hardness = 207 μg/l, 200 mg/l hardness = 365 μg/l. AL	None	e(0.8190[ln (hardness)] +1.561), where hardness is expressed in mg/l $CaCO_3$ and the resultant objective is expressed in μg/l. (e.g.) 50 mg/l $CaCO_3$ = 120 μg/l, 100 mg/l $CaCO_3$ = 210 μg/l, 200 mg/l $CaCO_3$ = 370 μg/l. AL	None	Manitoba and Minnesota for the protection of aquatic life.
Chromium, Hexavalent	Total The chronic standard is 11 μg/l AL	None	11 μg/l AL	None	Manitoba and Minnesota for the protection of aquatic life.
Copper	Total The chronic standard shall not exceed: exp.(0.62[ln(total hardness mg/l)]-0.57). For hardness values greater than 400 mg/l, 400 mg/l shall be used in the calculation of the standard. Copper standards in μg/l at various hardness values: 50 mg/l hardness = 6.4 μg/l,	Total The one-hour average concentration in μg/l cannot exceed the numerical value given by $e^{(.9422[\ln (\text{hardness as mg/l})]-1.464)}$ more than once every 3 years on the average. The four-day average concentration in μg/l cannot exceed the numerical value given by e(.8545[ln(hardness as mg/l)]-1.465) more than	e(0.8545[ln(hardness)]-1.465), where hardness is expressed in mg/l $CaCO_3$ and the resultant objective is expressed in μg/l. (e.g.) 50 mg/l $CaCO_3$ = 6.5 μg/l, 100 mg/l $CaCO_3$ = 12 μg/l, 200 mg/l $CaCO_3$ = 21 μg/l.		Minnesota and Manitoba for the protection of aquatic life.

(continued)

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
	100 mg/l hardness = 9.8 μg/l, 200 mg/l hardness = 15 μg/l. AL	once every three years on the average. AL			
Iron	300 μg/l DW	None	300 μg/l DW	300 μg/l	Minnesota, Manitoba based on domestic consumption
Lead	Total The chronic standard shall not exceed: exp. (1.273[ln(total hardness mg/l)]-4.705). For hardness values greater than 400 mg/l, 400 mg/l shall be used in the calculation of the standard. Lead standards in μg/l at various hardness values: 50 mg/l hardness = 1.3 μg/l 100 mg/l hardness = 3.2 μg/l 200 mg/l hardness = 7.7 μg/l AL	Total The one-hour average concentration in μg/l cannot exceed the numerical value given by $e^{(1.266[\ln(\text{hardness as mg/l})-1.416)}$ more than once every 3 years on the average. The four-day average concentration in μg/l cannot exceed the numerical value given by $e^{(1.266[\ln(\text{hardness as mg/l})]-4.661)}$ more than once every 3 years on the average. AL	e(1.273[ln(hardness)]-4.705), where hardness is expressed in mg/l $CaCO_3$ and the resultant objective is expressed in μg/l. (e.g.) 50 mg/l $CaCO_3$ = 1.3 μg/l, 100 mg/l $CaCO_3$ = 3.2 μg/l, 200 mg/l $CaCO_3$ = 7.7 μg/l,		Manitoba, Minnesota and North Dakota for the protection of aquatic life and wildlife.

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
Manganese	50 μg/l DW	None	50 μg/l DW	50 μg/l	Minnesota and Manitoba based on domestic consumption.
Mercury	Total 0.0069 μg/l AL	Total Acute 2.4 μg/l Chronic 0.012 μg/l AL	Acid soluble mercury 0.006 μg/l	Less than detection in water. 0.5 micrograms per gram in fish fillets.	Minnesota, North Dakota and Manitoba for protection of aquatic life, animal life and humans as a result of bioconcentrations in tissue in the food chain.
Nickel	Total The chronic standard (CS) shall not exceed the human health-based criterion of 88 μg/l. For waters with total hardness values less than 50 mg/l, the CS shall not exceed: exp.(0.846[ln(total hardness mg/l)]+1.1645). AL and HH	None	e(0.76[ln(hardness)] +1.06), where hardness is expressed in mg/l $CaCO_3$ and the resultant objective is expressed in μg/l (e.g.) 50 mg/l $CaCO_3$ = 56 μg/l 100 mg/l $CaCO_3$ = 96 μg/l 200 mg/l $CaCO_3$ = 160 μg/l AL	None	Minnesota for the protection of aquatic life and human health. Manitoba for the protection of aquatic life.
Selenium	Total 5 μg/l AL	10 μg/l DW	10 μg/l DW	10 μg/l	Manitoba and North Dakota based on domestic consumption. Minnesota for the protection of aquatic life.

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
Silver	Total The chronic standard shall not exceed 1.0 μg/l. AL	The one-hour average concentration in μg/l cannot exceed the numerical value given by e(1.72[ln(hardness as mg/l)]-6.52) more than once every three years on the average. AL	0.1 μg/l AL	None	Manitoba, Minnesota and North Dakota for protection of aquatic life.
Zinc	Total The chronic standard shall not exceed: exp.(0.8473[ln(total hardness mg/l)] + 0.7615). For hardness values greater than 400 mg/l, 400 mg/l shall be used in the calculation of the standard. Zinc standards in μg/l at various hardness values: 50 mg/l hardness 59 μg/l 100 mg/l hardness = 106 μg/l 200 mg/l hardness = 191 μg/l. AL	Total The one-hour average concentration in μg/l cannot exceed the numerical value given by $e^{(.8473[\ln(\text{hardness as mg/l})]+.8604)}$ more than one every 3 years on the average. The four-day average concentration in μg/l cannot exceed the numerical value given by $e^{(.8473[\ln(\text{hardness as mg/l})]+.7614)}$ more than once every 3 years on the average. AL	47 μg/l AL	47 μg/l	Minnesota, North Dakota and Manitoba for the protection of aquatic life.

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
			Nutrients		
Nitrates (N)	Total 10 mg/l DW	Dissolved 1.0 mg/l DW	Total 10 mg/l DW	Total 10 mg/l	Minnesota and Manitoba based on domestic consumption.
			Toxic Substances		
Arsenic	Total 50 μg/l DW and AL	Total 50 μg/l DW	Acid soluble arsenic 50 μg/l DW	Total 10 μg/l. (under review)	Minnesota based on domestic consumption and for protection of aquatic life.
Boron	500 μg/l IR	750 μg/l IR	500 μg/l IR	Total 500 μg/l	Minnesota, Manitoba based on irrigation water.
Chlorine	Total residual 6 μg/l	None	None	None	Minnesota for protection of aquatic life.
Cyanide	Free cyanide 5.2 μg/l AL	Total 5 μg/l AL	Free cyanide 5.2 μg/l cyanide AL	Total 5 μg/l	Minnesota and North Dakota for protection of aquatic life.
Dioxin	None	None	None	Not detectable in any media analyzing to parts per trillion.	Task Force
PCBs	Total 0.000029 μg/l AL and HH	Total Acute 2.0 μg/l Chronic 0.014 μg/l AL	.014 μg/l AL	Not detectable in water, in fish total PCBs not exceeding 2 micrograms per gram in fillets.	Body burden: Manitoba, North Dakota and Minnesota for protection of aquatic life, animal life and human life.

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
Phenolics	None	None	1 μg/l DW	10 μg/l	North Dakota to protect against taste and odor in water and fish.
Phenol	123 μg/l AL	Total 10 μg/l DW	1.0 μg/l AL	None	North Dakota to protect against taste and odor in water and fish.
Pentachlorophenol	The chronic standard shall not exceed: exp.(1.005[pH]-5.290). Pentachlorophenol standards in μg/l at, various pH values: pH 7.0 = 5.7 μg/l, pH 7.5 = 9.5 μg/l, pH 8.0 = 16 μg/l. AL	Acute 20.0 μg/l Chronic 13.0 μg/l AL	0.06 mg/l DW	None	Minnesota and North Dakota for the protection of aquatic life. Manitoba based on domestic consumption.
Pesticides and Volatile Hydrocarbons	Acenapthene 12 μg/l Acrylonitrile 0.38μg/l Anthracene 0.029μg/l Benzene 6.9 μg/l Bromoform 128 μg/l Carbon Tetrachloride 1.9 μg/l Chlordane 0.00029 μg/l Chlorobenzene 10 μg/l Chloroform 55 μg/l Chlorpyrifos 0.041 μg/l	Aldrin (total) Acute 3.0 μg/l Chlordane (total) Acute 2.4 μg/l Chronic 0.0043 μg/l Dieldrin (total) Acute 2.5 μg/l Chronic .002 μg/l Endosulfan (total) Acute .22 μg/l Chronic .06 μg/l	Aldicarb 0.009 mg/l Aldrin + Dieldrin 0.0007 mg/l Atrazine 0.06 mg/l Azinphos-methyl 0.02 mg/l Bendiocarb 0.04 mg/l	Not detectable in water*	All agencies for the protection of aquatic life, animal life domestic consumption and human health.

(continued)

*Limits in fish tissue are being researched by the Task Force. Tissue samples have been collected by North Dakota and Manitoba.

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
	DDT 0.0017 μg/l	Endrin (total)	Benzene		
	1,2-Dichloroethane	Acute .18 μg/l	0.005 mg/l		
	3.8 μg/l	Chronic .0023 μg/l	Benzo(a)pyrene		
	Dieldrin 0.000026 μg/l	Heptachlor (total)	0.00001 mg/l		
	Di-2-Ethylhexyl	Acute .52 μg/l	Bromoxynil		
	phthalate 1.9 μg/l	Chronic .004 μg/l	0.005 mg/l		
	Di-n-Octyl phthalate	Lindane (Hexachlorocyclohexane)			
	30 μg/l	Acute 2.0 μg/l	Carbaryl		
	Endosulfan 0.15 μg/l	Chronic .06 μg/l	0.09 mg/l		
	Endrin 0.016 μg/l	Toxaphene (total)	Carbofuran		
	Ethylbenzene 68 μg/l	Acute .73 μg/l	0.09 mg/l		
	Fluoranthene 4.1 μg/l	Chronic .0002 μg/l	Carbon tetrachloride		
	Heptachlor 0.00039 μg/l	AL	0.005 mg/l		
	Heptachlor epoxide		Chlordane		
	0.00048 μg/l		0.0043 μg/l		
	Hexachlorobenzene		Chlorpyrifos		
	0.00022 μg/l		0.09 mg/l		
	Lindane 0.032 μg/l		Cyanazine		
	Methylene chloride		0.01 mg/l		
	46 μg/l		Diazinon		
	Parathion 0.013 μg/l		0.02 mg/l		
	Phenanthrene 2.1 μg/l		Dicamba		
	1,1,2,2-Tetrachloroethane		0.12 mg/l		
	1.54 μg/l		1,2-Dichlorobenzene		
	Tetrachloroethylene 3.8 μg/l		0.2 mg/l		
	1,1,1-Trichloroethane 263 μg/l		1,4-Dichlorobenzene		
	1,1,2-Trichloroethylene 25 μg/l		0.005 mg/l		
	2,4,6-Trichlorophenol 2.0 μg/l		DDT and metabolites		
	Toluene 253 μg/l		0.001 μg/l		
	Toxaphene 0.0013 μg/l		1,2-Dichloroethane		
	Vinyl Chloride 0.15 μg/l		0.005 mg/l		
	Xylene (total m, p and o)		Dichloromethane		
	166 μg/l		0.05 mg/l		
			2,4-Dichlorophenol		
			0.9 mg/l		
			2,4-D - 0.9 mg/l		

(continued)

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
			Diclofop-methyl 0.009 mg/l		
			Dieldrin - 0.0019 μg/l		
			Dimethoate - 0.02 mg/l		
			Diquat - 0.07 mg/l		
			Diuron - 0.15 mg/l		
			Endosulfan - 0.056 μg/l		
			Endrin - 0.0023 μg/l		
			Glyphosate - 0.28 mg/l		
			Heptachlor and heptachlor epoxides - 0.0038 μg/l		
			Hexachlorobutadiene 0.1 μg/l		
			Lindane - 0.080 μg/l		
			Malathion - 0.19 mg/l		
			Methoxychlor - 0.9 mg/l		
			Metolachlor - 0.05 mg/l		
			Metribuzin - 0.08 mg/l		
			Monochlorobenzene 0.08 mg/l		
			Nitrilotriacetic acid 0.05 mg/l		
			Paraquat - 0.01 mg/l		
			Parathion - 0.05 mg/l		
			Phthalic acid esters:		
			Dibutylphthalate - 4.0 μg/l		
			Di-(2-ethylhexyl) phthalate 0.6 μg/l		
			Other phthalates - 0.2 μg/l		
			Phorate - 0.002 mg/l		
			Picloram - 0.19 mg/l		
			Polychlorinated biphenyls 0.014 μg/l		
			Simazine - 0.01 mg/l		
			Temephos - 0.28 mg/l		
			Terbufos - 0.001 mg/l		

(continued)

WATER QUALITY ALERT LEVELS FOR THE RED RIVER OF THE NORTH

Parameter	Minnesota Standards	North Dakota Standards	Manitoba Objectives	Red River Pollution Board Alert Levels	Origin/ Rational
			2,3,4,6-Tetrachlorophenol 0.1 mg/l Toxaphene - 0.013 μg/l Triallate - 0.23 mg/l Trichloroethylene 0.05 mg/l 2,4,6-Trichlorophenol 0.005 mg/l 2,4,5-T - 0.28 mg/l Trifluralin - 0.045 mg/l Trihalomethanes 0.35 mg/l DW and AL		
Oil and Grease	500 μg/l HH	No visable film or sheen upon the waters.	Free from oil and grease residues which cause a visible film or sheen upon the waters or any discolouration of the surface of adjoining shorelines, or cause a sludge or emulsion to be deposited beneath the surface of the water or upon adjoining shorelines.	No visible sheen on the surface.	All agencies based on aesthetics, taste and odor in water and fish, and bathing.

Red River Pollution Board Alert Levels

Unionized Ammonia Table

pH	0°C	5°C	10°C	15°C	20°C	25°C	30°C
6.50	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184
6.75	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184
7.00	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184
7.25	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184	0.0184
7.50	0.0184	0.0184	0.0184	0.0184	0.026	0.026	0.026
7.75	0.0184	0.0184	0.022	0.031	0.043	0.043	0.043
8.00	0.0184	0.0184	0.025	0.035	0.050	0.050	0.050
8.25	0.0184	0.0184	0.025	0.035	0.050	0.050	0.050
8.50	0.0184	0.0184	0.025	0.035	0.050	0.050	0.050
8.75	0.0184	0.0184	0.025	0.035	0.050	0.050	0.050
9.00	0.0184	0.0184	0.025	0.035	0.050	0.050	0.050

Red River Pollution Board Alert Levels

North Dakota Standard for Unionized Ammonia as N (dissolved)

The NH_3-N in mg/l concentration resulting from intermittent waste discharges cannot exceed the numerical value given by .427/FT/FPH/2 where:

$$FT = 10^{0.03(20-TCAP)} \quad ; \quad TCAP \leq T \leq 30$$

$$10^{0.03(20-T)} \quad ; \quad 0 \leq T \leq TCAP$$

$$FPH = 1 \quad ; \quad 8 \leq pH \leq 9$$

$$\frac{1 + 10^{7.4-pH}}{1.25} \quad ; \quad 6.5 \leq pH \leq 8$$

TCAP = 20 C; salmonids or other sensitive cold water species present

= 25 C; salmonids and other sensitive cold water species absent

The NH_3-N in mg/l concentration from a continuous waste discharge cannot exceed the numerical value given by .658/FT/FPH/Ratio where:

$$Ratio = 16 \quad ; \quad 7.7 \leq pH \leq 9$$

$$= 24 \cdot \frac{10^{7.7-pH}}{1+10^{7.4-pH}} \quad ; \quad 6.5 \leq pH \leq 7.7$$

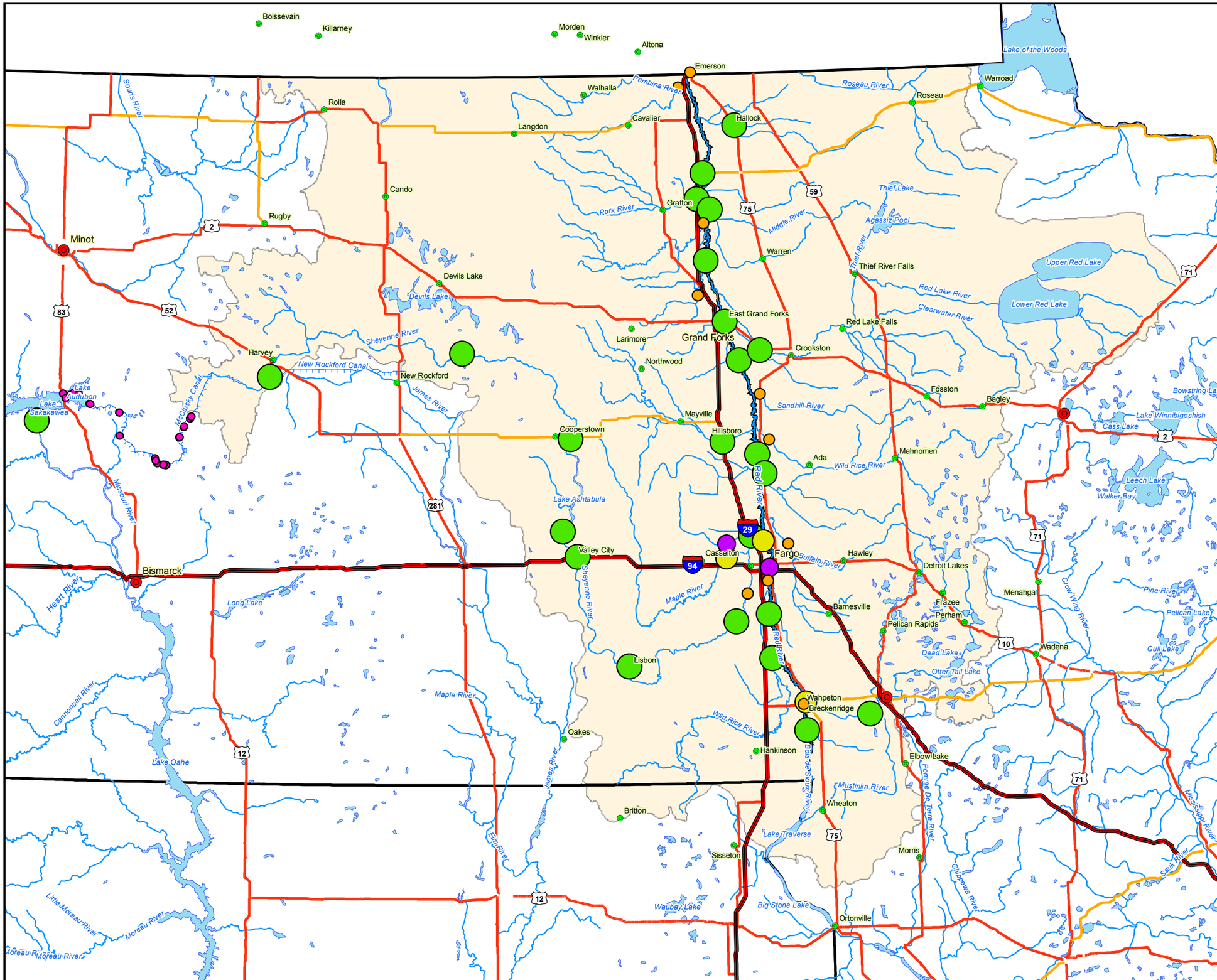
TCAP = 15 C; salmonids or other sensitive cold water species present

= 20 C; salmonids and other sensitive cold water species absent

APPENDIX D

SAMPLE SIZE BY PARAMETER AND LOCATION CODE (LOCCODE)

Red River Valley Water Supply Project (Ammonia Nitrogen)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

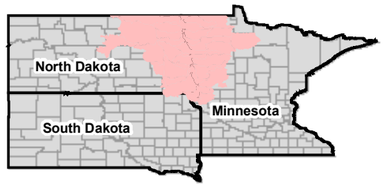
Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 301

N W E S

0 12.5 25 50 75 Miles

Location Map

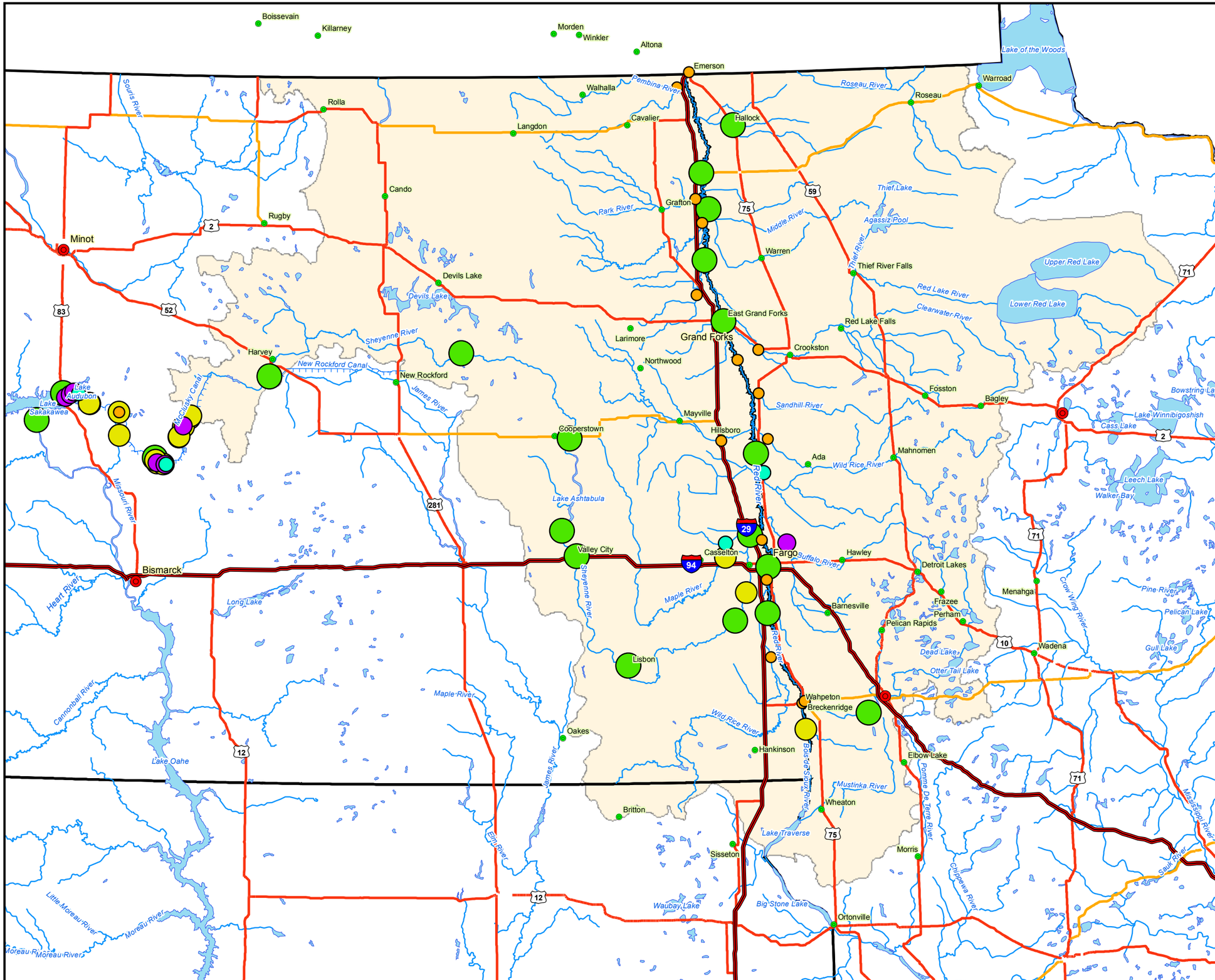


Appendix D: Ammonia Nitrogen sample size by LOCCODE		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U. S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Calcium)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

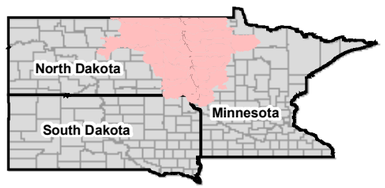
Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 69

N W E S

0 12.5 25 50 75 Miles

Location Map

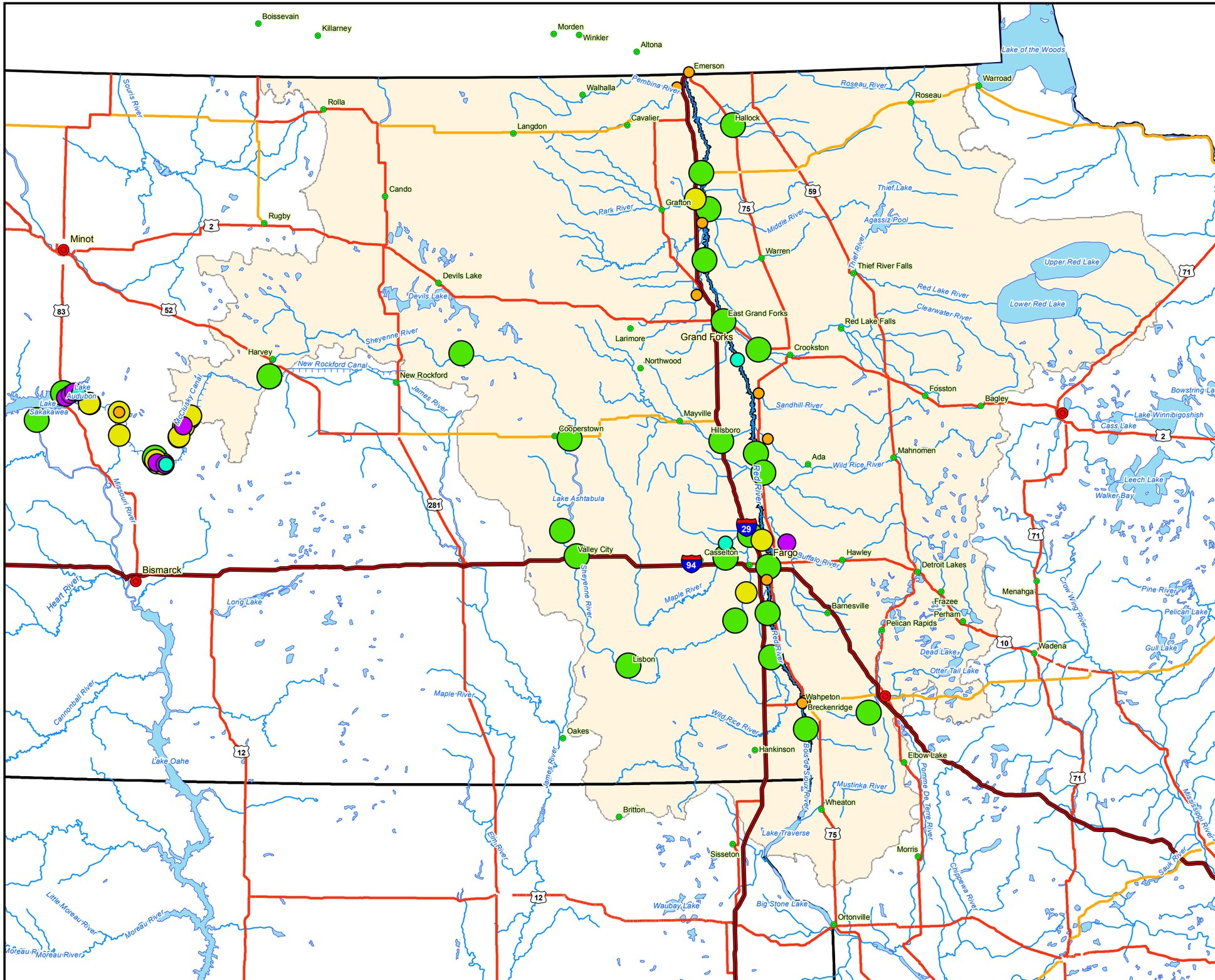


Appendix D: Calcium sample size by LOCCODE		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U. S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Chloride)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

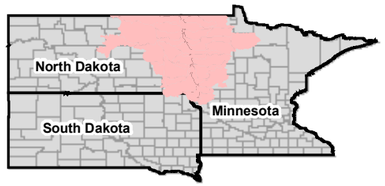
Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 69

N W E S

0 12.5 25 50 75 Miles

Location Map

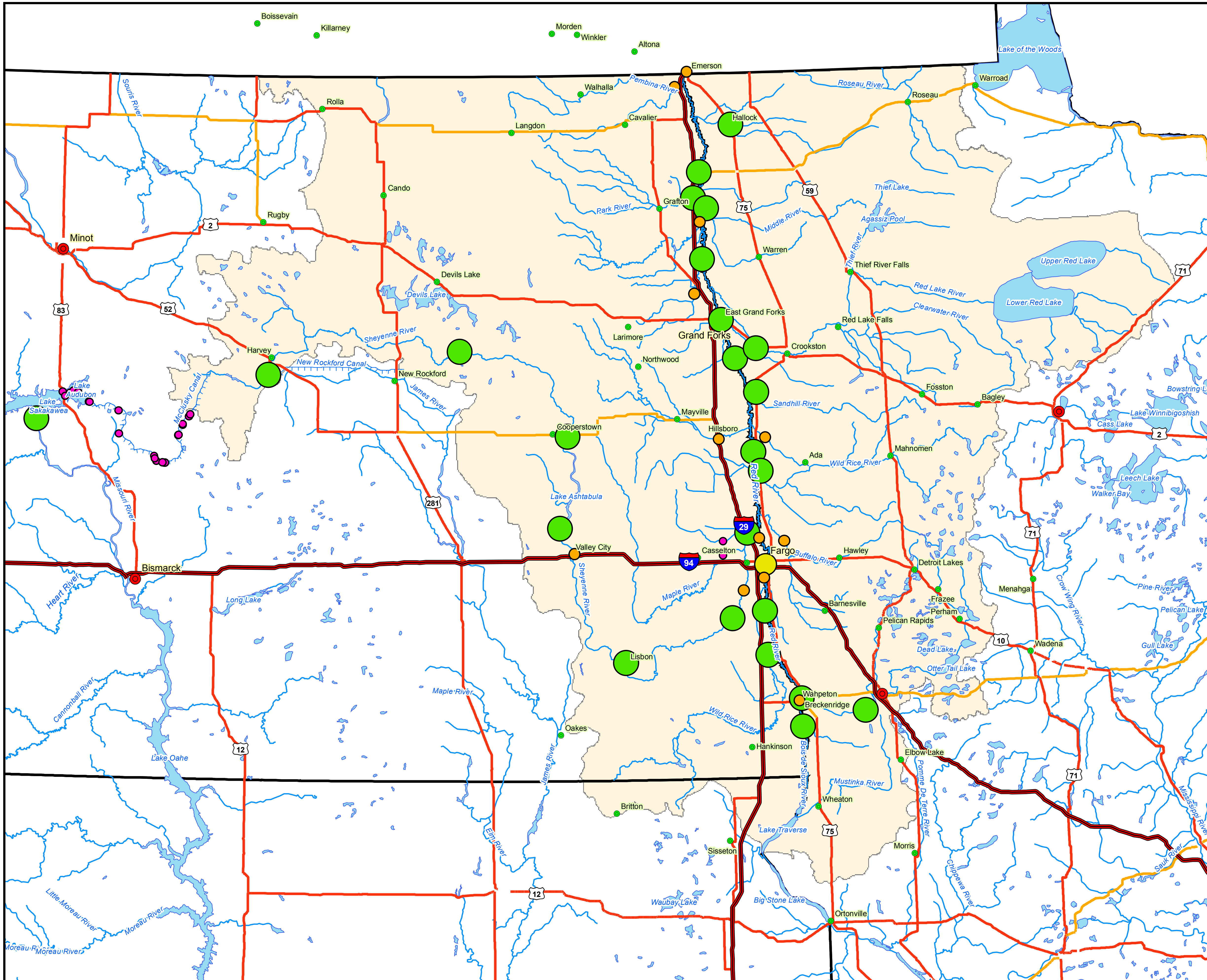


Appendix D: Chloride sample size by LOCCODE		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U. S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Dissolved Oxygen)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

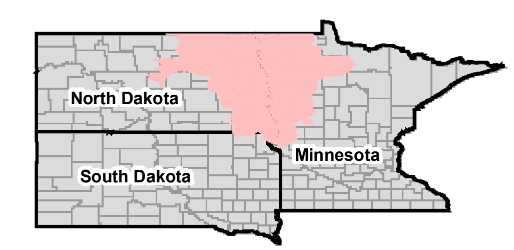
Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 69

N W E S

0 12.5 25 50 75 Miles

Location Map

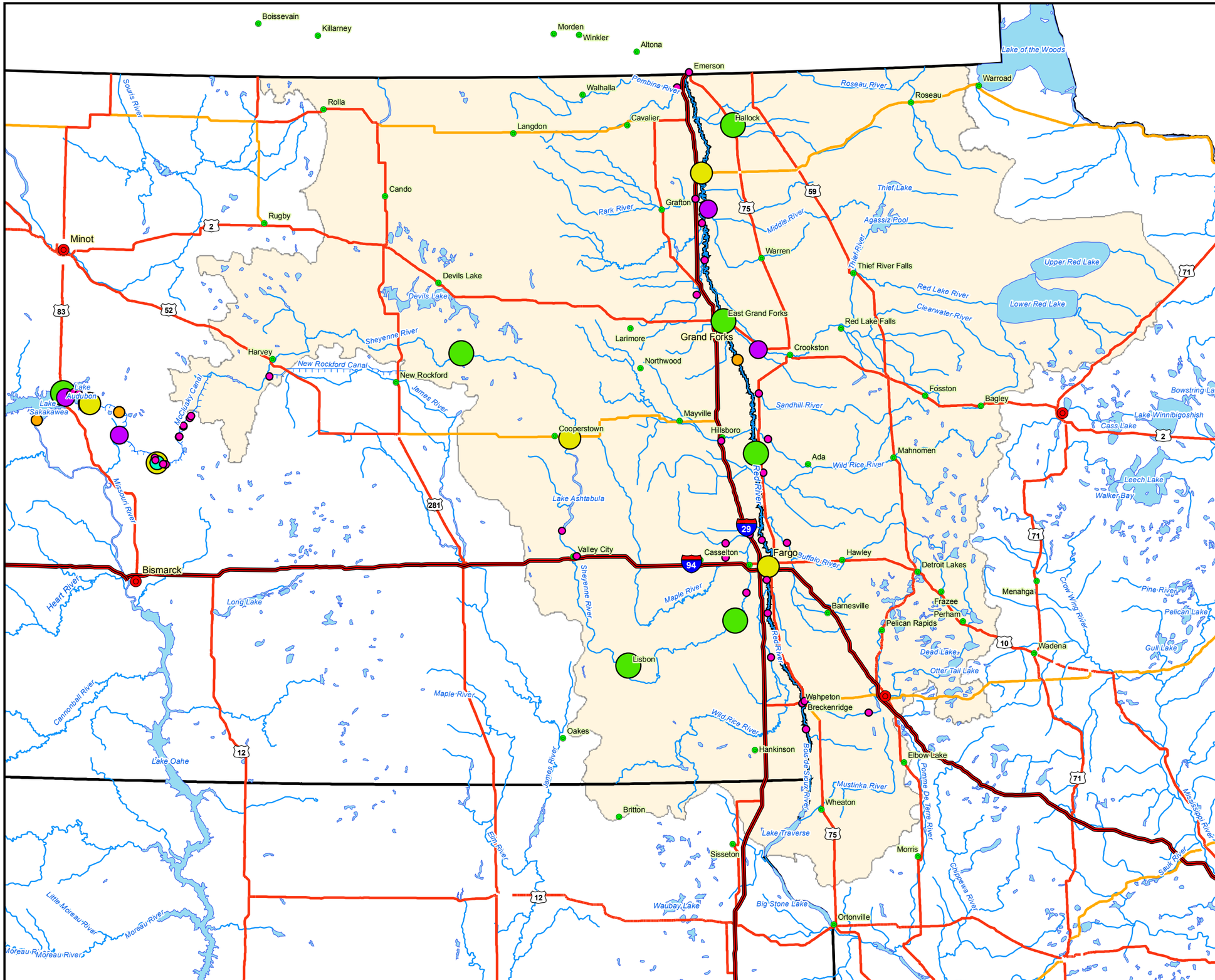


Appendix D: Dissolved oxygen sample size by LOCCODE		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project
(Fecal Coliform Bacteria)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

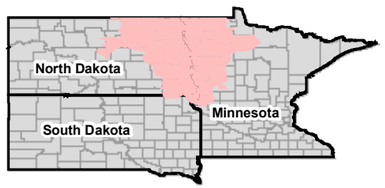
Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 69

N W E S

0 12.5 25 50 75 Miles

Location Map

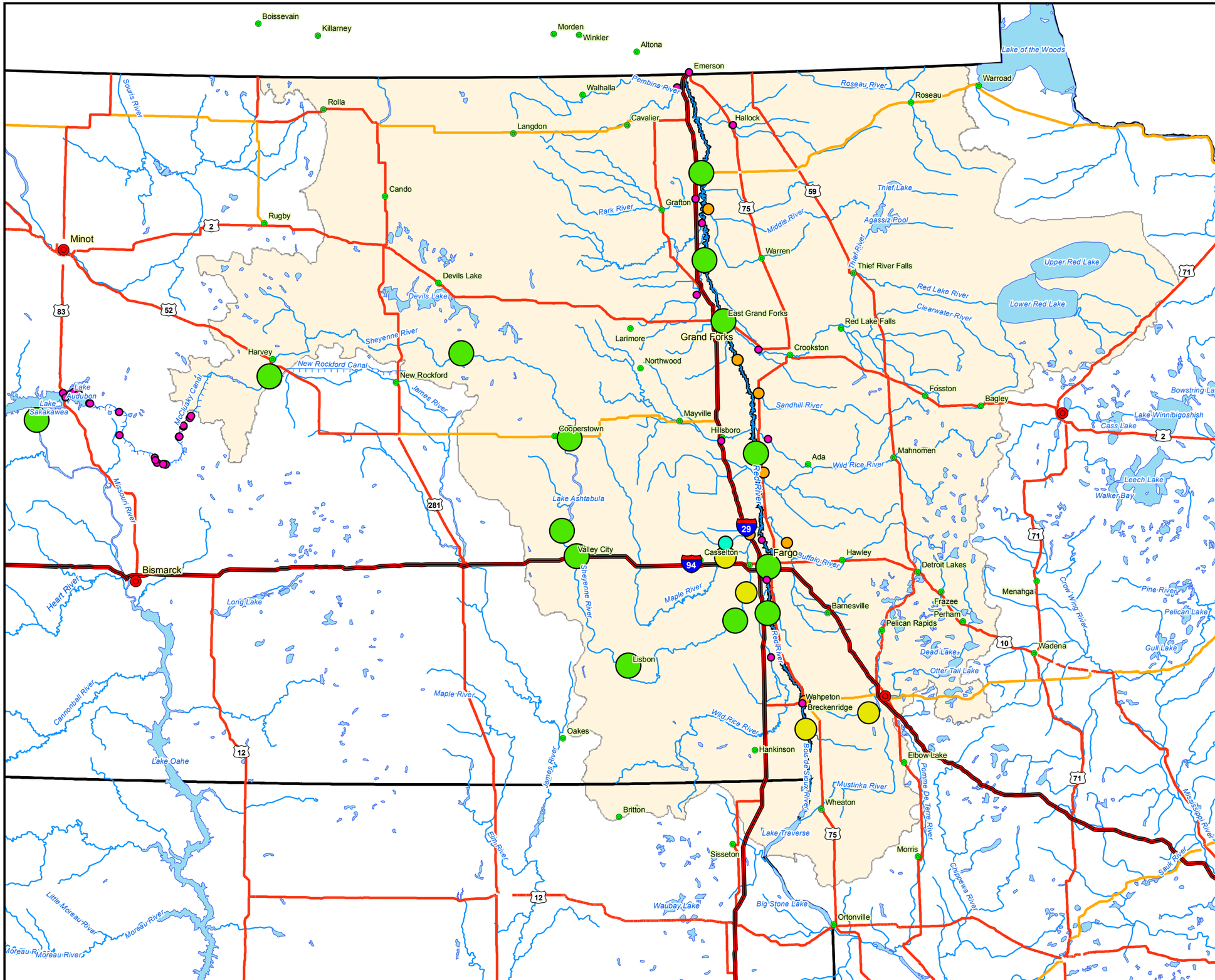


Appendix D: Fecal coliform bacteria sample size by LOCCODE		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U. S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Iron)

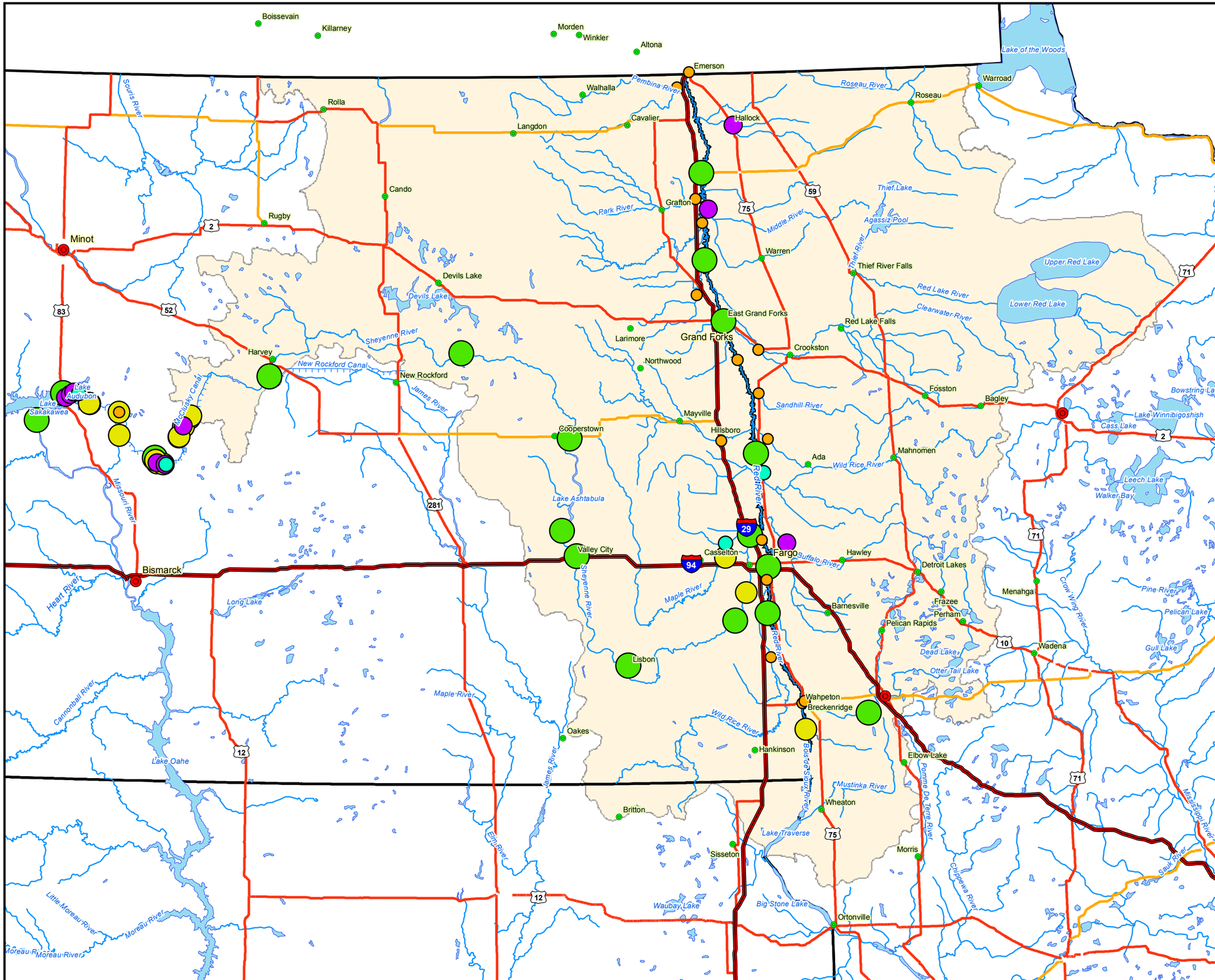


Appendix D: Iron sample size by LOCCODE

Notes:

Scale: As Shown	Project No: 3750-059	Date: 03/14/05

Red River Valley Water Supply Project (Magnesium)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

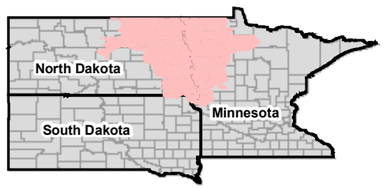
Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 69

N W E S

0 12.5 25 50 75 Miles

Location Map

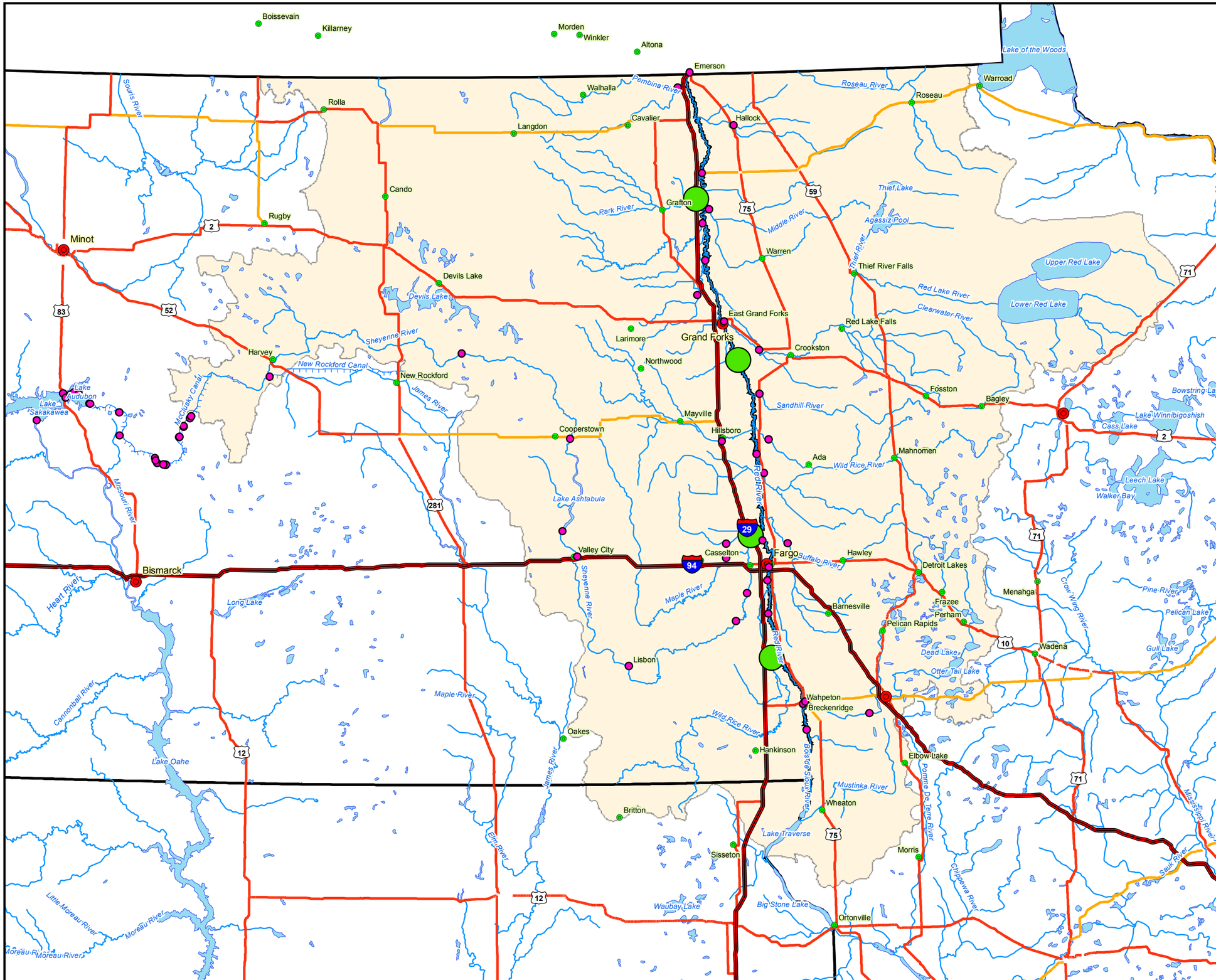


Appendix D: Magnesium sample size by LOCCODE		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U. S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

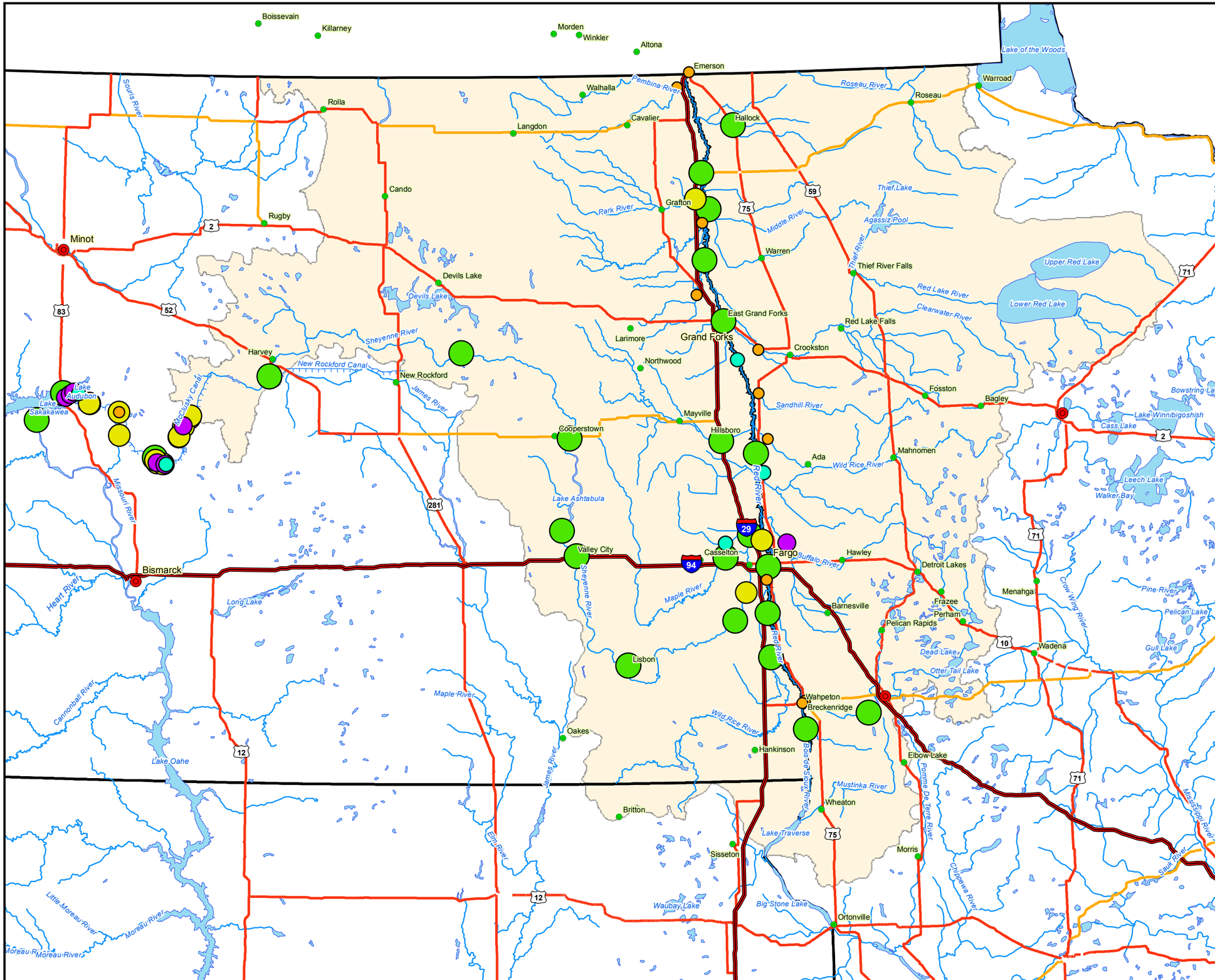
GARRISON DIVERSION

Red River Valley Water Supply Project (Nitrate Nitrogen)



Appendix D: Nitrate Nitrogen sample size by LOCCODE		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

Red River Valley Water Supply Project (Sulfate)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

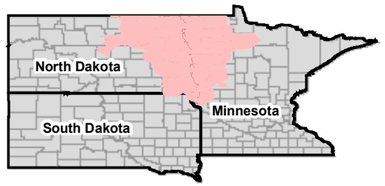
Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 69

N W E S

0 12.5 25 50 75 Miles

Location Map



Appendix D: Sulfate sample size by LOCCODE

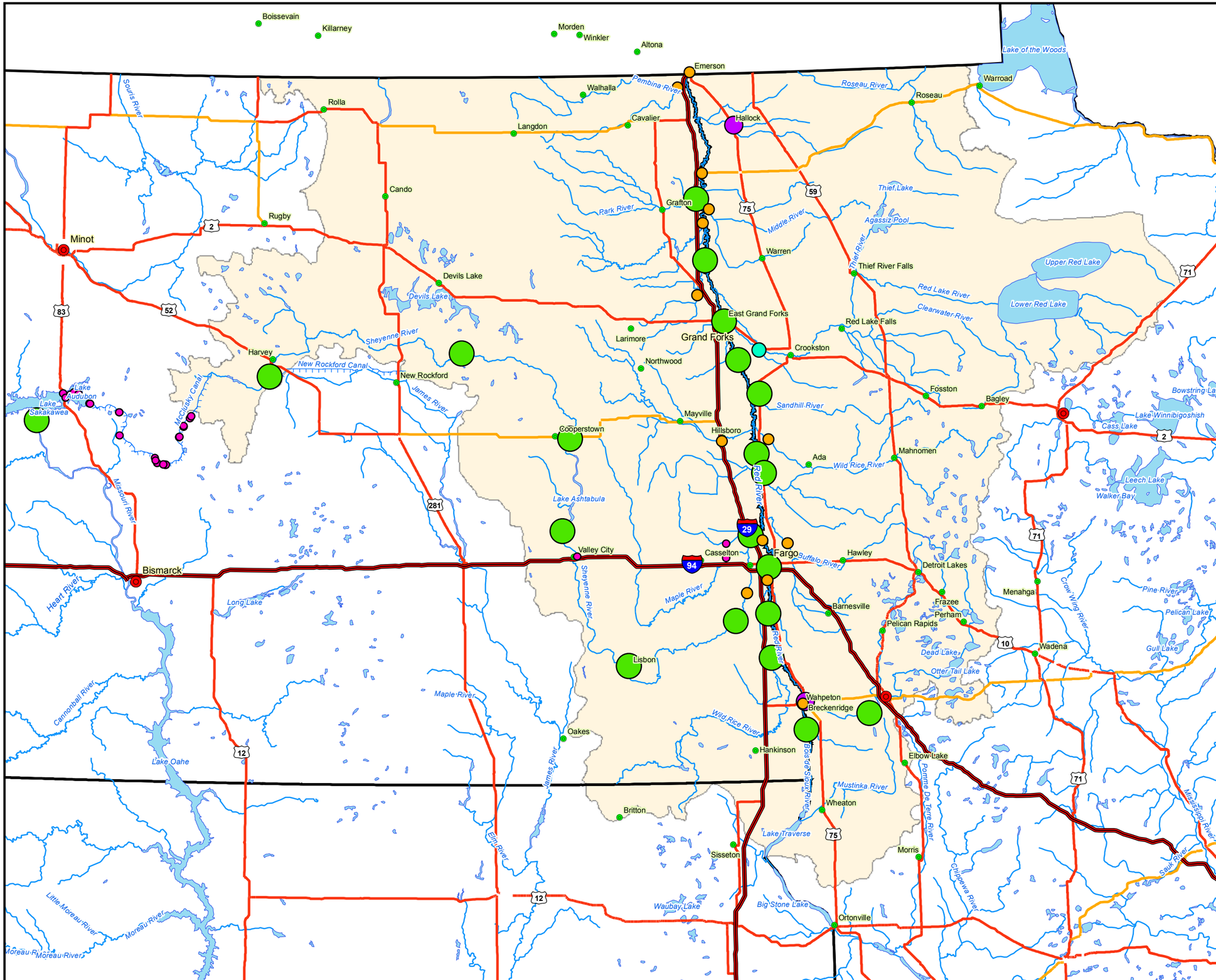
Notes:

Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U. S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Total Phosphorus)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

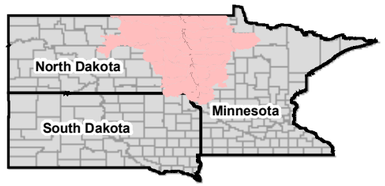
Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 241

N W E S

0 12.5 25 50 75 Miles

Location Map

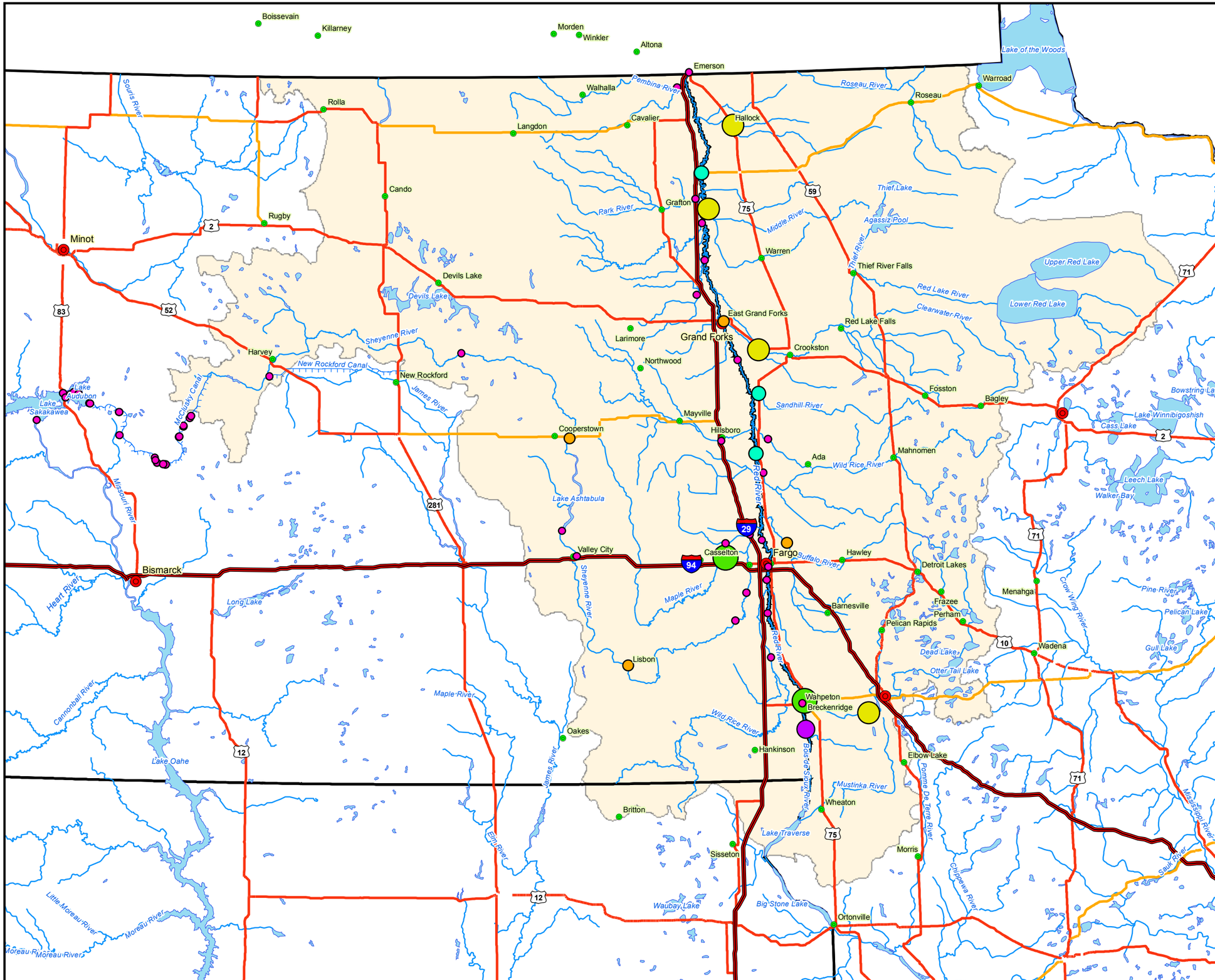


Appendix D: Total phosphorus sample size by LOCCODE		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U. S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Turbidity)

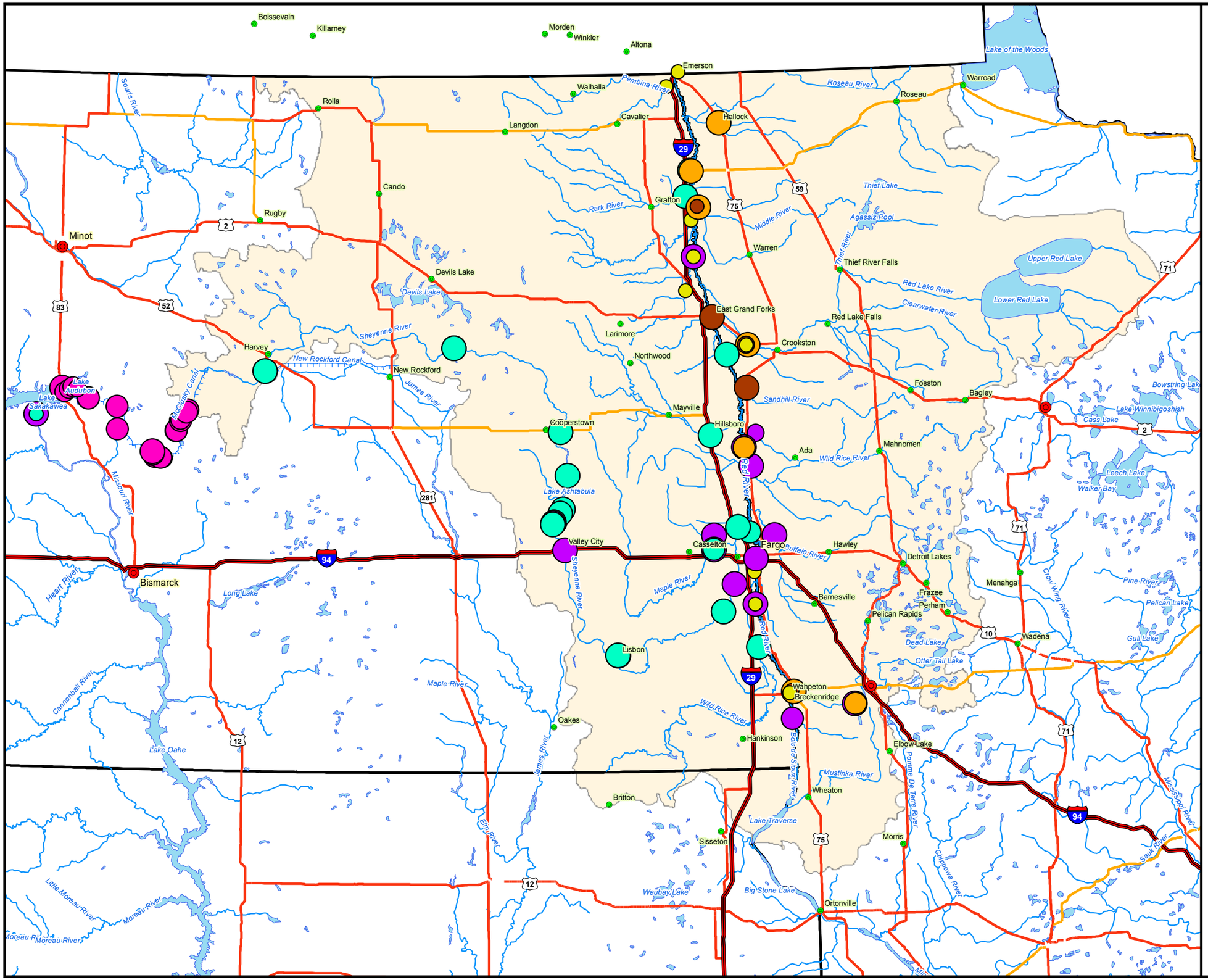


Appendix D: Turbidity sample size by LOCCODE		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

APPENDIX E

SAMPLE SIZE BY PARAMETER AND MONITORING LOCATION

Red River Valley Water Supply Project (Ammonia Nitrogen)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

Counts by Monitoring Location

Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 373

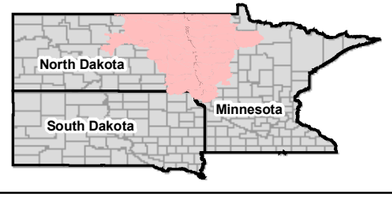
Station Type

- MCCLUSKY CANAL
- MN STORET
- ND STORET
- NWIS
- RIVERWATCH
- USGS SYNOPTIC

N W E S

0 12.5 25 50 75 Miles

Location Map

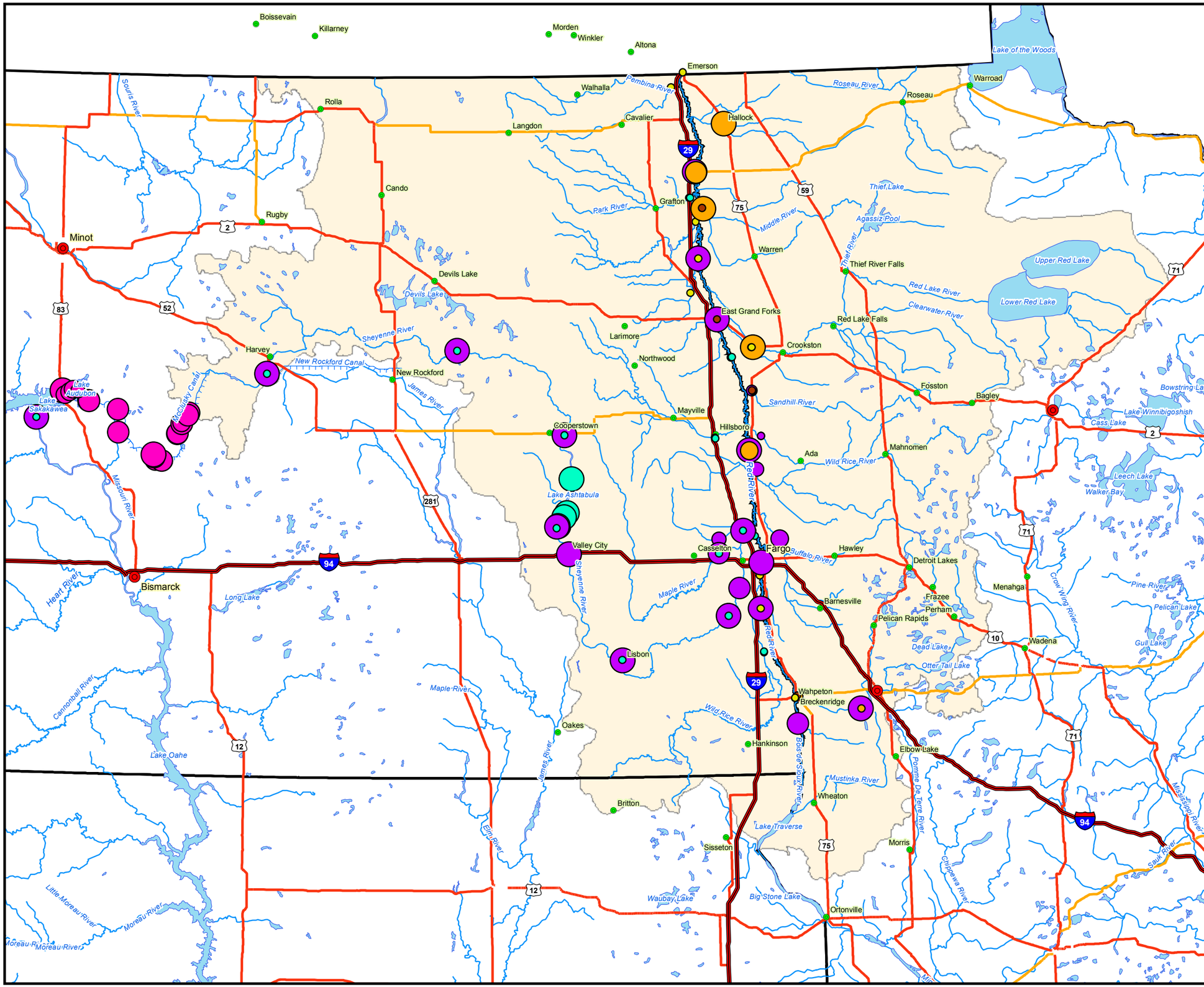


Appendix E: Ammonia nitrogen sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

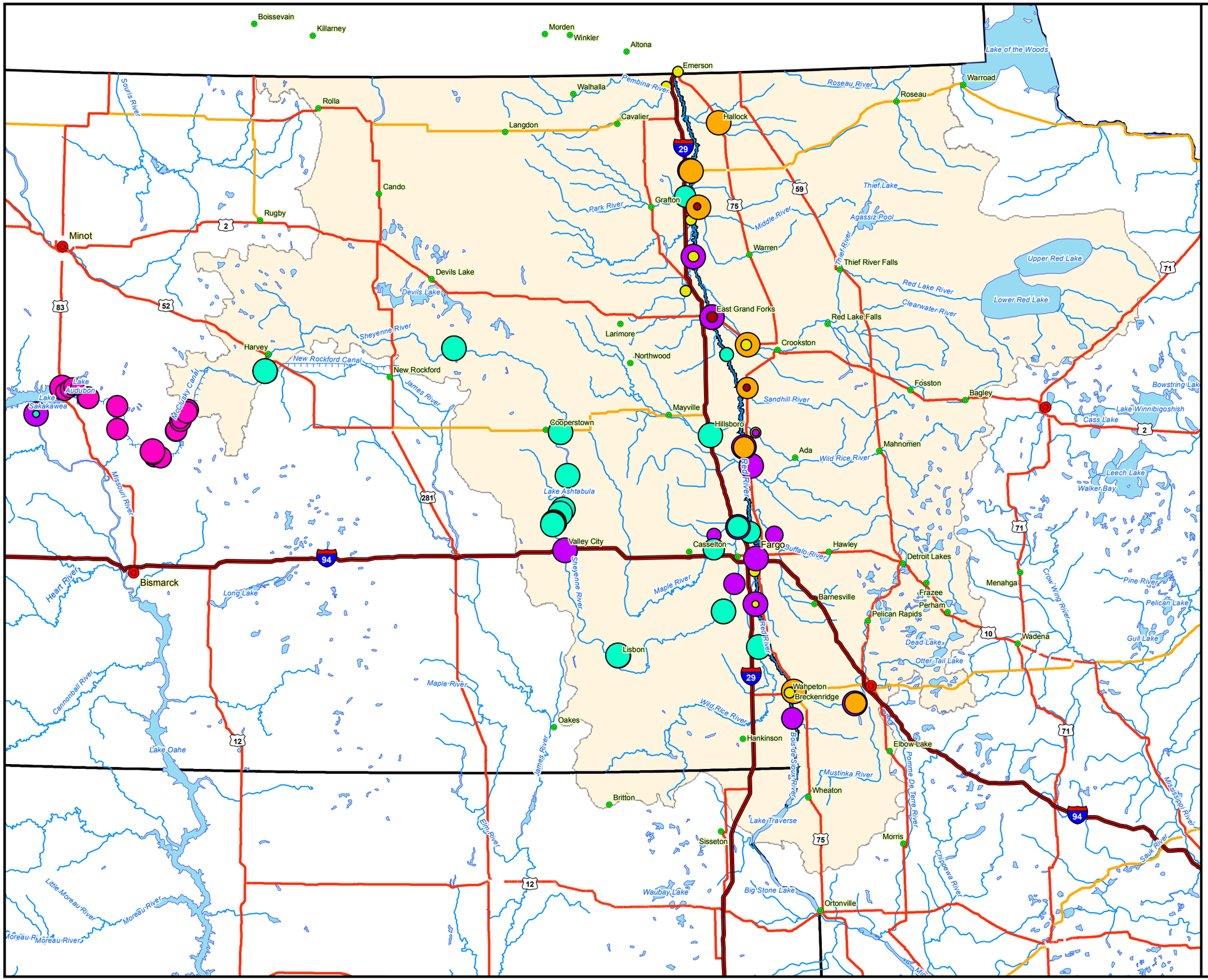
GARRISON DIVERSION

Red River Valley Water Supply Project (Calcium)



Appendix E: Calcium sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

Red River Valley Water Supply Project (Chloride)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

Counts by Monitoring Location

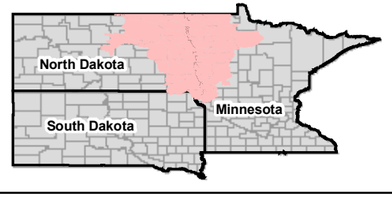
Sample Size
- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 373

Station Type
- MCCLUSKY CANAL
- MN STORET
- ND STORET
- NWIS
- RIVERWATCH
- USGS SYNOPTIC

N W E S

0 12.5 25 50 75 Miles

Location Map

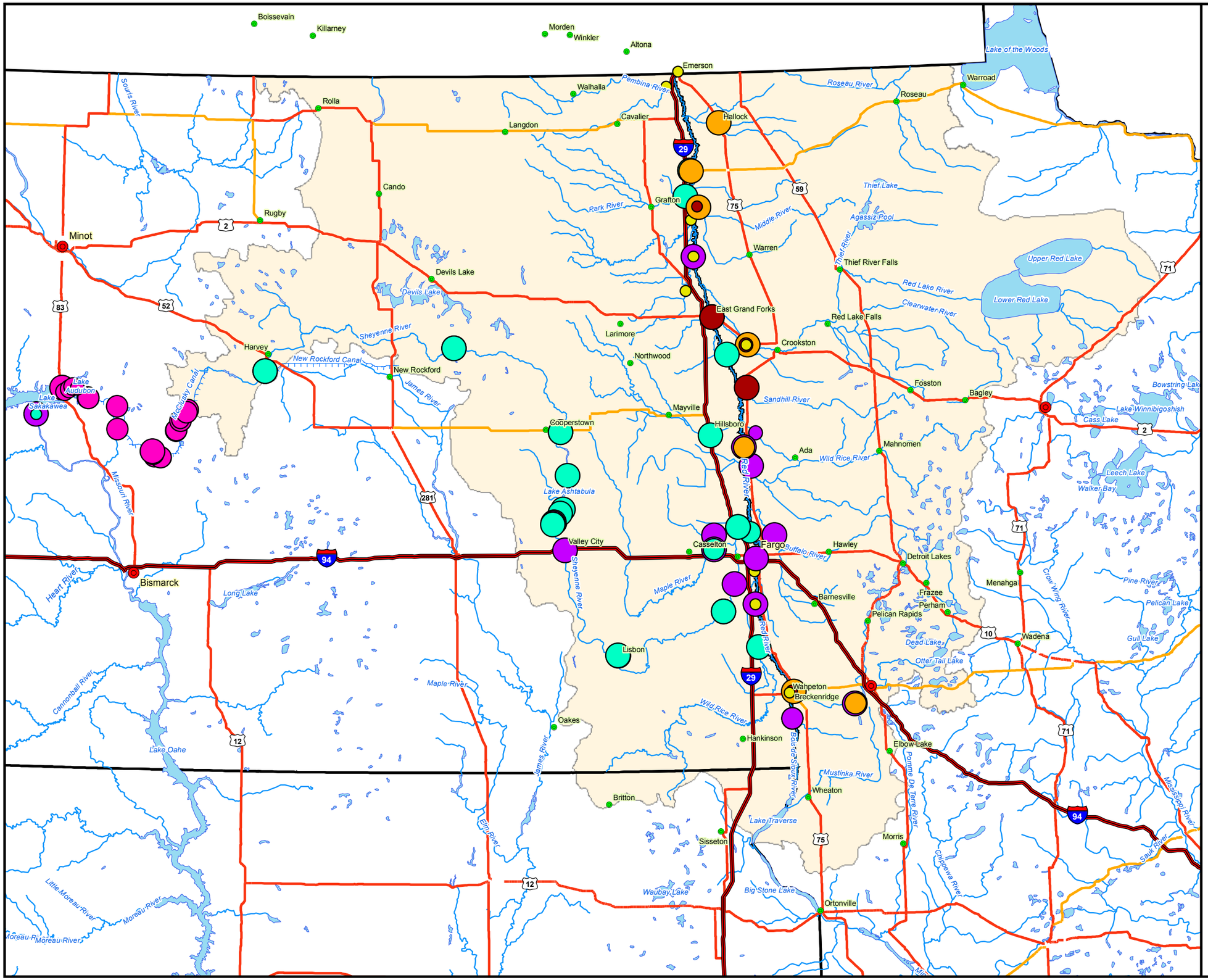


Appendix E: Chloride sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Dissolved Oxygen)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

Counts by Monitoring Location

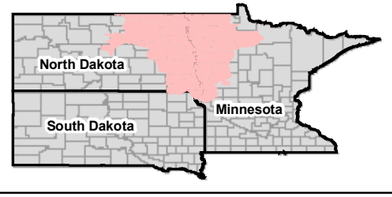
Sample Size
- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 373

Station Type
- MCCLUSKY CANAL
- MN STORET
- ND STORET
- NWIS
- RIVERWATCH
- USGS SYNOPTIC

N W E S

0 12.5 25 50 75 Miles

Location Map

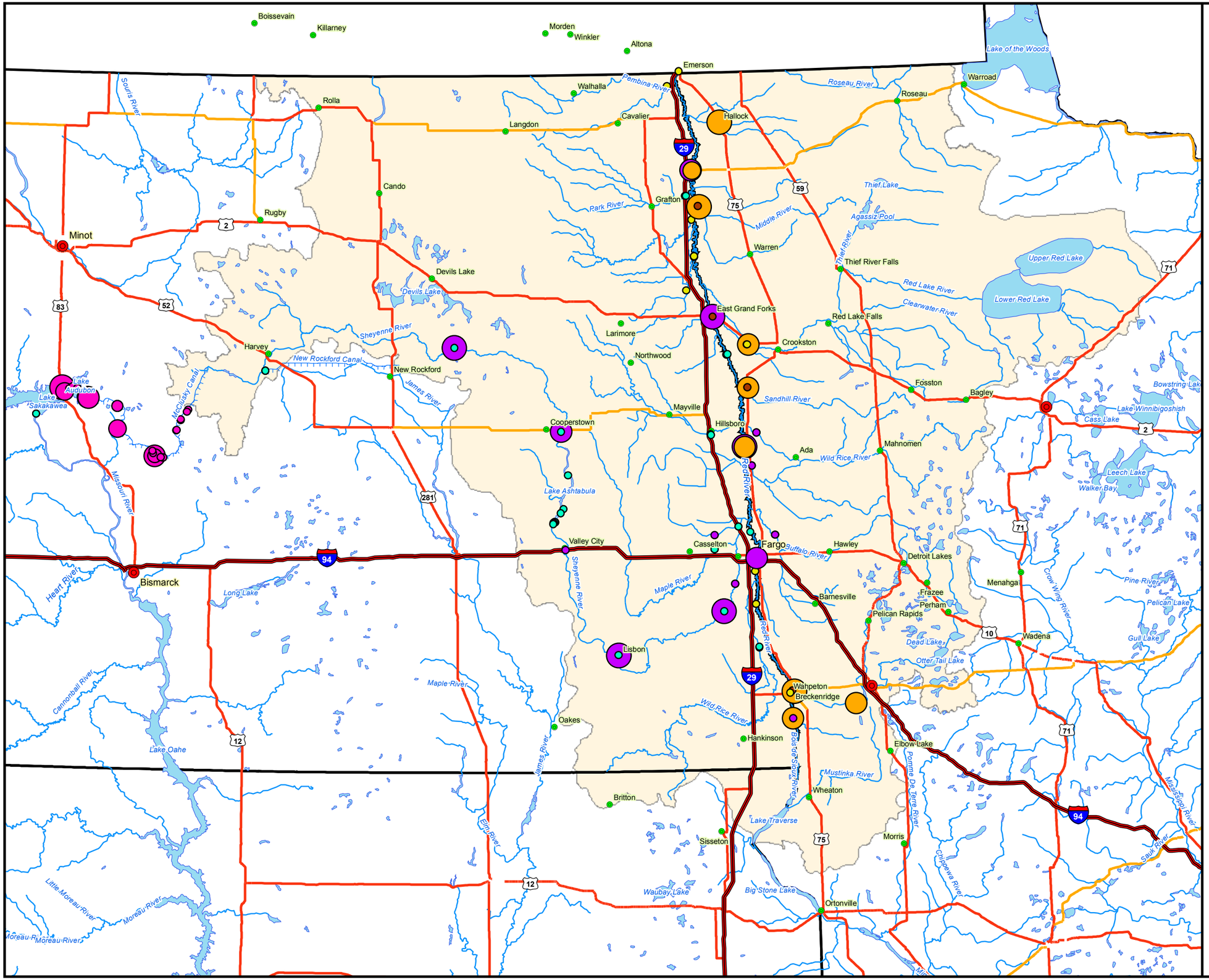


Appendix E: Dissolved oxygen sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Fecal Coliform)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

Counts by Monitoring Location

Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 373

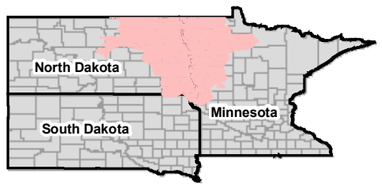
Station Type

- MCCLUSKY CANAL
- MN STORET
- ND STORET
- NWIS
- RIVERWATCH
- USGS SYNOPTIC

N W E S

0 12.5 25 50 75 Miles

Location Map

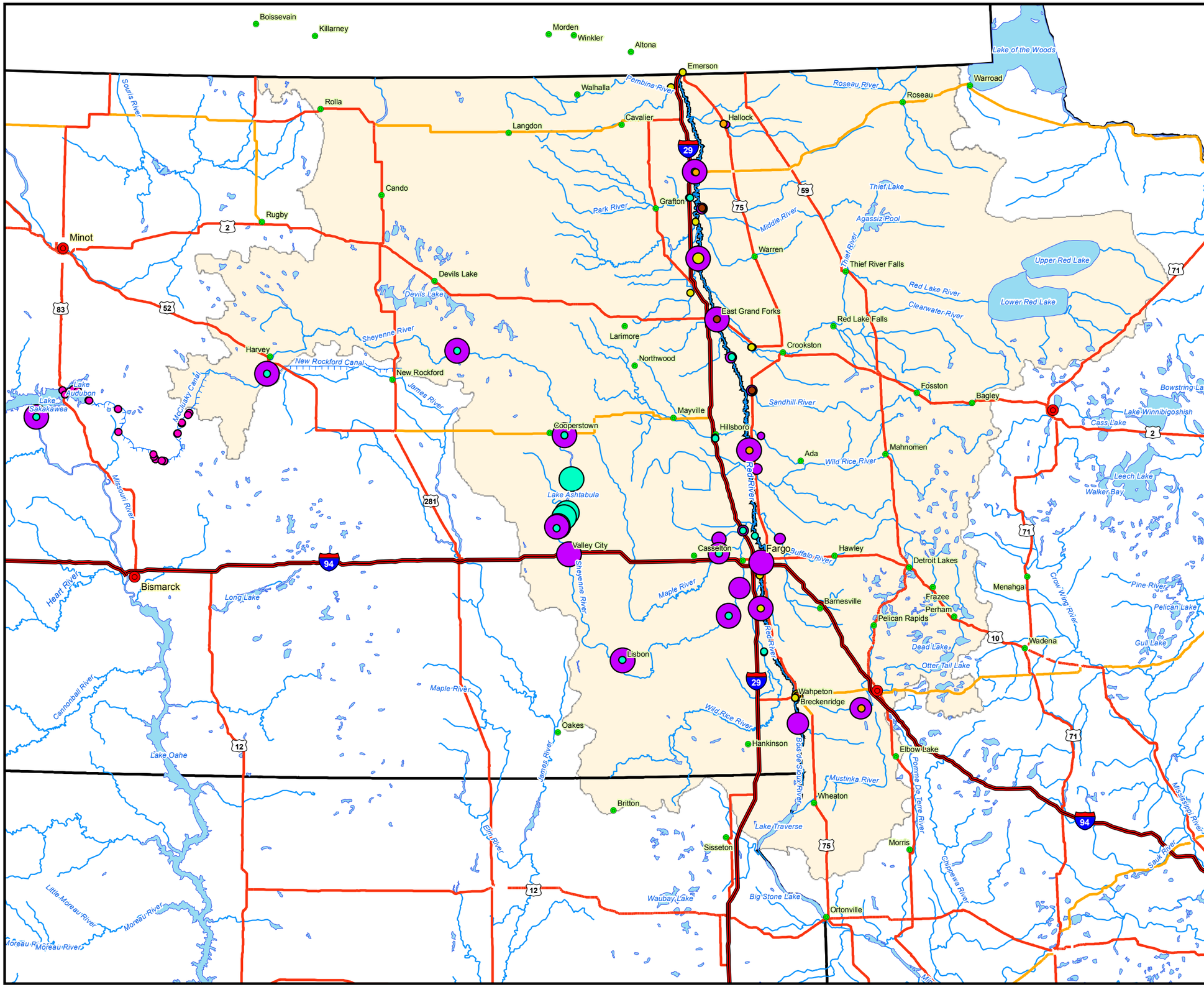


Appendix E: Fecal coliform sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U. S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Iron)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

Counts by Monitoring Location

Sample Size
- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 373

Station Type
- MCCLUSKY CANAL
- MN STORET
- ND STORET
- NWIS
- RIVERWATCH
- USGS SYNOPTIC

N W E S

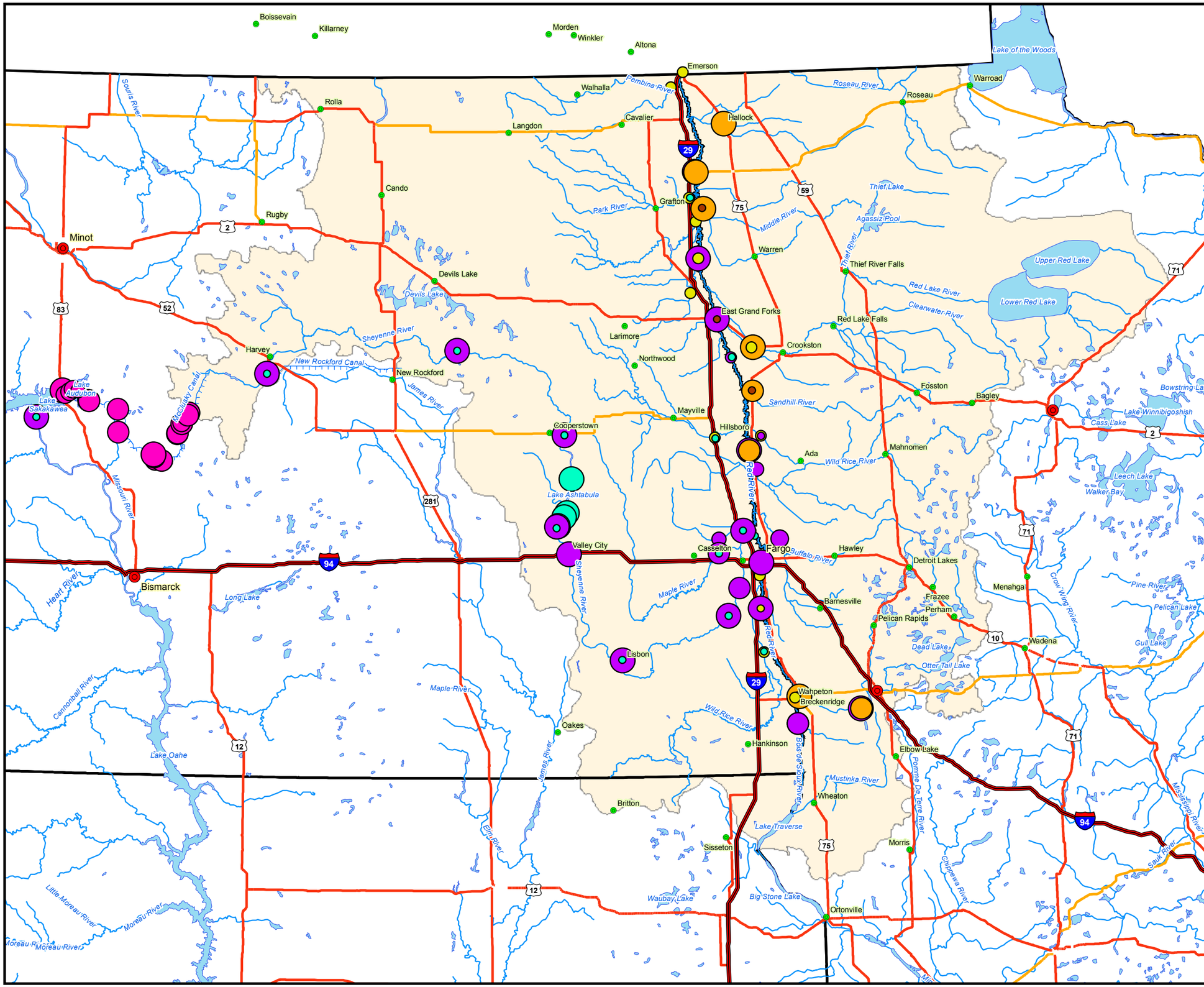
0 12.5 25 50 75 Miles

Appendix E: Iron sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Magnesium)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

Counts by Monitoring Location

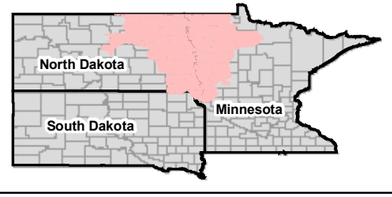
Sample Size
- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 373

Station Type
- MCCLUSKY CANAL
- MN STORET
- ND STORET
- NWIS
- RIVERWATCH
- USGS SYNOPTIC

N W E S

0 12.5 25 50 75 Miles

Location Map

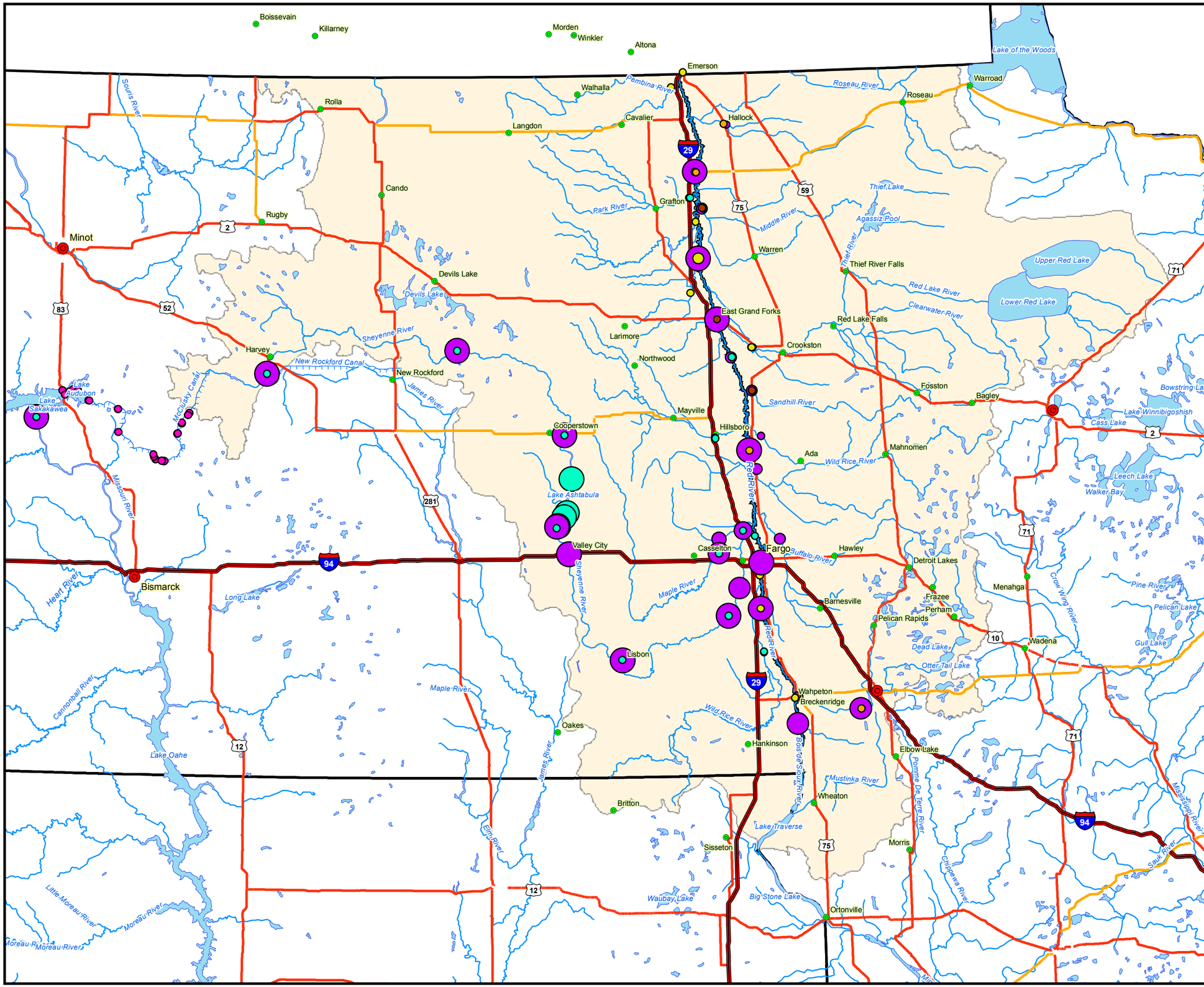


Appendix E: Magnesium sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

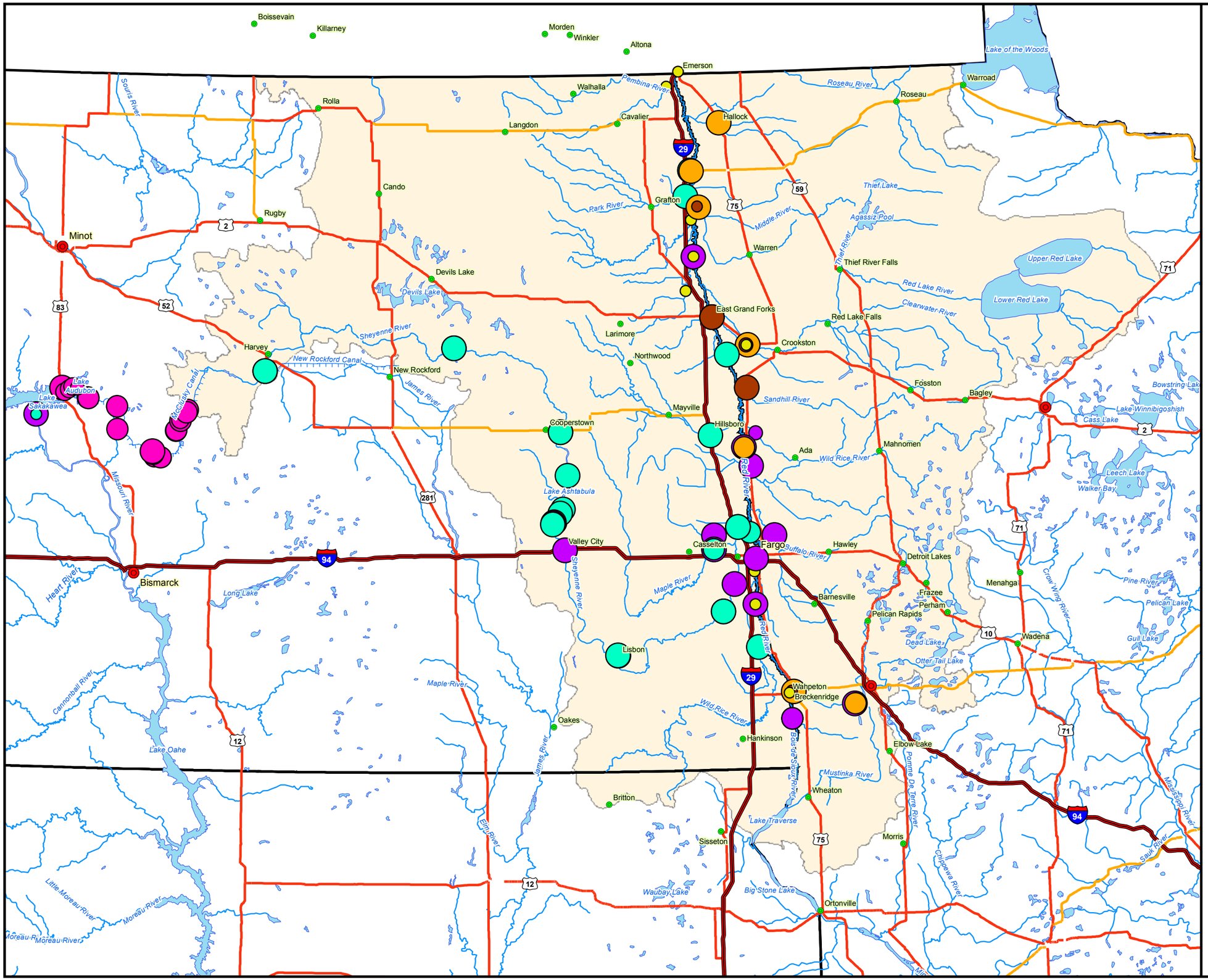
GARRISON DIVERSION

Red River Valley Water Supply Project (Manganese)

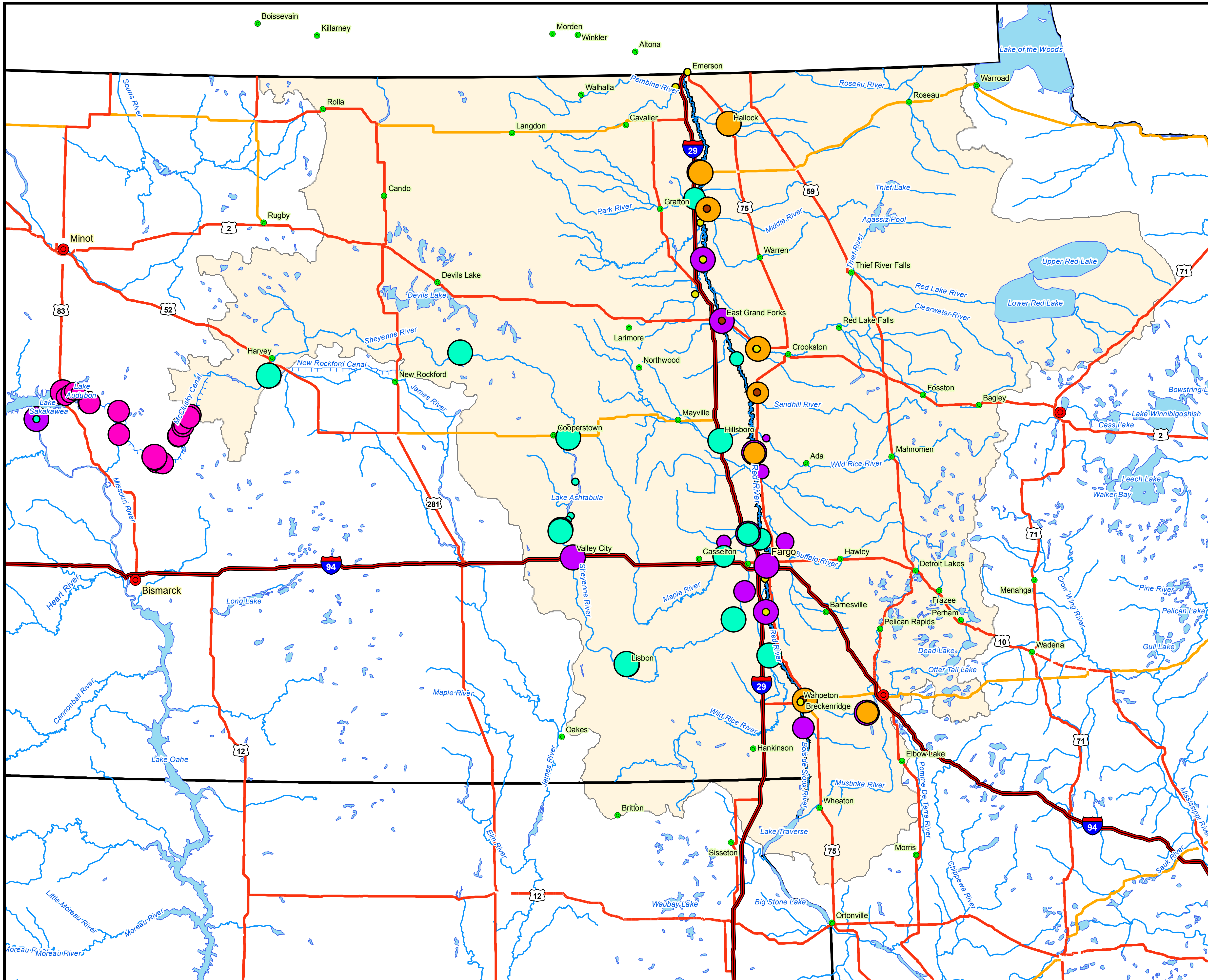


Appendix E: Manganese sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

Red River Valley Water Supply Project (Nitrate Nitrogen)



Appendix E: Nitrate nitrogen sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05



Red River Valley Water Supply Project (Sulfate)

Legend

Major Watershed Boundary	Interstate
Major City	US Highway
Intermediate City	State Highway
Lake or Resevoir	
Stream or River	
Major Canal	

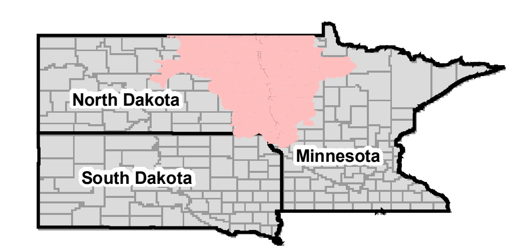
Counts by Monitoring Location

Sample Size	Station Type
0	MCCLUSKY CANAL
1 - 5	MN STORET
6 - 10	ND STORET
11 - 15	NWIS
16 - 30	RIVERWATCH
31 - 373	USGS SYNOPTIC

N
W E
S

0 12.5 25 50 75 Miles

Location Map



Appendix E: Sulfate sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U. S. DEPARTMENT OF THE INTERIOR
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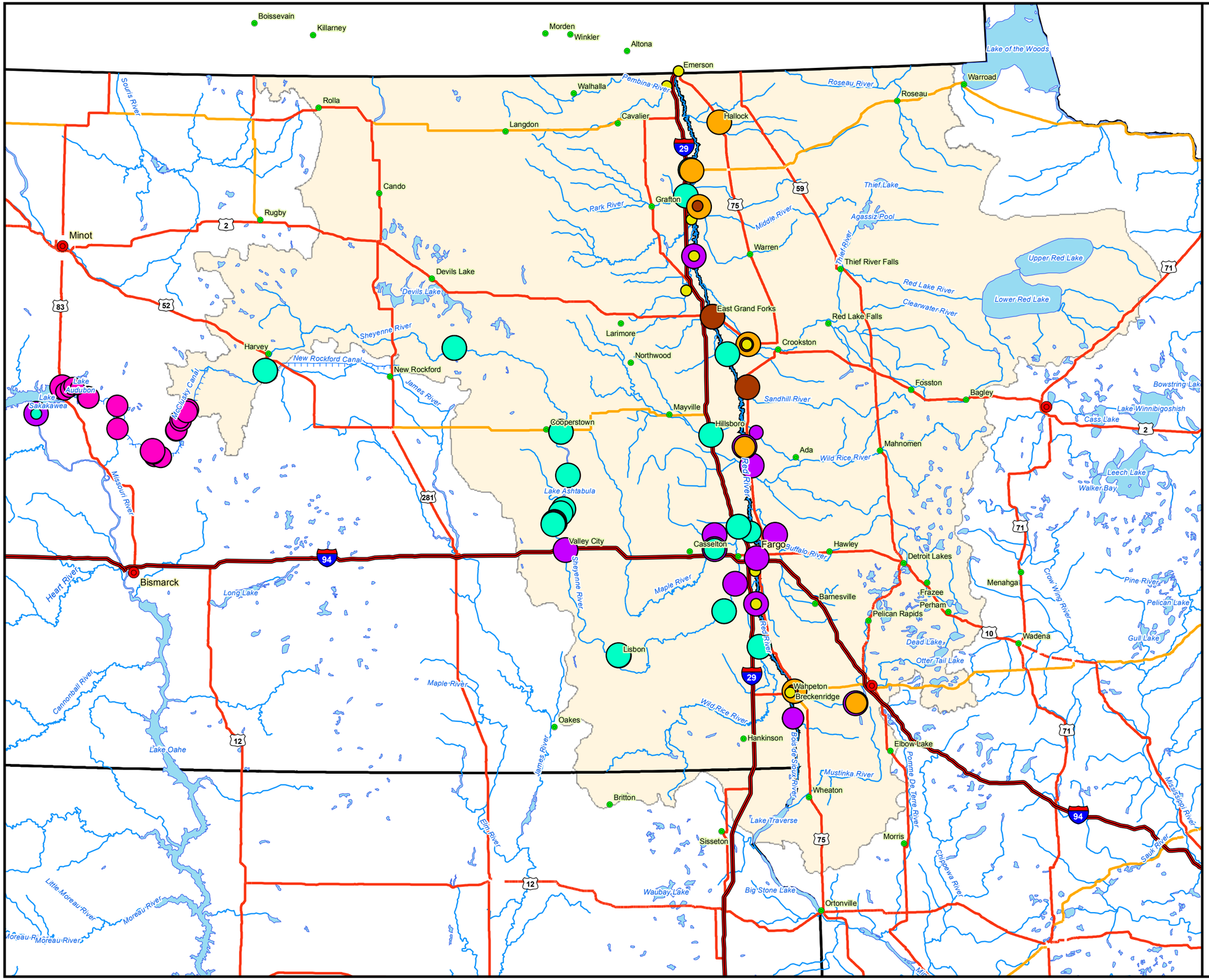
Red River Valley Water Supply Project (Total Phosphorus)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

Counts by Monitoring Location

Sample Size

- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 373

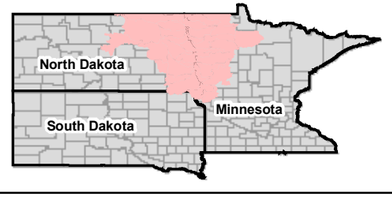
Station Type

- MCCLUSKY CANAL
- MN STORET
- ND STORET
- NWIS
- RIVERWATCH
- USGS SYNOPTIC

N W E S

0 12.5 25 50 75 Miles

Location Map

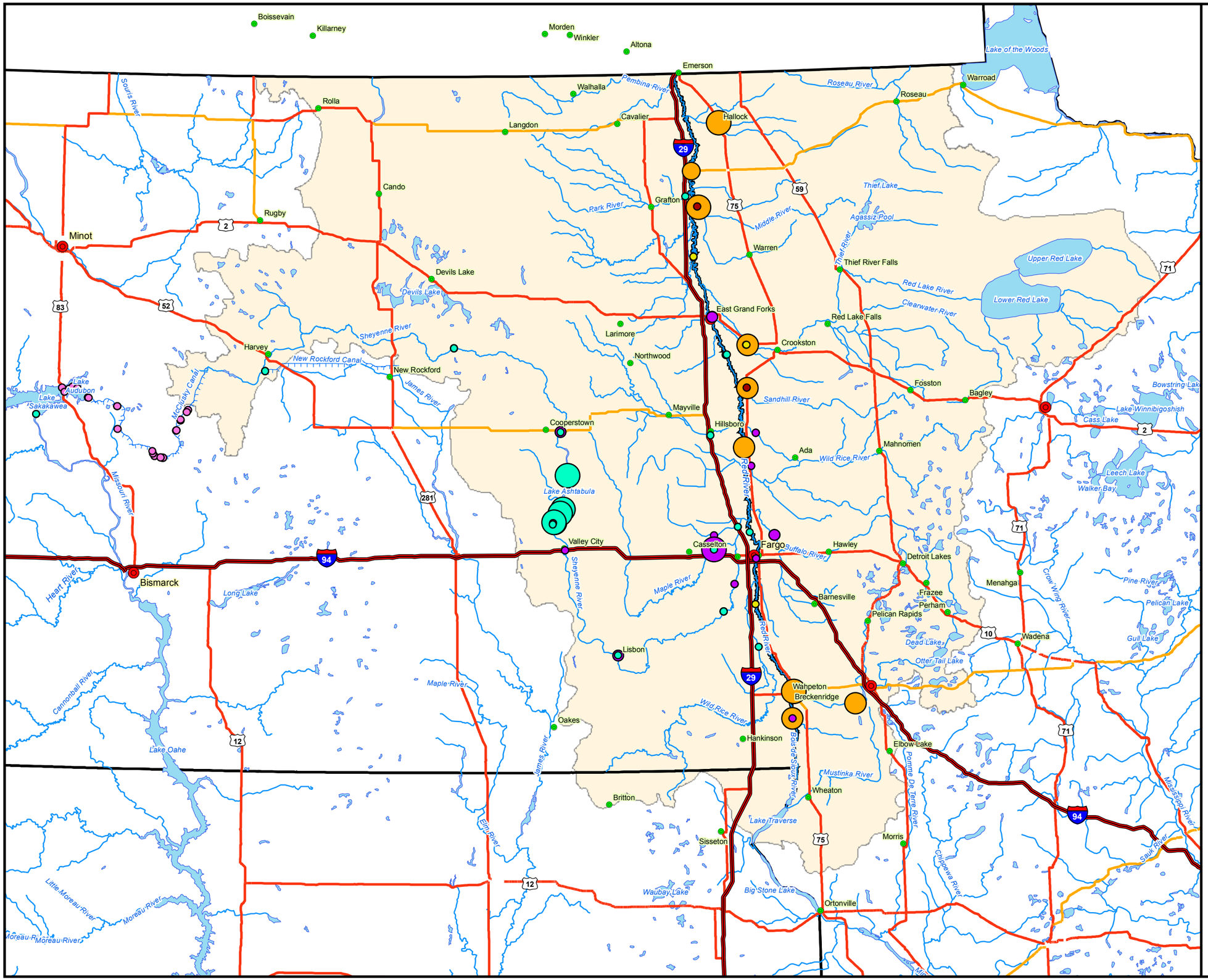


Appendix E: Total Phosphorus sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project (Turbidity)



Legend

- Major Watershed Boundary
- Major City
- Intermediate City
- Lake or Resevoir
- Stream or River
- Major Canal
- Interstate
- US Highway
- State Highway

Counts by Monitoring Location

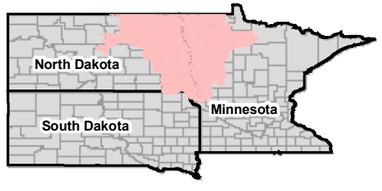
Sample Size
- 0
- 1 - 5
- 6 - 10
- 11 - 15
- 16 - 30
- 31 - 373

Station Type
- MCCLUSKY CANAL
- MN STORET
- ND STORET
- NWIS
- RIVERWATCH
- USGS SYNOPTIC

N W E S

0 12.5 25 50 75 Miles

Location Map



Appendix E: Turbidity sample size by monitoring location		
Notes:		
Scale: As Shown	Project No: 3750-059	Date: 03/14/05

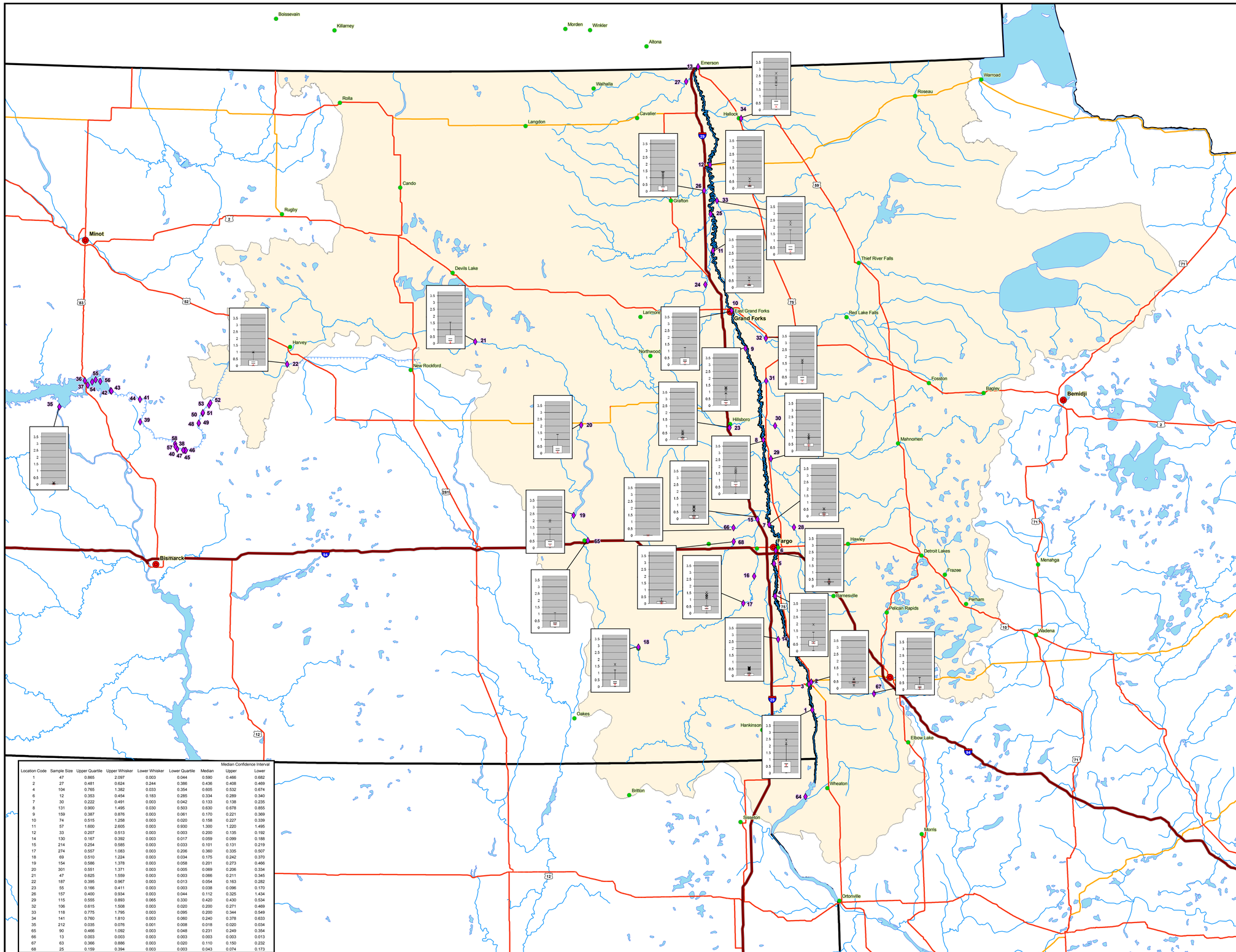
U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

APPENDIX F

MODIFIED BOX PLOTS
BY LOCCODE

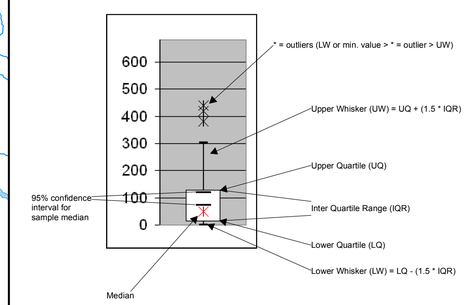
Red River Valley Water Supply Project



Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Notched Box Plot for Ammonia Nitrogen (mg/L)



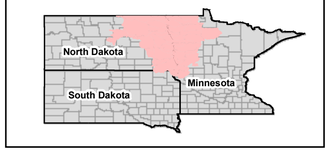
Note: Location codes with less than 10 data points not charted

Data are for LOCCODES;
i.e. may be from 2 or more stations

N
W E
S

0 10 20 40 60 Miles

Location Map



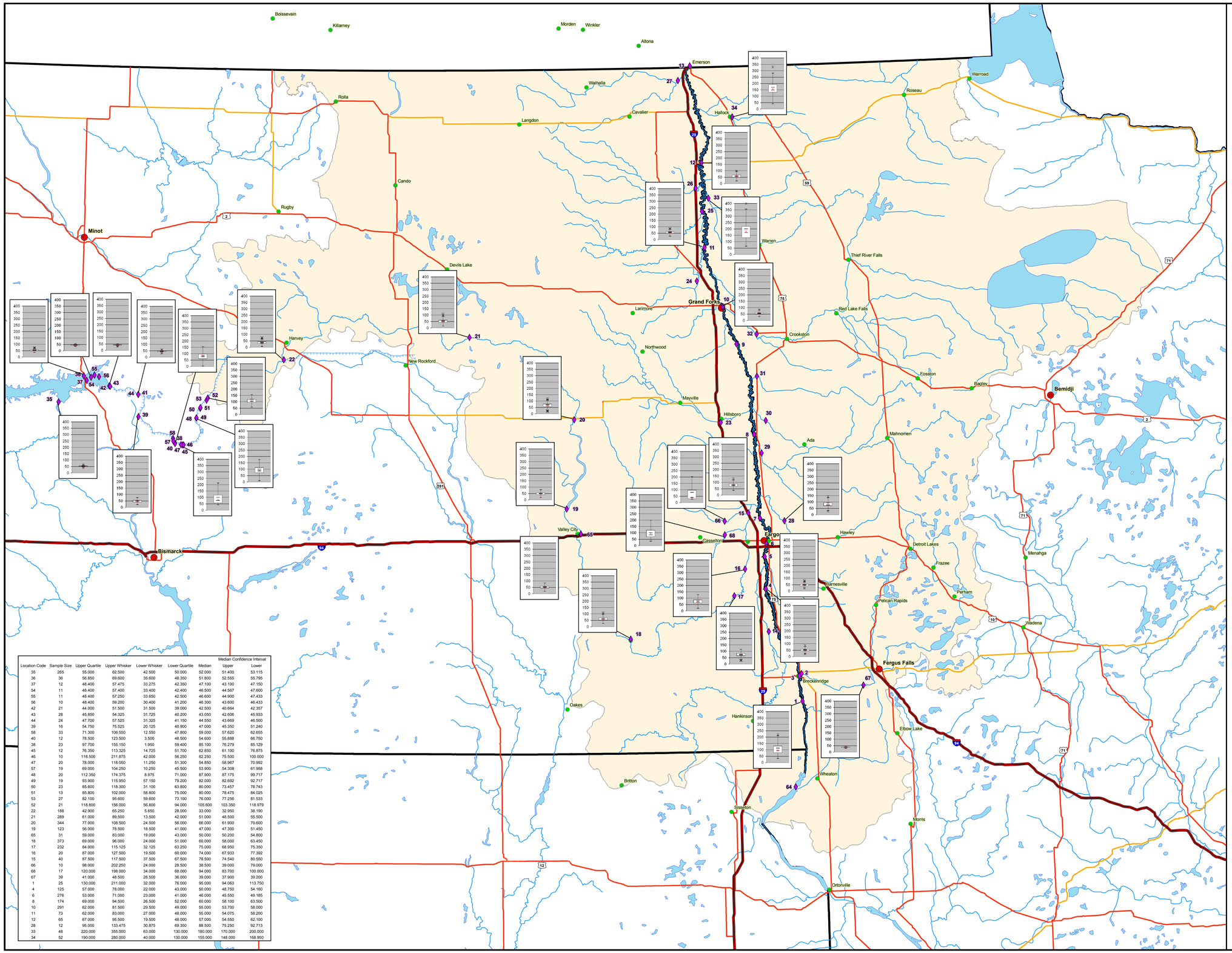
Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
1	47	0.865	2.097	0.003	0.044	0.590	0.466	0.682
2	27	0.481	0.624	0.244	0.386	0.436	0.408	0.469
4	104	0.765	1.382	0.033	0.354	0.605	0.532	0.674
6	12	0.353	0.454	0.183	0.285	0.334	0.289	0.340
7	30	0.222	0.491	0.003	0.042	0.133	0.138	0.235
8	131	0.900	1.495	0.030	0.503	0.630	0.678	0.855
9	159	0.387	0.876	0.003	0.061	0.170	0.221	0.369
10	74	0.515	1.258	0.003	0.020	0.158	0.227	0.339
11	57	1.600	2.605	0.003	0.930	1.300	1.220	1.495
12	33	0.207	0.513	0.003	0.003	0.200	0.135	0.192
14	130	0.167	0.392	0.003	0.017	0.059	0.099	0.188
15	214	0.254	0.585	0.003	0.033	0.101	0.131	0.219
17	274	0.557	1.083	0.003	0.206	0.360	0.335	0.507
18	69	0.510	1.224	0.003	0.034	0.175	0.242	0.370
19	154	0.586	1.378	0.003	0.058	0.201	0.273	0.466
20	301	0.551	1.371	0.003	0.005	0.069	0.206	0.334
21	47	0.625	1.559	0.003	0.003	0.066	0.211	0.345
22	187	0.395	0.967	0.003	0.013	0.054	0.163	0.282
23	55	0.166	0.411	0.003	0.003	0.038	0.096	0.170
26	157	0.400	0.934	0.003	0.044	0.112	0.325	1.434
29	115	0.555	0.893	0.065	0.330	0.420	0.430	0.534
32	106	0.615	1.508	0.003	0.020	0.200	0.271	0.469
33	118	0.775	1.795	0.003	0.095	0.200	0.344	0.549
34	141	0.760	1.810	0.003	0.060	0.240	0.378	0.633
35	212	0.035	0.076	0.001	0.008	0.018	0.020	0.034
65	90	0.466	1.092	0.003	0.048	0.231	0.249	0.354
66	13	0.003	0.003	0.003	0.003	0.003	0.003	0.013
67	63	0.366	0.886	0.003	0.020	0.110	0.150	0.232
68	25	0.159	0.394	0.003	0.003	0.043	0.074	0.173

Appendix F: Ammonia nitrogen modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION



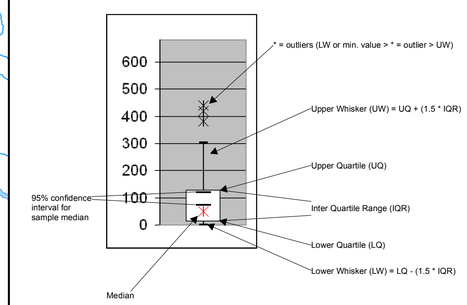
Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
35	265	55.000	62.500	42.500	50.000	52.000	51.400	53.115
36	36	56.850	69.600	35.600	48.350	51.800	52.555	55.795
37	12	48.400	57.475	33.275	42.350	47.100	43.100	47.150
54	11	48.400	57.400	33.400	42.400	46.500	44.567	47.600
55	11	48.400	57.250	33.650	42.500	46.600	44.900	47.433
56	10	48.400	59.200	30.400	41.200	46.300	43.600	46.433
42	21	44.000	51.500	31.500	39.000	42.500	40.664	42.357
43	28	45.850	54.325	31.725	40.200	43.050	42.606	45.933
44	24	47.700	57.525	31.325	41.150	44.550	43.669	46.500
39	16	54.750	75.525	20.125	40.900	47.000	45.350	51.240
58	33	71.300	106.550	12.550	47.800	59.000	57.620	62.655
40	12	78.500	123.500	3.500	48.500	54.600	55.888	66.750
38	23	97.700	155.150	1.950	59.400	85.100	76.279	85.129
45	12	76.350	113.325	14.725	51.700	62.850	61.100	76.875
46	10	118.500	211.875	42.000	56.250	82.250	75.500	100.000
47	20	78.000	118.050	11.250	51.300	54.850	58.967	70.992
57	19	69.000	104.250	10.250	45.500	53.900	54.308	61.958
48	20	112.350	174.375	8.975	71.000	87.900	87.175	99.717
49	19	93.900	115.950	57.150	79.200	82.000	82.692	92.717
50	23	85.600	118.300	31.100	63.800	80.000	73.457	78.743
51	13	85.800	102.000	58.800	75.000	80.000	78.475	84.025
53	27	82.100	95.600	59.600	73.100	76.000	77.256	81.533
52	21	118.800	156.000	56.800	94.000	105.600	103.350	118.979
22	188	42.900	65.250	5.650	28.000	33.000	32.950	38.190
21	289	61.000	89.500	13.500	42.000	51.000	48.500	55.500
20	344	77.000	108.500	24.500	56.000	66.000	61.900	70.600
19	123	56.000	78.500	18.500	41.000	47.000	47.300	51.450
65	31	59.000	83.000	19.000	43.000	50.000	50.200	54.800
18	373	69.000	96.000	24.000	51.000	60.000	58.000	63.450
17	232	84.000	115.125	32.125	63.250	75.000	68.950	75.350
16	20	87.000	127.500	19.500	60.000	74.000	67.933	77.392
15	40	87.500	117.500	37.500	67.500	78.500	74.540	80.550
66	10	98.000	202.250	24.000	28.500	38.500	39.000	79.000
68	17	120.000	198.000	34.000	68.000	94.000	83.700	100.000
67	39	41.000	48.500	28.500	36.000	39.000	37.900	39.200
1	25	130.000	211.000	32.000	76.000	95.000	94.063	113.750
4	125	57.000	78.000	22.000	43.000	50.000	48.750	54.160
6	276	53.000	71.000	23.000	41.000	46.000	45.550	49.185
8	174	69.000	94.500	26.500	52.000	60.000	58.100	63.500
10	291	62.000	81.500	29.500	49.000	55.000	53.700	58.000
11	73	62.000	83.000	27.000	48.000	55.000	54.075	58.200
12	65	67.000	95.500	19.500	48.000	57.000	54.550	62.100
28	12	95.000	133.475	30.875	69.350	88.500	75.250	92.713
33	48	220.000	355.000	63.000	130.000	180.000	170.000	200.000
34	52	190.000	280.000	40.000	130.000	155.000	148.000	168.950

Red River Valley Water Supply Project

Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Notched Box Plot for Calcium (mg/L)



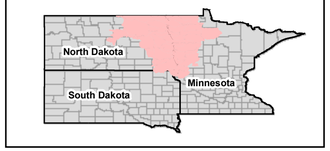
Note: Location codes with less than 10 data points not charted

Data are for LOCCODES;
i.e. may be from 2 or more stations

N
W E
S

0 10 20 40 60 Miles

Location Map



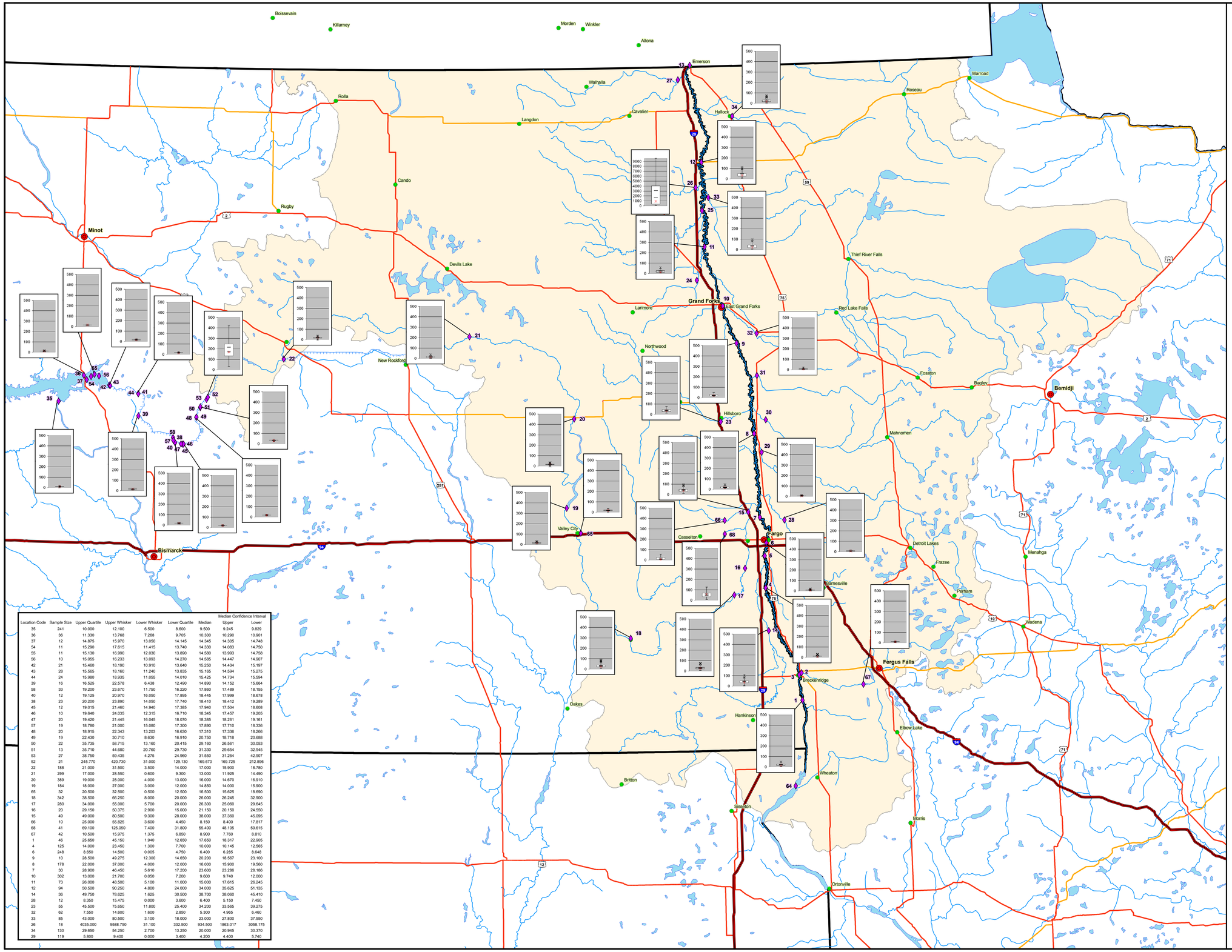
Appendix F: Calcium modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

Red River Valley Water Supply Project

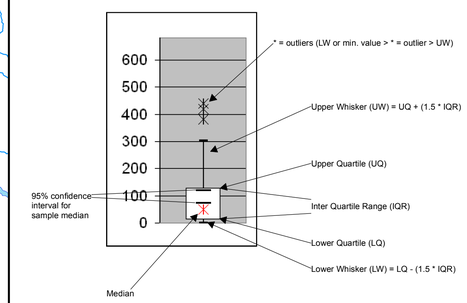


Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
35	241	10.000	12.100	6.500	8.600	9.500	9.245	9.829
36	36	11.330	13.768	7.268	9.705	10.300	10.290	10.901
37	12	14.875	15.970	13.050	14.145	14.345	14.305	14.748
54	11	15.290	17.615	11.415	13.740	14.330	14.083	14.750
55	11	15.130	16.990	12.030	13.890	14.580	13.993	14.758
56	10	15.055	16.233	13.093	14.270	14.585	14.447	14.907
42	21	15.460	18.190	10.910	13.640	15.250	14.404	15.197
43	28	15.565	18.160	11.240	13.835	15.165	14.594	15.275
44	24	15.980	18.935	11.055	14.010	15.425	14.704	15.594
39	16	16.525	22.578	6.438	12.490	14.890	14.152	15.664
58	33	19.200	23.670	11.750	16.220	17.860	17.489	18.155
40	12	19.125	20.970	16.050	17.895	18.445	17.999	18.678
38	23	20.200	23.890	14.050	17.740	18.410	18.412	19.289
45	12	19.015	21.460	14.940	17.385	17.940	17.504	18.608
46	10	19.640	24.035	12.315	16.710	18.345	17.457	19.205
47	20	19.420	21.445	16.045	18.070	18.385	18.261	19.161
57	19	18.780	21.000	15.080	17.300	17.890	17.710	18.336
48	20	18.915	22.343	13.203	16.630	17.310	17.336	18.266
49	19	22.430	30.710	8.630	16.910	20.750	18.718	20.688
50	22	35.735	58.715	13.160	20.415	29.160	26.561	30.053
51	13	35.710	44.680	20.760	29.730	31.330	29.654	32.945
53	27	38.750	59.435	4.275	24.960	31.550	31.264	42.907
52	21	245.770	420.730	31.000	129.130	169.670	169.725	212.896
22	188	21.000	31.500	3.500	14.000	17.000	15.900	18.780
21	299	17.000	28.550	0.600	9.300	13.000	11.925	14.490
20	389	19.000	28.000	4.000	13.000	16.000	14.670	16.910
19	184	18.000	27.000	3.000	12.000	14.850	14.000	15.900
65	32	20.500	32.500	0.500	12.500	16.500	15.625	18.690
18	342	38.500	66.250	8.000	20.000	26.000	26.245	32.900
17	280	34.000	55.000	5.700	20.000	26.300	25.060	29.645
16	20	29.150	50.375	2.900	15.000	21.150	20.150	24.550
15	49	49.000	80.500	9.300	28.000	38.000	37.360	45.095
66	10	25.000	55.825	3.600	4.450	8.150	8.400	17.817
68	41	69.100	125.050	7.400	31.800	55.400	48.105	59.615
67	42	10.500	15.975	1.375	6.850	8.900	7.760	8.810
1	46	25.650	45.150	1.940	12.650	17.650	18.317	22.905
4	125	14.000	23.450	1.300	7.700	10.000	10.145	12.565
6	248	8.650	14.500	0.005	4.750	6.400	6.285	8.648
9	10	28.500	49.275	12.300	14.650	20.200	18.567	23.100
8	178	22.000	37.000	4.000	12.000	16.000	15.900	19.560
7	30	28.900	46.450	5.610	17.200	23.600	23.286	28.186
10	302	13.000	21.700	0.050	7.200	9.600	9.740	12.000
11	73	26.000	48.500	5.100	11.000	15.000	17.615	26.245
12	94	50.500	90.250	4.800	24.000	34.000	35.625	51.135
14	36	49.750	78.625	1.625	30.500	38.700	38.060	45.410
28	12	8.350	15.475	0.000	3.600	6.400	5.150	7.450
23	55	45.500	75.650	11.800	25.400	34.200	33.565	39.275
32	62	7.550	14.600	1.600	2.850	5.300	4.965	6.460
33	85	43.000	80.500	3.100	18.000	23.000	27.800	37.550
26	18	4035.000	9588.750	31.100	332.500	934.500	1863.017	3058.175
34	130	29.650	54.250	2.700	13.250	20.000	20.945	30.370
29	119	5.800	9.400	0.000	3.400	4.200	4.400	5.740

Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Notched Box Plot for Chloride (mg/L)



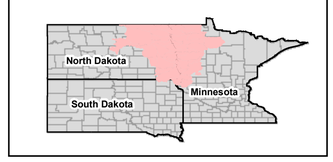
Note: Location codes with less than 10 data points not charted

Data are for LOCCODES;
i.e. may be from 2 or more stations

N W E S

0 10 20 40 60 Miles

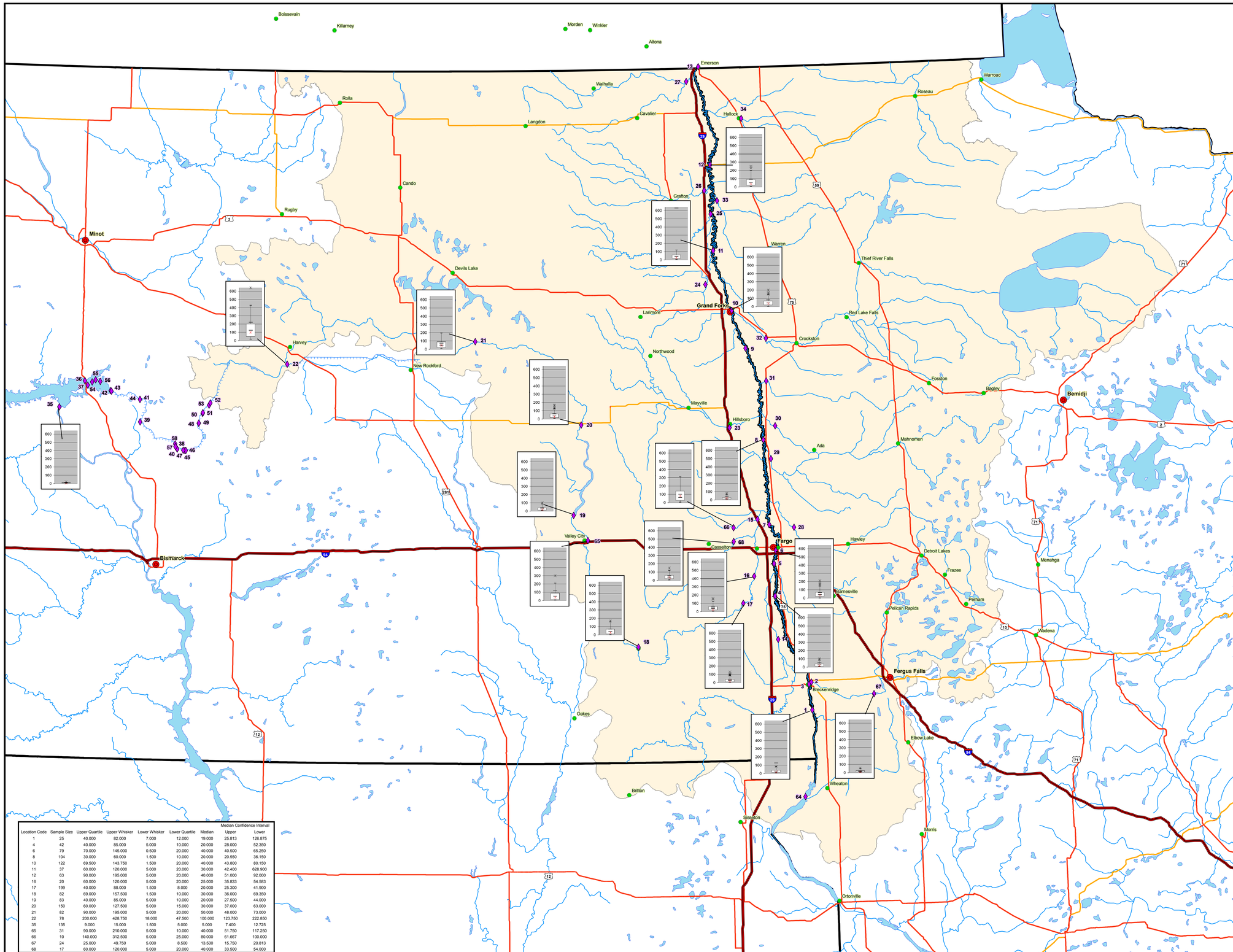
Location Map



Appendix F: Chloride modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

Red River Valley Water Supply Project



Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
1	25	40.000	82.000	7.000	12.000	19.000	25.813	126.875
4	42	40.000	85.000	5.000	10.000	20.000	28.000	52.350
6	79	70.000	145.000	0.500	20.000	40.000	40.500	65.250
8	104	30.000	60.000	1.500	10.000	20.000	20.550	36.150
10	122	69.500	143.750	1.500	20.000	40.000	43.800	80.150
11	37	60.000	120.000	5.000	20.000	30.000	42.400	628.900
12	63	90.000	195.000	5.000	20.000	40.000	51.000	92.000
16	20	60.000	120.000	5.000	20.000	25.000	35.833	54.583
17	199	40.000	88.000	1.500	8.000	20.000	25.300	41.900
18	82	69.000	157.500	1.500	10.000	30.000	36.000	69.350
19	83	40.000	85.000	5.000	10.000	20.000	27.500	44.000
20	150	60.000	127.500	5.000	15.000	30.000	37.000	63.000
21	82	90.000	195.000	5.000	20.000	50.000	48.000	73.000
22	78	200.000	428.750	18.000	47.500	100.000	123.750	222.850
35	135	9.000	15.000	1.500	5.000	5.000	7.400	12.725
65	31	90.000	210.000	5.000	10.000	40.000	51.750	117.250
66	10	140.000	312.500	5.000	25.000	80.000	61.667	100.000
67	24	25.000	49.750	5.000	8.500	13.500	15.750	20.813
68	17	60.000	120.000	5.000	20.000	40.000	33.500	54.000

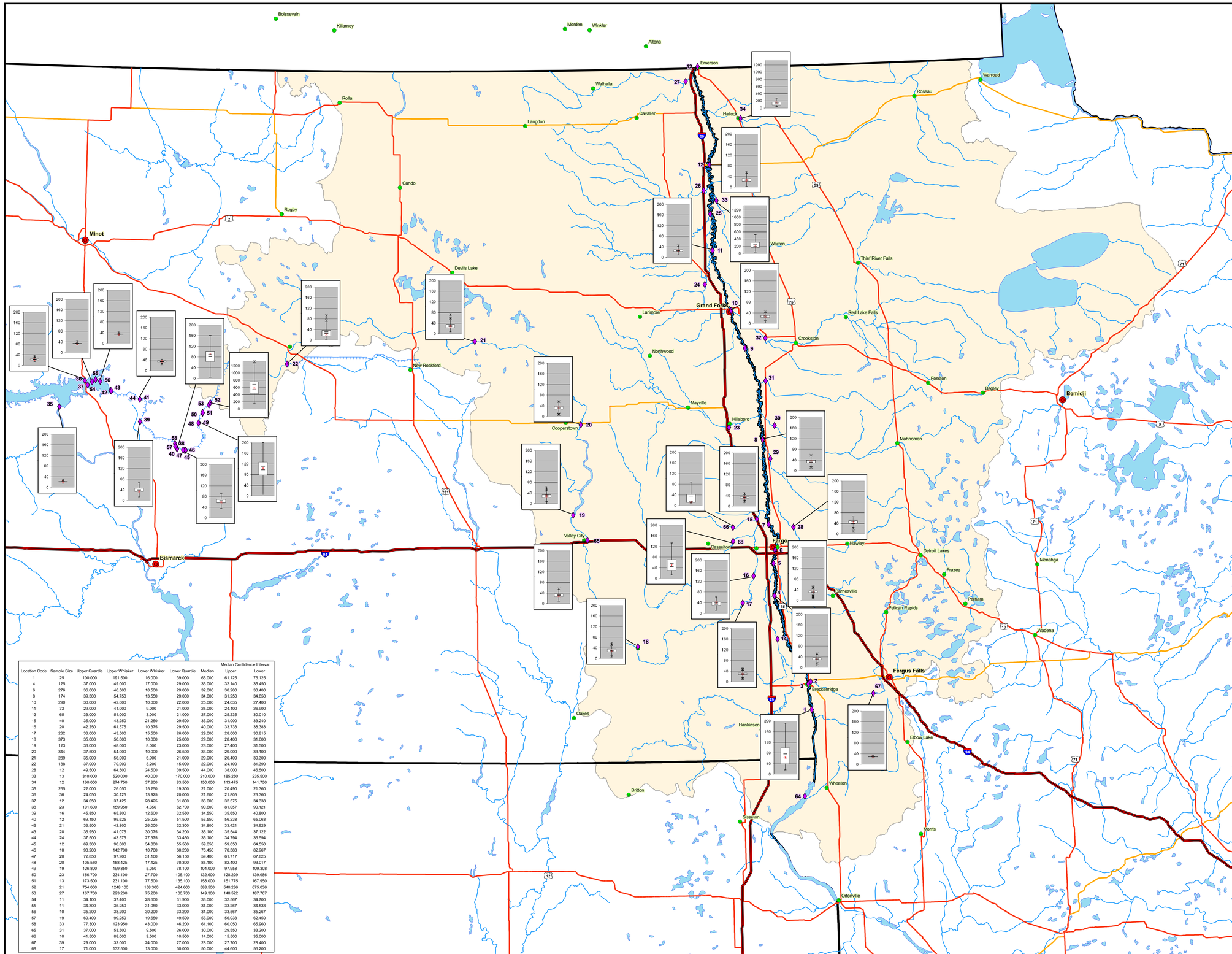
Appendix F: Iron modified box plots by LOCCODE

Scale: As Shown | Project No: 3750-059 | Date: 04/25/05

U. S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

GARRISON DIVERSION

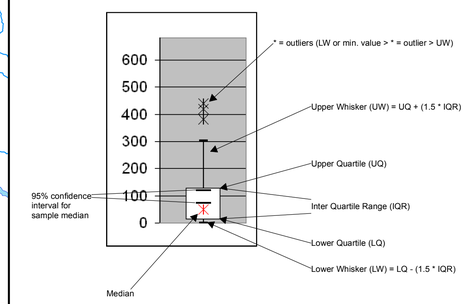
Red River Valley Water Supply Project



Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Notched Box Plot for Magnesium (mg/L)



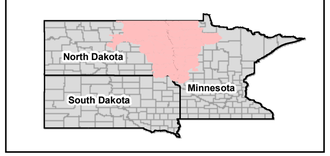
Note: Location codes with less than 10 data points not charted

Data are for LOCCODES;
i.e. may be from 2 or more stations

N
W E
S

0 10 20 40 60 Miles

Location Map

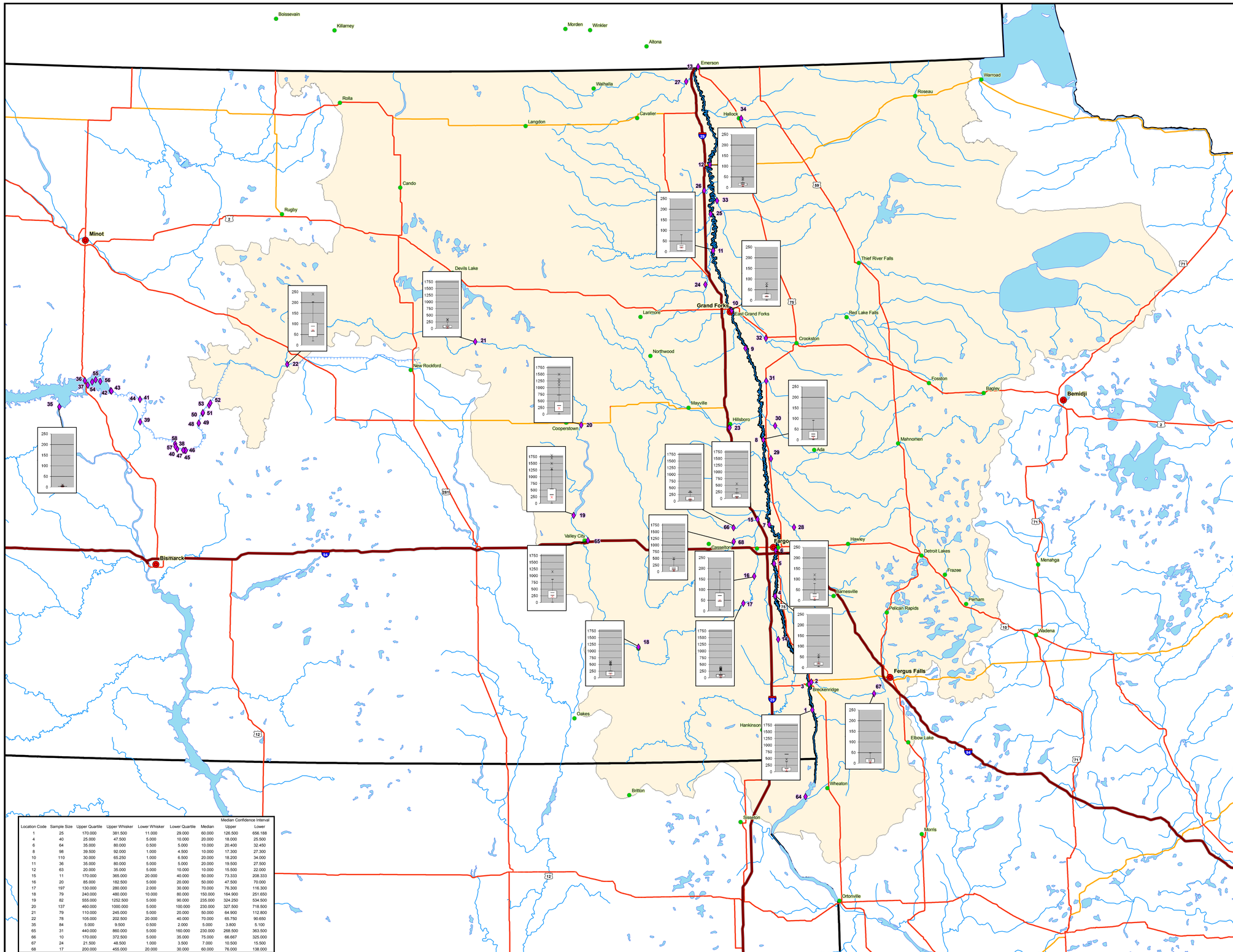


Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
1	25	100.000	191.500	16.000	39.000	63.000	61.125	76.125
4	125	37.000	49.000	17.000	29.000	33.000	32.140	35.450
6	276	36.000	46.500	18.500	29.000	32.000	30.200	33.400
8	174	39.300	54.750	13.550	29.000	34.000	31.250	34.850
10	290	30.000	42.000	10.000	22.000	25.000	24.635	27.400
11	73	29.000	41.000	9.000	21.000	25.000	24.100	26.900
12	65	33.000	51.000	3.000	21.000	27.000	25.235	30.010
15	40	35.000	43.250	21.250	29.500	33.000	31.000	33.240
16	20	42.250	61.375	10.375	29.500	40.000	33.733	38.383
17	232	33.000	43.500	15.500	26.000	29.000	28.000	30.815
18	373	35.000	50.000	10.000	25.000	29.000	28.400	31.600
19	123	33.000	48.000	8.000	23.000	28.000	27.400	31.500
20	344	37.500	54.000	10.000	26.500	33.000	29.000	33.100
21	289	35.000	56.000	6.900	21.000	29.000	26.400	30.300
22	188	37.000	70.000	3.200	15.000	22.000	24.100	31.390
28	12	49.500	64.500	24.500	39.500	44.000	38.000	46.500
33	13	310.000	520.000	40.000	170.000	210.000	185.250	235.500
34	12	160.000	274.750	37.800	83.500	150.000	113.475	141.750
35	265	22.000	26.050	15.250	19.300	21.000	20.490	21.360
36	36	24.050	30.125	13.925	20.000	21.600	21.805	23.360
37	12	34.050	37.425	28.425	31.800	33.000	32.575	34.338
38	23	101.600	159.950	4.350	62.700	90.600	81.057	90.121
39	16	45.850	65.800	12.600	32.550	34.550	35.650	40.800
40	12	69.150	95.625	25.025	51.500	53.550	56.238	65.063
42	21	36.500	42.800	26.000	32.300	34.800	33.421	34.929
43	28	36.950	41.075	30.075	34.200	35.100	35.544	37.122
44	24	37.500	43.575	27.375	33.450	35.100	34.794	36.594
45	12	69.300	90.000	34.800	55.500	59.050	59.050	64.550
46	10	93.200	142.700	10.700	60.200	76.450	70.383	82.967
47	20	72.850	97.900	31.100	56.150	59.400	61.717	67.825
48	20	105.550	158.425	17.425	70.300	85.100	82.400	93.017
49	19	126.800	199.850	5.050	78.100	104.000	97.958	109.308
50	23	156.700	234.100	27.700	105.100	132.600	128.229	139.986
51	13	173.500	231.100	77.500	135.100	158.000	151.775	167.950
52	21	754.000	1248.100	158.300	424.600	588.500	540.286	675.036
53	27	187.700	223.200	75.200	130.700	149.300	148.522	187.767
54	11	34.100	37.400	28.600	31.900	33.000	32.567	34.700
55	11	34.300	36.250	31.050	33.000	34.000	33.267	34.533
56	10	35.200	38.200	30.200	33.200	34.000	33.567	35.267
57	19	69.400	99.250	19.650	49.500	53.900	56.033	62.450
58	33	77.300	123.950	43.000	46.200	61.100	60.050	65.960
65	31	37.000	53.500	9.500	26.000	30.000	29.550	33.200
66	10	41.500	88.000	9.500	10.500	14.000	15.500	35.000
67	39	29.000	32.000	24.000	27.000	28.000	27.700	28.400
68	17	71.000	132.500	13.000	30.000	50.000	44.600	56.200

Appendix F: Magnesium modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

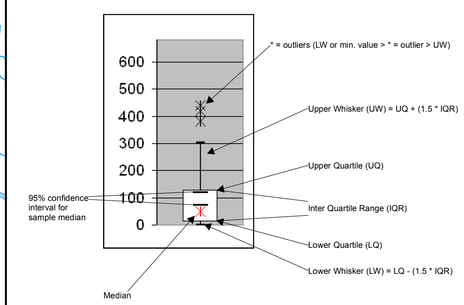
Red River Valley Water Supply Project



Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Notched Box Plot for Manganese (mg/L)



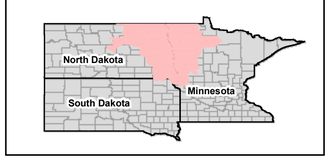
Note: Location codes with less than 10 data points not charted

Data are for LOCCODES;
i.e. may be from 2 or more stations

N W E S

0 10 20 40 60 Miles

Location Map

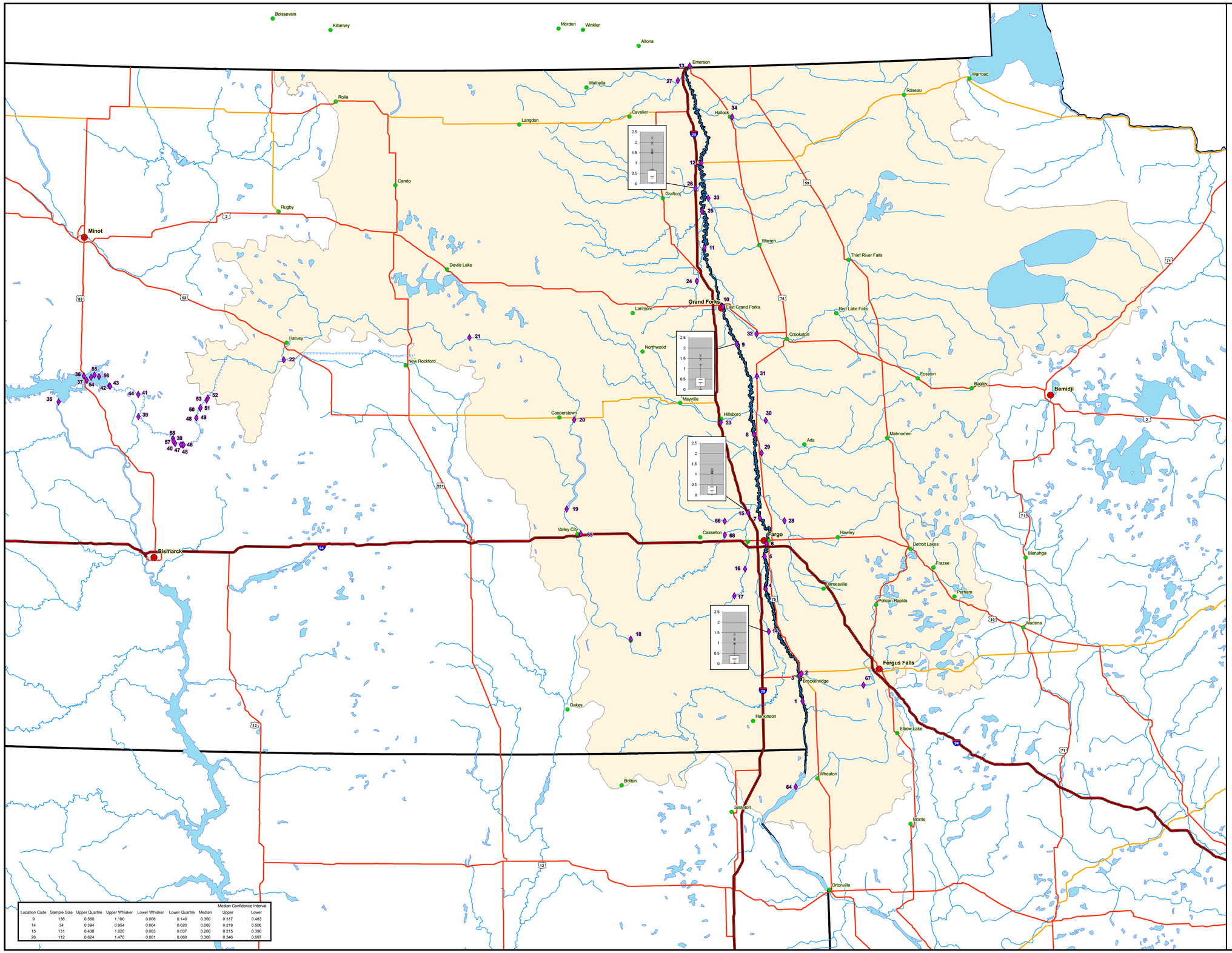


Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
1	25	170.000	381.500	11.000	29.000	60.000	126.500	656.188
4	40	25.000	47.500	5.000	10.000	20.000	18.000	25.500
6	64	35.000	80.000	0.500	5.000	10.000	20.400	32.450
8	98	39.500	92.000	1.000	4.500	10.000	17.300	27.300
10	110	30.000	65.250	1.000	6.500	20.000	18.200	34.000
11	35	35.000	80.000	5.000	5.000	20.000	19.500	27.500
12	63	20.000	35.000	5.000	10.000	10.000	15.500	22.000
15	11	170.000	365.000	20.000	40.000	50.000	73.333	208.333
16	20	85.000	182.500	5.000	20.000	50.000	47.500	70.000
17	197	130.000	280.000	2.000	30.000	70.000	76.300	116.300
18	79	240.000	480.000	10.000	80.000	150.000	164.900	251.650
19	82	555.000	1252.500	5.000	90.000	235.000	324.250	534.500
20	137	460.000	1000.000	5.000	100.000	230.000	327.500	718.500
21	79	110.000	245.000	5.000	20.000	50.000	64.900	112.800
22	78	105.000	202.500	20.000	40.000	70.000	65.750	90.650
35	84	5.000	9.500	0.500	2.000	5.000	3.800	5.100
65	31	440.000	860.000	5.000	160.000	230.000	298.500	363.500
66	10	170.000	372.500	5.000	35.000	75.000	66.667	325.000
67	24	21.500	48.500	1.000	3.500	7.000	10.500	15.500
68	17	200.000	455.000	20.000	30.000	60.000	76.000	138.000

Appendix F: Manganese modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

Red River Valley Water Supply Project

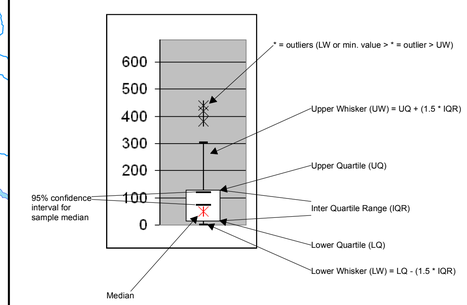


Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
9	136	0.560	1.190	0.008	0.140	0.300	0.317	0.483
14	34	0.394	0.954	0.004	0.020	0.060	0.219	0.506
15	131	0.430	1.020	0.003	0.037	0.200	0.215	0.390
26	112	0.624	1.470	0.001	0.060	0.300	0.346	0.697

Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Notched Box Plot for Nitrate-Nitrogen (mg/L)



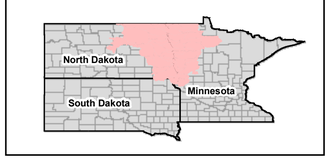
Note: Location codes with less than 10 data points not charted

Data are for LOCCODES;
i.e. may be from 2 or more stations

N
W E
S

0 10 20 40 60 Miles

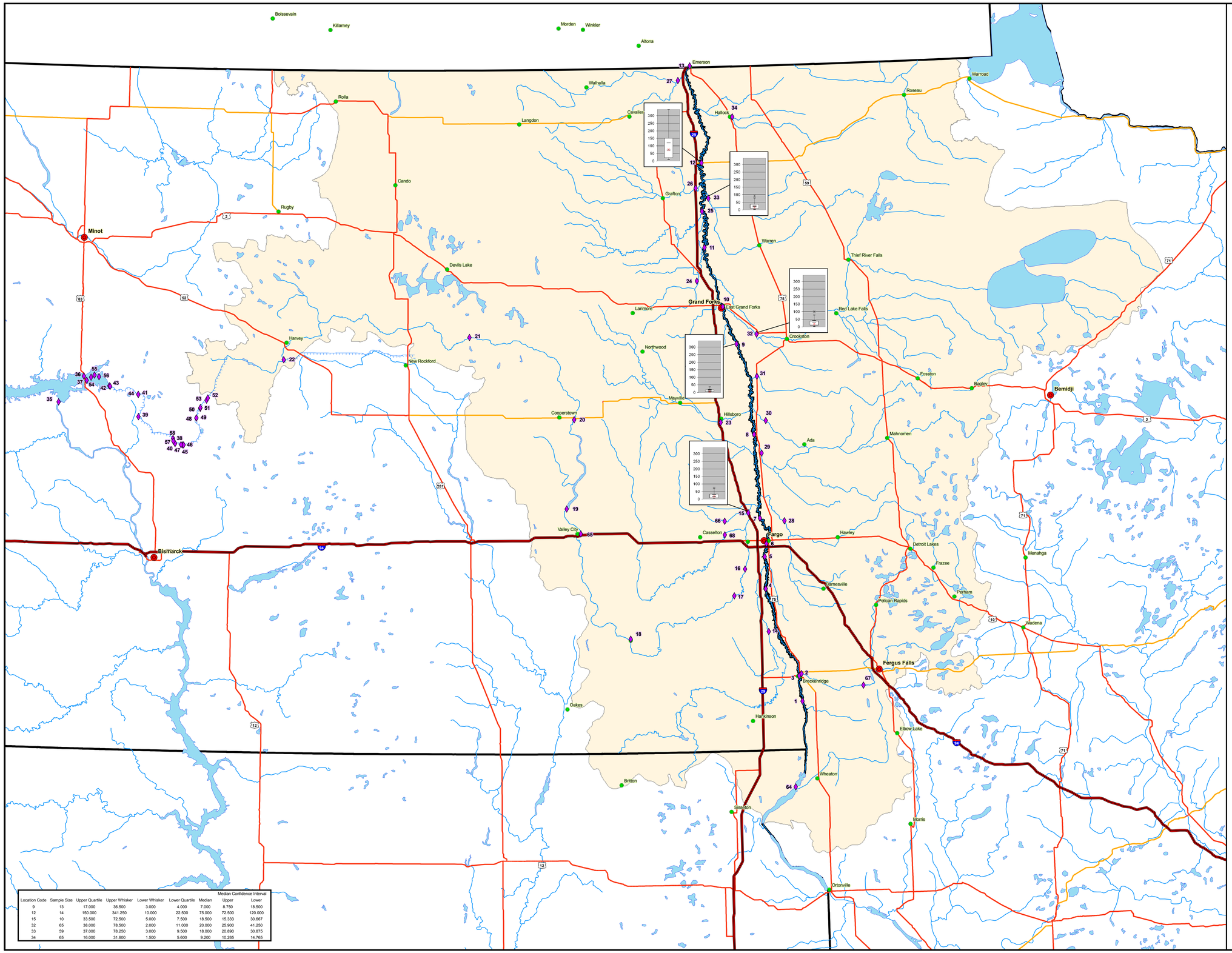
Location Map



Appendix F: Nitrate-nitrogen modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

Red River Valley Water Supply Project



Legend

- Location Code
- Major City
- Intermediate City
- Major Watershed Boundary
- State Boundary
- Interstate
- US Highway
- State Highway
- Lake or Resevoir
- Stream or River
- Major Canal

Location Code	Sample Size	Upper Quartile	Upper Whisker	Lower Whisker	Lower Quartile	Median	Median Confidence Interval Upper	Median Confidence Interval Lower
9	13	17.000	36.500	3.000	4.000	7.000	8.750	18.500
12	14	150.000	341.250	10.000	22.500	75.000	72.500	120.000
15	10	33.500	72.500	5.000	7.500	18.500	15.333	30.667
32	65	38.000	78.500	2.000	11.000	20.000	25.900	41.250
33	59	37.000	78.250	3.000	9.500	18.000	20.890	30.875
34	65	16.000	31.600	1.500	5.600	9.200	10.265	14.765

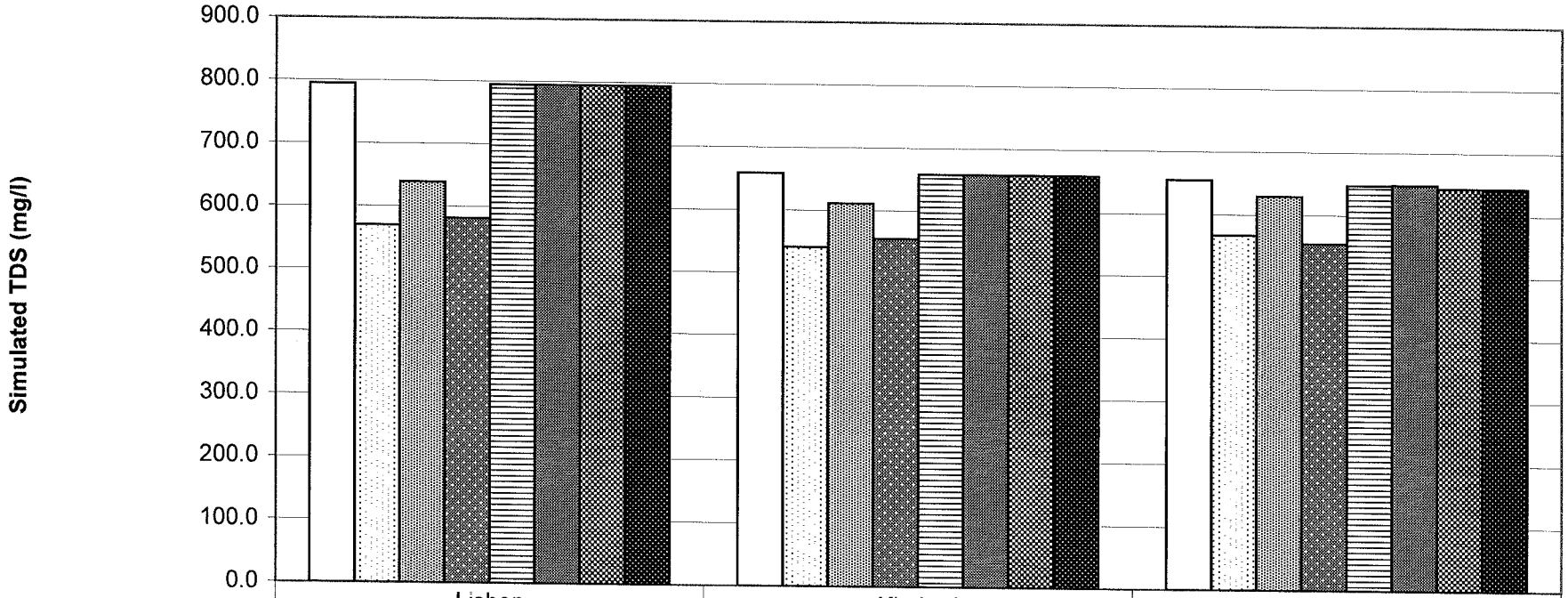
Appendix F: Turbidity modified box plots by LOCCODE

Scale: As Shown	Project No: 3750-059	Date: 04/25/05

APPENDIX G

USGS REDUCED DISCHARGE HEC-5Q MODELING RESULTS

Low Flow Hydrologic Conditions
HEC-5Q Simulated Total Dissolved Solids on the Sheyenne River



	Lisbon	Kindred	Horace
No Action	794.7	658.5	654.4
ND in-basin	569.8	541.4	567.0
GDU to Sh. River	638.9	611.4	629.4
Mo. River to RRV	581.6	555.0	554.1
RRV Alternative	794.4	658.3	647.9
Lake of the Woods	794.4	658.3	648.6
GDU Import	794.4	658.3	643.7
GDU Replacement	794.4	658.3	643.7

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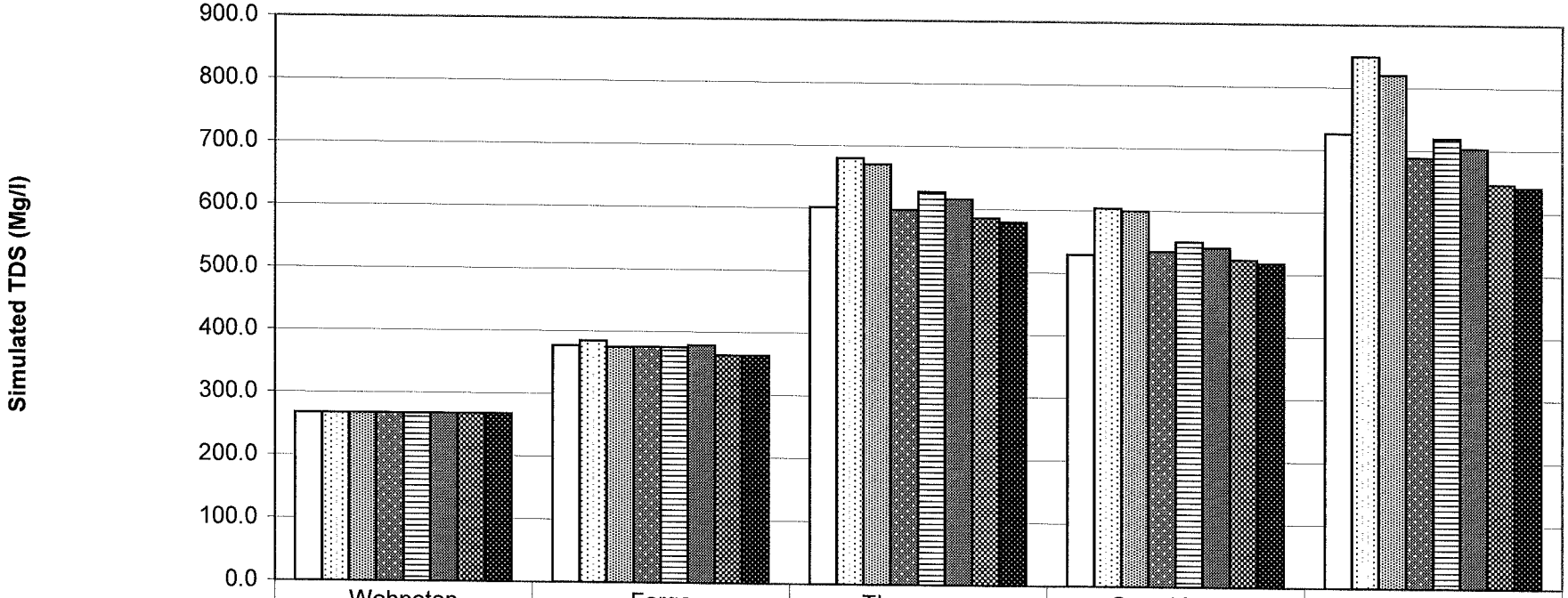
Low Flow Hydrologic Conditions
HEC-5Q Simulated Total Dissolved Solids on the Red River



	Wahpeton	Fargo	Thompson	Grand Forks	Emerson
No Action	267.2	377.0	601.5	529.7	726.0
ND in-basin	267.2	384.8	679.9	603.5	849.1
GDU to Sh. River	267.1	374.9	670.3	599.4	820.2
Mo. River to RRV	267.1	375.6	598.1	535.7	688.1
RRV Alternative	267.1	375.6	627.2	550.9	718.9
Lake of the Woods	267.1	378.8	615.8	542.0	702.6
GDU Import	267.1	363.4	586.1	522.9	645.9
GDU Replacement	267.1	363.4	579.3	517.4	640.5

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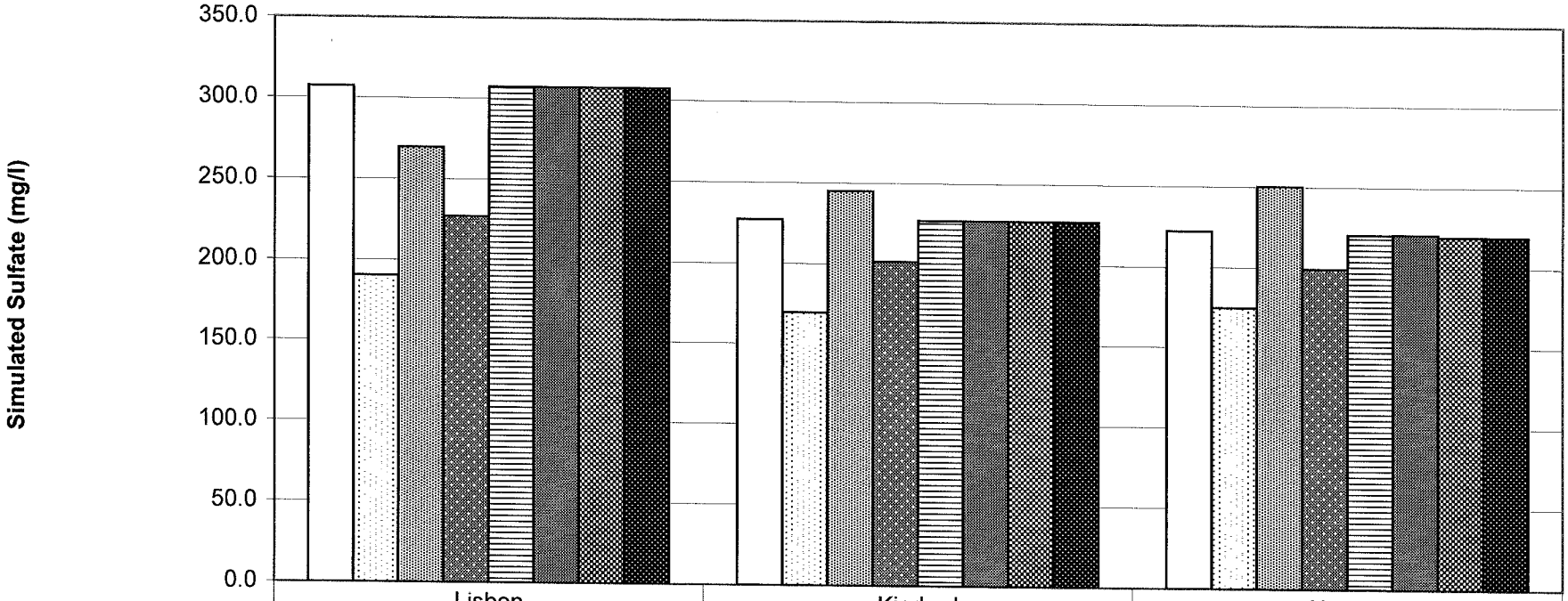
Low Flow Hydrologic Conditions
HEC-5Q Simulated Sulfate on the Sheyenne River



	Lisbon	Kindred	Horace
No Action	307.3	227.1	222.3
ND in-basin	190.2	169.5	174.8
GDU to Sh. River	269.5	245.1	250.3
Mo River to RRV	226.9	201.5	199.3
RRV Alternative	307.2	227.0	220.6
Lake of the Woods	307.2	227.0	220.8
GDU Import	307.2	227.0	219.6
GDU Replacement	307.2	227.0	219.6

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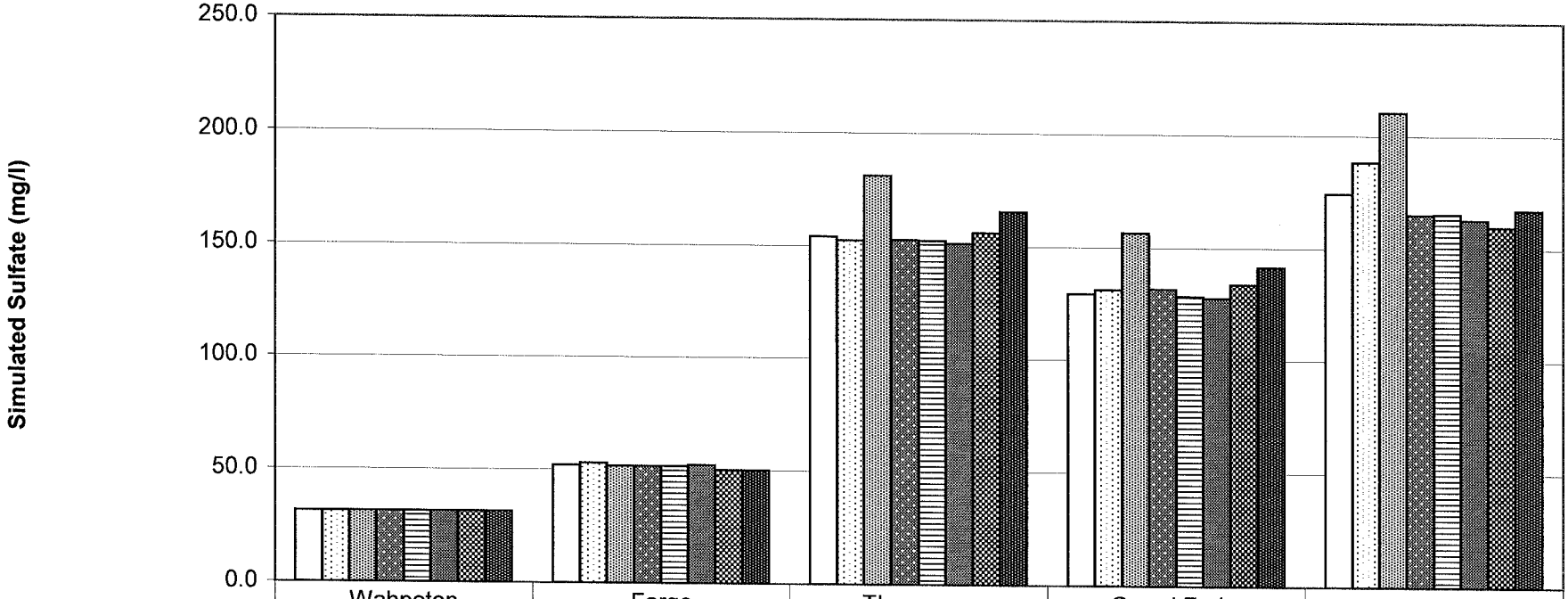
Low Flow Hydrologic Conditions
HEC-5Q Simulated Sulfate on the Red River



	Wahpeton	Fargo	Thompson	Grand Forks	Emerson
No Action	31.4	52.0	154.1	129.4	174.4
ND in-basin	31.4	53.0	152.5	131.3	188.4
GDU to Sh. River	31.4	51.7	181.1	156.6	210.3
Mo. River to RRV	31.4	51.8	152.8	131.7	165.3
RRV Alternative	31.4	51.8	152.5	128.5	165.5
Lake of the Woods	31.4	52.3	151.3	127.8	163.0
GDU Import	31.4	50.1	156.1	133.9	159.8
GDU Replacement	31.4	50.1	165.4	141.6	167.3

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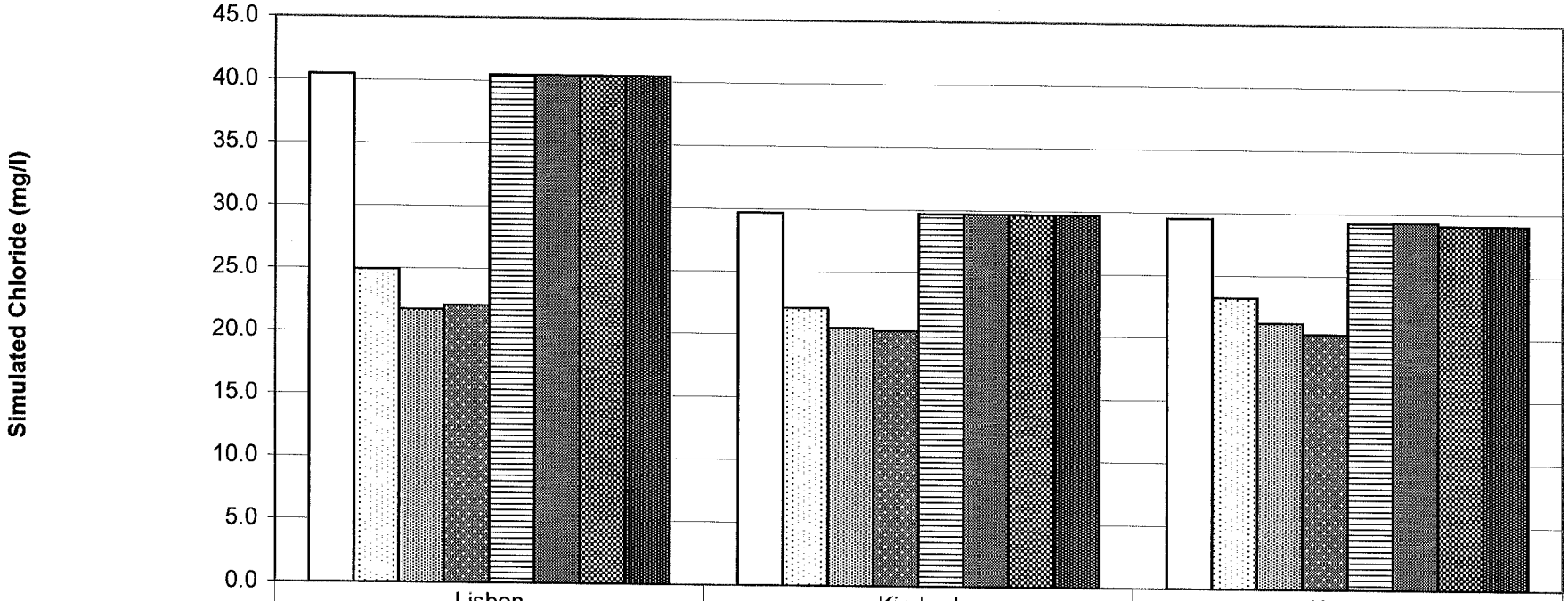
Low Flow Hydrologic Conditions
HEC-5Q Simulated Chloride on the Sheyenne River



	Lisbon	Kindred	Horace
No Action	40.5	29.7	29.6
ND in-basin	24.9	22.1	23.2
GDU to Sh. River	21.7	20.5	21.2
Mo. River to RRV	22.1	20.3	20.3
RRV Alternative	40.4	29.7	29.3
Lake of the Woods	40.4	29.7	29.3
GDU Import	40.4	29.7	29.1
GDU Replacement	40.4	29.7	29.1

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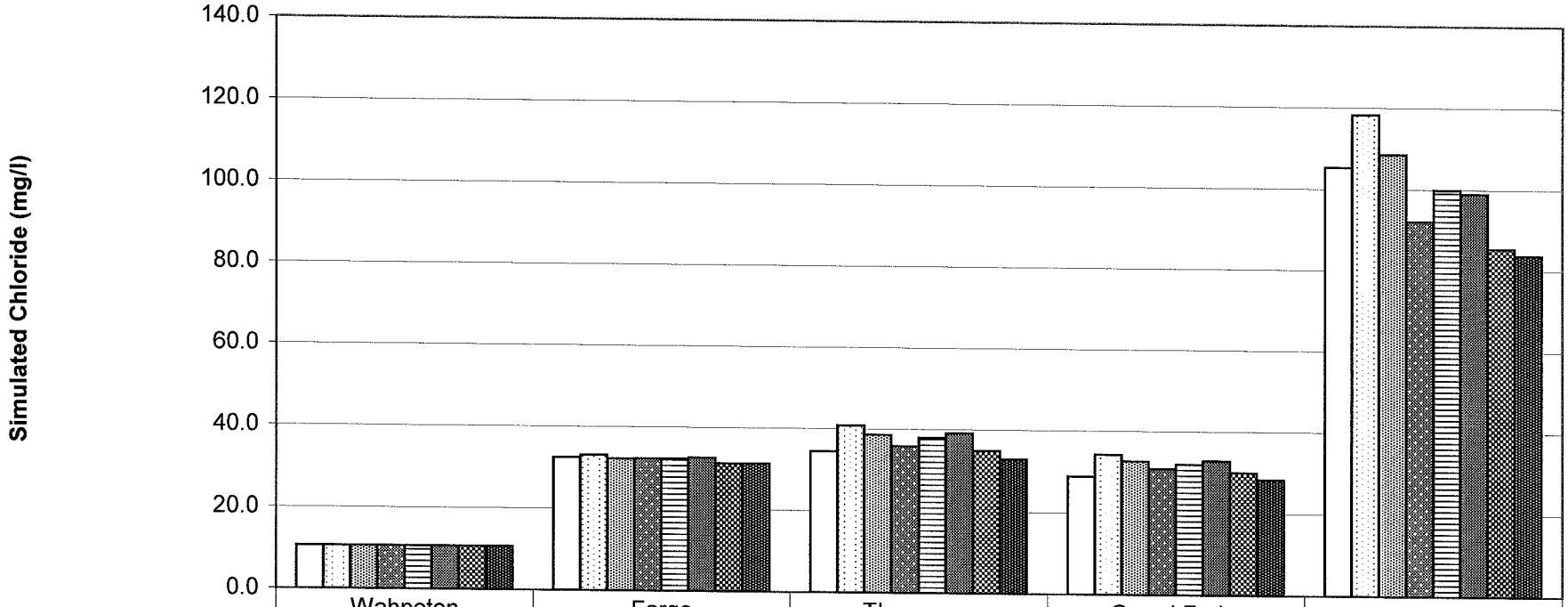
Low Flow Hydrologic Conditions
HEC-5Q Simulated Chloride on the Red River



	Wahpeton	Fargo	Thompson	Grand Forks	Emerson
No Action	10.6	32.5	34.5	28.9	105.3
ND in-basin	10.6	33.1	40.9	34.3	118.3
GDU to Sh. River	10.6	32.3	38.6	32.7	108.5
Mo. River to RRV	10.6	32.4	35.9	30.9	92.1
RRV Alternative	10.6	32.4	38.0	32.0	99.9
GDU Import	10.6	32.6	39.1	32.9	98.9
GDU Replacement	10.6	31.3	34.9	30.0	85.4
	10.6	31.3	32.9	28.4	83.8

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