RECLAMATION

Managing Water in the West

Final Report on Red River Valley Water Needs and Options

U.S. Department of the Interior
Bureau of Reclamation
Dakotas Area Office

November 2005

Acronym List

ac-ft - acre feet
ASR - aquifer storage and recovery
bgals - billion gallons
bgals/yr - billion gallons per year
BIA - Buearu of Indian Affairs
CDSS.-.Colorado Decision Support Systems
cfs - cubic feet per second
Corps - U.S. Army Corps of Engineers
DEB - Doug Emerson basin also DEBs Doug Emerson basins
DEIS - Draft Environmental Impact Statement
DWRA - Dakota Water Resources Act
EIS - Environmental Impact Statement
EOM - End of Month
EPA - U.S. Environmental Protection Agency
Garrison Diversion - Garrison Diversion Conservancy District
GDU - Garrison Diversion Unit
GIS - Geographical Information Systems
gpc/d - gallons per capita per day
gpm - gallons per minute
MAF - million acre feet
mg/L - milligrams per liter
Mgals - million gallons
mgd - million gallons per day
M&I - municipal and industrial
MNDNR - Minnesota Department of Natural Resources
MNGS - Minnesota Geological Survey
MOU - memorandum of understanding
MPCA - Minnesota Pollution Control Agency
MR&I - municipal, rural, and industrial
msl - above mean sea level
NDAC - North Dakota Administrative Code
NDCC - North Dakota Century Code
NDSWC - North Dakota State Water Commission
Needs and Options Report - *Report on Red River Valley Water Needs and Options*
NPDWR - National Primary Drinking Water Regulations
NSDWR - National Secondary Drinking Water Regulations
OM&R - operation, maintenance, and replacement
Phase IA report - Reclamation 1998 study
Phase IB report - Reclamation 1999 study
Phase II report - Reclamation 2000 study
Project - Red River Valley Water Supply Project
Q90 - MPCA's 90% exceedance flow guideline
Reclamation - Bureau of Reclamation
Red River - Red River of the North
Red River Basin - Red River of the North Basin
SCADA - supervisory control and data acquisition
SCPP - Snake Creek Pumping Plant
SDWA - Safe Drinking Water Act
Sheyenne National Grasslands see the Grasslands
TDS - total dissolved solids
the Grasslands - Sheyenne National Grasslands
USGS - United States Geological Survey
WC - water conservation
WCPA - water conservation potential assessment
WTP - water treatment plant

Table of Contents

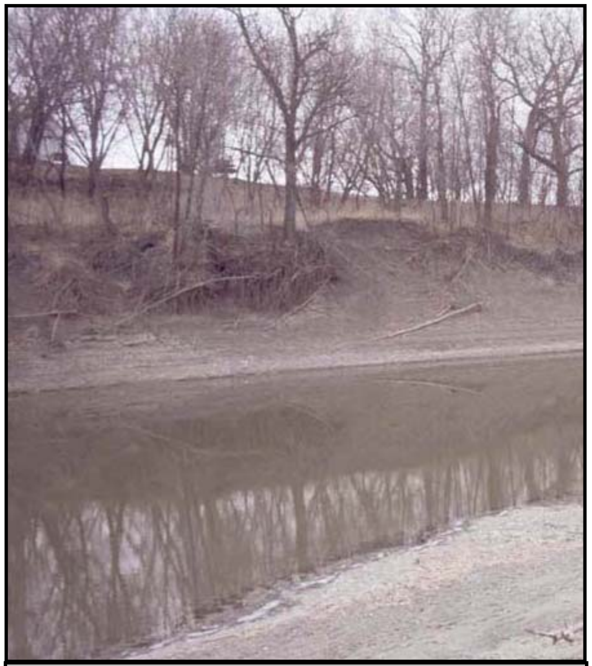
List of Tables

FIGURES

Chapter One
Introduction

1.1 Project Purpose

The *Final Report on Red River Valley Water Needs and Options* (Needs and Options Report) is a comprehensive study of the water quality and quantity needs of the Red River Valley through the year 2050 and seven possible options to meet those needs. The Project (Red River Valley Water Supply Project) proposes to supply bulk water to municipalities, rural water systems, and industries in the Red River Valley service area in North Dakota and Minnesota (Figure 1.1.1).

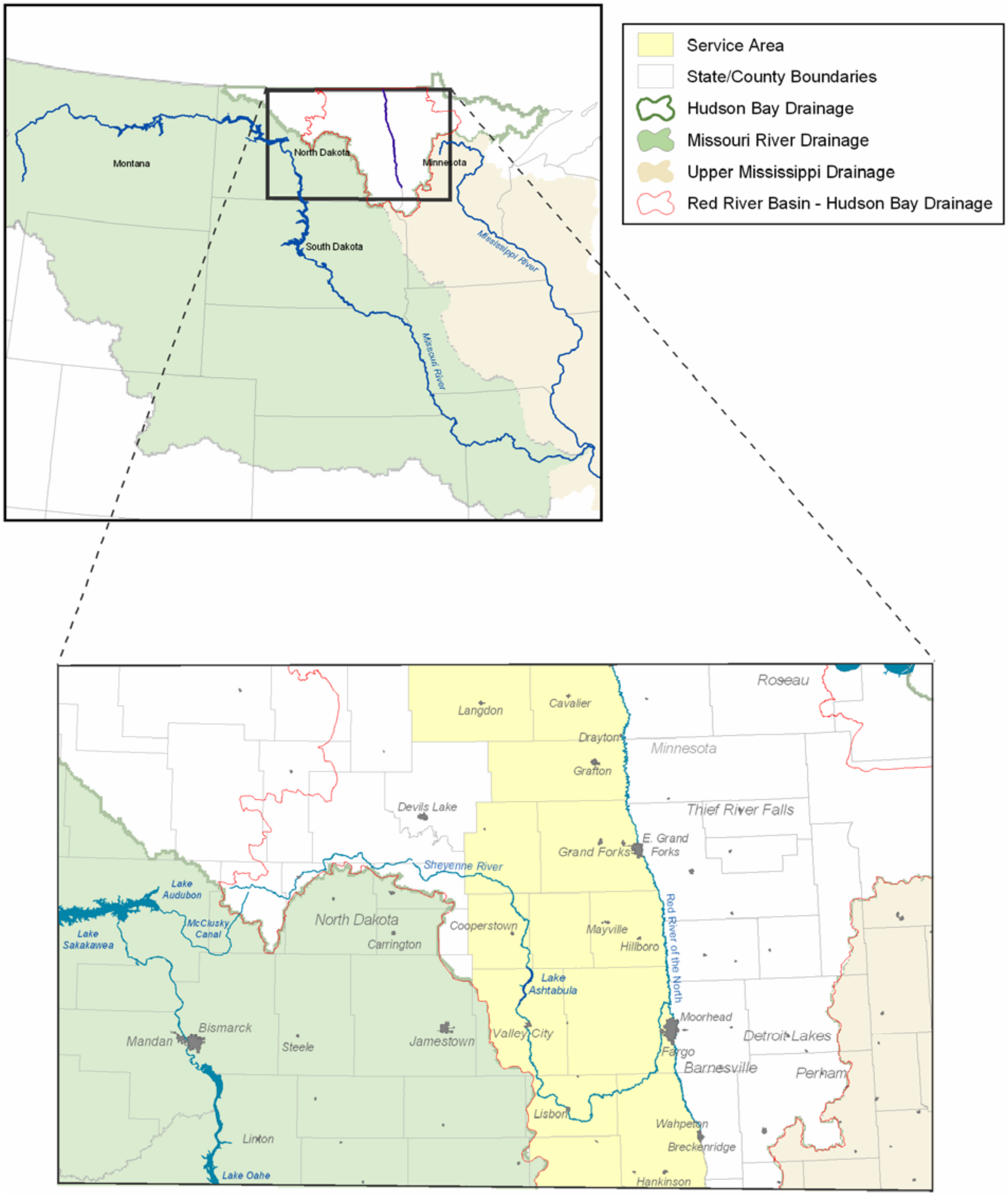


The Red River near Fargo, North Dakota

Most of the population of the Red River Valley, including the residents of Fargo and Grand Forks, North Dakota, and Moorhead and East Grand Forks, Minnesota, rely on the Red River of the North and its tributaries as a primary or sole source of water supply. Based upon results of surface water hydrologic modeling, the Red River Valley would face critical water shortages in the near future if a 1930s drought started today (2005).

For example, the 2005 MR&I (municipal, rural, and industrial) water users in the service area would experience significant water shortages during a drought like the one that occurred from 1931 to 1940. A drought frequency investigation by Meridian Environmental Technology, Inc. (2004) predicts a strong probability of an extreme drought event occurring before the year 2050. In such an event hydrologic modeling forecasts that the maximum annual water shortage could be 16% in the sixth year of an extended drought. The maximum single monthly shortage could be a 46% deficit in February of the seventh year.

What is most challenging is that the 46% shortage would occur during the winter when typical drought measures such as eliminating lawn watering are not applicable. In such an event the water users in the valley would have to dramatically cut their commercial and indoor water use. The most vulnerable cities are in the Fargo-Moorhead greater metropolitan area (Fargo, West Fargo, Horace, and Harwood, North Dakota and Moorhead and Dillworth, Minnesota), but other water systems along the Red River also would have shortages. As key population centers such



The area within the black box is the project area of the Red River Valley Water Supply Project. The yellow counties are in the Service Area.

Figure 1.1.1 – Project Area and Service Area of the Red River Valley Water Supply Project.

as Fargo, Moorhead, and Grand Forks grow, their dependence on surface water in the Red River Valley will make them increasingly vulnerable to future water shortages.

Recognizing the need for water supply solutions, Congress passed the DWRA (Dakota Water Resources Act of 2000). Sections 5 and 8 of DWRA authorize the Project. Section 8 directs the Secretary of the Interior to conduct a comprehensive study of the water quality and quantity needs of the Red River Valley in North Dakota and possible options for meeting those needs.

The Needs and Options Report quantifies the water needs of the Red River Valley and identifies seven options for meeting those needs. Reclamation (Bureau of Reclamation) has been delegated the authority to prepare the Needs and Options Report on behalf of the Secretary. The purpose of the Project is to meet the "comprehensive water quality and quantity needs of the Red River Valley" [DWRA Section 8(c)(2)(A)]. The needs as specified in DWRA are MR&I water supply, water quality, aquatic environment, recreation, and water conservation measures [DWRA Section 8(b)(2)].

The Act also directs the Secretary of the Interior to jointly prepare an EIS (environmental impact statement) for the Project with the State of North Dakota. The EIS is being jointly prepared by Reclamation, on behalf of the Secretary, with the State of North Dakota represented by Garrison Diversion (Garrison Diversion Conservancy District). The DEIS (draft EIS) evaluates the environmental effects of the options identified in the Needs and Options Report. The DEIS is scheduled for release for public comment in December 2005.

To demonstrate the potential consequences of not addressing future water needs, surface water hydrologic modeling was conducted, which compared future water demands against historically recorded water sources. In the DEIS this is referred to as the No Action Alternative, which is defined in this case as the future in the service area without the Project. While it is not typical to describe a No Action Alternative in an engineering report, some No Action hydrologic analysis was conducted during this study and described in chapter three. The No Action Alternative analysis assisted in demonstrating the need for the Project.

1.2 Study Scope

1.2.1 Purpose, Planning Horizon, Service Area and Project Area

Purpose

The options in this report propose to develop and deliver a bulk water supply to meet the long-term water needs of the Red River Valley in North Dakota and Minnesota. The proposed action would include construction of features and facilities needed to develop and deliver sufficient water to existing infrastructure for distribution to MR&I water users in the service area. The options do not include the cost of local water distribution infrastructure, water treatment, and wastewater treatment.

Planning Horizon

The planning horizon for the Project is the year 2050. Population and water demands were projected to 2050. Designing a water supply system for the year 2050 is consistent with the typical service life, without major rehabilitation, of project features such as water treatment plants, pumping plants, and storage reservoirs. Although the expected service life of pipelines is approximately 100 years, project planning horizons are based typically on the service life of nonpipeline components.

Service Area

DWRA identified the Project service area as the Red River Valley in North Dakota. In previous studies of the Red River Valley, Reclamation (1998, 1999, 2000) interpreted this to be the 13 eastern counties in North Dakota, including Barnes, Cass, Cavalier, Grand Forks, Griggs, Nelson, Pembina, Ransom, Richland, Sargent, Steele, Traill, and Walsh. These counties appear highlighted in yellow on figure 1.1.1.

Previous Red River studies also included the Minnesota cities of Breckenridge, East Grand Forks, and Moorhead in analyses, in addition to the North Dakota counties. These three Minnesota cities may also be dependent upon the Red River for water supply in the future, so they were included in the water supply analysis. The Minnesota cities requested inclusion in the study, and the service area was expanded to incorporate them in the Needs and Options Report.

Project Area

The geographic scope of Project features, water sources, and analyses varies by option. Hydrologic surface water quantity modeling focuses on the Red River, Sheyenne River, and major tributaries to these streams in the U.S. (United States). Groundwater resources in the Red River Basin in eastern North Dakota and western Minnesota are features in several options. Aquifer storage and recovery of the West Fargo North, West Fargo South, and Moorhead Aquifers are incorporated into a number of options. Another in-basin water source, Lake of the Woods, is an international lake that lies partially in Minnesota, U.S., and in Ontario and Manitoba, Canada.

The Project area also covers portions of the eastern half of North Dakota for options that propose an inter-basin transfer of Missouri River water into the Hudson Bay Basin. Biota containment features in proposed Missouri River transfer options include a biota water treatment plant south of Bismarck, North Dakota, in one option or a biota water treatment plant adjacent to the McClusky Canal three miles north of McClusky, North Dakota, in three other options. Some of the options incorporate GDU (Garrison Diversion Unit) Principal Supply Works features (Snake Creek Pumping Plant, Audubon Lake, and McClusky Canal) as well as pipelines interconnecting biota water treatment plants with the service area in the Red River Valley. Lake Ashtabula also plays an important role as a regulating reservoir for many of the proposed water supply options, both in-basin and import.

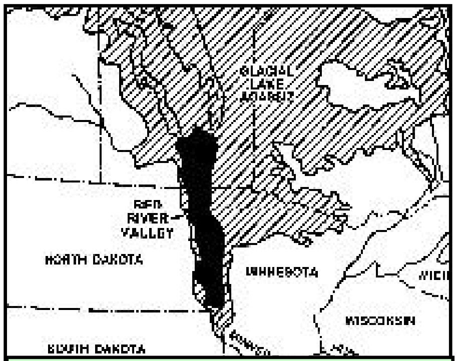
1.2.2 Setting

Geology and Physiography

The Red River begins at the confluence of the Bois de Sioux and Otter Tail Rivers in South Dakota and Minnesota and flows north. The river forms the border between North Dakota and Minnesota and crosses the U. S. border into Canada, ultimately draining into Lake Winnipeg, Manitoba. The slope of the mainstem drops about 200 feet in its 394-mile course from its beginning in South Dakota to the Canadian border.

The Red River Valley is a flat plain which previously was the bottom of glacial Lake Agassiz. The valley covers a strip of land about 35 miles wide on either side of the Red River in North Dakota and Minnesota. It is about 60 miles across at its widest point.

The Red River Basin is the watershed for the Red River, which is part of the Hudson Bay Drainage System. The Red River Basin includes the glacial Lake Agassiz lakebed and about 28,000 additional square miles for a total of about 45,000 square miles. Nearly 40,000 square miles of the basin are located in the U.S. (Krenz and Leitch 1993). The remainder is in Canada.



Glacial Lake Agassiz (from Krenz and Leitch 1993)

Climate

North Dakota's location at the geographic center of North America results in a typical continental climate. Primarily because of location, the climate is characterized by large annual, diurnal, and day-to-day temperature changes; light to moderate precipitation that tends to be irregular in time and coverage; low relative humidity; plentiful sunshine; and nearly continuous air movement (Jensen n.d.). The Red River Valley is characterized as a subhumid climate. In contrast, the upper Missouri River Basin is classified as semiarid and averages 40% less precipitation than the Red River Basin. The Missouri River Basin relies primarily on snowmelt from the Rocky Mountains, which is the principal water source supplying the Missouri River system (Meridian Environmental Technology, Inc. 2004).

Annual precipitation in the Red River Valley ranges from less than 13 inches in the northwest part of the valley to more than 20 inches in parts of the valley in southeastern North Dakota. The majority of annual precipitation and annual evaporation occurs in April through September. As a result, much of the precipitation is absorbed in the soil and transpired or evaporated back to the atmosphere, and very little results in runoff or groundwater recharge. Most runoff is in the early spring when snowmelt and precipitation generally exceed evapotranspiration (Sloan 1972).

Most precipitation that falls during the spring and summer occurs during thunderstorms. Floods and droughts have affected the northern Great Plains climate numerous times during the past 2,000 years. Two of the most severe droughts during recorded history were in the 1930s and the 1980s, and megadroughts occurred prior to A.D. 1200, as evidenced in lake salinity and tree rings (Meridian Environmental Technology, Inc. 2004). Since the early 1990s the Red River Valley has experienced above-normal precipitation, which is forecasted to continue through the current (2004) decade; however, recent research indicates a strong probability of an extreme drought event occurring before A.D. 2050 (Meridian Environmental Technology, Inc. 2004).

1.3 Background

1.3.1 Previous Studies

DWRA is an amendment to previous legislation. In 1944, the U.S. Congress passed the Flood Control Act (of which the Missouri-Basin Pick Sloan Act is a part), which authorized construction of dams on the Missouri River and its tributaries. GDU was authorized in 1965 and construction of the Principal Supply Works began in 1967. The Principal Supply Works are Snake Creek Pumping Plant, Audubon Lake, McClusky Canal, and New Rockford Canal, which were designed to divert Missouri River water to central and eastern North Dakota for irrigation; municipal and industrial water supply; fish and wildlife conservation and development; recreation; flood control; and other project purposes. Most of the currently authorized Principal Supply Works have been completed. The connecting link between the two canals, which would have been Lonetree Reservoir, has been deauthorized.

The project was reauthorized in 1986 which resulted in a reduced emphasis on irrigation and increased emphasis on meeting MR&I water needs throughout North Dakota. The 1986 Reformulation Act also authorized a Sheyenne River water supply and release feature and a water treatment plant capable of delivering 100 cubic feet per second of water to eastern North Dakota.

Appraisal-level studies of water needs and options for the Red River Valley began in 1994 and were completed in 2000 under the direction of the Executive Steering Committee, North Dakota Water Management Collaborative Process. The first phase of this investigation was completed in April 1998 with an appraisal-level Phase I Part A MR&I water-needs assessment (Reclamation 1998). An additional aspect of the first phase was the final Phase I Part B report, which addressed instream flows and aquatic life maintenance (Reclamation 1999a).

In January 2000, Reclamation completed the *Red River Valley Water Needs Assessment, Phase II; Appraisal of Alternatives to Meet Projected Shortages* (Reclamation 2000) report. The Phase II report presented a range of preliminary alternatives to meet the water shortages identified in the Phase IA report. These alternatives included both in-basin and out-of-basin water supplies including a variety of management and operational techniques. Water conservation and peak day analysis were not given much attention and were identified as topics deserving more attention in future studies. The report concluded that if no action is taken, the Red River Valley would experience significant MR&I water shortages in the future during periods of severe drought. These studies laid the foundation for the Needs and Options Report.

1.3.2 Public Involvement

Section 8(b)(3) of DWRA describes a public involvement process for the Needs and Options Report. It states:

> In conducting the study, the Secretary through an open and public process shall solicit input from gubernatorial designees from states that may be affected by possible options to meet such needs as well as designees from other federal agencies with relevant expertise. For any option that includes an out-of-basin solution, the Secretary shall consider the effect of the option on other states that may be affected by such option, as

> well as other appropriate considerations. Upon completion, a draft of the study shall be provided by the Secretary to such states and federal agencies. Such states and agencies shall be given not less than 120 days to review and comment on the study method, findings and conclusions leading to any alternative that may have an impact on such states or on resources subject to such federal agencies' jurisdiction. The Secretary shall receive and take into consideration any such comments and produce a final report and transmit the final report to Congress.

Preliminary work on the Project studies began in June 2000, prior to passage of DWRA through an MOU (memorandum of understanding) signed by Reclamation, the North Dakota State Water Commission, and the Garrison Diversion Conservancy District. The MOU was signed under the authority of the 1986 Garrison Diversion Unit Reformulation Act (P.L. 99-294).

After passage of DWRA two teams of stakeholders (Technical Team and Study Review Team) were formed to incorporate public involvement in study planning. Gubernatorial designees from states that could be affected by the Project and other representatives of federal, state, local agencies, tribes, and environmental groups were invited to serve on the teams.

In 2003 the Study Review Team was combined with the Technical Team. Technical Team members reviewed and commented on plans of study and draft reports. Organizations and agencies whose representatives attended Technical Team meetings are listed in table 1.3.1. The Draft Needs and Options Report was distributed to the Technical Team, the public, federal agencies, and potentially affected States for a 120-day review. Comments received from reviewers were given serious consideration and were used in preparing this Final Needs and Options Report.

Table 1.3.1. Technical Team Meeting Attendees.

- City of Fargo, North Dakota
- City of Grafton, North Dakota
- City of Moorhead, Minnesota
- City of West Fargo, North Dakota
- City of East Grand Forks, Minnesota
- City of Grand Forks, North Dakota
- City of Valley City, North Dakota
- Department of Fisheries and Oceans – Canada
- Eastern Dakota Water Users
- Environment Canada
- Garrison Diversion Conservancy District and Consultants
- Lake Agassiz Water Authority
- Manitoba Water Stewardship
- Meridian Environmental Technology, Inc.
- Minnesota Chapter of the American Fisheries Society
- MNDNR (Minnesota Department of Natural Resources)
- Minnesota Department of Health
- Minnesota Pollution Control Agency
- Missouri Department of Natural Resources
- National Audubon Society
- National Wildlife Federation
- North Central Division of American Fisheries Society
- The North Dakota Chapter of The Wildlife Society
- North Dakota Game & Fish Department
- North Dakota State Health Department
- NDSWC (North Dakota State Water Commission)
- North Dakota State University
- Red Lake Band of Chippewa
- Red River Basin Commission
- South Dakota Department of Environment & Natural Resources
- Corps (U.S. Army Corps of Engineers)
- U.S. Fish and Wildlife Service
- USGS (U.S. Geological Survey)
- EPA (U.S. Environmental Protection Agency)

Public involvement extended beyond the Technical and Study Review Teams. Reclamation, with the assistance of the North Dakota State Water Commission, conducted water users meetings in eight communities in the Red River Valley during October 2002. The purpose of the meetings was to present information about the studies being conducted for the Needs and Options Report and solicit the assistance of local communities in these efforts. This also gave the water users an opportunity to learn about previous Reclamation Red River Valley studies and to provide comments. Comments received during these meetings and during public scoping of the DEIS were taken into consideration and assisted Reclamation in developing the options described in this report.

1.4 Overview Of Report

This is a comprehensive report of the future water needs of the Red River Valley and options to meet those needs. Technical analyses were completed to quantify future water needs and to identify potential water sources. Basic questions answered in these analyses are as follows:

- How much water does the Red River Valley need through the year 2050 (i.e., what is the water demand)?
- How much water is currently available?
- How much water (surface and groundwater) would be available during a 1930s drought to meet the projected 2050 water demand?
- What reasonable and feasible options could supply the water demand using available in-basin water resources?
- What reasonable and feasible options could supply the water demand using water imported from the Missouri River?
- What is the estimated cost of each option?

Chapter two summarizes needs assessments which quantify the water demands of the service area through 2050. The chapter addresses all of the seven needs identified in DWRA. Municipal and rural water demands are quantified based on population projections through 2050 and historic per capita water demand estimates. To calculate water demands, population growth was projected by Reclamation, by an independent contractor, and by water users. To adjust per capita water demands and to reduce Project water use, water conservation measures were evaluated and applied to future per capita water demand estimates. Future industrial water demands were estimated by evaluating current industrial demands in addition to projecting future industrial water demands based upon an economic development analysis. An overview of proposed changes to SDWA (Safe Drinking Water Act) regulations was prepared and water systems were evaluated to determine if they would meet predicted changes in water quality standards. Aquatic environment and recreational needs were also evaluated.

Chapter three identifies existing Red River Valley water sources and determines which are adequate to meet the future demands. Where water shortages are predicted, the amount of water required to meet the future water demands is quantified. Surface water and groundwater sources in the Hudson Bay Basin in the U.S. are evaluated. The results of surface water hydrologic modeling and water shortages predicted by modeling are discussed. The potential for treating surface water and storing it underground for future use is also addressed in the aquifer storage and recovery section.

Chapter four describes seven options for serving the needs quantified in chapter two and the water shortage predicted in chapter three. Six of the seven options supplement existing water sources in order to eliminate future MR&I water shortages in the service area. The seventh option, the GDU Water Supply Replacement Pipeline Alternative, would replace all existing water supplies with water imported from the Missouri River. Engineering features that would reduce the risk of transferring biota from the Missouri River Basin to the Hudson Bay Basin and would meet the intent of the Boundary Waters Treaty are described. The chapter discloses estimated construction and annual OM&R (operation, maintenance, and replacement) costs of each option. The chapter also provides financial analysis results on monthly household and per 1,000 gallon repayment costs, identifies potential option cost savings if drought contingency measures are used to reduce water demand, and the additional option costs of meeting North Dakota Game and Fish flow targets to benefit aquatic environment.

Chapter five summarizes the results of the technical analyses and provides some basic conclusions about future water needs, hydrologic analysis, options identified to meet future water needs, and costs associated with each option.

Chapter Two
Needs Assessment

Comprehensive water supply needs identified in DWRA:
- **municipal, rural, and industrial water supply,**
- **water quality,**
- **aquatic environment,**
- **recreation and**
- **water conservation**

This chapter answers the question of how much water is needed in the Red River Valley through 2050. It quantifies all the needs identified in DWRA to the extent possible and focuses on MR&I (municipal, rural, and industrial) water supply.

In this report water needs are divided into two categories: *consumptive* and *nonconsumptive*. Consumptive water needs are those uses which withdraw water and do not return all of it to the source. The amount of water that a city withdraws from a river and does not return to the source as a discharge is an example of consumptive use.

Nonconsumptive water needs either do not withdraw water or effectively return all of the withdrawn water to the source. For instance, the amount of river water required for a canoe trip can be quantified, but it is not a consumptive use of the resource. This needs assessment chapter quantifies consumptive uses of water as future water demands. Nonconsumptive water needs are discussed, but are not included in the water demand.

Water demand is calculated by multiplying the estimated 2050 population by per capita water demand minus water conservation (the amount of water that can be saved with water conservation measures). Industrial water demands and recreation consumptive uses are added to the equation to determine the future water demand of the service area. Monthly water demand scenarios were developed to input into the surface hydrologic model to determine if there would be adequate future surface water supplies for surface water dependent systems in 2050.

Water demand = population x (per capita water demand – water conservation) + industrial water demands + recreation consumptive use.

Per capita/per day is the amount of water that a person uses in a day.

The chapter generally is organized following the water demand formula (see blue box above). It begins in section 2.1 with an overview of water systems in the Project’s service area. The methods used in calculating water demands are explained in section 2.2, and population projections are quantified in section 2.3. The next section (2.4) summarizes future per capita water demands for municipalities and rural water systems. Water conservation measures are described in section 2.5 followed by MR&I water demand analyses in sections 2.6, 2.7, and 2.8. Consumptive recreation water use is summarized in section 2.9, and nonconsumptive needs, such as water quality, aquatic environment, and recreation are consolidated in section 2.10. The chapter concludes with a summary in section 2.11.

All results discussed in this chapter are documented in more detail in Appendix A, except for aquatic needs, which are discussed in Appendix C. The appendix includes spreadsheets that show water demand estimates for every water system discussed in this chapter. Appendix A also describes assumptions and methods used for the analysis.

2.1 Red River Valley Water Systems

The Project proposes to supply bulk water to municipalities, rural water systems, and industries in the service area. This section of the report identifies the type and number of existing water systems in the Red River Valley. It explains how these water systems would be served through 2050. As explained in the previous chapter, the study service area includes 13 eastern counties in North Dakota and the Minnesota cities of Breckenridge, East Grand Forks, and Moorhead (figure 1.1.1, page 1-2). The Minnesota cities were included in the needs assessment, because some of them already use the Red River as source of water and could increase that dependence in the future. Table 2.1.1 identifies the type and number of MR&I systems evaluated.

The future water demand analysis is divided into three separate analyses: (1) municipal, (2) rural, and (3) industrial. Some municipal systems would be served in the future by rural water systems and some would continue to maintain their present water treatment facilities through the planning horizon of 2050. Ten industrial facilities have a site-specific water permit to meet their water needs. These facilities are evaluated separately and are discussed in section 2.8 (see table 2.8.1).

Table 2.1.1 – Existing (2005) Red River Valley Service Area MR&I Systems.

MR&I Systems	Number
Municipalities in North Dakota	175
Municipalities in Minnesota	3
Rural Water Systems	12
Water Associations	16
Industrial Facilities	10
Total	**216**

There are 175 municipalities in the Red River Valley of North Dakota, but a number of these towns have fewer than 100 residents and are no longer incorporated. Currently 12 rural water systems in eastern North Dakota serve approximately 130 of 175 municipalities. These are primarily small towns with populations under 500. There are also 16 water associations that are not chartered municipalities but are considered public water systems by the EPA (Environmental Protection Agency). The water associations are generally subdivisions outside larger cities. Currently four of the 16 water associations are served by rural water systems; the balance maintain their own water treatment facilities.

The number of small communities served by rural water systems has grown steadily as rural water systems have developed. This trend is expected to continue due to the high cost of maintaining small water treatment facilities and the increased difficulty of providing full time, trained, and certified personnel meeting the increasing stringent regulations. Figure 2.1.1 shows how many of the towns (175 + 3) and water associations (16) currently are served by rural water systems and how many are predicted to maintain independent water treatment capability in the future.

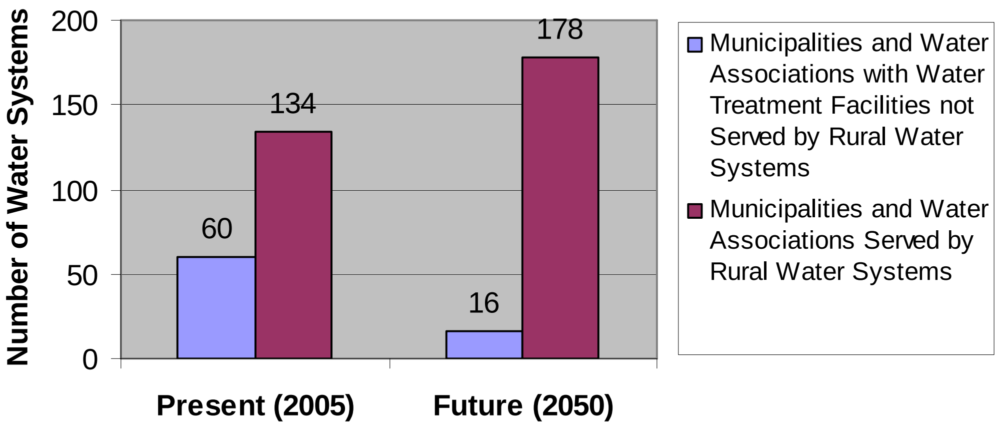


Figure 2.1.1 - Independent Municipalities vs. Municipalities Served by Rural Water Systems.

The needs assessment assumes that 44 of the 60 municipalities or water associations that presently have water treatment capabilities would contract with a rural water system for bulk or metered water service by 2050. Whether or not this occurs as predicted, all municipal water needs are incorporated in this needs assessment. Table 2.1.2 lists the 16 municipalities that are assumed to maintain their own water treatment facilities through 2050.

Table 2.1.2 – Municipalities Maintaining Water Treatment Facilities through 2050.

State	Municipality
North Dakota	Drayton, Enderlin, Fargo, Grafton, Grand Forks, Gwinner, Langdon, Larimore, Lisbon, Park River, Valley City, Wahpeton, West Fargo
Minnesota	Breckenridge, East Grand Forks, Moorhead

Table 2.1.3 lists each of the 12 rural water systems and the municipalities they now serve and those they would serve in the future. Not all of the municipal and water associations were evaluated individually. One hundred thirty-four municipalities and water associations already receive water service from rural water systems, so there was no need for individual evaluations. Evaluating 12 rural water systems was adequate to represent this portion of the Red River Valley population. Forty-four municipal or water association water systems that currently have their

own water treatment capability would be served by adjacent rural water systems by 2050 (figure 2.1.1).

Table 2.1.3 – Water Systems Served by Rural Water Systems through 2050.

Rural Water System	Currently Receiving Metered Service (2003)	Currently Receiving Bulk Service (2003)	Future Service From Rural Water System (2050)
Agassiz Water Users District	Gilby, Manvel, Mekinock, Forest River, Ardoch, Inkster, Johnstown, Honeyford		
Barnes Rural Water District	Urbana, Eckelson, Walum, Hastings, Leal, Rogers, Fort Ransom	Sanborn, Litchville, Oriska, Tower City, Verona, Ransom-Sargent Water District - 2 accounts, Fort Ransom State Park	Dazey, Kathryn, Wimbledon
Cass Rural Water Users District	Alice, Erie, Wheatland, Ayr, Absraka, Embden, Chaffee, Lynchburg, Durbin, Highland Park, Briarwood, Frontier Village, St. Benedict, Wild Rice, Warren, Hickson, Reiles Acres, Prosper	Amenia, Argusville, Buffalo, Casselton, Davenport, Gardener, Grandin, Hunter, Kindred, Mapleton, Tower City, Woodlawn Subdivision, Paririe Rose	Enderlin, Harwood, Horace, Oxbow, Page, Brooktree Wells Inc., Chrisan Water Users Assoc., County Acres Water Co., Fradets Orchard Water System, Horseshoe Bend Addition, Lake Shure Home Owners Assoc., Meadowbrook Park Road & Water Inc., Riverdale Subdivision, Selkirk Settlement, Sleepy Hollow Water Company
Dakota Rural Water District	Blabon, Luverne, Pillsbury, Kloten, Colgate, Jessie	Aneta, Finley, Hope, Sharon, Sibley	Binford, Cooperstown, Hannaford, McVille, Pekin, Tolna
Grand Forks-Traill Water District	Thompson, Reynolds, Buxton, Cummings	Northwood, Hatton, Emerado, Arvilla, Marshall-Polk	Arvilla Water Users Assoc.
Langdon Rural Water District	Hampden, Fairdale, Adams, Edinburg, Alsen	Edmore, Nekoma, Osnabrock	
North Valley Water District	Crystal, Glasston, Joliette, Bathgate, Leroy, Backoo, Hensel, Gardar, Hamilton	Cavalier, St. Thomas, Mountain, Milton, Walhalla, Neche, Cavalier Air Base Station, Bowesmont	Pembina
Ransom-Sargent Water Users District	Cogswell, Crete, Elliott, Fingal, Stirum	Nome	Forman, Marion, Sheldon, Sundale Hutterian Assoc.
Southeast Water District	Cayuga, DeLamere, Dwight, Glachutt, Graet Bend, Havana	Mooreton, Abercrombie, Mantador, Barney, Colfax, Milnor, Rutland	Fairmount, Hankinson, Lidgerwood, Wyndmere, Christine Water and Sewer
Traill Rural Water District	Blanchard, Caledonia, Clifford	Portland, Grandin, American Crystal Sugar at Hillsboro, Premium Foods at Grandin, Porter Dairy, Galesburg	Hillsboro, Mayville
Tri-County Water District	Lawton, Brocket, Dahlen, Petersburg, Michigan, Orr, Niagara, Kempton, Whitman		Lakota
Walsh Rural Water District	Hoople, Lankin, Pisek, Conway, Nash, Voss, Warsaw		Minto

This includes 12 water associations and 32 municipalities. Given that the 12 water associations only serve 50 – 150 residents, it is reasonable to assume they would be served by adjacent rural water systems in the future. Their future water demand would be similar to their rural water counterparts, so no additional individual analysis was performed.

In this study it is assumed that 32 municipal systems would be served by rural water systems in the future. Of the 32 municipal systems, 10 have a population of more than 500. These systems were evaluated individually to determine their future water demands. The 10 cities are listed in the third column of table 2.1.4. The remaining 22 towns have populations less than 500, and their water needs were assumed to be similar to the adjacent rural water systems that would provide them bulk or metered water service in the future. The population of these 22 towns was added to the rural water system populations in their area. The water systems which were assumed to be served by rural water systems in the future are listed in the last column of table 2.1.3.

Table 2.1.4 summarizes the municipal and rural water systems individually evaluated in the needs assessment. Water demands for those cities or water systems not listed in the table below are included in rural water system demand estimates.

Table 2.1.4 – Water Systems Individually Evaluated in Water Demand Analysis.

Municipalities with Water Treatment Capability through 2050	Rural Water Systems	Municipalities in a Rural Water System in 2050
Drayton Enderlin Fargo Grafton Grand Forks Gwinner Langdon Larimore Lisbon Park River Valley City Wahpeton West Fargo Breckenridge East Grand Forks Moorhead	Agassiz Water Users District Barnes Rural Water District Cass Rural Water Users District Dakota Rural Water District Grand Forks-Traill Water District Langdon Rural Water District North Valley Water District Ransom-Sargent Water Users District Southeast Water District Traill Rural Water District Tri-County Water District Walsh Rural Water District	Cooperstown Hankinson Harwood Hillsboro Horace Lidgerwood Mayville Minto Pembina Wyndmere

2.2 Water Demand Calculation Methods

An ac-ft is defined as one acre of land covered by one foot of water. There are 325,851 gallons in one ac-ft of water. Three ac-ft of water is about 1,000,000 gallons.

Methods for estimating various types of future water demands used in evaluating future water needs of municipal and rural water systems are described in this section. Water demands for municipalities and rural water systems are based predominately on future population projections and per capita demand estimates, although some city or rural systems include substantial bulk industrial demands. Municipal and rural water demands include per capita demands expressed as gpc/d (gallons per capita per day) and daily, monthly or annual water demands expressed as acre-feet. Ac-ft (acre-feet) units generally are used in this study because it is the unit of volume input for hydrologic modeling and water permits.

All examples, tables, and figures in this section use data from Fargo, because it is the largest MR&I water user within the geographic scope of the service area. The first part of section 2.2 discusses how future per capita water demands were estimated for municipal or rural water systems. The second part focuses on how water demands, on a volumetric basis (ac-ft) and flow rate (gallons per minute), were estimated. Industrial water needs are based on facilities' manufacturing or processing water requirements. Methods used to estimate industrial water demands are described in detail in section 2.8.

Water Demand Scenarios

Predicting future population (section 2.3) and industrial growth (section 2.8) introduces a level of uncertainty. The same can be said about projecting water demands. Recognizing this, two water demand scenarios were developed to quantify a reasonable range of future water demand estimates – Scenario One and Scenario Two (see text box). Projecting water demands through 2050 with absolute accuracy is difficult, which is reflected by the use of a range.

Scenario One: Reclamation's 2050 population projections x (per capita water demand – water conservation) + Bangsund and Leistritz (2004) intermediate future industrial water demands + recreation consumptive use.

Scenario Two: Water users' 2050 population projections x (per capita water demand – water conservation) + Bangsund and Leistritz (2004) high future industrial water demands + recreation consumptive use.

Historic Water Use and Unaccounted-for-Water Loss

Reclamation collected 15 years of water use data (1987 – 2001), if available, for each major municipality and rural water system as the basis for water use analysis. Table 2.1.4 lists these cities and rural water systems. Fifteen years of data were not available for all cities, so in some cases a shorter period of record was used in the water demand analysis. For example, Fargo had 14 years of data.

Monthly raw water diversion data in gallons were collected for each city/rural water system of interest. Data for unaccounted-for-water loss, which is the difference between the amount of water diverted (surface or groundwater) and the cumulative amount of water billed through each service connection meter, were also collected. Water loss generally can be attributed to unmetered connections, distribution system leakage, and treatment process.

The effects of unaccounted-for-water losses were factored in when calculating actual water use on a per capita basis. Water loss in some systems varied greatly from year to year depending on pipeline breaks and other factors. Some cities fixed water system leaks; their unaccounted-for-water-loss improved dramatically and are reflected in the data.

Figure 2.2.1 shows that by reducing its unaccounted-for-water-losses in the past few years, Fargo has noticeably reduced its per capita water use. Removing the effects of water losses gives a more accurate picture of historic water use. When the actual water use was estimated, a factor for water losses of 10% was added back into the estimate to determine a total water demand for Fargo. The water loss factor varies from water system to water system as noted in section 2.4.

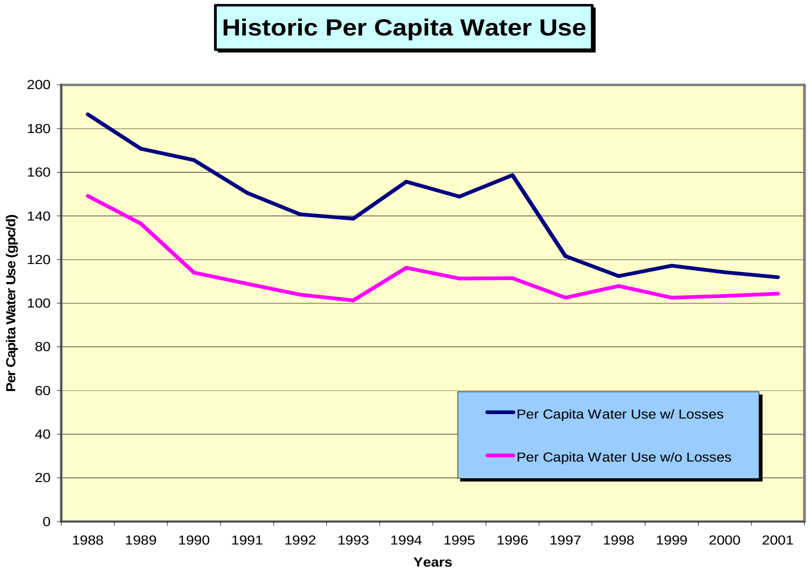


Figure 2.2.1 – Fargo Historic per Capita Water Use.

Table 2.2.1 shows the historic raw water diversion for Fargo in millions of gallons, while table 2.2.2 shows the same historic data with the influence of unaccounted-for-water-loss removed. The city provided historic data on annual water loss that varied from 6.7% to 31.1%. Data for 1988 and 1989 were not available, so the average of 20.0% was used in those years.

Figure 2.2.1 shows that water use was more uniform from 1988 – 2001 when the effects of water losses were removed mathematically (see lower line). Also note the higher water use from 1988 – 1990, which coincides with the last major drought event in the Red River Valley. Water losses were assumed to be uniform throughout the year and are not a function of the volume of water used in any month.

For example, the water system losses in a specific year may total 12,000,000 gallons. Therefore, it was assumed that the water system losses were approximately 1,000,000 gallons per month regardless of how much water was used in any one month. In some years water use may be doubled in the summer as compared to the winter, but this analysis assumed that water losses were generally uniform throughout the year. This assumption was validated in Fargo’s case as they attained significant reductions in unaccounted-for-water loss by aggressively fixing leaks and replacing aging pipe in the distribution systems. This demonstrated that most of their losses were related to pipeline leaks. Those losses are generally more uniform and are not related to variations in seasonal water use.

Monthly Demand Estimates

When estimating water demands for a water system, the most common unit of measure was expressed as an average annual per capita water demand. However, it is inadvisable to design a water system solely based on average water demands or conditions because water needs and

Table 2.2.1 – Fargo Historic Monthly Raw Water Diversion (millions of gallons).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Population	Percent Unaccounted for Losses (%)	Estimated Monthly Water Losses (millions of gallons)	Annual Per Capita Use (gpc/d)
1988	336	294	340	363	459	566	565	442	417	361	385	320	4,849	71,230	20.0	81.0	187
1989	338	294	316	326	399	445	618	484	347	308	286	367	4,528	72,660	20.0	75.6	171
1990	308	284	316	324	372	384	483	543	416	375	338	337	4,478	74,111	31.1	116.1	166
1991	323	278	292	300	372	393	407	464	389	356	298	297	4,169	75,883	27.6	95.9	151
1992	300	283	291	291	392	395	371	374	306	350	311	316	3,982	77,558	26.1	86.6	141
1993	318	297	297	300	336	326	339	413	388	362	312	322	4,010	79,164	27.0	90.2	139
1994	338	356	374	344	418	474	442	457	381	351	322	341	4,598	80,924	25.3	96.9	156
1995	340	290	324	312	375	517	392	525	424	361	310	310	4,480	82,442	25.2	94.1	149
1996	335	339	341	355	379	491	560	539	433	386	345	351	4,854	83,822	29.7	120.1	159
1997	362	328	375	324	300	345	329	361	297	280	244	243	3,790	85,358	15.7	49.6	122
1998	246	221	240	264	326	294	359	433	344	292	269	281	3,568	86,935	4.1	12.2	112
1999	327	254	286	271	323	365	400	371	309	303	279	281	3,770	88,128	12.5	39.3	117
2000	276	275	293	285	341	319	379	450	314	297	265	283	3,777	90,599	9.5	29.9	114
2001	276	246	292	281	323	331	436	407	332	302	272	276	3,774	92,410	6.7	21.1	112
Average	316	288	313	310	365	403	434	447	364	335	303	309	4,188		20.0		142.4

Table 2.2.2 – Fargo Historic Metered Water Usage (without system losses) (millions of gallons).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Population	Annual Per Capita Use (gpc/d)	High Monthly Water Use (millions of gallons)
1988	255	213	259	282	378	485	484	361	336	280	304	239	3,877	71,230	149	485
1989	262	218	241	250	324	369	543	408	272	232	210	292	3,620	72,660	137	543
1990	192	168	200	208	256	268	366	427	299	259	222	221	3,085	74,111	114	427
1991	227	182	196	204	276	297	311	368	293	261	202	202	3,018	75,883	109	368
1992	213	196	205	205	306	309	284	287	220	264	225	229	2,943	77,558	104	309
1993	228	207	207	209	246	236	249	323	298	271	222	232	2,928	79,164	101	323
1994	241	259	277	247	321	377	345	360	284	254	225	245	3,434	80,924	116	377
1995	246	196	230	218	280	423	298	431	330	267	216	216	3,351	82,442	111	431
1996	215	219	221	235	258	371	440	419	312	265	225	231	3,412	83,822	112	440
1997	313	279	326	275	251	295	280	311	247	231	195	194	3,195	85,358	103	326
1998	233	209	227	252	314	282	347	421	332	280	257	268	3,422	86,935	108	421
1999	288	215	247	231	284	326	361	332	270	264	240	241	3,299	88,128	103	361
2000	246	245	263	255	311	289	349	420	284	267	235	253	3,418	90,599	103	420
2001	255	225	271	260	302	310	415	386	311	281	251	255	3,521	92,410	104	415
Average	244	216	241	238	293	331	362	375	292	263	231	237	3,323		112.4	403.1
% Monthly Distribution	7.3	6.5	7.2	7.2	8.8	10.0	10.9	11.3	8.8	7.9	6.9	7.1	100.0			

climate can vary over a large range. Because monthly hydrologic modeling was used in the analysis, a scenario based on the maximum month water demand using 15 years of monthly water demand data (14 years for Fargo) was developed as an input to the model.

Table 2.2.3 shows month-by-month and year-by-year historic gallons per capita per day water use without system losses for Fargo. Per capita water use was calculated by dividing water use in gallons by population for the corresponding year. The highest gallons per capita per day for each month is highlighted in the table and was used in developing the maximum annual water demand.

Table 2.2.4 shows the same data as table 2.2.3 with the summer and winter months delineated separately. May through October were regarded as summer months with the remaining months considered as winter months. The average summer and winter per capita use in each year appears in the last two columns. Not surprisingly, average summer use was higher than the winter use. The majority of this difference was outdoor water use related to landscape watering.

Figure 2.2.2 compares summer and winter per capita water use (without losses) for Fargo over the past 14 years. This is a typical water use pattern in the northern plains unless a city serves a large industrial water user(s). Note that winter use from year to year varies little while summer use varies greatly. This is due to climatic fluctuations from year to year or month to month. The summer and winter use in 1997 is almost equal, which is unusual and probably related to the 1997 flood when there were known data recording problems.

The maximum monthly water demands for other MR&I systems in the service area were estimated in basically the same way as shown above. The actual spreadsheet analysis is provided in Appendix A, Attachment 4.

Water Conservation and Drought Contingency

The terms “water conservation” and “drought contingency” are often confused with one another. One misconception is that water conservation plans and drought contingency plans are interchangeable terms. While it is true that water conservation and drought contingency planning both address water use reduction, they are different in their application. *Water conservation* is something that water systems or users should practice daily to save water under all water supply conditions, while *drought contingency measures* are water saving actions implemented and enforced during times of drought or emergency water shortages.

Distinguishing between historic summer water use vs. historic winter water use facilitates incorporation of water conservation savings, which are season-specific, into per capita water demand calculations. Water conservation measures were separated into two categories associated with summer and winter water use. Some water conservation measures were applied to baseline (winter use), because these address water use types that remain uniform throughout the year. Other water conservation measures address outside landscaping water use, which applies to summer water use (see Water Conservation Measures, section 2.5). Water conservation is included in all Project alternatives as a feature (see chapter four).

Table 2.2.3 – Fargo Historic Monthly Metered Water Use without System Losses (gallons per capita/day)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Population	Average Per Capita Use (gpc/d)
1988	116	107	117	132	171	227	219	164	157	127	142	108	71,230	149.1
1989	116	107	107	115	144	169	241	181	125	103	96	129	72,660	136.5
1990	84	81	87	93	111	121	160	186	135	113	100	96	74,111	114.1
1991	96	86	83	90	117	130	132	156	129	111	89	86	75,883	109.0
1992	89	90	85	88	127	133	118	120	94	110	97	95	77,558	103.9
1993	93	93	84	88	100	99	101	132	125	111	93	95	79,164	101.3
1994	96	114	110	102	128	155	138	143	117	101	93	97	80,924	116.3
1995	96	85	90	88	110	171	117	169	133	104	87	85	82,442	111.4
1996	83	93	85	93	99	148	169	161	124	102	89	89	83,822	111.5
1997	118	117	123	107	95	115	106	118	96	87	76	73	85,358	102.5
1998	87	86	84	97	116	108	129	156	127	104	99	100	86,935	107.8
1999	105	87	90	88	104	123	132	121	102	97	91	88	88,128	102.6
2000	88	97	94	94	111	106	124	150	105	95	87	90	90,599	103.4
2001	89	87	95	94	105	112	145	135	112	98	91	89	92,410	104.4
Average	97	95	95	98	117	137	145	149	120	104	95	94		112.4
Maximum	118	117	123	132	171	227	241	186	157	127	142	129		

Table 2.2.4 – Fargo Historic Summer and Winter Monthly per Capita Water Use Data without System Losses (gallons per capita/day).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Population	Winter Per Capita Use (gpc/d)	Summer Per Capita Use (gpc/d)
1988	116	107	117	132	171	227	219	164	157	127	142	108	71,230	120	178
1989	116	107	107	115	144	169	241	181	125	103	96	129	72,660	112	161
1990	84	81	87	93	111	121	160	186	135	113	100	96	74,111	90	137
1991	96	86	83	90	117	130	132	156	129	111	89	86	75,883	88	129
1992	89	90	85	88	127	133	118	120	94	110	97	95	77,558	91	117
1993	93	93	84	88	100	99	101	132	125	111	93	95	79,164	91	111
1994	96	114	110	102	128	155	138	143	117	101	93	97	80,924	102	130
1995	96	85	90	88	110	171	117	169	133	104	87	85	82,442	89	134
1996	83	93	85	93	99	148	169	161	124	102	89	89	83,822	89	134
1997	118	117	123	107	95	115	106	118	96	87	76	73	85,358	102	103
1998	87	86	84	97	116	108	129	156	127	104	99	100	86,935	92	123
1999	105	87	90	88	104	123	132	121	102	97	91	88	88,128	92	113
2000	88	97	94	94	111	106	124	150	105	95	87	90	90,599	91	115
2001	89	87	95	94	105	112	145	135	112	98	91	89	92,410	91	118
Average	97	95	95	98	117	137	145	149	120	104	95	94		95.7	128.9
Max Month	118	117	123	132	171	227	241	186	157	127	142	129			

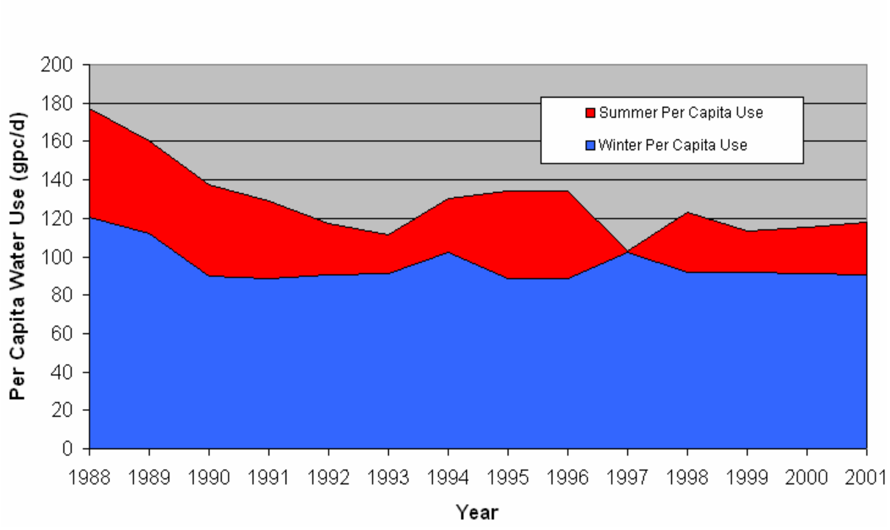


Figure 2.2.2 – Fargo Summer and Winter Historic Per Capita Water Use (without Losses).

When developing water demand estimates, water conservation savings were applied on a month-by-month basis depending on whether it was a summer or winter demand month. Table 2.2.5 shows the summer and winter estimated water saving in gpc/d from the *Water Conservation Potential Assessment Final Report* (Reclamation 2004b). Fargo's indoor annual water conservation savings were estimated at 6.67 gpc/d, while outdoor water savings were estimated to be 1.26 gpc/d. The 1.26 gpc/d was actually an annualized estimate. Since it only applies in the summer, the actual water savings were two times 1.26 gpc/d or 2.52 gpc/d. Therefore, water savings in the winter were 6.67 gpc/d and in the summer were 9.19 gpc/d, with an annual average of 7.93 gpc/d.

Table 2.2.5 – Water Conservation Potential Assessment Results.

Water System(s)	Average Water Savings (gpc/d)	Summer Water Savings (gpc/d)	Winter Water Savings (gpc/d)
Fargo	7.93	9.19	6.67
Grand Forks	8.25	9.12	7.38
West Fargo	6.54	7.19	5.89
Moorhead	8.07	8.70	7.44
Medium Size Municipal Water Systems (population 1,000 to 15,000)	9.02	9.57	8.47
Rural Water Systems including cities <1,000 in population	8.80	9.45	8.15

All of the options described in chapter four meet future water demands without incorporating drought contingency measures in the water demand estimates. This assumption was made because of uncertainty in estimating future water needs and future water supplies and reserving drought contingency measures as an important safety factor that would be implemented if unforeseen events would occur. An analysis of potential option (alternative) cost savings under certain levels of drought contingency demand reduction are described Appendix C, Attachment 9 and are briefly summarized in chapter four.

Average and Annual Maximum Month Per Capita Water Demand Calculations

Two categories of monthly per capita water demand estimates were considered in this needs assessment – average monthly and maximum monthly. Average monthly per capita water demands are important when describing typical annual water use, while maximum monthly per capita water demands are important when analyzing the limits of the hydrologic system. Each of these two water demands are further expressed with or without water conservation and/or losses in table 2.2.6.

Table 2.2.6 shows per capita monthly water demand estimates for Fargo. The average annual per capita water demand without water losses was 112.4 gpc/d and 104.5 gpc/d with water conservation savings. The average annual per capita water demand of 112.4 gpc/d is <u>not</u> the average of the 12 monthly values, but the proportional average which takes into account the actual number of days per month, which varies from month to month. Because some water system losses were expected, an additional factor of 10% water loss (which is Fargo's current water loss) was added back into the average annual per capita estimate. This resulted in 116.1 gpc/d. Figure 2.2.3 graphs how the average annual per capita water demand was modified to account for water conservation and water loss.

Table 2.2.6 shows the annual maximum month per capita water demand without water losses at 156.1 gpc/d. This table uses the highest per capita historic water use for each month from the 1988 – 2001 data collected (highlighted in table 2.2.3). This represents the highest water use year based on maximum month water demand for each of the 12 months. The annual maximum month per capita water demand with water conservation and losses was 164.6 gpc/d.

Monthly Water Demand Scenarios

Monthly water demands scenarios were developed for input into the surface hydrologic model. This was done to determine if there would be adequate future surface water supplies for surface water dependent systems in 2050. The maximum month for each of the twelve months from 15 years of historic monthly water use data from 1988 – 2001 was used to develop future water demand scenarios. This is a key time period in which the Red River Valley experienced a wide variety of climatic conditions. The analysis assumed that there were no shortages during this period and that actual water use data represented future water use on a per capita basis.

Table 2.2.7 shows 15 lowest historic flow years ranked in the Red River Valley for the period of 1931 – 2001 at Emerson, Manitoba in ac-ft. Emerson, Manitoba is the closest USGS (United States Geological Survey) gaging station to the U.S. – Canadian border. The table shows naturalized flows which represent the amount of water flowing by that gage without the influence of humans (depletions or additions).

Table 2.2.6 – Fargo Water Demand Estimates (from 1988 – 2001 Historic Water Use Data).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Per Capita (gpc/d)
Average Monthly Demand without Losses (gpc/d)	96.8	95.0	95.4	97.7	117.1	137.0	145.0	149.4	120.2	104.5	94.9	94.4	112.4
Average Monthly Demand with Water Conservation (gpc/d)	90.1	88.3	88.7	91.1	107.9	127.8	135.8	140.2	111.0	95.3	88.3	87.7	104.5
Average Monthly Demand with Water Conservation and Losses (gpc/d) [1]	**100.1**	**98.1**	**98.6**	**101.2**	**119.9**	**142.0**	**150.9**	**155.7**	**123.3**	**105.8**	**98.1**	**97.4**	**116.1**
Maximum Month Data without Losses (gpc/d)	118.2	116.6	123.0	132.0	171.3	226.9	240.9	185.7	157.5	126.8	142.5	129.5	156.1
Maximum Month Data with Losses (gpc/d) [1]	**131.3**	**129.6**	**136.7**	**146.6**	**190.4**	**252.1**	**267.7**	**206.3**	**175.0**	**140.9**	**158.3**	**143.8**	**173.5**
Maximum Month Data with Water Conservation (gpc/d)	111.5	109.9	116.4	125.3	162.1	217.7	231.7	176.5	148.3	117.6	135.8	122.8	148.2
Maximum Month Data with Water Conservation and Losses (gpc/d) [1]	**123.9**	**122.1**	**129.3**	**139.2**	**180.2**	**241.8**	**257.5**	**196.1**	**164.7**	**130.7**	**150.9**	**136.4**	**164.6**

[1] **Assumes 10% water losses.**

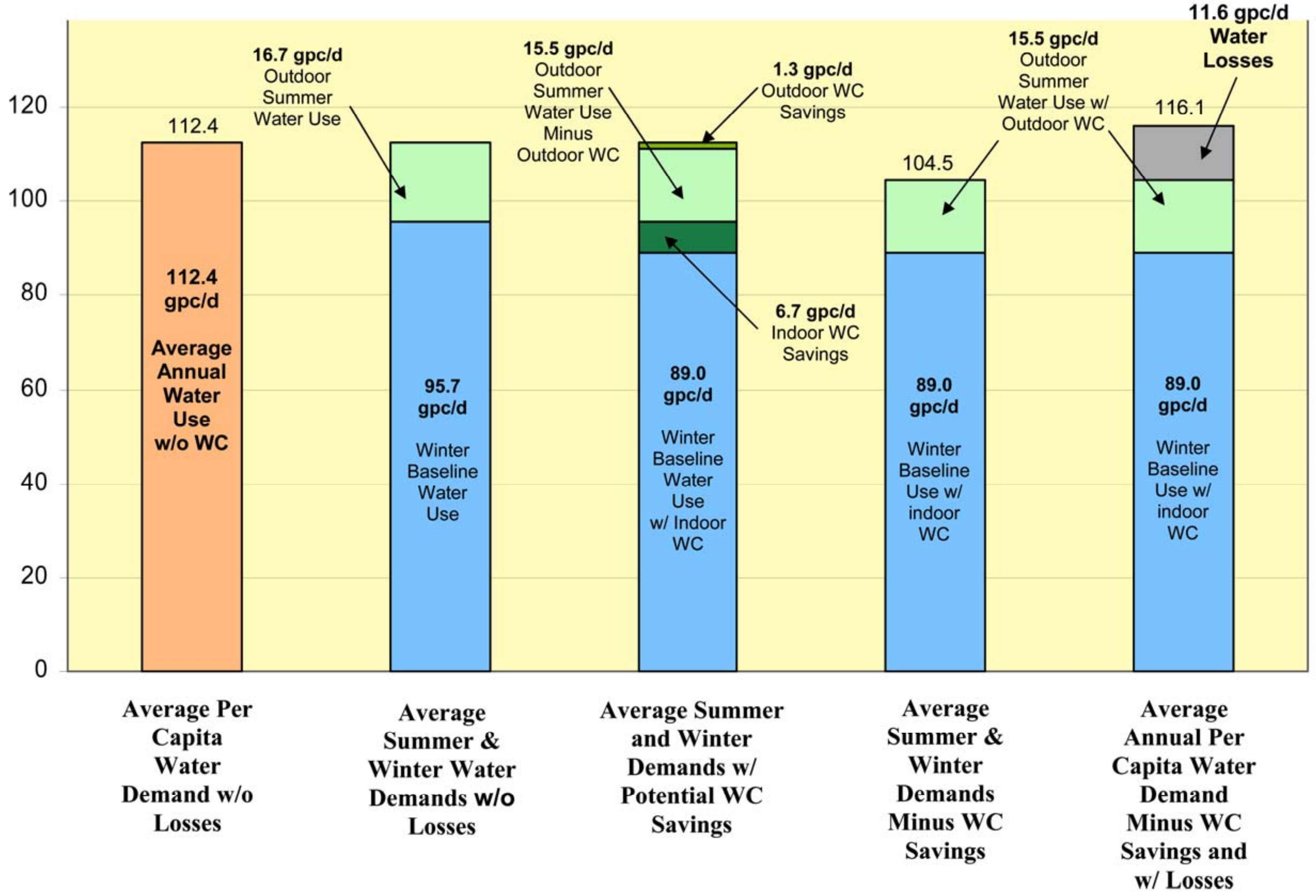


Figure 2.2.3 - Estimation of Fargo's Annual Average Water Demand including Water Conservation and Water Loss.
Note: The orange column (112.4 gpc/d) comes from table 2.2.3. The next column (95.7 gpc/d) is from table 2.2.4, and 16.7 gpc/d is the difference between average annual water demand at 112.4 gpc/d and average winter demand at 95.7 gpc/d. The per capita water demand with WC is 104.5 gpc/d which is 112.4 gpc/d – indoor WC at 6.7 gpc/d – outdoor WC at 1.3 gpc/d. The average annual per capita water demand with WC and losses is 116.1 gpc/d, which are the 104.4 gpc/d + losses of 11.6 gpc/d.

Table 2.2.7 – Ranked Lowest Naturalized Annual Flows at Emerson, Manitoba for 71 years (1931 – 2001).

Rank	Year	Annual Naturalized Flow (ac-ft)
1	1934	240,236
2	1931	442,037
3	1935	474,059
4	1939	498,179
5	1933	596,448
6	1937	603,458
7	1936	627,380
8	1940	638,087
9	1961	683,014
10	1977	712,585
11	1938	739,694
12	1932	757,457
13	1990	800,285
14	1988	976,287
15	1959	1,097,747
71 year statistics		
Minimum		240,236
Maximum		9,677,655
Average		3,115,424

These flow data approximate the amount of water available for use in any one year; however, using these data to approximate the amount of water available at any one location in the Red River Valley is not possible. Most of the water demand is in the upper part of the drainage near Fargo, while a significant amount of the basin runoff is below Fargo. If the Red River Valley had sufficient topographic relief for construction of an additional dam, then the volume of water in table 2.2.7 could be captured and stored. But in the flat Red River Valley, such potential dam sites do not exist, and the ability to capture water is very limited. Note that all of the years in the decade starting in 1931 are ranked in the 15 lowest flow years. This demonstrates that not only were there some very dry years during the 1930s, but the intensity of the drought persisted for 10 consecutive years. From a flow perspective the drought did not break until 1941 when the valley had runoff totaling just under 2 million ac-ft. Although that was still under the average annual runoff of 3.1 million ac-ft, it was enough to break the drought in terms of hydrologic flows.

The maximum month water demands used in this study were developed from much more recent water use data (1987 – 2001). As illustrated in table 2.2.7, the years 1990 and 1988 rank as the 13th and 14th years of lowest annual runoff flows at 800,000 ac-ft and 976,000 ac-ft, respectively. The decade of the 1980s is the second driest period in the valley since the 1930s, but the 1980s drought pales in comparison to the 1930s. The highest historic water use in the valley generally occurred in the 1988 – 1990 time period, which coincides with the lowest flow years during that period. Therefore, the study used the maximum month water demands which occurred in the 1988 – 1990 period to develop water demand scenarios for future droughts. Water use may be higher if drought conditions of the 1930s occurred now or in the future, but the use of maximum month water demands for each water system is a reasonable approach in evaluating future water supplies.

Table 2.2.8 shows the results of converting historic monthly per capita water use data (presented previously in table 2.2.6) into monthly water demand in ac-ft. Water demands generally are presented in ac-ft because it is the unit of measurement used in the hydrologic model. The monthly water demand values in the table are calculated by multiplying the per capita water demand by the estimated population.

In calculating water demands for each water user, Scenario One uses Reclamation's 2050 population projections and Scenario Two uses the water users' 2050 population projections, as discussed in the next section, Population Projections. This results in an average annual water demand for Fargo of 26,571 ac-ft under Scenario One or 31,613 ac-ft under Scenario Two. Likewise, the maximum annual water demand for Fargo is 37,682 ac-ft under Scenario One or 44,833 ac-ft under Scenario Two. These results include water conservation reductions and water losses.

Table 2.2.8 - Fargo Average and Maximum Monthly Water Demands in ac-ft (includes Water Conservation and Water Losses).

Water System Scenario	2050 Population Projection	Average per Capita Water Use (gpc/d)	Average Annual Water Demand (ac-ft)	Annual Maximum Month Per Capita Water Demand (gpc/d)	Annual Maximum Month Water Demand (ac-ft)
Fargo Scenario One	204,300	116.1	26,571	164.7	37,682
Fargo Scenario Two	243,073	116.1	31,613	164.7	44,833

Results similar to those shown in table 2.2.8 were developed for each water system listed in table 2.1.4. The maximum monthly water demand scenarios were incorporated into the surface water hydrologic model to determine the adequacy of surface water sources. The manner in which Fargo's (and other surface water supplied water systems) water demand values were used is explained in more detail in chapter three (Hydrology).

Peak Day Water Demand

Historic peak day water use data were gathered from all water systems listed in table 2.1.4. For those water systems lacking peak daily data or incomplete data, values from similar water systems were used in the analysis. Table 2.2.9 shows an example of historic peak daily water use data collected from Fargo. In this case only data from 1988 and 1997 – 2001 were available. Fargo also provided additional information related to their 1988 peak day water use event. The 1988 peak day data were modified to account for losses to storage and for drought contingency measures. The peak daily demand changes are reflected in table 2.2.10. Other water systems also reported unique circumstances associated with their historic peak day water use and modifications were made to some values to account for these specific water use events. Peak day water demand analysis for other water systems is documented in Appendix A.

Peak daily water use data includes water losses. To remove this influence, the peak daily values were first calculated without water losses. As shown in table 2.2.9, the maximum daily per capita water use in Fargo occurred in 1988 with a peak of 289 gpc/d without losses and a daily peaking factor of 2.57 when compared to the overall average of 112.4 gpc/d from table 2.2.3.

Table 2.2.10 outlines the process for estimating peak daily water demand including water conservation and water losses. In this example Fargo's water loss rates improved from 1988, so a lower loss rate of 10% was used. The resulting peak daily water demand is estimated at 381.7 gpc/d with a peaking factor of 3.29. This value was used in the following 31-day peak day water demand analysis for Fargo.

Table 2.2.9 - Fargo Historic Peak Daily Water Use.

Year	Peak Daily Water Use with Losses (gallons)	Estimated Daily Water Losses (gallons)	Peak Daily Water Use without Losses (gallons)	Peak Daily Per Capita Use without Losses (gpc/d)	Daily Peaking Factor
1988 [1]	23,220,000	2,662,681	20,557,319	289	2.57
1989 - 1996	No Data	No Data	No Data	No Data	-
1997	19,300,000	1,630,043	17,669,957	207	1.84
1998	20,900,000	400,840	20,499,160	236	2.10
1999	19,900,000	1,291,207	18,608,793	211	1.88
2000	21,700,000	982,982	20,717,018	229	2.03
2001	21,400,000	692,815	20,707,185	224	1.99
Average	21,070,000	1,276,761	19,793,239	233	2.07

[1] Information provided by Fargo and includes 2 million gallons of water lost in storage and approximately 2.5 million gallons attenuated through drought contingency enforcements.

Table 2.2.10 – Fargo Estimated Peak Daily Water Demand with Water Conservation and Losses.

Peak Daily Demand Estimate (with Water Conservation and Losses)	Per Capita Water Demand (gpc/d)
Maximum Daily Water Use (without water losses)	288.6
with Conservation Reduction	9.2
Subtotal	**279.4**
Estimated Storage Depletion	28.1
Estimated Peak Day Demand Attenuation	36.0
Subtotal	**343.5**
Peak Daily Demand with Water Conservation and Water Losses	**381.7**
Peak Daily Demand Factor with Water Conservation and Water Losses	**3.29**

Peak Day Water Demand Analysis Method

For systems or municipalities using groundwater when aquifers have been adequately assessed prior to issuance of water permits, evaluation of peak day demands for water systems is relatively uncomplicated. The maximum permitted daily withdrawal is compared to the estimated peak day water demand to determine if the current permit is adequate. Section 3.3 in the hydrology chapter compares existing peak day groundwater permits with estimated peak day water demands and identifies potential shortages.

For systems or municipalities using surface water, meeting peak day is much more complex because it requires the analysis of historic stream flow conditions on a daily time-step to identify potential daily shortages. Surface water hydrologic modeling was conducted on a monthly time-step after investigations into availability of daily flow data indicated there were inadequate data to use StateMod for modeling on a daily time-step (see chapter three for a detailed explanation). Therefore, peak day water demand analysis was conducted using a spreadsheet to analyze surface dependent water systems using flow and water withdrawal results from monthly modeling. Results of peak day analysis are found in section 3.5.6. Detailed analysis of each surface water dependent system's ability to meet peak day water demands are in Appendix A.

The peak day water demand analysis investigates three methods for meeting daily peaking demands are: (1) groundwater, (2) storage, and (3) import features. Storage could be either raw or treated water, depending on local circumstances.

Each alternative developed in this report guarantees that a certain in-stream volume of water is provided to each surface water dependent system in the Red River Valley on a monthly time-step. For example, Fargo has a maximum month water demand of 5,005 ac-ft under Scenario One. That means that the hydrologic model has allocated 5,005 ac-ft of stream flow in the maximum month (July) or 161.5 ac-ft per day. The problem is that Fargo has a peak day water demand estimated at 239.9 ac-ft (based on 381.7 gpc/d), which means that the city has a one day shortage of 77.9 ac-ft. These values are highlighted in table 2.2.11. Similar peak day analysis tables are provided for each water system in Appendix A.

The analysis presented in table 2.2.11 is based on the 31-day water demand distribution curve actually experienced by Grand Forks in July of 1989, which occurred in their historic maximum water demand month. Note that in the second column the percentage of the monthly water demand in each day of the month is listed. Similar daily demand data were not available for Fargo. The cities of Fargo, Moorhead, and West Fargo also experienced their maximum month water use during July 1989. Therefore, using the Grand Forks daily demand curve for these and other Red River Valley cities is reasonable, since they represent more than 75% of the service area population.

Table 2.2.11 shows the estimated daily water demand in cfs and ac-ft (columns three and four); the average daily water delivery in ac-ft (column five); water shortage, which is the difference between the water needed and the water delivered in ac-ft and millions of gallons, (columns eight and nine); and net storage (column 10). Net storage is the day-by-day storage volume simulation for the water system. In this example, Fargo's peak daily water demand can be met with 125.3 million gallons of storage (see highlighted value in column 10). The maximum value on column 10 represents the total storage Fargo would need to meet their peak day demands.

Column eight in table 2.2.11 shows all of the days and corresponding shortage Fargo would experience during their maximum month. The total shortage in the worst month is 449.1 ac-ft. That is the amount of water which would be provided in the maximum demand month from storage or provided from another source such as from groundwater or an import. The largest daily shortage occurred on the 21st day of the month at 77.9 ac-ft or an equivalent flow capacity of 39.3 cfs.

Figure 2.2.4 shows the water demand curve for Fargo under Scenario One in ac-ft. Peak day occurs on the 21st day of the month at a demand of 239.3 ac-ft or 120.7 cfs. Figure 2.2.5 shows the storage simulation for Fargo. A total storage of 125.3 million gallons (385 ac-ft) is required to meet peak day water demands during the maximum water demand month. In this simulation, the maximum volume of water required for peaking is achieved on the 15th day of the month at 125.3 million gallons as shown in column 10 of table 2.2.11.

Table 2.2.11 – Water Demand and Storage Analysis – Fargo – Scenario One.

Day of Max. Month	Daily Water Demand Distribution (%)	Daily Water Demand (cfs)	Daily Water Demand (ac-ft)	Average Daily Water Delivery (ac-ft)	Accum. Water Demand (ac-ft)	Accum. System Deliver (ac-ft)	Water Shortage or Surplus (ac-ft)	Water Shortage or Surplus (10^6 gallons)	Net Storage (10^6 gallons)
Column No.	2	3	4	5	6	7	8	9	10
1	3.37	84.9	168.5	161.5	168.5	161.5	-7.0	-2.3	57.7
2	2.76	69.6	138.0	161.5	306.5	322.9	23.5	7.6	65.3
3	2.24	56.6	112.2	161.5	418.7	484.4	49.3	16.1	81.4
4	2.29	57.7	114.5	161.5	533.2	645.8	46.9	15.3	96.7
5	3.76	94.8	188.1	161.5	721.3	807.3	-26.6	-8.7	88.0
6	3.93	99.1	196.6	161.5	917.9	968.7	-35.2	-11.5	76.5
7	3.28	82.8	164.2	161.5	1,082.1	1,130.2	-2.7	-0.9	75.7
8	2.99	75.5	149.7	161.5	1,231.8	1,291.6	11.7	3.8	79.5
9	2.37	59.7	118.4	161.5	1,350.3	1,453.1	43.0	14.0	93.5
10	2.41	60.9	120.8	161.5	1,471.1	1,614.5	40.7	13.2	106.7
11	2.99	75.5	149.7	161.5	1,620.8	1,776.0	11.7	3.8	110.6
12	2.99	75.5	149.7	161.5	1,770.5	1,937.4	11.7	3.8	114.4
13	2.99	75.5	149.7	161.5	1,920.3	2,098.9	11.7	3.8	118.2
14	2.99	75.5	149.7	161.5	2,070.0	2,260.3	11.7	3.8	122.0
15	3.02	76.3	151.4	161.5	2,221.4	2,421.8	10.1	3.3	125.3
16	3.50	88.3	175.1	161.5	2,396.4	2,583.2	-13.6	-4.4	120.9
17	3.59	90.6	179.8	161.5	2,576.2	2,744.7	-18.3	-6.0	114.9
18	3.59	90.6	179.8	161.5	2,755.9	2,906.1	-18.3	-6.0	108.9
19	3.59	90.6	179.8	161.5	2,935.7	3,067.6	-18.3	-6.0	103.0
20	3.63	91.7	181.9	161.5	3,117.6	3,229.0	-20.4	-6.7	96.3
21	4.78	120.7	239.3	161.5	3,356.9	3,390.5	-77.9	-25.4	70.9
22	4.20	106.1	210.4	161.5	3,567.3	3,551.9	-48.9	-15.9	55.0
23	3.77	95.2	188.8	161.5	3,756.1	3,713.4	-27.4	-8.9	46.1
24	3.34	84.4	167.3	161.5	3,923.4	3,874.8	-5.9	-1.9	44.2
25	3.58	90.3	179.1	161.5	4,102.5	4,036.3	-17.6	-5.7	38.4
26	4.42	111.6	221.3	161.5	4,323.8	4,197.7	-59.8	-19.5	18.9
27	4.25	107.1	212.5	161.5	4,536.3	4,359.2	-51.0	-16.6	2.3
28	2.44	61.7	122.4	161.5	4,658.6	4,520.6	39.1	12.7	15.0
29	1.38	34.9	69.2	161.5	4,727.8	4,682.1	92.3	30.1	45.1
30	2.36	59.5	118.1	161.5	4,845.9	4,843.5	43.4	14.1	59.2
31	3.18	80.2	159.1	161.5	5,005.0	5,005.0	2.3	0.8	60.0
Totals [1]			5,005.0	5,005.0			449.1	146.3	

[1] The total water shortage (ac-ft) is the absolute value of all the negative values in Column 8.

Note: values highlighted in blue are discussed in the text.

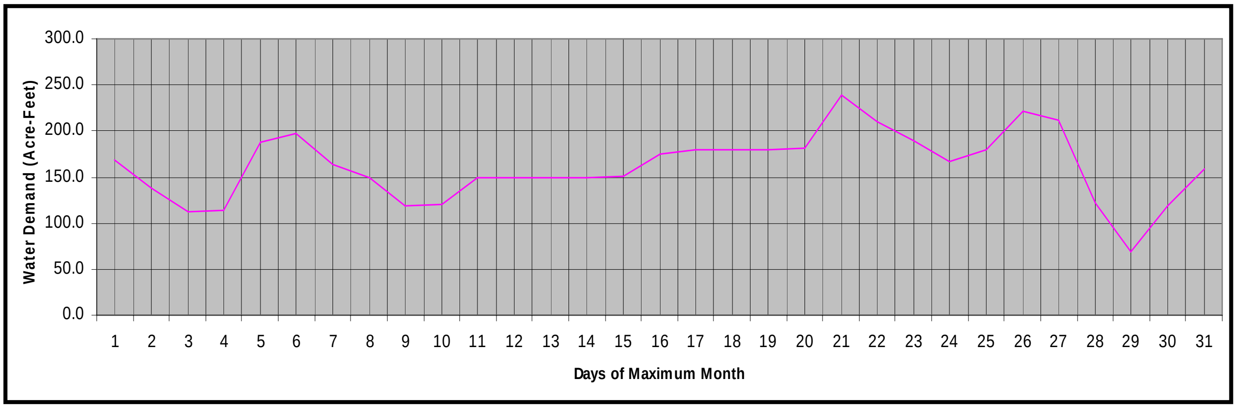


Figure 2.2.4 – Maximum Month Water Demand Curve – Fargo with Scenario One.

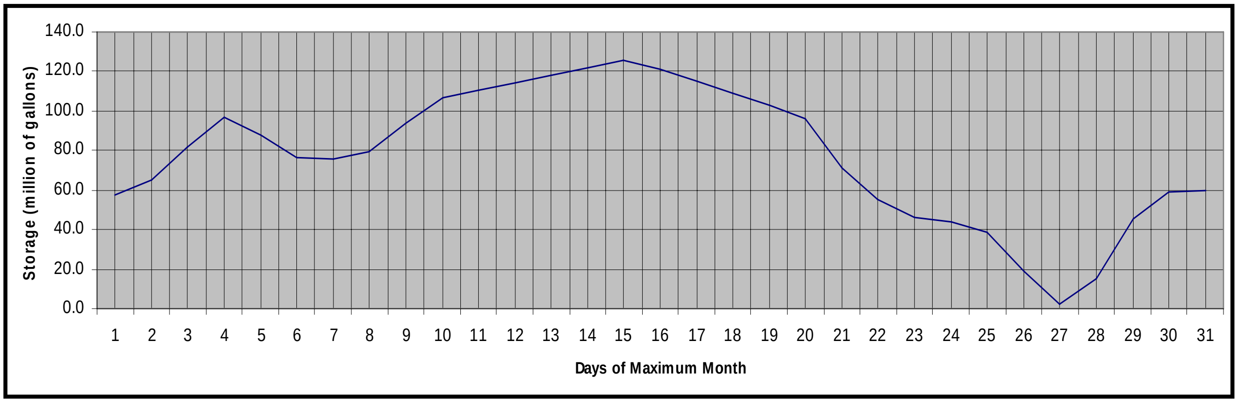


Figure 2.2.5 – Storage Simulation – Fargo with Scenario One.

The analysis shown in table 2.2.11 can be used to size the three different methods of addressing peak day water demands. The three methods for meeting daily peaking demands are: (1) groundwater, (2) storage, and (3) import features.

Groundwater

Column eight in table 2.2.11 shows that the largest daily shortage occurred on the 21st day of the month at 77.9 ac-ft or an equivalent flow capacity of 39.3 cfs. Therefore, if a groundwater source is used to meet peak day, the well capacity would have to be 39.3 cfs. The total shortage in the worst month is 449.1 ac-ft so the most water that would be withdrawn from groundwater is 449.1 ac-ft.

Storage

The storage method would work by capturing excess flows released from Lake Ashtabula (see chapter three for more information) when releases are higher than needed during the maximum month. Water would be withdrawn from storage on days where river flows (releases from Ashtabula and natural flows) are not adequate to meet peak day demands. Column five of table 2.2.11 shows the average volume of water which is allocated for Fargo's use during the maximum month scenario (161.5 ac-ft). In 16 of the 31 days, water demand exceeds available river flow based on hydrologic modeling.

Approximately 125.3 million gallons of storage would be required during these days to meet peaking demands. The other 15 days require less than average maximum month demand (<161.5 ac-ft), and excess allocated flows to Fargo could be used to fill the storage reservoir(s).

Additional Pipeline Capacity - Peak Day Water Demand Method

Some of the alternatives propose importing water from outside the Red River Valley. These water sources include the Missouri River, Lake of the Woods, and Minnesota groundwater. The capacity of the conveyance pipeline system from each of these water sources could be increased to meet peak day requirements. For example, in the case of Fargo under Scenario One, the difference between the average water allocation for Fargo during the maximum month (161.5 ac-ft) and their peak day water demand (239.3 ac-ft) is 77.9 ac-ft or 25.4 million gallons. This is equivalent to a flow of 39.3 cfs over a one day period. Therefore, the import feature to serve Fargo could be increased in capacity by 39.3 cfs to meet peak day water demands. This results in the same capacity requirements as discussed above for groundwater.

Section 3.5.6 of chapter three discusses the results of using all three methods of meeting peak day water demands for surface water dependent systems. The detailed peak day analysis spreadsheets are in Appendix A.

2.3 Population Projections

Predicting future population growth is a key component in estimating future water demands. Three sources of population projection data are used in this assessment. Projections were developed by Reclamation, Northwest (Northwest Economic Associates), and individual Red River Valley municipalities. Reclamation contracted with Northwest to independently estimate population growth to compare with Reclamation’s projections. However, some water users in the Red River Valley did not agree with Reclamation or with Northwest projections, so they provided their own estimates for consideration. Each of these is discussed below.

Reclamation Population Projections

Tables 2.3.1 and 2.3.2 show the 2000 Census population data and the 2050 Reclamation population projections for counties and municipalities. Reclamation’s population projections for the Red River Valley are documented in *Current and Future Population of the Red River Valley Region 2000 to 2050, Final Report* (Reclamation 2003b/Revised 2005). Population projections for the period of 2000 through 2050 were developed using data from the North Dakota Data Center, Minnesota State Demographic Center, and U.S. Census Bureau.

The cohort-component method was used to project future Red River Valley populations. This is the accepted standard method for estimating future populations (Reclamation 2003b/Revised 2005). A range of projections using the cohort-component method were estimated in the Reclamation report (Reclamation 2003b/Revised 2005). The range of population projections represents different assumptions about future net migration patterns. The estimates presented in this section are based on the assumption that past net migration patterns will continue in the “urban” counties and the decline in “rural” county populations will stabilize, as represented by the zero net migration scenario for “rural” counties. These assumptions were used to project future population for the entire region. The population of the region was then redistributed within the study area to account for growth in the most urbanized and rapidly growing areas.

The population in North Dakota (13 eastern counties) is projected to increase by 53% over 50 years, from 272,285 people in 2000 to 417,600 in 2050 based on the assumptions of continued urban growth and stabilized population in rural areas. The population in selected Minnesota counties (eight western counties) would potentially grow from 173,950 to 221,000 people based on the same population growth assumptions used for the North Dakota population, or an increase of 27%. The growth rate for the entire study area through 2050 was projected to be about 0.719% annually. The population projections were developed on a county and municipal basis to facilitate water demand estimating. Rural water system water demand estimates required estimating rural populations using both county and municipal population projections. Methods used to estimate the rural populations are described in section 2.7 and Appendix A.

Table 2.3.1 – County Population Projections.

County	2000 Census Data	Reclamation 2050 Population Projection	Northwest 2050 Population Projection
North Dakota			
Barnes	11,775	7,200	8,750
Cass	123,138	254,800	244,545
Cavalier	4,831	2,400	1,577
Grand Forks	66,109	107,100	85,459
Griggs	2,754	1,400	1,095
Nelson	3,715	1,800	1,695
Pembina	8,585	4,900	6,082
Ransom	5,890	3,300	5,302
Richland	17,998	18,800	16,978
Sargent	4,366	2,500	3,782
Steele	2,258	1,300	1,878
Traill	8,477	5,100	6,612
Walsh	12,389	7,000	6,766
North Dakota Totals	**272,285**	**417,600**	**390,521**
Minnesota			
Clay	51,313	83,600	58,286
Kittson	5,263	3,600	3,431
Marshall	10,114	6,900	6,204
Norman	7,434	5,100	5,602
Otter Tail	57,222	81,700	69,845
Polk	31,352	32,400	26,211
Traverse	4,119	2,800	3,180
Wilken	7,133	4,900	6,587
Minnesota Totals	**173,950**	**221,000**	**179,346**
Regional Totals	**446,235**	**638,600**	**569,867**

Table 2.3.2 shows the 2050 population projections for larger cities and towns in the 13 eastern counties of North Dakota and three cities in Minnesota. Generally, towns with a population less

than 500 were not included in the population projection analysis. The analysis was conducted in this manner based on the assumption that these smaller towns eventually would join adjacent rural water systems, if they were not already being served. Therefore, these smaller town populations were already included in the county population projections in table 2.3.1, and more specific information was not required for the future water demand analysis.

Table 2.3.2 – Municipal Population Projections.

Municipality	2000 Census	Reclamation 2050 Population Projection	Northwest 2050 Population Projection	Municipal 2050 Population Projections
Arthur	402	400	603	603
Casselton	1,855	2,380	3,160	3,160
Cavalier	1,537	1,710	1,389	1,710
Cooperstown	1,053	840	437	1,053
Drayton	913	920	642	920
Enderlin	947	860	776	947
Fargo	90,599	204,300	190,743	243,073
Finley	515	470	418	515
Forman	506	510	169	510
Grafton	4,516	4,130	2,722	6,244
Grand Forks	49,321	83,800	63,471	89,631
Gwinner	717	1,170	1,254	1,254
Hankinson	1,058	970	1,023	1,058
Harwood	607	1,120	433	1,120
Hatton	707	600	348	707
Hillsboro	1,563	1,930	809	1,930
Horace	915	1,950	3,132	3,132
Lakota	781	600	185	781
Langdon	2,101	2,100	1,137	2,100
Larimore	1,433	1,190	1,398	1,839
Lidgerwood	738	680	619	738
Lisbon	2,292	2,530	2,013	2,530
Mapleton	606	610	381	997
Mayville	1,953	1,660	1,319	2,066
McVille	470	470	234	470
Minto	657	660	896	896
Northwood	959	730	280	959
Park River	1,535	1,540	763	1,540
Pembina	642	640	574	640
Portland	604	600	339	600
Thompson	1,006	1,630	1,150	1,630
Valley City	6,826	5,840	5,225	7,500
Wahpeton	8,586	12,140	7,892	12,140
Walhalla	1,057	970	706	1,057
West Fargo	14,940	33,900	26,632	34,705
Wyndmere	533	530	697	697
North Dakota Total	**205,450**	**377,080**	**323,969**	**431,452**
Breckenridge	3,559	2,540	3,258	3,601
East Grand Forks	7,501	9,800	7,466	13,619
Moorhead	32,177	44,200	32,895	58,421
Minnesota Total	**43,237**	**56,540**	**43,619**	**75,641**
Grand Total	**248,687**	**433,620**	**367,588**	**507,093**

Northwest Economic Associates

Reclamation contracted with Northwest to conduct an independent population projection analysis for the Red River Valley. Northwest also used the cohort component method traditionally used when estimating future populations in preparing their report, *Population Projections for Red River Valley Counties and Municipalities, 2000 through 2050* (Northwest 2003).

Northwest estimates that the population in the Red River Valley in North Dakota would increase from 272,285 in 2000 to 390,521 in 2050, or 43%. The population in select counties in Minnesota would grow slightly from 173,950 to 179,346, or an increase of 3%. The overall Red River Valley county population would increase to 569,867 by 2050 as compared to Reclamation's estimate of 638,600. The Northwest prediction is a difference in population of 68,733 or approximately 11% lower than Reclamation's projection.

Municipal Population Projections

Some municipalities in the Red River Valley disagreed with Reclamation's and Northwest's population projections as being too conservative and requested that their own projections for selected municipalities be used in the study. These projections appear in table 2.3.2. The population projection data were provided to Reclamation in a letter dated July 18, 2003, from Advanced Engineering representing Eastern Dakota Water Users (Appendix A, Attachment 1).

Service Area Population Projections used in Analysis

Reclamation acknowledges a level of uncertainty when projecting populations through 2050 and in projecting water demands in general. Therefore, recognizing these uncertainties, Reclamation developed two water demand scenarios to use as a range in hydrologic modeling and in developing alternatives.

Table 2.3.3 summarizes the service area population projections used in future water demand estimates later in this chapter. Breakdown of municipal and rural water system populations are shown in tables 2.6.1 and 2.7.1, respectively. To estimate population growth Reclamation and Northwest used the same methods and achieved similar results. Reclamation projections were used in the first water demand scenario (Scenario One). Population projections provided by the municipalities were approximately 18% higher than the Reclamation estimates. These projections were used in the second water demand scenario (Scenario Two). The manner in which these two population projections were used in estimating future municipal water demands was previously discussed in section 2.2 (Water Demand Calculation Methods).

Table 2.3.3 – Service Area Population Projections Used in Analysis.

Water System	Scenario One 2050 Population Projection	Scenario Two 2050 Population Projection
North Dakota Municipalities	354,420	404,423
Minnesota Municipalities	62,551	81,652
12 North Dakota Rural Water Systems	62,281	79,578
Total Population Projection	**479,252**	**565,653**

2.4 Per Capita Water Demand

This section summarizes per capita water demands used in estimating future water demands for municipalities and rural systems. Per capita water demands were developed for three groups of water systems: (1) municipalities which would retain their own water treatment systems through 2050, (2) rural water systems, and (3) municipalities which would be served by a rural water system by 2050. The first group, municipal water systems with independent water treatment, are listed in table 2.4.1. The methods used to analyze water demands are described in section 2.2. Water demand analysis for industrial facilities is discussed in section 2.8.

Per capita water demand tables were developed for each of the three groups of water systems. The tables express per capita water demand results as gpc/d (gallons per capita per day). The analysis was based on the most recent 15 years or less of historic water use data. There are a few cities in the Red River Valley that have a significant percentage of industrial water use (i.e., Moorhead, Grand Forks, East Grand Forks, Drayton, Enderlin, and Gwinner), which can skew water demand estimates. The per capita water demand estimates for these cities were adjusted to account for the influence of industrial water use. This was done by deleting the industrial water use volume from the historic city total, estimating per capita water demand without the influence of industrial demand, estimating the future water demand without industrial demand, adding back in the volume of industrial demand, and recalculating the corrected per capita water demand with industrial demand.

Description of Water Demand Tables

Water demand tables in this section show historic water use and estimated water demands for North Dakota and Minnesota cities and rural water systems through 2050. These data came from individual water system historic water use and future water demand projection spreadsheets which are included in the Needs Assessment - Appendix A. The only calculated values in the tables appear in column 11, calculated average peak daily water demand w/ WC and losses in gpc/d. An example of these spreadsheets for Fargo is in section 2.2.

The second and fourth columns in table 2.4.1 list the historic annual average per capita water use with historic unaccounted-for-losses and without unaccounted-for-losses. Unaccounted-for-losses were defined as the percentage difference between the diverted volume of water and the metered volume of water at the customers' meters. The third column shows the historic unaccounted-for-losses as a percentage. The per capita water use without water losses is an important factor, because it represents the actual rate of water use metered at water system service connections. Historic water losses were tracked separately. They can vary greatly from year to year and have a significant effect on overall water system diversions.

In water demand tables 2.4.1 – 2.4.4, columns five through 11 report the results of the water demand estimates. The fifth column provides the assumed design water loss percentage rate. Generally this value is the same as the historic water loss except in some water systems which have demonstrated significant improvement in reducing water loss, such as Breckenridge, Fargo and Southeast Water Users. Grand Forks plans to change their water treatment process in the future increasing their water loss rate by 5% from 8.3% to 13.3%. Grand Forks-Traill Water

District Association also has a high water loss due to their treatment process. If a water system has an historic average loss less than 10%, a value of 10% was used in their analysis. The level of 10% is generally considered a reasonable water system water loss goal.

The sixth column lists the average per capita water demand with water conservation and design (assumed) losses. This water demand rate represents a water use pattern in a normal or wet water supply year. Conservation water savings were included in the demand estimates, because these were used under all water supply conditions. Unaccounted-for-water losses were also added based on the percentage in column five.

The seventh column provides the annual maximum month per capita water demand with water conservation and losses. This water demand rate represents a water use pattern during a dry, hot year when water use is high. Again, water conservation water losses apply as discussed above. The eighth column shows the historic average daily peaking factor. Column nine shows the maximum peak daily historic demand with water conservation and unaccounted-for-losses. This represents the highest historic peak daily water use reported by the water system in the past 15 years. The highest historic peak day water use does not necessarily occur in the same year as the annual maximum month water use. Column 10 is the estimated water conservation savings. Water conservation water savings used in the analysis are listed in column 10 and are based on results of the *Water Conservation Potential Assessment, Final Report* (Reclamation 2004b).

Column 11 is the calculated average daily peak water demand with water conservation and losses, which is estimated using the formula listed below:

$$\text{Column 11} = [(\text{Column 4} - \text{Column 10})/(1.0 - \text{Column 5})] \times \text{Column 8}$$

The actual maximum peak daily historic water demand with water conservation and loss is customarily used in system design rather than the calculated average peak daily water demand with water conservation and loss, unless there are no historic data available.

The water demand analysis assumes that historic water use represents future water demand on a per capita basis. Per capita water use rates could increase over time due to the increased popularity of existing or new water use devices, such as high volume whirlpool baths. Per capita water use could also decease in the future due to the improvement of water conserving devices. The water demand analysis assumes that both of these situations are equally likely to happen and therefore neutralize each other.

Water Demand Results – North Dakota Cities with Water Treatment Plants through 2050

Table 2.4.1 lists the North Dakota cities that would continue to have water treatment capabilities through 2050. The table shows historic water use and estimated water demands (monthly and daily) for each of the cities. The paragraphs below describe the results for each city.

Table 2.4.1 – Water Demands for North Dakota Cities with Water Treatment Plants through 2050 (gpc/d).

City	Historic Water Use			Estimated Water Demands						
	Average Annual Per Capita Water Use w/ Historic Losses (gpc/d)	Historic Water Losses (%)	Average Annual Per Capita Water Use w/o Historic Losses (gpc/d)	Design Water Losses (%)	Average Annual Per Capita Water Use w/ WC and Losses (gpc/d)	Maximum Annual Per Capita Water Demand w/ WC and Losses (gpc/d)	Historic Average Daily Peaking Factor	Maximum Peak Daily Historic Water Demand w/ WC and Losses (gpc/d)	Estimated WC Savings[4] (gpc/d)	Calculated Average Peak Daily Water Demand w/ WC and Losses (gpc/d)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Drayton[1]	282.7	11.0	251.6	11.0	272.8	588.5	na	na	9.5	1087.8
Enderlin	540.3	18.9	469.4	18.9	790.0	823.2	1.97	1522.1	9.5	1117.3
Fargo	142.4	20.0	112.4	10.0	116.1	164.6	2.07	381.7	9.2	237.4
Grafton	164.4	19.6	132.0	19.6	152.5	200.3	1.77	339.7	9.6	269.5
Grand Forks[2]	147.6	8.3	135.4	13.3	137.6	204.6	1.82	526.3	9.1	265.1
Gwinner[3]	305.9	27.5	221.7	27.5	293.7	393.3	na	na	9.5	637.6
Langdon	127.3	25.9	94.8	25.9	115.7	245.3	3.21	552.4	9.6	369.2
Larimore[3]	108.6	10.0	97.7	10.0	98.6	151.2	na	na	9.6	213.3
Lisbon	131.6	14.4	112.5	14.4	120.8	146.4	1.58	223.5	9.6	190.0
Park River	124.1	22.1	96.6	22.1	112.3	142.4	2.79	399.3	9.6	311.7
Valley City	116.4	15.8	97.2	15.8	104.7	136.6	2.27	386.2	9.6	236.2
Wahpeton	122.8	17.9	100.7	17.9	111.7	135.5	1.78	240.1	9.6	197.6
West Fargo [5]	91.2	Na	91.2	0.0	91.8	112.2	2.52	275.4	7.2	211.7
Averages	185.0	17.6	154.9		193.7	264.9	2.18	484.7		411.1

[1] No historic daily peaking factor information were available. The peaking equation from the following page would yield a gpc/d under the maximum annual gpc/d shown in column 7. The peak daily water demand was calculated using the maximum month/peak day relationship from Grand Forks where the peak day is 4.53% of the maximum.

[2] Grand Forks will revise their future water treatment plant process which will increase their water loss rate by 5 % for a total of 13.3%. The average and annual maximum month per capita demands are prorated to account for a large industrial water demand in Grand Forks.

[3] No historic daily peaking factor was available, so the calculated average peak day water demand w/ WC and losses used an average peaking factor of 2.18.

[4] Summer water conservation savings.

[5] No water loss data were provided so water use data were assumed to include losses.

WC = Water Conservation na = lack of available data

Drayton

Drayton's estimated annual average per capita water demand is 272.8 gpc/d and an annual maximum month per capita water demand estimate is 588.5 gpc/d. Water use by American Crystal Sugar has been significantly reduced in the last 10 years from high of 299 million gallons in 1993. Drayton reported that American Crystal Sugar now uses about 60 million gallons per year.

American Crystal Sugar facility periodically has used its own water permit through the past 15 years. The study assumed that American Crystal Sugar would continue to receive water from Drayton, in addition to using their own water permit. The majority of American Crystal Sugar water use occurs in the winter to process sugar beets.

Drayton had very high water use between 1988 and 1990, which was included in the water demand estimates. Unaccounted-for-water losses were estimated at 11% per year, but no actual data were provided. Only one year (2001) of usable daily peaking data was available. The historic average peaking factor for 2001 was 1.71, which is very low considering an annual maximum month water demand with water conservation and losses of approximately 588.5 gpc/d. The maximum month occurred in March of 1990, a year without peaking data. A 31-day scenario was developed for Drayton using the maximum month, 588.5 gpc/d, distributed according to information provided by Grand Forks on daily water use. A peak day of 1087.8 gpc/d was determined through that analysis.

Enderlin

Enderlin's estimated annual average per capita water demand is 790.0 gpc/d and an annual maximum month per capita water demand estimate is 823.2 gpc/d. Enderlin has high industrial water use and also serves water to Sheldon. Unaccounted-for-water losses were estimated at 18.9% per year. No data were provided for 1988 through 1991.

Northern Sun Industries and Sheldon water demands were included in Enderlin's water demand analysis but were not adjusted based on population. They are not expected to grow in proportion to Enderlin.

Fargo

Fargo has an estimated annual average per capita water demand of 116.1 gpc/d and an annual maximum month per capita water demand of 164.6 gpc/d. Fargo has made significant improvements in their unaccounted-for-water loss demands, which resulted in a value of 10% for their future unaccounted-for-water loss demand.

Fargo had a high peak day demand with water conservation and water losses of 381.7 gpc/d. Fargo's historical peak day water demand was in 1988. Fargo estimated it lost at least two million gallons of system storage and implemented drought management measures, which saved approximately 2.5 million gallons of water. The historic peak day demand was adjusted to account for the water lost in storage and saved by implementing drought management measures.

Grafton

Grafton's estimated annual average per capita water demand is 152.5 gpc/d and an annual maximum month per capita water demand estimate is 200.3 gpc/d. Grafton served Walsh Water Users in 2000 and 2001. The water demands for Walsh Water Users were not included in the water demand analysis for Grafton, because a separate analysis was conducted for Walsh Water Users. Grafton's average unaccounted-for-water loss rate was 19.6 %.

Grand Forks

Grand Forks has an estimated annual average per capita water demand of 137.6 gpc/d and an annual maximum month per capita water demand estimate of 204.6 gpc/d. This rate was prorated to account for large industrial water use by J. R. Simplot and other smaller industrial users. The existing industrial water demand is not expected to grow proportionally with the city, so it was not adjusted based on population growth. However, future industrial water demands are estimated in the Grand Forks area in section 2.8.

Grand Forks also delivers water to the Grand Forks Air Force Base, which was included in city estimates. The Air Force Base population was assumed to grow at the same rate as the city, so water demand for the Air Force Base was analyzed with the water demand for Grand Forks.

Grand Forks noted a future operational change in water treatment, which would increase water loss. Overall water loss was estimated at 13.3%, which is 5% above their average of 8.3%. The city had a high peak day demand with water conservation and water losses of 526.3 gpc/d. The historical peak day water demand was in 1989. The city estimates it lost at least 2.5 million gallons of system storage and implemented drought management measures, which saved approximately 1.8 million gallons of water. J. R. Simplot was not in operation when the historical peak day water demand occurred. The historic peak day demand was adjusted to account for water lost in storage, water saved by implementing drought management measures, and water demand of J. R. Simplot in operation.

Gwinner

Gwinner's estimated annual average per capita water demand is 293.7 gpc/d and an annual maximum month per capita water demand estimate is 393.3 gpc/d. The city had unaccounted-for-water losses averaging 27.5%. A single year of historic daily peak data was available. The historic average peaking factor for 2001 was 1.53, which is very low considering a maximum month water demand with water conservation and losses of approximately 533 gpc/d. The maximum month occurred in June of 1996, but no daily peaking factor data were available for that year.

Langdon

Langdon has an estimated annual average per capita water demand of 115.7 gpc/d and an annual maximum month per capita water demand estimate of 245.3 gpc/d. The city serves Langdon Rural Water District. Since Langdon Rural Water District per capita water use was being estimated, the water demands of Langdon Rural Water District were not included in Langdon's water demand analysis.

Data for both Langdon Rural Water District and Langdon were difficult to separate in this analysis. Water for both systems was pumped to the city's water treatment plant and distributed. Combined, the systems have five permits, some of which are located at approximately the same location. At times water was withdrawn for both systems from one of the permits. Water use for Langdon Rural Water District was extracted from the city's permit data.

Larimore

Larimore has an estimated annual average per capita water demand of 98.6 gpc/d and an annual maximum month per capita water demand estimate of 151.2 gpc/d. No historical unaccounted-for-water loss data were provided, so 10% loss was assumed.

Lisbon

Lisbon has an estimated annual average per capita water demand of 120.8 gpc/d and an annual maximum month per capita water demand estimate of 146.4 gpc/d. Lisbon had a low historic average peaking factor of 1.58 and peak daily demand with water conservation and losses of 223.5 gpc/d. No historical data were provided from 1988 through 1995. The city provides water service to Ransom-Sargent Water Users; however, historic water service volumes were not included in annual totals.

Park River

Park River has an estimated annual average per capita water demand of 112.3 gpc/d and an annual maximum month per capita water demand estimate of 142.4 gpc/d. Park River plans to switch from Park River surface water source to the Fordville Aquifer. The city had unaccounted-for-water losses averaging 22%.

Valley City

Valley City has an estimated annual average per capita water demand of 104.7 gpc/d and an annual maximum month per capita water demand estimate of 136.6 gpc/d. The average unaccounted-for-water loss is 15.8%.

Wahpeton

Wahpeton's estimated annual average per capita water demand is 111.7 gpc/d and an annual maximum month per capita water demand estimate is 135.5 gpc/d. The average unaccounted-for-water loss is 17.9%.

West Fargo

West Fargo has an estimated annual average per capita water demand of 91.8 gpc/d and an annual maximum month per capita water demand estimate of 112.2 gpc/d. Unaccounted-for-water losses data were substantially below 10% , so a 10% loss was not used for West Fargo, because it would overestimate the water demand.

Water Demand Results and Data Comments – Minnesota Cities with Water Treatment Plants through 2050

Table 2.4.2 lists Minnesota cities that would operate water treatment plants through 2050. The table also shows historic water use and estimated water demands (monthly and daily) for each of the cities. The following paragraphs describe results by city.

Breckenridge

Breckenridge has an annual average per capita water demand of 79.5 gpc/d and an annual maximum month per capita water demand estimate of 86.8 gpc/d. Unaccounted-for-water losses average 22.3%; however, recent data show a decline in unaccounted-for-water losses. The new loss is approximately 10%, which was used in the analysis.

East Grand Forks

East Grand Forks' estimated annual average per capita water demand is 151.4 gpc/d and an annual maximum month per capita water demand estimate is 217.1 gpc/d. The city also serves a large industrial water user (American Crystal Sugar), which affects per capita water use. Unaccounted-for-water losses average 18.1%, but data were only provided from 1997-2001.

Moorhead

Moorhead has an estimated annual average per capita water demand of 122.8 gpc/d and an annual maximum month per capita water demand estimate of 153.7 gpc/d. Moorhead served a substantial industrial water demand, which was accounted for in their future water demand analysis. The June 2001 historic raw water diversion data appears to be in error. The value was changed from 38.9 to 138.9 millions of gallons. This change had little impact on the results. Unaccounted-for-water loss appeared low at 9%, so 10% was used in the analysis for future unaccounted-for-water losses.

Table 2.4.2 – Water Demands for Minnesota Cities with Water Treatment Plants through 2050 (gpc/d).

	Historic Water Use			Estimated Water Demands						
City	Average Annual Per Capita Water Use w/ Historic Losses (gpc/d)	Historic water Losses (%)	Average Annual Per Capita Water Use w/o Historic Losses	Design Water Losses (%)	Average Annual Per Capita Water Use w/ WC and Losses (gpc/d)	Maximum Annual Per Capita Water Demand w/ WC and Losses (gpc/d)	Historic Average Daily Peaking Factor	Maximum Peak Daily Historic Water Demand w/ WC and Losses (gpc/d)	Estimated WC Savings (gpc/d)	Calculated Average Peak Daily Water Demand w/ WC and Losses (gpc/d)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Breckenridge	98.0	22.3	75.0	10.0%	79.5	86.8	2.17	237.7	9.6	157.8
East Grand Forks	162.5	18.1	136.4	18.1%	151.4	217.1	2.44	522.6	9.6	377.9
Moorhead	122.0	9.0	119.0	10.0%	122.8	153.7	1.77	289.2	8.7	216.9
Averages	127.5	16.5	110.1		117.9	152.5	2.13	349.8		250.8

WC = Water Conservation

Water Demand Results – North Dakota Cities to be Served by Rural Water Systems

Table 2.4.3 lists North Dakota cities which currently have their own water treatment capability but are predicted to be serviced by a rural water system by 2050. The table also shows historic water use and estimates monthly and daily water demands for each city.

Water demand results for the cities listed in table 2.4.3 were added to water demands of an adjacent rural water system for analysis. As mentioned in section 2.1, some of these cities may use their own water treatment plants through 2050, but for purposes of this evaluation, it was assumed they would be served by a rural water system. All cities not listed in table 2.4.3 or table 2.4.1 that are in the 13 counties of eastern North Dakota were assumed to either already be served by a rural water system, or to be served by one in the future.

Demand Results – North Dakota Rural Water Systems

Table 2.4.4 shows the results of the North Dakota rural water system water demand analysis and identifies historic water use and estimated water demands (monthly and daily) for each of the rural water systems. The results are discussed in the following paragraphs.

Section 2.1, table 2.1.4 identifies the cities which were assumed to be served by rural water systems in the future. The per capita water demand estimates for these cites are listed in table 2.4.3. Incorporation of these cities into a rural water system could influence the overall rural water system per capita water demand. To account for that possibility, table 2.4.5 shows how city and rural water system per capita demands are prorated into composite water demand estimates. Data for the average year per capita demand with water conservation and losses, maximum annual per capita demand with water conservation and losses, and maximum peak daily water demand with water conservation and losses in table 2.4.5 originated in tables 2.4.3 and 2.4.4.

Reclamation population projections were used in table 2.4.5 to simplify analysis rather than to develop two different per capita water demands based on different population projections. The differences in population projections would have had a minor impact on per capita results.

The maximum historic peak daily water demand with water conservation and losses is from column nine in tables 2.4.3 and 2.4.4 when data were available. If data were unavailable, the calculated average peak daily water demand with water conservation and losses (column 11) was used. Reclamation prorated columns four, six, and eight of table 2.4.5 using Reclamation's estimated 2050 population. Population projections for rural water systems are listed in table 2.7.1, and projections for each city are listed in table 2.3.2. Population projections were multiplied by the average per capita per day water use with conservation and losses found in column six of tables 2.4.3 and 2.4.4. This sum was divided by the total population to be served by the rural water system in 2050. For example the prorated average year per capita demand w/wc and loss for Cass Rural Water Users District is:

$$((13{,}174*85.6)+(1{,}120*57)+(1{,}950*70.7))/(13{,}174+1{,}120+1{,}950) = 81.8 \text{ gpc/d}$$

Table 2.4.3 – Water Demands for North Dakota Cities Served by Rural Water Systems (gpc/d).

City	Historic Water Use			Estimated Water Demands						
	Average Annual Per Capita Water Use w/ Historic Losses (gpc/d)	Historic water Losses (%)	Average Annual per Capita Water Use w/o Historic Losses	Design Water Losses (%)	Average Annual Per Capita Water Use w/ WC and Losses (gpc/d)	Maximum Annual Per Capita Water Demand w/ WC and Losses (gpc/d)	Historic Average Daily Peaking Factor	Maximum Peak Daily Historic Water Demand w/ WC and Losses (gpc/d)	Estimated WC Savings (gpc/d)	Calculated Average Peak Daily Water Demand w/ WC and Losses (gpc/d) [1]
Column No.	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Cooperstown [3]	125.3	na	125.3	0.0	114.8	151.7	1.39	185.7	9.5	161.0
Hankinson	127.1	na	127.1	0.0	118.3	152.0	na	na	9.5	256.2
Harwood [4]	65.8	na	65.8	0.0	57.0	68.0	na	na	9.5	122.7
Hillsboro	126.3	7.5	116.7	10.0	119.6	162.3	2.07	335.6	9.6	246.4
Horace [4]	79.5	na	79.5	0.0	70.7	79.2	na	na	9.5	152.6
Lidgerwood	153.3	na	153.3	0.0	144.5	167.8	1.96	322.8	9.5	281.9
Mayville [2]	99.2	20.0	79.4	15.0	82.8	107.2	2.11	250.1	9.6	173.3
Minto [5]	93.4	10.0	84.0	10.0	83.6	114.4	2.44	217.3	9.5	202.1
Pembina	105.6	na	105.6	0.0	96.8	138.8	na	na	9.5	209.4
Wyndmere	110.5	na	110.5	0.0	101.7	137.8	na	na	9.5	220.1
Averages	108.6		104.7		99.0	127.9				202.6

WC = Water Conservation na = lack of available data

[1] When no data were available, the average daily peaking factor of 2.18 from larger North Dakota cities was used (see table 2.4.1).

[2] Limited information was available on unaccounted-for-water losses; however, Mayville has improved their unaccounted-for-water losses in recent years to approximately 15%, which was used in the analysis.

[3] Cooperstown lacked monthly data from 1988 to 1995 and submitted daily peaking values from 1993 to 1997.

[4] Harwood and Horace reported very low per capita water use of 65.8 and 79.5 gpc/d, respectively. Harwood only provided data from 1995 to 2001.

[5] Minto had daily peak data for 1990, which was 2.44. It was used in the analysis.

Table 2.4.4 – Water Demands for North Dakota Rural Water Systems (gpc/d).

	Historic Water Use			Estimated Water Demands						
Rural Water System	**Average Annual per Capita Water Use w/ Historic Losses (gpc/d)**	**Historic water Losses (%)**	**Average Annual Per Capita Water Use w/o Historic Losses**	**Design Water Losses (%)**	**Average Annual Per Capita Water Use w/ WC and Losses (gpc/d)**	**Maximum Annual Per Capita Water Demand w/ WC and Losses (gpc/d)**	**Historic Average Daily Peaking Factor [1]**	**Maximum Peak Daily Historic Water Demand w/ WC and Losses (gpc/d)**	**Estimated WC Savings (gpc/d)**	**Calculated Average Peak Daily Water Demand w/ WC and Losses (gpc/d)**
Column No.	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Agassiz Water Users District	96.7	11.7	84.5	11.7	85.7	128.5	na	na	9.5	175.6
Barnes Rural Water District	140.1	37.4	87.6	37.4	125.9	176.1	1.69	305.5	9.5	211.0
Cass Rural Water Users District	97.5	23.1	74.7	23.1	85.6	108.0	1.74	157.0	9.5	147.6
Dakota Rural Water District	104.1	15.0	88.5	15.0	93.7	112.2	2.65	264.5	9.5	246.5
Grand Forks-Traill Water District	101.0	19.2	81.5	33.5	109.3	169.9	1.54	na	9.5	241.3
Langdon Rural Water District	65.8	8.2	60.7	10.0	56.7	81.3	1.92	206.3	9.5	109.3
North Valley Water District	93.0	22.5	72.2	22.5	81.9	105.1	2.33	206.7	9.5	188.7
Ransom-Sargent Water Users District	na	Na	Na	10.0	80.9	90.3	na	148.3	9.5	na
Southeast Water District	80.9	21.4	63.7	15.0	64.5	84.8	1.60	121.6	9.5	102.1
Traill Rural Water District	130.0	37.0	81.9	37.0	116.0	168.6	3.70	465.8	9.5	425.5
Tri-County Water District	84.8	Na	84.8	0.0	75.9	127.5	na	na	9.5	155.6
Walsh Rural Water District	132.4	41.8	77.1	41.8	117.3	152.8	1.42	215.7	9.5	165.1
Averages	102.4		77.9		91.1	125.4	2.07	232.4		197.1

[1] No historic average daily peaking factor was available. The peaking factor was calculated using a rural water system average peaking factor of 2.07.
WC = Water Conservation na = lack of available data

In this equation the values of 13,174, 1,120 and 1,950 are the populations of Cass Rural Water Users District, Harwood, and Horace, and 85.6, 57, and 70.7 are the average per capita water demand in gpc/d of these same water systems. The three population values times the associated gpc/d values results in a total average day water demand. This in turn is divided by the total population to arrive at the composite per capita water demand of 81.8 gpc/d.

Table 2.4.5 – Prorated Annual Maximum Month and Peak Daily Water Demands of Rural Water Systems including Cities to be Served in the Future.

Rural Water System	2050 Reclamation Population Projection	Average Year Per Capita Demand w/ WC and Losses (gpc/d)	Prorated Average Year Per Capita Demand w/ WC and Losses (gpc/d)	Annual Max Month Per Capita Water Demand w/ WC and Losses (gpc/d)	Prorated Annual Max Month Per Capita Demand w/ WC and Losses (gpc/d)	Maximum Peak Daily Water Demand w/ WC and Losses (gpc/d)	Prorated Max Peak Daily Water Demand w/ WC and Losses (gpc/d)
Agassiz Water Users	5,355	85.7	85.7	128.5	128.5	175.6	175.6
Barnes Rural Water	2,266	125.9	125.9	176.1	176.1	305.5	305.5
Cass Rural Water	13,174	85.6	81.8	108.0	101.8	157.0	154.1
Harwood	1,120	57.0		68.0		122.7	
Horace	1,950	70.7		79.2		152.6	
Dakota Rural Water District	2,581	93.7	98.9	112.2	121.9	264.5	245.2
Cooperstown	840	114.8		151.7		185.7	
Grand Forks-Traill Water District Assoc.	12,176	109.3	109.3	169.9	169.9	241.3	241.3
Langdon Rural Water	1,568	56.7	56.7	81.3	81.3	206.3	206.3
North Valley Water Users	4,461	81.9	83.8	105.1	109.3	206.7	207.0
Pembina	640	96.8		138.8		209.4	
Ransom-Sargent Rural Water Users	1,036	80.9	80.9	90.3	90.3	148.3	148.3
Southeast Water Users	4,893	64.5	83.3	84.8	107.2	121.6	169.2
Hankinson	1,170	118.3		152.0		256.2	
Lidgerwood	680	144.5		167.8		322.8	
Wyndmere	530	101.7		137.8		220.1	
Traill County Water Users	937	116.0	105.4	168.6	143.4	465.8	331.2
Hillsboro	1,930	119.6		162.3		335.6	
Mayville	1,660	82.8		107.2		250.1	
Tri-County Water District	2,185	75.9	75.9	127.5	127.5	155.6	155.6
Walsh Rural Water District	469	117.3	97.6	152.8	130.4	215.7	216.6
Minto	660	83.6		114.4		217.3	
Average			90.4		124.0		213.0

Agassiz Water Users District

Agassiz Water Users District has an estimated annual average per capita water demand of 85.7 gpc/d and an annual maximum month per capita water demand estimate of 128.5 gpc/d. The district also provides a 20 gallon per minute service connection to the Grand Forks Air Force Base, but it is not the primary water service provider to that facility. Unaccounted-for-water loss data were not available from 1988 to 1991, so average losses from later years were used in the analysis. Daily peak water use data were not provided.

Barnes Rural Water District

Barnes Rural Water District has an estimated annual average per capita water demand of 125.9 gpc/d and an annual maximum month per capita water demand estimate of 176.1 gpc/d. The system has water losses averaging 37%, which are very high.

Cass Rural Water Users District

Cass Rural Water Users District has an estimated annual prorated average per capita water demand of 81.8 gpc/d and a prorated annual maximum month per capita water demand estimate of 101.8 gpc/d. Unaccounted-for-water losses average 23%. Reclamation assumed the communities of Harwood and Horace would be served by Cass Rural Water Users District by 2050. Daily peak water use data were only provided for 2001. The daily peak factor for 2001 of 1.74 was used in the analysis.

Dakota Rural Water District

Dakota Rural Water District has an estimated annual prorated average per capita water demand of 98.9 gpc/d and a prorated annual maximum month per capita water demand estimate of 121.9 gpc/d. No unaccounted-for-water loss or daily peak water use data were provided, so 15% was used in the analysis. One year (2001) of daily peak data were provided, and the daily peaking factor of 2.65 was used in the analysis.

Grand Forks-Traill Water District

Grand Forks-Traill Water District has an estimated annual average per capita water demand of 109.3 gpc/d and an annual maximum month per capita water demand estimate of 169.9 gpc/d. This system previously delivered approximately 261 ac-ft of water annually to the Air Force Base, but the Base currently receives water from Grand Forks, with a supplemental backup from Agassiz Water Users District. It is possible that Grand Forks-Traill Water District could serve as a supplemental or backup supply for the Air Force Base in the future, but that is not reflected in the analysis.

The system has an average unaccounted-for-water loss demand rate of 19.5%. However, in recent years losses increased to 33.5% due to losses associated with membrane softening and greensand filtration processes.

Langdon Rural Water District

Langdon Rural Water District has an estimated annual average per capita water demand of 56.7 gpc/d and an annual maximum month per capita water demand estimate of 81.3 gpc/d. Although Langdon serves Langdon Rural Water District, Langdon Rural Water District water demands are listed in table 2.4.4 and not in 2.4.1.

North Valley Water District

North Valley Water District has an estimated annual prorated average per capita water demand of 83.8 gpc/d and a prorated annual maximum month per capita water demand of 109.3 gpc/d. Reclamation assumed that Pembina with a projected population of 640 would be served by the district in the future. The system experienced water losses averaging 23%.

Ransom-Sargent Water Users District

Through 2001, Ransom-Sargent Water Users District received their water from three sources: Lisbon, Barnes Rural Water District, and Southeast Water District. Table 2.4.5 incorporates the portion of Ransom-Sargent Water User District water demands served by Barnes Rural Water District and Southeast Water District in the providers' water demands. But Lisbon's water demand does not include Ransom-Sargent Water Users District water demand in table 2.4.1. The population served by Ransom-Sargent Water Users District in table 2.4.5 is 1,036.

Ransom-Sargent Water Users District provided the planning numbers used in the analysis. The district has an estimated annual average per capita water demand of 80.9 gpc/d and an annual maximum month per capita water demand estimate of 90.3 gpc/d.

Southeast Water District

Southeast Water District has an estimated prorated annual average per capita water demand of 83.3 gpc/d and a prorated annual maximum month per capita water demand estimate of 107.2 gpc/d. The district also serves a portion of Ransom-Sargent Water Users District, which is included in this analysis. Reclamation assumed the cities of Hankinson, Lidgerwood, and Wyndmere would be served by the district by 2050. Historically, the system has unaccounted-for-water losses averaging 21%, but water system managers suggested using 15% in the analysis based on more recent data.

Traill Rural Water District

Traill Rural Water District has an estimated prorated annual average per capita water demand of 105.4 gpc/d and a prorated annual maximum month per capita water demand estimate of 143.4 gpc/d. Reclamation assumed the cities of Hillsboro and Mayville would be served by the system by 2050.

This system serves one large industry, American Crystal Sugar. American Crystal Sugar's water demand was separated from the system's water demand in the analysis. The water demand for American Crystal Sugar is not expected to grow proportionately to the population of Traill Rural Water District. The system has a very high unaccounted-for-water loss of 37% based on their historical operational data (see table 2.4.4).

Tri-County Water District

Tri-County Water District has an estimated annual average per capita water demand of 75.9 gpc/d and an annual maximum month per capita water demand estimate of 127.5 gpc/d. No historic peak day demand data were provided.

Walsh Rural Water District

Walsh Rural Water District has an estimated prorated annual average per capita water demand of 97.6 gpc/d and a prorated annual maximum month per capita water demand estimate of 130.4 gpc/d. Reclamation assumed that Minto would be served by Walsh Rural Water District by 2050. The district reported the purchase of 662,000 gallons of water in 2000 and 7,879,000 gallons in 2001 from Grafton. This increase was added to the monthly water use and reflected in analysis. Very high unaccounted-for-water losses averaged 42% between 1998 and 2001 and are included in future water demands.

2.5 Water Conservation Measures

The *Water Conservation Potential Assessment Final Report* (Reclamation 2004b) evaluates potential water conservation measures and identifies reasonable and achievable water reduction activities. DWRA specifies that water conservation measures are to be used in quantifying the comprehensive water quality and quantity needs of the Red River Valley. The cost of implementing water conservation was also estimated in the WCPA (Water Conservation Potential Assessment). These costs are included as one of the features that comprise each of the alternatives described in chapter four. The following discussion summarizes the WCPA results.

There are more than 175 MR&I water systems in the Red River Valley ranging in size from small towns with under 100 inhabitants to Fargo, which has about 100,000 residents (2000 census). In addition to evaluating Fargo, Grand Forks, Moorhead, and West Fargo, two groups of medium and small/rural water systems were consolidated to simplify analysis. The two groups included medium-sized water systems (cities) with a population ranging from 1,000 to 15,000 and rural water systems and small community water systems with a population less than 1,000.

Table 2.5.1 shows the 16 water conservation measures analyzed in the WCPA. There are two supply management measures that relate to water use up to and including the water service meter, and 14 demand management measures that relate to consumer water.

Table 2.5.2 summarizes the per capita and annual water savings plus estimated water conservation costs for four individual municipalities, medium-sized, and rural/small communities evaluated in the WCPA. The most important result of the WCPA analysis is the per capita per day water savings estimate for each of the systems. Per capita water savings range from 6.54 to 9.02 gallons per person per day. This is a savings of 6.1% to 8.6%. Water conservation measures cost implementation ranges from $0.51 to $0.68 per 1000 gallons saved for community water systems. Annual water savings are estimated based on population served and per capita water savings rate for each water system. These savings reflect population projections in the *Current and Future Population of the Red River Valley Region 2000 through 2050, Final Report* (Reclamation 2003b/Revised 2005).

Table 2.5.1 - Specific Water Conservation Measures Evaluated in WCPA.

Supply Management
1. Install Water Meters
2. Audit Water Use, Detect Leaks, and Repair Distribution Systems
Demand Management
1. Program Administration and Public Education Programs
2. Promote Installation of 1.6 Gallon ULF Toilets[1]
3. Promote Installation of Low-Flow Shower Heads[1]
4. Promote Installation of Faucet Aerators[1]
5. In-Home Low-Flow Water Fixtures Giveaway Program[1]
6. Promote Installation of Water Efficient Dishwashers[1]
7. Install Low-Water-Use Turf and Plants in Landscaping – Xeriscaping Rebate Program
8. Install Water Efficient Landscape Irrigation Systems – ET Controller Rebate Programs
9. Efficient Landscape Irrigation Scheduling
10. Industrial Water Use Efficiency Measures
11. Commercial Water Use Efficiency Measures
12. Institutional Water Use Efficiency Measures
13. Conservation Pricing
14. Promote Installation of Efficient Clothes Washers[1]

[1] These measures will be enforced by new plumbing and appliance codes and be implemented prior to 2050.

Annual costs of implementing water conservation programs range from $54,700 to $326,000. The cost largely depends on the size of the service population, so Fargo, which has the highest population, would have the highest cost. The overall annual water conservation cost is estimated to be $780,000. This cost is in all options (alternatives) described in this report.

The WCPA analysis shows that approximately 1.4 billion gallons (4,300 ac-ft) of water could be saved annually with implementation of reasonable water conservation measures. The per capita water demand used to estimate future Red River Valley water system needs is reduced by 6.54 to 9.02 gpc/d. These measures would cost about $780,000 per year to implement and are included in the cost of alternatives evaluated in this report (see chapter four). The Project water conservation program may take a number of years to achieve the water savings goals, but the desired water demand reductions are not immediately needed for the Project to met future water needs.

Table 2.5.3 lists the summer and winter estimated water savings for each of the cities or groups of water systems. The potential water savings differ between summer and winter primarily because of increased summer outdoor water use.

Table 2.5.2 - WCPA Summary Results.

Water System(s)	Water Savings (gals/yr)	Annual Costs	Cost Per 1,000 Gallons	Average Water Savings (gpc/d)	Estimated Average Daily Per Capita Water Demand (gpc/d)	Percent Water Savings
Fargo	591,178,000	$325,914	$0.55	7.93	112.4	7.1
Grand Forks	252,445,000	$137,863	$0.55	8.25	135.4	6.1
West Fargo	80,920,000	$54,709	$0.68	6.54	91.2	7.2
Moorhead	130,212,000	$74,054	$0.57	8.07	118.4	6.8
Medium Size Municipal Water Systems (population 1,000 to 15,000)	149,444,000	$76,526	$0.51	9.02	110.0	8.2
Rural Water Systems including cities <1,000 in population	202,702,000	$110,796	$0.55	8.80	102.9	8.6
Totals	**1,406,901,000**	**$779,863**				

Table 2.5.3 – Summer and Winter Water Savings.

Water System(s)	Average Water Savings (gpc/d)	Summer Water Savings (gpc/d)	Winter Water Savings (gpc/d)
Fargo, North Dakota	7.93	9.19	6.67
Grand Forks, North Dakota	8.25	9.12	7.38
West Fargo, North Dakota	6.54	7.19	5.89
Moorhead, Minnesota	8.07	8.70	7.44
Medium Size Municipal Water Systems (population 1,000 to 15,000)	9.02	9.57	8.47
Rural Water Systems including cities <1,000 in population	8.80	9.45	8.15

2.6 Municipal Water Demand Analysis

Of nearly 175 municipal or water associations in the Red River Valley, only 16 are assumed to maintain their own water treatment capability through the 2050 planning horizon. The remaining systems are or will be served by one of 12 existing rural water systems. These municipal and water association systems are discussed in section 2.7, Rural Water Demand Analysis.

Section 2.2, Water Demand Calculation Methods, uses Fargo as an example to explain how monthly and peak day water demands were estimated. Analyses discussed in this section used those methods.

Water systems assessments were conducted for each of the municipal water systems to identify primary or secondary water quality regulation concerns that may affect the future viability of their present water source(s). Results of these assessments are in section 2.10. No municipal water systems were identified as having problems meeting the national primary drinking water standards. Some systems have secondary standards that exceed recommended levels, but these do not preclude future use of the water source.

Some municipal water systems report large system water losses. For those systems facing potential future water demand shortages, their water losses were evaluated to determine if improved system efficiencies could resolve their water supply problem. The *Water Conservation Potential Assessment, Final Report* (Reclamation 2004b) established a water loss goal of 10% for municipal water systems.

Municipal Water Systems - Future Population Projections

Population and per capita water demand data were used to estimate future municipal water demands. Table 2.6.1 shows Scenario One and Scenario Two projected municipal populations through 2050. Reclamation projections are used in water demand Scenario One and population projections provided by the municipalities are used in water demand Scenario Two. More detailed discussion of scenarios is in section 2.2.

The second column of table 2.6.1 shows the 2000 Census Bureau population data. Columns four and six show the calculated percentage change in population from 2000 to 2050 based on each scenario. Data are taken from Reclamation’s report titled, *Current and Future Population Red River Valley Region 2000 through 2050* (Reclamation 2003b/Revised 2005) and water user projections.

Municipal Monthly and Daily Per Capita Water Demands

Section 2.4 reports a detailed estimate of per capita water demands for 16 municipalities. The estimated per capita water demands are in table 2.6.2. Table 2.6.2 includes four types of per capita water demands: average annual, maximum annual, calculated peak daily, and maximum historic peak daily originally presented in tables 2.4.1 and 2.4.2. The calculated and maximum historic peak daily water demand is used to estimate maximum daily withdrawal rates.

Column two is the average annual per capita water demand based upon historic municipal water system data from the past 15 years (1987-2001). Column three lists the maximum annual per capita water demand, which represents the highest annual water use from the maximum month demand for each month from the past 15 years of data. Columns four and five specify two types of peak daily water demands - calculated average peak daily and peak daily historic.

The calculated average peak daily water demand is an estimate, while the historic maximum peak daily is an observed water demand. The historic peak daily water demand is generally higher than the calculated value and was used unless historic data were lacking, as is the case with Drayton, Gwinner and Larimore. All values in table 2.6.2 include water conservation and water losses.

Table 2.6.1 – Municipal Current and Future Populations.

Municipality	U.S. Census Bureau 2000 Population	Scenario One Population Projection	Percent Change in Population (%)	Scenario Two Population Projection	Percent Change in Population (%)
North Dakota:					
Drayton	913	920	0.8	920	0.8
Enderlin	947	860	-9.2	947	0.0
Fargo	90,599	204,300	125.5	243,073	168.3
Grafton	4,516	4,130	-8.5	6,244	38.3
Grand Forks	49,321	83,800	69.9	89,631	81.7
Gwinner	717	1,170	63.2	1,254	74.9
Langdon	2,101	2,100	0.0	2,100	0.0
Larimore	1,433	1,190	-17.0	1,839	28.3
Lisbon	2,292	2,530	10.4	2,530	10.4
Park River	1,535	1,540	0.3	1,540	0.3
Valley City	6,826	5,840	-14.4	7,500	9.9
Wahpeton	8,586	12,140	41.4	12,140	41.4
West Fargo	14,940	33,900	126.9	34,705	132.3
Minnesota:					
Breckenridge	3,559	2,540	-28.6	3,601	1.2
East Grand Forks	7,501	9,800	30.6	13,619	81.6
Moorhead [1]	36,553	50,211	37.4	64,432	76.3
Totals	232,339	416,971	79.5	486,075	109.2

[1] Moorhead 2050 population includes Dilworth and Oakport and the Americana Townships.

Table 2.6.2 – Municipal Average and Maximum Annual and Peak Daily Water Demand.

Municipality	Average Annual Per Capita Water Demand (gpc/d)	Maximum Annual Per Capita Water Demand (gpc/d)	Calculated Average Peak Daily Water Demand (gpc/d)	Maximum Peak Daily Historic Water Demand (gpc/d)
North Dakota:				
Drayton	272.8	588.5	1087.8	na
Enderlin	790.0	823.2	1117.3	1522.1
Fargo	116.1	164.6	237.4	381.7
Grafton	152.5	200.3	269.5	339.7
Grand Forks	137.6	204.6	265.1	526.3
Gwinner	293.7	393.3	637.6	na
Langdon	115.7	245.3	369.2	552.4
Larimore	98.6	151.2	213.3	na
Lisbon	120.8	146.4	190.0	223.5
Park River	112.3	142.4	311.7	399.3
Valley City	104.7	136.6	236.2	386.2

Municipality	Average Annual Per Capita Water Demand (gpc/d)	Maximum Annual Per Capita Water Demand (gpc/d)	Calculated Average Peak Daily Water Demand (gpc/d)	Maximum Peak Daily Historic Water Demand (gpc/d)
Wahpeton	111.7	135.5	197.6	240.1
West Fargo	91.8	112.2	211.7	275.4
Minnesota:				
Breckenridge	79.5	86.8	157.8	237.7
East Grand Forks	151.4	217.1	377.9	522.6
Moorhead	122.8	153.7	216.9	289.2

na = lack of available data

Municipal Monthly and Daily Water Demand Results

Tables 2.6.3 and 2.6.4 list maximum annual water demands on a monthly basis in ac-ft for each of the 16 municipal water systems for Scenario One and Two, respectively. Water demands were developed on a monthly basis for potential surface water modeling. The total 2050 annual maximum municipal water demand for Scenario One is 79,441 ac-ft. The maximum water demand for each water system is highlighted. Note that most, but not all, of the maximum demands occur in July. The maximum month of water demand is 10,262 ac-ft in July. The total 2050 annual maximum municipal water demand for Scenario Two is 91,807 ac-ft. The maximum month of water demand is 11,853 ac-ft in July.

Daily peak water demands may be factored into sizing treatment and conveyance features depending on how instantaneous capacity needs are balanced with storage. Tables 2.6.5 and 2.6.6 show the municipal water demands in ac-ft and cfs for Scenarios One and Two. Column four shows the municipal maximum month water demand. This maximum water demand does not necessarily occur in the annual maximum month, as shown in tables 2.6.3 and 2.6.4. The total maximum month water demand listed at the bottom of column four in tables 2.6.5 and 2.6.6 is more than the July totals shown in tables 2.6.3 and 2.6.4. The last two columns in tables 2.6.5 and 2.6.6 show the peak daily water demands as calculated in ac-ft and cfs.

In calculating Grand Forks monthly water demand Reclamation assumed that water demand for the Grand Forks Air Force Base would increase proportionately to the projected population of Grand Forks. However, the population shown for Grand Forks includes only the city projection and not the Air Force Base projection. The Air Force Base water demand was treated as a bulk service in this analysis.

Grand Forks also has one large industrial user, J. R. Simplot. The Simplot industrial water demand was included in the Grand Forks water demand, but was not assumed to increase proportionately to the population of Grand Forks. The maximum and average year per capita water use for Grand Forks was prorated to account for this large industrial water user. The maximum month of water use for J. R. Simplot was incorporated into water demand analysis.

Table 2.6.3 – Annual Maximum Month Municipal Water Demand Scenario One Projections (ac-ft).

Municipality	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
North Dakota:													
Drayton	64.0	56.0	67.8	34.5	30.4	33.7	49.7	38.4	40.9	66.6	57.2	67.3	606.6
Enderlin	68.4	64.4	64.1	68.7	70.4	67.1	65.0	68.4	65.9	64.0	63.7	63.0	792.9
Fargo	2,408.1	2,144.4	2,513.1	2,619.0	3,501.7	4,549.3	5,005.0	3,812.2	3,099.0	2,540.4	2,838.1	2,651.8	37,681.9
Grafton	68.1	72.1	60.8	72.2	85.4	97.6	101.3	92.0	82.5	69.7	64.1	61.1	926.8
Grand Forks	1,249.2	1,217.4	1,314.3	1,286.3	1,565.1	2,108.3	2,533.2	1,998.7	1,559.0	1,536.9	1,506.9	1,329.3	19,204.6
Gwinner	32.8	34.9	38.0	36.8	44.9	57.5	58.9	52.6	45.8	50.1	33.5	29.7	515.5
Langdon	63.1	65.7	62.4	44.4	45.5	46.7	47.9	50.0	48.3	36.0	31.1	36.1	577.0
Larimore	17.0	18.5	19.9	13.8	16.3	17.9	20.1	15.2	11.8	15.2	18.1	17.8	201.6
Lisbon	36.3	35.0	28.6	31.9	36.7	39.6	38.9	38.5	36.1	32.3	30.0	31.1	414.9
Park River	19.2	19.0	20.2	18.4	20.1	24.3	26.0	22.7	19.4	18.2	18.2	19.8	245.7
Valley City	64.9	66.1	60.7	60.8	79.8	116.5	103.9	110.7	66.8	57.6	53.0	52.7	893.6
Wahpeton	124.0	122.7	125.0	135.0	149.0	202.5	205.6	203.5	171.6	143.0	130.3	131.0	1,843.2
West Fargo	257.0	240.2	265.6	274.6	345.1	445.7	669.3	505.1	338.7	317.6	340.6	261.1	4,260.7
Minnesota:													
Breckenridge	17.1	15.0	17.4	18.0	21.2	25.2	27.3	29.7	22.2	19.5	17.0	17.2	246.9
East Grand Forks	184.7	157.8	172.6	150.0	223.6	219.1	244.4	254.1	220.4	190.0	188.6	178.5	2,383.9
Moorhead	559.9	608.5	646.0	661.1	711.4	952.5	1,065.3	845.8	798.5	621.5	598.9	576.1	8,645.7
Totals	5,233.8	4,937.7	5,476.6	5,525.4	6,946.7	9,003.3	10,262.0	8,137.8	6,626.8	5,778.6	5,989.4	5,523.5	79,441.4

Note: Water demand projections include water conservation and water losses.

Table 2.6.4 – Annual Maximum Month Municipal Water Demand Scenario Two Projections (ac-ft).

Municipality	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
North Dakota:													
Drayton	64.0	56.0	67.8	34.5	30.4	33.7	49.7	38.4	40.9	66.6	57.2	67.3	606.6
Enderlin	69.6	65.2	64.9	69.9	71.9	68.2	65.9	69.6	66.9	64.8	64.5	63.7	805.0
Fargo	2,865.1	2,551.3	2,990.0	3,116.0	4,166.3	5,412.6	5,954.9	4,535.7	3,687.1	3,022.6	3,376.7	3,155.1	44,833.3
Grafton	102.9	109.0	91.9	109.2	129.0	147.5	153.1	139.2	124.8	105.3	96.9	92.3	1,401.2
Grand Forks	1,321.6	1,289.0	1,389.4	1,363.2	1,658.3	2,226.6	2,685.8	2,124.8	1,652.4	1,630.1	1,597.3	1,409.2	20,347.9
Gwinner	35.2	37.4	40.7	39.4	48.1	61.6	63.2	56.4	49.1	53.7	35.9	31.9	552.5
Langdon	63.1	65.7	62.4	44.4	45.5	46.7	47.9	50.0	48.3	36.0	31.1	36.1	577.0
Larimore	26.3	28.6	30.8	21.4	25.2	27.6	31.0	23.5	18.2	23.5	28.0	27.4	311.5
Lisbon	36.3	35.0	28.6	31.9	36.7	39.6	38.9	38.5	36.1	32.3	30.0	31.1	414.9
Park River	19.2	19.0	20.2	18.4	20.1	24.3	26.0	22.7	19.4	18.2	18.2	19.8	245.7
Valley City	83.4	84.9	78.0	78.1	102.5	149.6	133.5	142.2	85.7	74.0	68.1	67.6	1,147.6
Wahpeton	124.0	122.7	125.0	135.0	149.0	202.5	205.6	203.5	171.6	143.0	130.3	131.0	1,843.2
West Fargo	263.1	245.9	271.9	281.1	353.3	456.2	685.2	517.1	346.7	325.2	348.7	267.3	4,361.8
Minnesota:													
Breckenridge	24.2	21.3	24.7	25.5	30.1	35.7	38.7	42.1	31.5	27.7	24.1	24.4	350.0
East Grand Forks	256.7	219.4	239.9	208.5	310.8	304.5	339.6	353.1	306.2	264.0	262.0	248.0	3,312.9
Moorhead	685.3	747.6	795.8	815.2	879.7	1,189.1	1,333.8	1,052.2	991.4	764.3	735.3	706.1	10,695.7
Totals	**6,040.0**	**5,698.1**	**6,322.0**	**6,391.6**	**8,056.9**	**10,426.1**	**11,853.0**	**9,409.0**	**7,676.3**	**6,651.3**	**6,904.5**	**6,378.3**	**91,807.0**

Note: Water demand projections include water conservation and water losses.

Table 2.6.5 - Municipal Water Demands Scenario One.

Municipality	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs)[1]	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
North Dakota:						
Drayton	281	607	67.8	1.1	3.07	1.55
Enderlin	761	793	70.4	1.2	4.02	2.03
Fargo	26,571	37,682	5,005.0	84.1	239.32	120.66
Grafton	706	927	101.3	1.7	4.31	2.17
Grand Forks	12,922	19,205	2,533.2	42.6	135.35	68.24
Gwinner	385	516	58.9	1.0	2.29	1.15
Langdon	272	577	65.7	1.1	3.56	1.79
Larimore	131	202	20.1	0.3	0.78	0.39
Lisbon	342	415	39.6	0.7	1.74	0.87
Park River	194	246	26.0	0.4	1.89	0.95
Valley City	685	894	116.5	2.0	6.92	3.49
Wahpeton	1,519	1,843	205.6	3.5	8.95	4.51
West Fargo	3,486	4,261	669.3	11.2	28.65	14.45
Minnesota:						
Breckenridge	226	247	29.7	0.5	1.85	0.93
East Grand Forks	1,662	2,384	254.1	4.3	15.72	7.92
Moorhead	6,909	8,646	1,065.3	17.9	44.56	22.47
Totals	**57,052**	**79,441**	**10,329**	**173.6**	**502.96**	**253.58**

[1] Maximum month water demand in cfs based on 30 days in a month.

Table 2.6.6 - Municipal Water Demands Scenario Two.

Municipality	Average Year Water Demand (ac-ft)	Maximum Year Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs)[1]	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
North Dakota:						
Drayton	281	607	67.8	1.1	3.07	1.55
Enderlin	769	805	71.9	1.2	4.42	2.23
Fargo	31,613	44,833	5,954.9	100.1	284.73	143.55
Grafton	1,067	1,401	153.1	2.6	6.51	3.28
Grand Forks	13,727	20,348	2,685.8	45.1	144.77	72.99
Gwinner	413	552	63.2	1.1	2.45	1.24
Langdon	272	577	65.7	1.1	3.56	1.79

Municipality	Average Year Water Demand (ac-ft)	Maximum Year Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs)[1]	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
Larimore	203	311	31.0	0.5	1.20	0.61
Lisbon	342	415	39.6	0.7	1.74	0.87
Park River	194	246	26.0	0.4	1.89	0.95
Valley City	880	1,148	149.6	2.5	8.89	4.48
Wahpeton	1,519	1,843	205.6	3.5	8.95	4.51
West Fargo	3,569	4,362	685.2	11.5	29.33	14.79
Minnesota:						
Breckenridge	321	350	42.1	0.7	2.63	1.32
East Grand Forks	2,310	3,312	353.1	5.9	21.84	11.01
Moorhead	8,465	10,696	1,333.8	22.4	57.18	28.83
Totals	**65,944**	**91,806**	**11,928**	**200.5**	**583.17**	**294.01**

[1] Maximum month water demand in cfs based on 30 days in a month.

Moorhead has a significant portion of their water demand allocated to industrial water demand. The demand analysis assumed that industrial water use would not increase proportionately to the projected population of Moorhead. The maximum month of industrial water demand was used in the water demand analysis.

For more detail on how individual municipal water demands were estimated, refer to the Needs Assessment - Appendix A which includes original analysis spreadsheets and detailed discussion of assumptions and methods to supplement this section.

Municipal Water System Peak 31-Day Water Demands

Section 2.2, Water Demand Calculation Methods, explains how peak 31-day water demands were estimated. Results of peak day analysis are presented in Section 3.5.6 of the hydrology chapter. Peak 31-day water demands used in Scenario One and Two water demand analysis are shown for Fargo. Peak 31-day water demands were also developed for Drayton, East Grand Forks, Grafton, Grand Forks, Langdon, Moorhead, Valley City and West Fargo. Detailed results for each of the surface water dependent municipal water systems required to meet peak day water demands appear in the Needs Assessment - Appendix A.

Grand Forks daily water use data from historic peak month of water use in July1989 were used for this analysis (see section 2.2). Water use percentages were developed for each day within that peak month. Percentages for each day were then applied to the maximum month for each system to develop a 31-day water demand. The historic peak day demand was analyzed and the remaining 30 days were adjusted to account for the peak day. Langdon and Valley City daily water demands in ac-ft were adjusted for a 31 day analysis because their maximum month water demand occurred in a month with less than 31 days.

Daily water demand scenarios for surface water modeling used a combination of maximum monthly and peak daily water demand data. For example, in table 2.6.7 Fargo has a maximum month water demand of 5,005.0 ac-ft and a daily peak of 239.3 ac-ft for Scenario One or a maximum month water demand of 5,954.9 ac-ft and daily peak of 284.8 ac-ft for Scenario Two, as shown in table 2.6.8. The data in table 2.6.7 are the same as in table 2.2.11, section 2.2.

Table 2.6.7 – Fargo 31-Day Maximum Month and Peak Day Water Demand Scenario One.

Projected Population = 204,300

Day of Month	Per Capita Water Demand (gpc/d)	Daily Water Demand (ac-ft)	% of Monthly Demand Req.
1	268.7	168.5	3.37
2	220.1	138.0	2.76
3	178.9	112.2	2.24
4	182.7	114.5	2.29
5	299.9	188.1	3.76
6	313.6	196.6	3.93
7	261.9	164.2	3.28
8	238.8	149.7	2.99
9	188.9	118.4	2.37
10	192.6	120.8	2.41
11	238.8	149.7	2.99
12	238.8	149.7	2.99
13	238.8	149.7	2.99
14	238.8	149.7	2.99
15	241.4	151.4	3.02
16	279.2	175.1	3.50
17	286.7	179.8	3.59
18	286.7	179.8	3.59
19	286.7	179.8	3.59
20	290.1	181.9	3.63
21	381.7	239.3	4.78
22	335.5	210.4	4.20
23	301.1	188.8	3.77
24	266.9	167.3	3.34
25	285.6	179.1	3.58
26	352.9	221.3	4.42
27	338.9	212.5	4.25
28	195.2	122.4	2.44
29	110.3	69.2	1.38
30	188.3	118.1	2.36
31	253.8	159.1	3.18
Average/ Total	**257.5**	**5005.0**	**100.00%**

Table 2.6.8 – Fargo 31-Day Maximum Month and Peak Day Water Demand Scenario Two.

Projected Population = 243,073

Day of Month	Per Capita Water Demand (gpc/d)	Daily Water Demand (ac-ft)	% of Monthly Demand Req.
1	268.7	200.5	3.37
2	220.1	164.2	2.76
3	178.9	133.5	2.24
4	182.7	136.3	2.29
5	299.9	223.7	3.76
6	313.6	234.0	3.93
7	261.9	195.4	3.28
8	238.8	178.1	2.99
9	188.9	140.9	2.37
10	192.6	143.7	2.41
11	238.8	178.1	2.99
12	238.8	178.1	2.99
13	238.8	178.1	2.99
14	238.8	178.1	2.99
15	241.4	180.1	3.02
16	279.2	208.3	3.50
17	286.7	213.9	3.59
18	286.7	213.9	3.59
19	286.7	213.9	3.59
20	290.1	216.4	3.63
21	381.7	284.8	4.78
22	335.5	250.3	4.20
23	301.1	224.7	3.77
24	266.9	199.1	3.34
25	285.6	213.0	3.58
26	352.9	263.3	4.42
27	338.9	252.8	4.25
28	195.2	145.6	2.44
29	110.3	82.3	1.38
30	188.3	140.5	2.36
31	253.8	189.3	3.18
Average/ Total	**257.5**	**5954.9**	**100.00%**

The maximum monthly water demand for Scenario One is a month where the total 31-day water demand totals 5,005.0 ac-ft and the daily water demands vary with one peak day of 239.3 ac-ft. The maximum monthly water demand for Scenario Two is a month where the total 31 day water demand totals 5,954.9 ac-ft and daily water demands vary with one peak day of 284.8 ac-ft. The peak 31-day water demand scenarios for the other nine municipalities relying on surface water sources are in the Needs Assessment - Appendix A. The peak day water demands will be used in sections 3.3 and 3.5.6 to evaluate groundwater and surface water supplies.

2.7 Rural Water Demand Analysis

Table 2.7.1 lists the 12 rural water systems in the Red River Valley service area. These 12 rural water systems were assumed to serve the rural population plus approximately 178 smaller communities (figure 2.1.1) through the 2050 planning horizon. A map showing the location of the 12 rural water systems is provided in Appendix A.

Each of the 12 rural water systems were assessed to identify primary or secondary water quality regulation concerns that could affect the future viability of their water source. The detailed assessments are in *Water System Assessment Executive Summary, Final Report* (Reclamation 2004c). Arsenic is a regulated contaminate on the national primary drinking water contaminate list and has been a problem for a few systems supplied by groundwater and when the standard is lowered by EPA, more systems may exceed it (Dakota Water Users, Hankinson, Lakota, Lidgerwood, and Wyndmere). Because arsenic compliance problems must be resolved by 2006, this problem cannot be affectively addressed by the Project. Some systems currently exceed National Secondary Drinking Water Standards in recommended levels of total dissolved solids, pH, and sulfate, but these concerns do not preclude future use of the water source.

As previously shown in table 2.4.4, rural water system water losses range from 11.7% to 41.8%. For those systems with future water demand shortages (see analysis in section 3.3), their water losses were evaluated to determine if improved system efficiencies would contribute to solving their water supply problem. The *Water Conservation Potential Assessment Final Report,* (Reclamation 2004b*)* set 10% as a water loss goal for municipal water systems based on recommendations of various governmental agencies and private water organizations.

Such recommendations however, did not address rural water systems. An analysis of municipal and rural water systems shows that rural systems can have a ratio of miles of pipeline per service connection many times higher than a comparable urban area. Most losses are attributed to pipeline leaks. For example, Fargo serves approximately 200 residents for every mile of distribution pipeline, while Southeast Water District serves four customers per mile of pipe. Rural water systems may have miles of pipeline per service connection ratios that are 50 times higher than a municipal area. Under these circumstances, a higher water loss goal of 15% was set as a reasonable goal for rural water systems.

Rural Water Systems - Future Population Projections

Rural water systems serve a variety of customers including rural farms (including some livestock watering), municipalities, commercial users, and some industrial sites. All of the rural water systems, with the exception of Langdon Rural Water District, use groundwater as a water source. The current (2000) percentage of rural residents served by rural water systems varies from system to system. Older systems serve over 90% of eligible customers while newer systems serve a smaller percentage. This analysis assumes that nearly 100% of eligible rural residents would be served by a rural water system by 2050. More detailed explanation of rural water system population projections is presented in Needs Assessment – Appendix A.

Reclamation (2003b/Revised 2005) presents population estimates by county and city, while focusing on cities with a population of 500 or greater. The report assumes that all cities with fewer than 500 residents would be served by rural water systems. Section 2.1 of the Needs and Options Report specifies which smaller communities would be served by rural water systems.

Present and future rural population data can be generated from county and city data as shown on table 2.7.1. It is challenging to predict the number of users who would be served by a rural water system because rural water system boundaries do not coincide with county boundaries, and population projections are by county. Some rural water systems serve portions of up to five counties. Table 2.7.1 lists the rural water system service population projections. Column two lists the counties and the percent of each county's rural population served by rural water. Although LaMoure, Ramsey, and Towner counties are outside the boundary of the Red River Valley, they are listed in the table because some county residences currently are served by Red River Valley rural water systems.

Column three lists the 2000 rural service area population as estimated by Reclamation. This is the rural water system service population if all district residents are served by the rural system. The actual percentage of rural county residents presently served by rural water systems varies from approximately 75% to 95% based on information provided by the rural water systems (Thielman 2003).

Table 2.7.1 - Rural Water System Current and Future Population Projections.

Rural Water System	Counties and Cities in the Service Area and Percentage of Rural Population	Reclamation 2000 Population Estimate	Reclamation 2050 Population Projection	Rural System 2050 Population Projection
Agassiz Water Users District	Grand Forks (35%), Walsh (20%)	4,132	5,355	5,300
Barnes Rural Water District	Barnes (70%), Griggs(10%), LaMoure (20%), Ransom (5%)	5,433	2,266	4,897
Cass Rural Water Users District	Barnes (10%), Cass (99%), Richland (10%), Ransom (10%)	18,050	16,244	21,048
Dakota Rural Water District	Barnes (10%), Cass (1%), Griggs (90%), Nelson (25%), Steele (65%)	6,116	3,421	2,600

Rural Water System	Counties and Cities in the Service Area and Percentage of Rural Population	Reclamation 2000 Population Estimate	Reclamation 2050 Population Projection	Rural System 2050 Population Projection
Grand Forks-Traill Water District	Grand Forks (60%), Steele (15%), Traill (45%)	9,711	12,176	15,000
Langdon Rural Water District	Cavalier (90%), Towner (50%), Ramsey (15%)' Walsh (5%)	4,673	1,568	2,900
North Valley Water District	Pembina (100%), Cavalier (10%)	9,091	5,101	8,900
Ransom-Sargent Water Users District	Barnes (10%), Dickey (10%), LaMoure (10%), Ransom (85%), Sargent (30%)	4,727	1,036	2,673
Southeast Water District	Richland (90%), Sargent (70%)	11,425	7,273	7,500
Traill Rural Water District	Steele (20%), Traill (55%)	6,476	4,527	2,800
Tri-County Water District	Grand Forks (5%), Nelson (75%), Ramsey (10%), Walsh (5%)	3,674	2,185	2,800
Walsh Rural Water District	Walsh (70%)	4,634	1,129	3,160
Totals		**88,140**	**62,281**	**79,578**

Column four lists 2050 population projections assuming that all rural residents would be served by rural water systems by 2050 (Reclamation 2003b/Revised 2005). Given that rural water systems already serve from 75% to 90% of their service area population, it is reasonable to expect a 100% sign-up rate by 2050.

Column five discloses the 2050 rural service population projections provided by rural water systems. These data were received in July of 2003 and subsequently were updated based on new information from some rural water systems provided in late 2003 and early 2004. Population data for Ransom-Sargent Water Users District were reduced and adjacent rural water systems increased because some of Ransom-Sargent's customers actually are served by Cass, Southeast, and Barnes rural water systems. Reclamation population projections in table 2.7.1 include cities that currently receive bulk or metered service from rural water systems and cities that would be served by the rural water systems in the future. The list of currently served cities and cities to be served in the future is in table 2.7.2 (same as table 2.1.3).

Table 2.7.2 – Cities Served by Rural Water Systems.

Rural Water System	Currently Receiving Metered Service (2003)	Currently Receiving Bulk Service (2003)	Future Service From Rural Water System (2050)
Agassiz Water Users District	Gilby, Manvel, Mekinock, Forest River, Ardoch, Inkster, Johnstown, Honeyford		
Barnes Rural Water District	Urbana, Eckelson, Walum, Hastings, Leal, Rogers, Fort Ransom	Sanborn, Litchville, Oriska, Tower City, Verona, Ransom-Sargent Water District - 2 accounts, Fort Ransom State Park	Dazey, Kathryn, Wimbledon
Cass Rural Water Users District	Alice, Erie, Wheatland, Ayr, Absraka, Embden, Chaffee, Lynchburg, Durbin, Highland Park, Briarwood, Frontier Village, St. Benedict, Wild Rice, Warren, Hickson, Reiles Acres, Prosper	Amenia, Argusville, Buffalo, Casselton, Davenport, Gardener, Grandin, Hunter, Kindred, Mapleton, Tower City, Woodlawn Subdivision, Paririe Rose	Enderlin, Harwood, Horace, Oxbow, Page, Brooktree Wells Inc., Chrisan Water Users Assoc., County Acres Water Co., Fradets Orchard Water System, Horseshoe Bend Addition, Lake Shure Home Owners Assoc., Meadowbrook Park Road & Water Inc., Riverdale Subdivision, Selkirk Settlement, Sleepy Hollow Water Company
Dakota Rural Water District	Blabon, Luverne, Pillsbury, Kloten, Colgate, Jessie	Aneta, Finley, Hope, Sharon, Sibley	Binford, Cooperstown, Hannaford, McVille, Pekin, Tolna
Grand Forks-Traill Water District	Thompson, Reynolds, Buxton, Cummings	Northwood, Hatton, Emerado, Arvilla, Marshall-Polk	Arvilla Water Users Assoc.
Langdon Rural Water District	Hampden, Fairdale, Adams, Edinburg, Alsen	Edmore, Nekoma, Osnabrock	
North Valley Water District	Crystal, Glasston, Joliette, Bathgate, Leroy, Backoo, Hensel, Gardar, Hamilton	Cavalier, St. Thomas, Mountain, Milton, Walhalla, Neche, Cavalier Air Base Station, Bowesmont	Pembina
Ransom-Sargent Water Users District	Cogswell, Crete, Elliott, Fingal, Stirum	Nome	Forman, Marion, Sheldon, Sundale Hutterian Assoc.
Southeast Water District	Cayuga, DeLamere, Dwight, Glachutt, Graet Bend, Havana	Mooreton, Abercrombie, Mantador, Barney, Colfax, Milnor, Rutland	Fairmount, Hankinson, Lidgerwood, Wyndmere, Christine Water and Sewer
Traill Rural Water District	Blanchard, Caledonia, Clifford	Portland, Grandin, American Crystal Sugar at Hillsboro, Premium Foods at Grandin, Porter Dairy, Galesburg	Hillsboro, Mayville
Tri-County Water District	Lawton, Brocket, Dahlen, Petersburg, Michigan, Orr, Niagara, Kempton, Whitman		Lakota
Walsh Rural Water District	Hoople, Lankin, Pisek, Conway, Nash, Voss, Warsaw		Minto

Reclamation's 2050 population projections are higher than those from Dakota Rural Water District and Traill Rural Water District. This is because Reclamation assumed some adjacent cities would be served by these rural water systems in the future.

Reclamation population projections predict declines in rural water system service populations by 2050. This reflects generally declining rural populations and migration of residents into urban areas, such as Fargo and Grand Forks. Agassiz Water Users District, Cass Rural Water Users District, and Grand Forks-Traill Water District are exceptions because Cass County and Grand Forks County populations are expected to grow in the future. This may offset losses in rural populations in these counties.

The 2050 water user population projections obtained from water users generally exceed Reclamation 2050 projections, although 2000 projections are similar. The only exceptions are Reclamation's 2050 estimates for Agassiz Water Users District, Dakota Rural Water District, and Traill Rural Water District which exceed estimates from the water systems. In these cases Reclamation assumed some communities would join rural water systems, as shown in table 2.7.2. The population projections provided by the water systems assume that rural populations would stabilize and remain unchanged from 2000 through 2050.

Projecting populations below the county level was challenging because distribution of population between adjacent counties or within the same county was difficult to predict. Cass County was separated into three population groups: (1) Fargo, (2) West Fargo, and (3) rural Cass County. While the future population of Cass County was estimated with some confidence, the exact distribution was more difficult to estimate. Nevertheless, the study incorporates the entire Cass County population to ensure that they would have an adequate supply of water through 2050, regardless of which water system ultimately serves that population.

How the service population of a rural water system would change between 2000 and 2050 was also difficult to predict, because it depends on water system expansion and as well as fluctuation in population. The exact year in which a rural water system would peak in population or in water demand was also difficult to predict. For those rural water systems serving counties with increasing population through 2050, one expects that the maximum population and water demand would occur around 2050. For rural water systems serving counties with declining population, the exact year of their maximum water demand could vary between now and 2050 because their service area could expand or a municipality could be added to the system.

Reclamation predicts a total rural 2050 projection of 62,281, and rural water systems predict a total of 79,578 users. Reclamation sees declining rural population similar to past decades, except for Agassiz Water Users District and Grand Forks–Traill Rural Water District. Rural water system projections reflect stable populations at approximately the same level as in 2000 (see table 2.7.1). Although Reclamation's 2050 projections are generally lower than water system projections, it is reasonable to analyze future water demands using both populations given the uncertainties in making such projections.

Rural Water Systems Monthly and Daily Per Capita Water Demand

Table 2.7.3 lists estimated per capita demands for rural water systems originally presented in table 2.4.5 and described in section 2.4. There are four types of per capita water demands: (1) average, (2) annual maximum month, (3) calculated peak daily, and (4) maximum historic peak daily. The calculated and maximum historic peak daily water demands are used to estimate maximum daily withdrawal rates.

Table 2.7.3 – Rural Water System Water Demands.

Rural Water System	Average Annual Per Capita Water Demand (gpc/d)	Maximum Annual Per Capita Water Demand (gpc/d)	Calculated Average Peak Daily Water Demand (gpc/d)	Maximum Peak Daily Historic Water Demand (gpc/d)
Agassiz Water Users District	85.7	128.5	175.6	175.6
Barnes Rural Water District	125.9	176.1	211.0	305.5
Cass Rural Water Users District	81.9	101.8	147.6	154.1
Dakota Rural Water District	98.9	121.9	246.5	245.2
Grand Forks-Traill Water District	109.3	169.9	241.3	241.3
Langdon Rural Water District	56.7	81.3	109.3	206.3
North Valley Water District	83.8	109.3	188.7	207.0
Ransom-Sargent Water Users District	80.9	90.3	na	148.3
Southeast Water District	83.3	107.2	102.1	169.2
Traill Rural Water District	105.4	143.4	425.5	331.2
Tri-County Water District	75.9	127.5	155.6	155.6
Walsh Rural Water District	97.6	130.4	165.1	216.6

Column two specifies average annual per capita water demand using historic municipal water system data from the past 15 years (1987-2001). Column three lists maximum annual per capita water demand, which is the highest annual water use from the maximum month demand for each month from the past 15 years of data.

Columns four and five list two types of peak daily water demands - calculated average peak daily and peak daily historic. The calculated average peak daily water demand is an estimate, while the maximum peak daily historic is an actual water demand. The historic peak daily water demand (column five) is generally higher than the calculated value (column four) and was used in the analysis, unless there were no historic data. All values in table 2.7.3 include water conservation and water losses.

Rural Water System Monthly and Peak Day Water Demand Results

Rural water system monthly and peak daily water demands were calculated in the same manner as the municipal water demands as reported in section 2.6. Section 2.2, Water Demand Calculation Methods, explains how monthly water demand scenarios were developed for water systems.

Tables 2.7.4 and 2.7.5 present rural water system water demands in ac-ft and cubic feet per second for Scenario One and Two population projections. Column four shows the value of the maximum month water demand of the listed rural water systems. This maximum water demand does not always coincide with the annual maximum month in tables 2.7.6 and 2.7.7. The total maximum month water demand shown at the bottom of column four is more than the July totals as shown in tables 2.7.6 and 2.7.7 because the maximum month varies from system to system. The last two columns in tables 2.7.4 and 2.7.5 show the peak daily water demands in ac-ft and cfs.

Tables 2.7.6 and 2.7.7 list the maximum annual water demands by month for each of the 12 rural water systems for Scenarios One and Two. The maximum month water demands for each rural water system are highlighted. The total 2050 annual maximum rural water demand for Scenario One is 8,804 ac-ft with the maximum month of water demand occurring in June at 959 ac-ft. The total 2050 annual maximum rural water demand for Scenario Two is 11,174 ac-ft with the maximum month of water demand in June at 1,214 ac-ft.

Table 2.7.4 – Rural Water System Water Demands Scenario One.

Rural Water System	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs) [1]	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
Agassiz Water Users District	514	771	87.1	1.5	2.89	1.45
Barnes Rural Water District	320	447	46.9	0.8	2.12	1.07
Cass Rural Water Users District	1,490	1,852	212.3	3.6	7.68	3.87
Dakota Rural Water District	379	467	55.5	0.9	2.57	1.30
Grand Forks-Traill Water District	1,491	2,317	299.1	5.0	9.02	4.55
Langdon Rural Water District	100	143	17.1	0.3	0.99	0.50
North Valley Water District	479	625	71.1	1.2	3.24	1.63
Ransom-Sargent Water Users District	94	105	11.0	0.2	0.47	0.24
Southeast Water District	679	874	99.1	1.7	3.78	1.90
Traill Rural Water District	534	727	73.4	1.2	4.60	2.32
Tri-County Water District	186	312	40.8	0.7	1.04	0.53
Walsh Rural Water District	123	165	16.8	0.3	0.75	0.38
Totals	**6,388**	**8,804**	**1,030**	**17.3**	**39.16**	**19.74**

[1] Maximum month water demand in cfs based on 30 days in a month.

Table 2.7.5 – Rural Water System Water Demands Scenario Two.

Rural Water System	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs) [1]	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
Agassiz Water Users District	509	763	86.2	1.45	2.86	1.44
Barnes Rural Water District	691	966	101.4	1.70	4.59	2.31
Cass Rural Water Users District	1,929	2,399	275.1	4.62	9.95	5.02
Dakota Rural Water District	288	355	42.1	0.71	1.96	0.99
Grand Forks-Traill Water District	1,837	2,854	368.5	6.19	11.11	5.60
Langdon Rural Water District	184	264	31.5	0.53	1.84	0.93
North Valley Water District	835	1,090	124.0	2.08	5.66	2.85
Ransom-Sargent Water Users District	242	270	28.4	0.48	1.22	0.61
Southeast Water District	700	901	102.2	1.72	3.90	1.96
Traill Rural Water District	331	450	45.4	0.76	2.85	1.43
Tri-County Water District	238	400	52.3	0.88	1.34	0.67
Walsh Rural Water District	346	462	46.7	0.78	2.10	1.06
Totals	**8,131**	**11,174**	**1,304**	**21.9**	**49.36**	**24.88**

[1] Maximum month water demand in cfs based on a 30 day month.

Section 2.2, Water Demand Calculation Methods, explains how peak 31-day water demands were estimated. None of the rural water systems directly receive their water supply from surface water sources; however, Langdon Rural Water District uses treated water from Langdon, which has a surface water source. Chapter three explains that Cass Rural Water Users District and Grand Forks-Traill Water District have groundwater shortages and in the future would need to tap surface water supplies to meet their water shortages. Peak 31-day water demands for these three rural water systems are discussed in chapter three, section 3.5.6 and in the Needs Assessment - Appendix A.

Table 2.7.6 – Annual Maximum Month Rural Water System Water Demand Projections Scenario One (ac-ft).

Rural Water System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
Agassiz Water Users District	53.9	59.0	51.7	62.8	84.8	87.1	76.1	78.1	60.0	51.9	46.5	58.9	770.9
Barnes Rural Water District	33.7	28.7	37.2	38.0	46.9	46.3	42.4	39.0	36.9	34.0	28.8	35.2	447.0
Cass Rural Water Users District	130.0	127.8	125.8	145.9	171.4	182.4	212.3	197.7	151.6	143.7	121.7	141.2	1,851.6
Dakota Rural Water District	37.1	46.1	33.9	31.3	35.6	44.5	46.2	55.5	43.8	32.2	29.9	31.1	467.3
Grand Forks-Traill Water District	169.0	169.3	139.5	299.1	226.2	284.3	184.4	217.3	148.2	175.3	168.7	135.7	2,317.0
Langdon Rural Water District	13.1	8.7	10.8	12.0	12.5	17.1	12.4	11.1	9.7	9.8	12.2	13.5	142.9
North Valley Water District	43.1	37.0	43.6	49.6	64.0	69.9	71.1	63.7	53.6	45.8	39.5	43.7	624.6
Ransom-Sargent Water Users District [1]	7.9	7.1	7.9	8.7	9.9	10.7	11.0	9.9	8.5	7.7	7.6	7.9	104.8
Southeast Water District	59.9	55.6	59.9	63.5	91.7	99.1	97.2	88.9	67.8	64.0	63.8	62.3	873.6
Traill Rural Water District	59.3	44.5	53.1	56.5	69.7	73.4	66.3	65.5	51.6	60.8	53.1	73.3	727.1
Tri-County Water District	20.8	22.0	23.3	21.9	25.9	28.8	40.8	23.2	19.5	37.3	25.8	22.7	312.0
Walsh Rural Water District	13.1	10.3	13.9	16.8	13.7	15.1	16.7	15.7	14.5	11.8	11.2	12.0	164.9
Totals	**640.8**	**616.1**	**600.5**	**806.1**	**852.5**	**958.5**	**876.9**	**865.8**	**665.9**	**674.3**	**608.8**	**637.5**	**8,803.7**

[1] – No maximum water demand data were available, so planning data from Ransom-Sargent Water Users District were used.

Note: Water demand projections incorporate water conservation and water losses. Maximum values are highlighted in blue.

Table 2.7.7 – Annual Maximum Month Rural Water System Water Demand Projections Scenario Two (ac-ft).

Rural Water System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
Agassiz Water Users District	53.3	58.4	51.2	62.2	83.9	86.2	75.4	77.3	59.4	51.4	46.0	58.3	763.0
Barnes Rural Water District	72.9	62.1	80.3	82.0	101.4	100.0	91.5	84.3	79.7	73.5	62.3	76.0	965.9
Cass Rural Water Users District	168.4	165.6	163.0	189.0	222.1	236.4	275.1	256.2	196.5	186.3	157.7	183.0	2,399.2
Dakota Rural Water District	28.2	35.1	25.8	23.8	27.1	33.8	35.1	42.2	33.3	24.5	22.7	23.6	355.2
Grand Forks-Traill Water District	208.2	208.6	171.9	368.5	278.7	350.2	227.2	267.7	182.5	215.9	207.8	167.2	2,854.4
Langdon Rural Water District	24.2	16.0	19.9	22.2	23.2	31.5	23.0	20.4	18.0	18.2	22.6	24.9	264.2
North Valley Water District	75.2	64.5	76.0	86.5	111.6	122.0	124.0	111.2	93.4	79.9	69.0	76.3	1,089.7
Ransom-Sargent Water Users District [1]	20.3	18.3	20.3	22.4	25.6	27.5	28.4	25.6	22.0	19.9	19.6	20.3	270.3
Southeast Water District	61.7	57.3	61.7	65.4	94.6	102.2	100.2	91.7	70.0	66.0	65.8	64.2	900.9
Traill Rural Water District	36.7	27.5	32.8	34.9	43.1	45.4	41.0	40.5	31.9	37.6	32.8	45.4	449.7
Tri-County Water District	26.6	28.2	29.9	28.1	33.2	36.9	52.3	29.8	25.0	47.7	33.1	29.1	399.8
Walsh Rural Water District	36.7	28.8	39.0	47.1	38.4	42.2	46.7	44.0	40.7	33.0	31.4	33.6	461.6
Totals	**812.4**	**770.5**	**771.8**	**1,032.3**	**1,082.9**	**1,214.3**	**1,119.9**	**1,090.9**	**852.4**	**853.9**	**770.7**	**802.0**	**11,174.1**

[1] – No maximum water demand data were available, so planning data from Ransom-Sargent Water Users District were used.

Note: Water demand projections include water conservation and water losses. Maximum values are highlighted in blue.

2.8 Industrial Water Demand Analysis

Two types of industrial water demands were evaluated in this study in compliance with the Act: (1) water demands for existing industrial facilities and (2) water demands for future industrial facilities. Water demands of existing facilities were relatively easy to evaluate based on historic water use data, but predicting the future was more challenging.

Future industrial water needs include a broad spectrum of water use: industrial (manufacturing and agricultural processing), institutional (universities, schools, hospitals, local and state government), and commercial (service trade, retail trade, financial, utilities, communications and wholesale trade). Water demands for future industries were estimated by three industrial development reports. Reclamation prepared two of these - *Assessment of Commercial Needs, Future Business and Industrial Activity in the Red River Valley, Final Report* (2004a) and *Industrial Needs Assessment: Future Red River Valley Commercial Water Demands, Final Report* (2004d). Bangsund and Leistritz (2004), Department of Agribusiness and Applied Economics, North Dakota State University, documented its study in the third report – *Industrial Water Needs Assessment for the Red River Valley Water Supply Project.*

Existing and future agricultural processing facilities are assumed to have no limitation on raw agricultural products due to drought, because the facilities currently receive products from outside the geographic area and would continue to do so under local drought conditions.

Existing Industrial Facilities

Existing industrial facilities are listed in table 2.8.1. These include industrial facilities which use more than 12.5 ac-ft of water annually and require a permit from the State Engineer, North Dakota State Water Commission. Industrial facilities using more than 10,000 gallons per day or 1,000,000 gallons per year require a permit in Minnesota. Table 2.8.1 shows historic water use for existing industrial facilities with individual water permits. Reclamation assumed that these existing water demands will continue through 2050. There are more industrial water users in the valley, but these are not listed in the table because they purchase their water from municipal or rural water systems. Their future water demands are included in municipal and rural water demand estimates.

The second column of table 2.8.1 identifies the water source(s) for each industrial facility. The Cargill Corn Processing Plant in Wahpeton holds permits for both surface and groundwater. The ADM Corn Processing plant in Walhalla has one groundwater permit with two diversions - one from the Icelandic Aquifer, and one from the Pembina River Aquifer. The division point (wells) for the Pembina River Aquifer is beside the Pembina River, so that permit was treated as a surface permit because of hydraulic connection between the river and the aquifer.

The third column of table 2.8.1 lists maximum annual water demand in ac-ft. The fourth column shows annual average water demand. Column five displays average annual water use for the years in which water actually was used, because there are years during which some industrial facilities do not use water. Eliminating zero-use-years in planning a project provides a higher average water use figure which ensures that supply will meet the comprehensive need. The sixth column reveals the estimated daily peaking for each facility. Very few facilities could provide these data, so peak daily water demand requirements were calculated using historic maximum monthly water use data divided by 30 (number of days in a month).

The Minn-Dak Farmers Cooperative facility tabulates historic water use in two ways. In 1987 they experienced very high water use, which was their first recorded water use. Since 1987 water use has been relatively uniform. The water demands shown in parentheses are probably more representative of their future water needs than if actual 1987 data were included in this analysis.

Table 2.8.1 – Historic Industrial Water Use.

Industry	Water Source	Maximum Annual Water Demand (ac-ft)	Average Annual Water Demand (1986-2001) (ac-ft)	Average Annual Water Demand for Actual Withdrawal Years (ac-ft)	Daily Peaking (gpm)
ADM Corn Processing	Icelandic Aquifer	183.6	68.1	85.8	250
ADM Corn Processing	Pembina River Aquifer	297.8	104.3	128.4	250
American Crystal Sugar Company – Drayton	Red River	1155.8	377.5	377.5	na
American Crystal Sugar Company – Hillsboro	Goose River	732.6	100.9	269	na
American Crystal Sugar Company – Moorhead	Red River	104.3	23.9	63.4	na
Cargill Corn Processing Plant	Red River	2,104	1,929.5	1929.5	2,083
Cargill, Inc. - West Fargo	West Fargo Aquifer	161.9	134.8	134.8	na
Cass-Clay Creameries, Inc.	West Fargo Aquifer	150.8	118.6	118.6	na
Central Livestock	West Fargo Aquifer	360.5	66.3	66.3	
Minn-Dak Farmers Coop [1]	Wahpeton Buried Valley Aquifer	1536.5 (622.8)	349.3 (277.2)	436.7 (323.4)	na
RDO Foods Company	Grand Forks Aquifer	256.9	161.2	161.2	na

[1] Values shown in parenthesis are results if 1987 (plant startup) data are not used in analysis.

Water Demands for Future Industrial Facilities

Determining potential future industrial water demands for new industries in the Red River Valley as well as additional demands for expansion of existing facilities was part of the needs assessment.

Reclamation Industrial Needs Assessment Results

Reclamation developed two reports to address future industrial water demands. Reclamation (2004a) evaluated past industrial and commercial economic activity to predict future economic growth. Past economic trends in the Red River Valley and the economic trends of municipalities similar to the cities of Fargo and Grand Forks were examined. The first analysis projected commercial growth projections from historic Red River Valley data as shown in Reclamation (2004a), table 12, page 23. The second analysis researched and compared historic development in three comparable municipalities, which is summarized on pages 24 and 25 of the report.

Reclamation (2004a) used the commercial growth rates developed in the first report to estimate the future water demands of specific economic activities. The economic sectors evaluated included manufacturing, retail, services and wholesale trade. The Reclamation investigations did not address the potential for new agricultural processing facilities. This type of activity was evaluated by the Bangsund and Leistritz (2004) study.

Each economic sector was evaluated to determine how each compared to population growth rate through 2050. If a sector of the economy grew at a faster rate than population, additional water demand was estimated to account for that increased future demand. Some sectors grew at the same rate as population; therefore, no additional water demands were estimated. Other economic sectors, such as the service sector, grew even though population projections showed a decline.

Table 2.8.2 shows the water demand results based on high and low demand scenarios. The high scenario assumed that all commercial sectors would grow at a rate faster than the population. This resulted in an estimated 2050 annual water demand of 2,619 ac-ft. The low water demand scenario assumed that only manufacturing and services would grow faster than population and resulted in an estimated 2050 annual water demand of 1,836 ac-ft. Tables 21 and 22 in Reclamation (2004a) show a detailed breakdown of the estimated water demands and associated water systems.

Table 2.8.2 – Future Annual Red River Valley Commercial Water Demand (ac-ft).

Sector	Low Demand Scenario	High Demand Scenario
Manufacturing	1,215	1,215
Retail	0	589
Services	621	621
Wholesale Trade	0	194
Totals	**1,836**	**2,619**

The approximate location of future commercial water demands were identified for hydrologic modeling. Based on results shown in Reclamation (2004a) tables 22 and 23, approximately 60% of water demand would be in Cass County, 35% in Grand Forks County, and the remaining 5% in Richland County. Table 2.8.3 shows the estimated water demand, under the low and higher demand scenarios, for each location. Chapter three discusses Reclamation’s assumption that all of the above estimated commercial water demand would be served from surface water sources because there is no available groundwater capacity for this use, particularly in the Fargo, Grand Forks, and Wahpeton areas.

Table 2.8.3 - Location of Annual Commercial Water Demands (non agricultural processing).

Red River Valley Location	Distribution of Water Demand (%)	Low Water Demand Scenario (ac-ft)	High Water Demand Scenario (ac-ft)
Cass County	60	1,101	1,571
Grand Forks County	35	643	917
Richland County	5	92	131
Totals		**1,836**	**2,619**

Bangsund and Leistritz (2004) Industrial Water Needs Assessment Results

Bangsund and Leistritz (2004) analysis estimated the future water demands of agricultural processing and nonagricultural manufacturing under low, intermediate, and high scenarios. The nonagricultural manufacturing analysis focused on economic sectors similar to those evaluated in Reclamation's study. Agricultural processing analysis was not addressed in Reclamation's study, so the Bangsund and Leistritz (2004) study results were used extensively in estimating future industrial water demands.

Tables 2.8.4, 2.8.5, and 2.8.6 summarize Bangsund and Leistritz (2004) results. Table 2.8.4 shows estimated water demands for agriculture processing and nonagricultural manufacturing as low, intermediate, and high analysis scenarios in ac-ft. This is a future North Dakota industrial water demand ranging from 7,668 ac-ft to 31,112 ac-ft. Table 2.8.6 also includes a minor amount of future estimated industrial water demand for Minnesota.

Table 2.8.4 – Bangsund and Leistritz (2004) North Dakota 2050 Projected Industrial Water Demand.

Future Scenarios	Agricultural Processing (ac-ft)	Nonagricultural Manufacturing (ac-ft)	Total Industrial and Commercial (ac-ft)
Low	4,590	3,078	7,668
Intermediate	11,096	6,662	17,758
High	18,828	12,284	31,112

Table 2.8.5 shows approximately where agricultural processing and nonagricultural manufacturing water demand would be located in the Red River Valley. Fargo/Cass County had the highest allocation of water demand followed by Grand Forks/Grand Forks County, Wahpeton/Richland County, and an unidentified location within the study area.

For hydrologic surface water modeling purposes, the "remaining study area" water demand had to be more specifically located within the Red River Valley. Since the "remaining study area" basically covered 10 counties of the study area, the water demand was proportionately divided between three identified areas for modeling purposes. Table 2.8.6 redistributes the "remaining study area" water demand and shows future industrial water demands in the Minnesota portion of the Red River Valley. Since water demand estimates for Minnesota are relatively small, the demand is allocated to the Clay County/Moorhead area.

Table 2.8.5 – Allocation of North Dakota 2050 Projected Industrial Water Demands.

City/County	Agricultural Processing Allocation (%)	Nonagricultural Manufacturing Allocation (%)	Allocated Water Demands (ac-ft)		
			Low Scenario	Intermediate Scenario	High Scenario
Fargo/Cass County	30	45	2,762	6,327	11,176
Grand Forks/Grand Forks	35	30	2,530	5,882	10,275
Wahpeton/Richland County	20	15	1,380	3,219	5,608
Remaining Study Area	15	10	996	2,331	4,053
Totals			**7,668**	**17,758**	**31,112**

Table 2.8.6 - Redistribution of Bangsund and Leistritz (2004) Industrial Water Demands.

City/County	Allocated Water Demands (ac-ft)		
	Low Scenario	Intermediate Scenario	High Scenario
Fargo/Cass County	3,175	7,282	12,850
Grand Forks/Grand Forks	2,908	6,771	11,814
Wahpeton/Richland County	1,586	3,705	6,448
Moorhead/Clay County	652	1,150	1,740
Totals	**8,321**	**18,908**	**32,852**

Selection of Future New Industrial Water Demands

Reclamation and Bangsund and Leistritz (2004) evaluated the nonagricultural manufacturing component of future industrial water demand; agricultural processing water demands were evaluated only by Bangsund and Leistritz (2004).

Scenario One: Reclamation's 2050 population projections x (per capita water demand – water conservation) + Bangsund and Leistritz (2004) intermediate future industrial water demands + recreation consumptive use.

Scenario Two: Water users' 2050 population projections x (per capita water demand – water conservation) + Bangsund and Leistritz (2004) high future industrial water demands + recreation consumptive use.

Red River Valley water users preferred using Bangsund and Leistritz (2004) high scenario results for planning purposes. They stated that this scenario best represented their goals for economic development. They wanted assurance that there would be adequate water quantity and quality to achieve their future economic development goals.

Two demand scenarios were developed to quantify water demands as described in section 2.2, Water Demand Calculation Methods. The intermediate industrial need is part of Scenario One and the high industrial need is in Scenario Two.

The full range of estimated future industrial water demands is 6,426 ac-ft to 32,852 ac-ft. The low range combines low Reclamation estimates at 1,836 ac-ft for nonagricultural commercial demand shown in table 2.8.3 and low agricultural processing at 4,590 ac-ft shown in table 2.8.4.

The average of the low and high water demand estimate is 19,639 ac-ft. The intermediate total water demand estimate using the Bangsund and Leistritz (2004) results is 18,908 ac-ft. Given that the average projected water demand is very similar to the intermediate Bangsund and Leistritz (2004) estimate, Reclamation is using the Bangsund and Leistritz (2004) intermediate water demand results from Bangsund and Leistritz (2004) industrial water assessment both for agricultural processing and for nonagricultural manufacturing for Scenario One.

The Scenario Two water demand includes the high industrial water demand estimates from Bangsund and Leistritz (2004), as requested by the water users. It totals 32,852 ac-ft annually for both agricultural and nonagricultural industry.

Tables 2.8.7 and 2.8.8 show the monthly and peak daily water demands for Scenario One and Two based on Bangsund and Leistritz (2004). The maximum monthly water demand assumes uniformity throughout the year, and is estimated based on the annual demand divided by 12 months per year. Review of existing industries reveals that historic water use remains generally uniform on a monthly basis throughout the year. Columns 5 and 6 list peak daily water demands in ac-ft and cfs. Reclamation assumes that in the future large industrial water users would construct their own water storage facilities to assure reliable water supplies in meeting peak day water demand. The best example of this is the Cargill Corn Processing Plant which has raw water storage ponds capable of meeting the facility's water needs for several weeks. Since similar facilities are proposed in Bangsund and Leistritz (2004), it seems reasonable to assume that future industries would bear the costs of meeting their peak day needs using on-site storage similar to the Cargill facility.

The water demands in tables 2.8.7 and 2.8.8 were created for input into the surface hydrologic model, which is described in chapter three. Peak day water demand estimates were estimated by dividing annual demand requirements by 365 days in a year.

Table 2.8.7 – Monthly and Peak Day Future Industry Water Demands Scenario One.

City/County	Average Year Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand [1] (cfs)	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
Fargo/Cass County	7,282	607	10.2	20.0	10.1
Grand Forks/Grand Forks	6,771	564	9.5	18.6	9.4
Moorhead/Clay County	1,150	96	1.6	3.2	1.6
Wahpeton/Richland County	3,705	309	5.0	10.1	5.1
Total	**18,908**	**1,576**	**26.3**	**51.8**	**26.1**

[1] Maximum month water demand in cfs based on 30 days in a month.

Table 2.8.8 – Monthly and Peak Day Future Industry Water Demands Scenario Two.

City/County	Average Year Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand [1] (cfs)	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
Fargo/Cass County	12,850	1,071	18.0	35.2	17.7
Grand Forks/Grand Forks	11,814	984	16.5	32.4	16.3
Moorhead/Clay County	1,740	145	2.4	4.8	2.4
Wahpeton/Richland County	6,448	537	8.7	17.7	8.9
Totals	**32,852**	**2,738**	**45.7**	**90.0**	**45.4**

[1] Maximum month water demand in cfs based on 30 days in a month.

Industrial Water System Peak 31-Day Water Demands

No peak 31-day water demands for industries were analyzed except those industries served from a municipal or rural water system where analysis included peak day factors for industrial water demands. Reclamation assumes that industrial facilities will address their own peak 31-day water demand needs through storage.

Summary of Industrial Water Demands

Tables 2.8.9 and 2.8.10 summarize future industrial water demands for Scenario One and Two estimated through 2050. This includes existing and future water demands served by surface and groundwater sources. The tables show the average annual and maximum annual water demands in ac-ft. The maximum month and peak daily water demand requirements are also shown in ac-ft and cfs.

Water demands for industries served from surface water sources (not shaded) were included in the hydrologic modeling to determine whether adequate surface water supplies exist during drought conditions. Industries served from groundwater in the future (shaded) were evaluated individually based on the condition of their groundwater source which is discussed in section 3.3.

Table 2.8.9 – Summary of Future Industrial Water Demands Scenario One.

Industry	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs)[1]	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
Existing Industries						
ADM Corn Processing (Icelandic Aquifer)	85.8	183.6	15.36	0.3	1.10	.56
ADM Corn Processing	128	298	24.8	0.4	1.10	0.55
American Crystal Sugar Co. - Drayton	378	1,156	518.6	8.7	16.95	8.54
American Crystal Sugar Co. – Hillsboro	269	733	319.2	5.4	9.51	4.80
American Crystal Sugar Co. – Moorhead	63	104	54.3	0.9	1.81	0.91
Cargill Corn Processing Plant	1,930	2,104	196.9	3.3	9.21	4.64
Cargill, Inc. - West Fargo [2]	135	162	13.5	0.2	0.45	0.23
Cass-Clay Creameries, Inc. [2]	119	151	12.6	0.2	0.42	0.21
Minn-Dak Farmers Coop	323	623	51.9	0.9	1.00	0.50
RDO Foods Co.	161	257	21.4	0.4	1.73	0.87
Central Livestock	66	361	30.0	0.5	0.71	0.36
New Industries						
Fargo/Cass County	7,282	7,282	618.5	10.4	19.95	10.06
Grand Forks/Grand Forks County	6,771	6,771	575.1	9.7	18.55	9.35
Moorhead/Clay County	1,150	1,150	97.7	1.6	3.15	1.59
Wahpeton/Richland County	3,705	3,705	314.7	5.3	10.15	5.12
Totals	**22,566**	**25,039**	**2,864.3**	**48.1**	**95.79**	**48.29**

[1] Maximum month water demand in cfs based on 30 days in a month.

[2] Industries presently use the West Fargo Aquifer, but were assumed to use the Red and Sheyenne Rivers in the future.

By the year 2050, the Red River Valley is projected to need 22,566 ac-ft of water for industrial facilities in an average year and 25,039 ac-ft in maximum water use year for Scenario One. For Scenario Two, the Red River Valley is projected to need 36,510 ac-ft of water for industrial facilities in an average year and 38,983 ac-ft in the maximum water use year. The reason the difference between average and maximum annual water use is so minor is because industries were assumed to use water uniformly and not be heavily influenced by climatic conditions.

Table 2.8.10 –Summary of Future Industrial Water Demands Scenario Two.

Industry	Average Year Water Demand (ac-ft)	Maximum Year Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs)[1]	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
Existing Industries						
ADM Corn Processing (Icelandic Aquifer)	85.8	183.6	15.36	0.3	1.10	.56
ADM Corn Processing	128	298	24.8	0.4	1.10	0.55
American Crystal Sugar Co. - Drayton	378	1,156	518.6	8.7	16.95	8.54
American Crystal Sugar Co. – Hillsboro	269	733	319.2	5.4	9.51	4.80
American Crystal Sugar Co. – Moorhead	63	104	54.3	0.9	1.81	0.91
Cargill Corn Processing Plant	1,930	2,104	196.9	3.3	9.21	4.64
Cargill, Inc. - West Fargo [2]	135	162	13.5	0.2	0.45	0.23
Cass-Clay Creameries, Inc. [2]	119	151	12.6	0.2	0.42	0.21
Minn-Dak Farmers Coop	323	623	51.9	0.9	1.00	0.50
RDO Foods Co.	161	257	21.4	0.4	1.73	0.87
Central Livestock	66	361	30.0	0.5	0.71	0.36
New Industries						
Fargo/Cass County	12,850	12,850	1,091.4	18.3	35.21	17.75
Grand Forks/Grand Forks County	11,814	11,814	1,003.4	16.9	32.37	16.32
Moorhead/Clay County	1,740	1,740	147.8	2.5	4.77	2.40
Wahpeton/Richland County	6,448	6,448	547.6	9.2	17.67	8.91
Totals	**36,510**	**38,983**	**4,049**	**68**	**134**	**68**

[1] Maximum month water demand in cfs based on 30 days in a month.

[2] Industries presently use the West Fargo Aquifer, but were assumed to use the Red and Sheyenne Rivers in the future.

2.9 Recreation Water Demand Analysis

Reclamation conducted an assessment of the future recreational water needs of the Red River Valley titled *Recreation Needs Assessment, Final Report* (Reclamation 2003c). The investigation assessed consumptive and nonconsumptive uses of water for recreation activities. Consumptive water demands are those water uses which withdraw and do not return water to the source. The difference between the amount of water that a golf course withdraws from a river and does not return as a discharge to that river system is an example of a consumptive use. Water needs that are nonconsumptive either do not withdraw water from its source or have 100% return flow to the source. Consumptive uses of water are quantified as future water demands but nonconsumptive water needs are not. The relative success of each option meeting the nonconsumptive recreational water needs will be compared and disclosed in the Project's draft environmental impact statement. Recreation nonconsumptive are described in section 2.10.

Population growth increases the need for more urban recreation facilities. Urban recreation facilities were investigated by Reclamation (2003c) to determine future water demands for urban parks, ball fields, swimming pools, and golf courses. The investigation found that water use data for urban parks, ball fields, swimming pools, and some golf courses were included in overall municipal historical water use records. However, some golf courses did have individual water permits. The assessment concluded that parks, ball fields, and swimming pools were mainly served by municipal systems, or in the case of parks and ball fields, not irrigated. The water demands for these areas were accounted for as part of the municipal or rural per capita demands in section 2.6 and 2.7.

Golf courses were the only consumptive water users not completely served by municipal or rural water systems. Currently there are 29 golf courses in the 13 eastern counties of North Dakota and the cities of East Grand Forks and Moorhead. Twelve of the golf courses are served by municipal systems; the balance have individual surface or groundwater permits.

To determine water demand for future golf courses, an evaluation to estimate the need for new golf courses in the Red River Valley through 2050 was conducted. In the study it was assumed that additional golf courses would be needed in counties with population growth, and that counties with little or no growth would have sufficient facilities through 2050. Using Reclamation population projections for 2050, the number of new golf courses and their associated water demands were estimated for Cass, Grand Forks, and Clay counties as shown in table 2.9.1.

Recreation water demand estimates for Cass, Clay, and Grand Forks counties were calculated using reported annual water use data from the past 15 years. Using these data, the average and maximum water use per golf hole was determined. Assuming the number of golf courses would increase in relation to an increase in population, the total average annual water demand in 2050 would increase by 267 ac-ft per year. The maximum annual demand would increase by 384 ac-ft per year.

Richland and Polk Counties have slight increases in their population projections; however, the recreation analysis determined the demand for a new golf course was less than one 9-hole golf course, based on current population. Otter Tail County showed measurable population growth and is included in table 2.9.1. The additional water demands for golf courses in Otter Tail County are not included in the recreational water demand totals, because they were outside the Project service area but the demands were included in the hydrologic surface water modeling analysis, because it was a potential additional withdrawal from the surface water supply.

Table 2.9.1 - Golf Courses Annual Water Demands Projected through 2050.

Annual Water Demand	Cass County	Clay County[1]	Grand Forks County	Totals for Recreational Water Needs	Otter Tail County[2]
Current Golf Course Holes	126	54	72	**252**	18
Percent Served by Surface or Groundwater Permit	50%	33%	25%	**--**	100%
Population Increase through 2050 (%)	206.9%	162.9%	162.0%	**--**	142.8%
New Golf Holes (#)	135	34	45	**213**	8
New Golf Holes Served from Surface Water Permit (#)	67	11	11	**90**	8
Average Annual Water Use Per Hole (ac-ft)	3.0	3.0	3.0	--	3.0
Average Annual Water Demand (ac-ft)	201	34	33	**267**	23
Annual Maximum Month Water Use Per Golf Hole (ac-ft)	4.3	4.3	4.3	--	4.3
Annual Maximum Month Annual Water Demand (ac-ft)	288	48	48	**384**	33

[1] Clay County demands reflect the increase water demands only for Moorhead.

[2] The additional water demands for future golf holes in Otter Tail County were used in hydrologic modeling, but were not included in recreational water demand totals for the Red River Valley service area.

Monthly Water Demand Scenarios

Table 2.9.2 shows the monthly water demand scenario of future golf courses through 2050. The water demands are presented in ac-ft and represent a historically-based monthly water use scenario that was input into the hydrologic surface water model.

Table 2.9.2 – Annual Maximum Monthly Golf Course Water Demand Projections (ac-ft).

Future Golf Course Water Demands	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Max Year Water Demand (ac-ft)
Cass County	0.0	0.0	0.0	2.9	30.7	59.2	70.7	76.9	35.1	12.6	0.0	0.0	288.1
Clay County	0.0	0.0	0.0	0.5	5.1	9.8	11.7	12.7	5.8	2.1	0.0	0.0	47.7
Grand Forks County	0.0	0.0	0.0	0.5	5.2	10.0	11.9	12.9	5.9	2.1	0.0	0.0	48.4
Otter Tail County	0.0	0.0	0.0	0.3	3.5	6.8	8.1	8.8	4.0	1.4	0.0	0.0	32.9
Totals	0.0	0.0	0.0	4.2	44.5	85.8	102.4	111.3	50.8	18.2	0.0	0.0	417.1

Annual water demand projections were converted into monthly demand projections using Fargo’s outdoor water use distribution. This distribution was used for all projected county golf course water demand scenarios. The distribution assumed that 1.0% of annual water use was in

April, 10.7% in May, 20.5% in June, 24.5% in July, 26.7% in August, 12.2% in September, and 4.4% in October. These golf course water demands are based on historical withdrawals and do not include a reduction factor for water conservation.

Peak Day Water Demand Projections

Daily water use data gathered from Grand Forks has been discussed previously in developing a 31-day water demand distribution for the Project. The distribution was based on the peak month demand which occurred in July of 1989. This distribution was also used to estimate peak day water demand estimates for golf courses. The peak 31-day water demand estimating method was described in section 2.2.

Based on Grand Forks data, the peak day water demand is 4.53% of the maximum month water demand. For example, Cass County has a maximum month water demand of 76.9 ac-ft so 4.53% of that monthly amount is 3.49 ac-ft or 1.76 cfs. Table 2.9.3 summarizes the future water demand projections for new golf courses. The average annual water demand for golf courses served by the Project is 267.5 ac-ft with a maximum annual water demand of 384.2 ac-ft. Water demand for golf courses in Otter Tail County would not be served by the Project, but the demand is included in hydrologic modeling to account for the depletion. The estimated peak daily water demand served by the Project is 2.34 cfs based on the maximum month water demand as shown previously.

Table 2.9.3 – Water Demands for Golf Courses.

Golf Courses	Average Year Water Demand (ac-ft)	Annual Maximum Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs)	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
Cass County	201	288	76.9	1.3	3.49	1.76
Clay County	33	48	12.9	0.2	0.58	0.29
Grand Forks County	34	48	12.7	0.2	0.58	0.29
Red River Project Total	267	384	102.5	1.8	4.65	2.34
Otter Tail County	23	33	8.8	0.1	0.40	0.20
Red River Valley Total	290	417	111.3	1.9	5.05	2.54

2.10 Other Red River Valley Water Needs

The objective of the Project is to meet the MR&I water needs through year 2050 and to optimize water resources in an attempt to meet identified water quality, aquatic environment, and recreation needs. This section of the report will discuss water quality, aquatic, and recreation needs and identify how these needs will influence the development of options discussed in chapter four.

Water Quality

Water quality needs were investigated from two perspectives in this study: 1) a review of historic water quality trends in the Red River and its tributaries and 2) drinking water treatment problems associated with source water. The majority of current and future water users in the Red River Valley will be supplied by the Red River and its tributaries, so an analysis of this source of water is important. This section also reviews water system water treatment to identify any water quality problems related to source water. Some water systems, particularly rural systems, depend on groundwater sources. Groundwater quality is discussed in chapter three in the hydrologic discussion of aquifers.

Water Quality Trends

In general, surface waters in the Red River Valley are suitable for most designated uses. At most locations exceedances of water quality standards are fairly rare, and when they occur, often are caused naturally.

The water quality within lakes, reservoirs, streams and rivers is determined largely by interaction of water with the landscape and by human activities. Water moving across and through the landscape is exposed to different minerals within the soils and rocks of 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. It is typical to find differences in surface water quality across a large region like the Red River Basin.

Water quality may change over time as a result of many factors, including streamflow, surface runoff, interaction with groundwater, agricultural practices (e.g., cropping patterns and fertilizer application), and point source discharges (e.g., municipal or industrial wastewater). Vecchia (2005) conducted a water-quality trend analysis to evaluate the amount of natural water-quality variability that can be expected to occur in the Red River Basin, and to determine if water quality has changed significantly because of human activities. The following discussion is summarized from that report.

The time-series model used for analyzing trends separated long-term (year-to-year) variability of the concentration data into an annual concentration anomaly, which described long-term variability in concentration as a result of natural streamflow variability, and a concentration trend, which described the long-term changes in concentrations presumably related to human activities. Numerous concentration trends were detected, and the trends could not be attributed to natural streamflow-related variability.

From the late 1970s to the mid-1990s, significant increases occurred in flow-adjusted concentrations of dissolved sulfate, dissolved chloride, and dissolved solids for most stations analyzed. Significant increases also occurred from the early 1980s to the mid-1990s for flow-adjusted concentrations of dissolved nitrite plus nitrate for stations on the mainstem of the Red

River. The increasing dissolved nitrite plus nitrate concentrations may be related to changes in municipal wastewater discharges, urban runoff, or industrial sources along the main stem.

For the Sheyenne River at Kindred, the Red River at Halstad, and the Red River at Emerson, the flow-adjusted concentration of total ammonia plus organic nitrogen increased from the late 1970s to the early 1980s, and then decreased from the early 1980s to the mid-1990s. These trends were related to changes in agricultural activities that occurred in parts of the basin. Significant decreases in flow-adjusted concentrations of total phosphorus occurred for the Sheyenne River at Kindred and the Red Lake River at Crookston, but no trends were detected on the mainstem of the Red River. The decreasing total phosphorus concentrations for the tributary stations may have been related to changes in agricultural activities.

Because water quality may change over time, future needs may be different from those currently being experienced. Existing water quality problems may be reduced by remedial actions or changes in human activities (e.g., farming practices). Conversely, increasing human populations and new sources of pollution may place additional stress on aquatic resources in the Red River Valley.

Several local, state, 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 and Minnesota Pollution Control Agency monitor and assess the condition of surface waters within their borders. Some oversight of state programs is provided by the EPA. The USGS 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. Water bodies may be assigned more than one beneficial use.

Not all surface waters can be used for their intended purpose, 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 that cause use impairment are most often associated with the following: ammonia concentrations, materials that consume oxygen (e.g., biochemical oxygen demand), dissolved solids, sedimentation, suspended solids (turbidity), bacteria from mammals, and trace metals like mercury. Ammonia (particularly in the unionized state) is toxic to many aquatic organisms. 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). Excessive sediment load decreases light penetration, and settling of sediments alters aquatic substrates. Excessive bacteria from mammalian waste are a human health hazard for recreation. Mercury contamination of fish is a hazard for human consumption.

There are three types of standards used to establish a regulatory limit that supports a designated use. These are: 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 water bodies 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 portions of stream reaches are evaluated according to the “degree” that each beneficial use (e.g., water supply, aquatic life, etc.) is achieved. This is done 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 that a numeric water quality standard is occasionally exceeded. *Not supporting* typically means that the frequency and severity of the water quality problem is greater than threatened and a documented problem exists (e.g., an observed fish kill would indicate that a water body does not support the aquatic life designated use).

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 differ between Minnesota and North Dakota for some parameters.

Houston Engineering, Inc. (2005b) compiled existing water quality data from the Red River and several of its tributaries. The water quality data came from multiple sources including the North Dakota Department of Health, the Minnesota Pollution Control Agency, USGS, and the River Watch program. Data from STORET (an EPA database) were also obtained. Over 12,000 water quality records collected at 70 stations between 1951 and 2004 are included in the database. 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 (general indicator of quality) based only on Minnesota samples as North Dakota has no TDS standard; and
- 4% of the dissolved oxygen samples (indicator of aquatic biology health).

There are no numeric standards for phosphorus in Minnesota or North Dakota. Both states, however, recognize “recommended maximum levels.” The total phosphorus concentration exceeds the recommended levels more than 50% of the time within the Red River Basin.

The USGS, in cooperation with 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 a summary of the report results.

Sheyenne River Water Quality

The physical and chemical data for the Sheyenne River indicate the water is suitable for most currently designated uses. The values for pH rarely exceed 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 river is relatively constant. The water contains a mixture of calcium, sodium, bicarbonate, and sulfate ions. At many sites, the sulfate concentrations occasionally exceed the recommended drinking water standard of 250 milligrams per liter.

Chromium, lead, mercury, nickel, and zinc are infrequently detected, and concentrations have decreased over time. This indicates better control of 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 site were within established guidelines, standards, and criteria.

Several reaches of the free flowing portions of the Sheyenne River are classified as threatened or not supporting (North Dakota Department of Health 2004). In all cases, the identified impairment is caused by sedimentation/siltation or total fecal coliform bacteria, or is indicated by reduced biological diversity. 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 Water Quality

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 Water Quality

Red River at Emerson The Red River site at Emerson, Manitoba, provides data on the quality of water that enters Canada. It integrates flow from all of the streams that drain the U. S. 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 streamflow in 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 International Joint Commission has established water quality objectives for the Red River at the international border. These objectives are the primary means by which the International Red River Board identifies major water quality issues. The objectives are:

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

The following discussion is summarized from Tornes (2005).

The pH value 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 discharge from aquifers into streams 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 Water Quality Assessment Program indicate the maximum ammonia concentration for that site during 1993-95 was 0.37 mg/L (Tornes et al. 1997).

Based upon the most recent monitoring information available from the 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. A dissolved oxygen concentration lower than the 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.

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 not met 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 not met 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. These exceedances could be attributed to natural occurrences, pollution, or to 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 the result of sample collection, processing, handling, or analysis (Windom et. al.1991).

The Red River is classified as not supporting fish consumption designated use due to high methyl-mercury or PCB concentrations in fish (North Dakota Department of Health 2004, Minnesota Pollution Control Agency 2004). The sources of methyl-mercury in fish are largely unknown. The reach of the Red River from Fargo to the confluence with the Sheyenne River is classified as threatened due to ammonia, biological oxygen demand, dissolved oxygen, and fecal coliform bacteria (North Dakota Department of Health 2004). In addition, several reaches of the Red River are impaired by excessive turbidity (Minnesota Pollution Control Agency 2004).

Drinking Water

The *Water System Assessment Executive Summary, Final Report* (Reclamation 2004c) reports the results of an evaluation of current and future water quality conditions of selected MR&I water systems in the Red River Valley. These systems were evaluated to identify present or future water quality and quantity problems.

Data on water quantity and quality, water demands, population, water system characteristics, and water rates were compiled by Reclamation in cooperation with water system managers and/or their consultants. Water system data sheets, which contain similar but more detailed information, were also completed for each water system.

MR&I systems were analyzed to determine the quality of their existing water sources compared with the Environmental Protection Agency's primary, secondary and potential future regulations under the SDWA (Safe Drinking Water Act). Drinking water standards considered in the assessments are described in the *Water Quality Needs, Regulatory Overview of the Safe Drinking Water Act, Final Report* (Reclamation 2003d).

Table 2.10.1 identifies the significant water quality concerns noted during the water system assessments. All water systems currently meet NPDWR (National Primary Drinking Water Regulations); however, a few will not be able to meet a future lower arsenic standard (i.e., Dakota Water Users, Hankinson, Lakota, Lidgerwood, and Wyndmere). Some of the water systems have problems meeting NSDWR (National Secondary Drinking Water Regulations), TDS, pH, and sulfate exceed NSDWR for these water systems. Water systems with concerns of meeting future arsenic standards will have to resolve their treatment concerns by 2006. This timeframe is prior to the earliest possible date that the Project could address any water quality issues. Therefore, no action is proposed to resolve arsenic compliance problems as part of this project.

There are also some systems which exceed one or more NSDWR. These standards are not enforceable by the Environmental Protection Agency, but exceedances in these standards generally result in aesthetic complaints (related to taste, odor, or staining of laundry or plumbing fixtures) or health concerns related to sulfate or other constituents. While aesthetic or other non-enforceable water quality health concerns are important, no water system was assumed to need to have their present water source changed based on NSDWR.

Table 2.10.1 – MR&I Water System Data Summary Results.

Water System	Water Service	Primary Water Source	Comments
North Dakota Communities and Rural Water Systems			
Agassiz Water Users	Agassiz Water Users	Groundwater	No water quality or quantity issues were listed.
Barnes Rural Water District	Barnes Rural Water	Groundwater	TDS exceeds NSDWR.
Cass Rural Water - Phase I, II & III	Cass RWS – Phase I, II & III	Groundwater	Phase II pH level is lower than the recommended level for NSDWR. Current permitted water withdrawal would be exceeded in 15 years if population continues to increase.
Cooperstown	Cooperstown	Groundwater	TDS exceeds NSDWR.
Dakota Rural Water District	Dakota Rural Water District	Groundwater	Arsenic in the northern system exceeds NPDWR.
Drayton	Drayton	Surface water	Aluminum and pH exceed NSDWR.
Enderlin	Enderlin	Groundwater	Sulfate and TDS exceed the NSDWR. The pH level is lower than the recommended level for NSDWR.
Fargo	Fargo	Surface water	The pH level is lower than the recommended level for NSDWR.
Grafton	Grafton	Surface water	Current pH levels exceed NSDWR. The current water source has seasonal aesthetic problems.

Water System	Water Service	Primary Water Source	Comments
Grand Forks	Grand Forks	Surface water	Current pH levels exceed NSDWR.
Grand Forks-Traill Water District	Grand Forks-Traill	Groundwater	No water quality or quantity issues were identified.
Gwinner	Gwinner	Groundwater	No water quality or quantity issues were identified.
Hankinson	Hankinson	Groundwater	Arsenic level exceeds NPDWR. Iron and manganese levels both exceed NSDWR.
Harwood	Harwood	Groundwater	TDS and iron exceed NSDWR.
Hillsboro	Hillsboro	Groundwater	TDS, manganese, and sulfate levels exceed NSDWR.
Horace	Horace	Groundwater	Water quality, aesthetically, is marginal. Chloride, iron, manganese, sulfate, and TDS all exceed NSDWR.
Lakota	Lakota	Groundwater	Arsenic levels may become a problem if the standard is lowered to 0.005mg/l.
Langdon	Langdon	Surface water	TDS, pH, and sulfate levels exceed NSDWR.
Langdon Rural Water District	Langdon	Purchase water from the city of Langdon	Langdon has concerns about the reliability of the existing supply during an extreme drought. TDS, pH, and sulfate levels exceed NSDWR.
Larimore	Larimore	Groundwater	Total hardness concentration is technically very high -364 mg/l as calcium carbonate.
Lidgerwood	Lidgerwood	Groundwater	Arsenic levels exceed the NPDWR. TDS and sulfate levels exceed NSDWR.
Lisbon	Lisbon	Groundwater	New well fields may be needed due to quality and quantity issues. TDS and sulfate levels exceed NSDWR.
Mayville	Mayville	Surface water	TDS, pH, and sulfate levels exceed NSDWR. Mayville anticipates problems meeting future lower turbidity and disinfection byproduct standards.
Minto	Minto	Groundwater	Aluminum and pH levels exceed NSDWR.
North Valley Water District - System II Akra	North Valley WUA - System II Akra	Groundwater	Proposed radon maximum contaminant level may impact the city of Gardar supply.
Park River	Park River	Surface water	Sulfate levels exceed NSDWR.

Water System	Water Service	Primary Water Source	Comments
Pembina	Pembina	Surface water	Trihalomethane levels exceed the NPDWR.
Ransom-Sargent Water Users District	Ransom Sargent Water Users	Purchased groundwater	TDS, sulfate, and pH levels exceed NSDWR.
Southeast Water District	Southeast Water Users	Groundwater	No water quality or quantity issues were identified.
Traill Rural Water District, Inc.	Traill Rural Water District	Groundwater	Sulfate and TDS levels exceed NSDWR. The hardness level is 572 mg/l, which is considered very hard.
Tri-County Water District	Tri-County Water District	Groundwater	No water quality or quantity issues were listed.
Valley City	Valley City	Surface and groundwater	Trihalomethane level exceeds the NPDWR.
Wahpeton	Wahpeton	Groundwater	No water quality or quantity issues were listed.
Walsh Rural Water District	Walsh Water Users	Groundwater	Some scaling problems were reported due to the hardness of the water.
West Fargo	West Fargo	Groundwater	Some residents may experience problems with lead and copper in their tap water due to the composition of the service lines. This issue is outside the scope of the Red River Valley Water Supply Project.
Wyndmere	Wyndmere	Groundwater	Wyndmere is having trouble meeting the new lower standard for arsenic. TDS and sulfate levels exceed the NSDWR.
North Dakota Industries			
American Crystal Sugar Co. – Drayton	Own WTP – process water Traill RWS – potable	Surface water	No information on water treatment, quality, or quantity was provided
American Crystal Sugar Co. – Hillsboro	Own WTP – process water City of Grafton – potable	Surface water	No information on water treatment, quality, or quantity was provided
ADM Corn Processing – Walhalla	Water is pumped to reservoir tank – no treatment is needed	Groundwater	No treatment is performed. Water is only used in cooling towers.
Cargill Corn Processing Plant	Cargill, Inc.	Surface water	Water treatment is provided at the plant.
Cargill, Inc. of West Fargo	West Fargo	Groundwater	No information on water treatment, quality, or quantity was provided.

Water System	Water Service	Primary Water Source	Comments
Minnesota Communities and Rural Water Systems			
Breckenridge	Breckenridge	Groundwater	No water quality or quantity issues were listed.
East Grand Forks	East Grand Forks	Surface water	East Grand Forks Water Treatment Plant expects that capital improvements will be required to meet future drinking water standards.
Moorhead	Moorhead	Surface and groundwater	Future surface water standards are expected to make compliance with drinking water standards more difficult to achieve.
Minnesota Industries			
American Crystal Sugar Co. – Moorhead	Moorhead	Surface and groundwater	No information on water treatment, quality, or quantity was provided.

Wastewater Return Flows Effects on Water Quality

Future wastewater returns flows in the Red River could also affect surface water quality in the Red River Valley. This is particularly a concern with Fargo return flows due to Grand Forks' dependence on these flows for water supply during periods of low flows. During a October 24, 2005, water quality modeling meeting with Reclamation staff, the North Dakota Department of Health staff stated that Fargo has a good wastewater treatment plant that should have no problems producing water of acceptable quality to release into the Red River under low flow conditions. While the water quality of Red River flows to Grand Forks is unknown under low flow conditions, Reclamation assumes that Grand Forks would be able to treat it using the new and more sophisticated water treatment plant they are planning to construct in the near future.

Water Quality Need Conclusions

A review of historic water quality indicates the surface waters in the Red River Valley are suitable for most designated uses, and at most locations exceedances of water quality standards are fairly rare. Some water systems do have problems meeting the arsenic primary drinking water standard due to their source water, but this must be resolved in the near-term and is outside the scope of this project. Some water systems also have secondary standard problems, but none of these problems are so severe as to require changes to the proposed water supply options. Grand Forks will be using a Fargo return flow dominated supply during low flow periods, but the new Grand Forks water treatment plant will be able to provide adequate SDWA treatment of this water. Therefore, water quality needs will not influence the development of the options proposed in this report.

Aquatic Environment Needs

Part of the scope of this comprehensive study of water quality and quantity needs of the Red River Valley is to identify the aquatic environment need. While it is recognized that there is a need to maintain and manage reservoir levels and instream flows to protect the basic needs of aquatic life in the Red River Valley, instream flow needs are not necessarily additive to MR&I water needs. For example, reservoir releases to meet a downstream MR&I demand could benefit aquatic environment needs, if such releases were made at times, quantities, and durations needed for that purpose. Flows beneficial to some aquatic species may be detrimental to others, or as Bovee (1982) noted, more water does not necessarily mean more habitat.

A seasonal habitat-based flow regime that would maintain aquatic life in the Sheyenne and Red Rivers is explained in the final report, *Aquatic Needs Assessment, Instream Flows for Aquatic Life and Riparian Maintenance* (Reclamation 2003a). The study focused on hydrologic and geomorphologic aspects of aquatic needs in the Sheyenne River from Harvey, North Dakota, to the confluence with the Red River of the North (Red River) just downstream of Fargo, North Dakota. It also covered the Red River from upstream of Fargo, North Dakota, near Wahpeton, North Dakota, and downstream to the international gaging station at Emerson, Manitoba, Canada.

The relationship between fish habitat stream discharge was quantified using the Physical Habitat Simulation System component of the Instream Flow Incremental Methodology. (Bovee 1997, Stalnaker et. al. 1995). Reclamation selected six reference sites in the Sheyenne and Red Rivers to represent general ecoregion boundaries for North Dakota.

Representative fish species from six habitat guilds (shallow pool, medium pool, deep pool, raceway, slow riffle, and fast riffle) were used to assess aquatic life maintenance flow needs. An optimization technique described by Bovee (1982) was applied to identify the flow for a particular time of the year (generally monthly) with the least detrimental effect on aquatic organisms without imposing liabilities on other water users. The optimization technique identifies the flow that maximizes the quantity of habitat for the species and life stage with the least habitat. Results are summarized in table 2.10.2

Table 2.10.2 - Community-based Flow Regime for Sheyenne River and Red River Reference Sites (in cfs).

Time Period	**Sheyenne River**				**Red River**	
	Warwick	Lisbon	Pigeon Point	Norman	Moorhead	Frog Point
January	4	11	24	12	161	316
February	4	13	29	10	145	323
March	31	37	116	90	210	638
April	62	134	742	190	329	1139
May 1-15	49	100	144	104	204	755
May 16-31	21	148	234	104	516	2103
June	6	129	120	64	320	1573
July	9	26	104	89	191	732
August	7	25	66	66	148	632
September	6	21	41	16	174	609
October	7	23	45	19	129	529
November	8	25	48	17	158	501
December	5	15	33	11	137	405

The recommended flow regimes for the Sheyenne River and the Red River are intended to balance the needs of the aquatic community. These community-based flows are useful to compare relative effects of water supply alternatives on aquatic resources. However, they do not consider water year types, water quality, resource management goals, or channel maintenance and riparian flows.

In addition, Reclamation estimated bankfull and floodplain flows using hydraulic outputs from Physical Habitat Simulation System at the six sites (table 2.10.3). Periodic bankfull flows in March - May are important for maintaining channel stability of the rivers and their diversity of habitat. The recommended community-based and bankfull flows would maintain the existing floodplain forest community in its present status.

Table 2.10.3 - Estimated Bankfull and Floodplain Flows for Sheyenne River and Red River Reference Sites.

Reference Site	Bankfull Flow (cfs)	Floodplain Flow (cfs)
Sheyenne River:		
Warwick	300	>300
Lisbon	1,000	>1,000
Pigeon Point	1,000	>1,000
Norman	1,200	>10,000
Red River:		
Moorhead	2,500	>3,000
Frog Point	4,000	21,000

The seasonal instream flow regimes were provided for consideration by decision makers and managers as a means to protect basic needs of aquatic life in the Sheyenne and Red Rivers. The recommended community-based flows could generally be maintained during most years by most of the options described in chapter four. However, during extreme droughts such as the 1930s, natural flows in the Sheyenne River and the Red River would frequently be lower than the recommended flows.

The North Dakota Game and Fish Department, in a letter dated September 28, 2005, recommended establishing minimum instream flows on the Sheyenne River and the Red River as part of the project. Their recommendations, based on the Tennant method (Tennant 1976) include:

- A minimum release of 23 cfs from Baldhill Dam year round
- A minimum spring flush of 215 cfs for a period of 48 - 72 hours from June 6 - 10
- April flows averaging a minimum of 69 cfs below Baldhill Dam
- Year round instream flows of 68 cfs on the Red River at Fargo
- Year round instream flows of 23 cfs below the Fargo intake on the Sheyenne River

For this report, neither the community-based flow regime developed by Reclamation or the flow regime recommended by the North Dakota Game and Fish Department were included in the design of the options, although the costs of meeting the North Dakota Game and Fish Department recommended flows were estimated. The least expensive option would cost an additional $108 million to meet the recommended flows (see chapter four and Appendix C).

Basic aquatic needs were incorporated into the options by including certain minimum reservoir levels and releases, such as a minimum fish and wildlife conservation pool of 28,000 ac-ft in Lake Ashtabula and a minimum release of 13 cfs from Baldhill Dam. Other actions and/or alternatives to meet the needs of the aquatic environment may be identified in the final EIS.

Recreation Nonconsumptive Needs

Consumptive recreation needs were discussed in section 2.9, Recreation Water Demand Analysis. Nonconsumptive recreation water needs were also identified in Reclamation's (2003c) recreation needs assessment. Nonconsumptive recreation needs are the flows and reservoir levels that facilitate boating, fishing, canoeing, hiking, and camping.

Recreation priorities in North Dakota that apply to the Sheyenne River and the Red River of the North are to provide appropriate numbers of trails, sports courts, campgrounds, water access, open space parks, playgrounds/picnic areas, beaches, amphitheaters, historic parks, support facilities, and renovation of existing facilities. Some of these priorities may involve consumptive uses of water, but it has been assumed that they will be served by MR&I systems and are accounted for in section 2.9.

Two issues that the State of North Dakota has to face are out migration and an emphasis on tourism. Out migration in rural communities has a major impact, given the large number of rural communities in the state. In addition, the state is also seeing many young adults moving out of state. Both populations have identified recreation as a major component for keeping them in the region. The state is also experiencing exploding growth in the tourism industry. The open landscape, rich history, and abundant nonconsumptive and consumptive recreational opportunities make the state a unique destination for travelers (North Dakota Parks and Recreation Department 2003).

In 1987, survey respondents reported that the types of recreation improvements most desired in the state were increased or improved river access followed by increased picnic and camping areas, riverfront park areas, and public swimming areas (North Dakota Parks and Recreation Department 1987). Overall, outdoor recreation respondents to the 1995 State Comprehensive Outdoor Recreation Plan household survey reported that playgrounds/picnic areas, developed campgrounds, and paved bicycle trails were the three most needed facility improvements (North Dakota Parks and Recreation Department 1995).

Minnesota has developed priorities for recreation in their State Comprehensive Outdoor Recreation Plan. They are (1) to protect and restore the natural resource base on which outdoor recreation depends, (2) sustain Minnesota's existing outdoor recreation facilities for future generations, (3) reserve prime recreation lands such as shoreland and significant natural areas, (4) respond to demands of Minnesota's changing population, (5) expand nature-based outdoor recreation experiences for youth living in urban areas through "close-by" access to natural areas, and (6) improve coordination of the recreation-related activities of governmental and nongovernmental providers.

River Flows River flows are attributes that can determine user satisfaction with a particular recreation site. Sufficient river flows increase the quality of the experience for users participating in both water-based and water-dependent recreation activities. Different recreation activities require different flows, and flow requirements vary between river segments.

The volume and velocity of flows are important in sustaining a quality recreation experience over an extended period. The amount, timing, and duration of flow in the rivers needed to conduct a certain type of river recreation activity differ among the many river users. Optimum flow for a quality recreation experience for one river recreation activity is not necessarily optimum for another (i.e., optimum flows for river canoeing are not necessarily optimum for swimming or fishing).

North Dakota Parks and Recreation Department (2003) recommends only three segments of the Sheyenne River for canoeing because of many hazards and low head dams in the river. The USGS maintains a website that posts current streamflow and recommendations from North Dakota Parks and Recreation Department on recommended flows for canoeing. The purpose of these recommendations is to assist canoeists in planning and scheduling canoe trips that avoid numerous portages around shallow areas during low flow. The recommendations for streamflow, as well as the percent of time the river sections flow at or above that level based on historic data, are in table 2.10.4.

Table 2.10.4. USGS Recommended Streamflow for Canoeing in the Sheyenne River.

Sheyenne River Reach	Recommended Streamflow (cfs)	Percent of Time Daily Streamflow is at or above Recommendation *
Cooperstown, ND	400	16.9
Baldhill Dam, ND	80	67.2
Lisbon, ND (near Ft. Ransom)	94	62.3

Source: USGS Sheyenne River Canoeing Recommendations Based on Streamflow and Stage retrieved 2003. *Percent of time is based on days during the open water season (April 1-September 30).

The river reach near Cooperstown historically has daily mean flows that meet or exceed recommended levels 16.9% of the time. Historic data reveal that times of adequate flow occur mainly in April and flows decrease throughout the rest of the summer.

The reaches of the Sheyenne River below Baldhill Dam and at Lisbon (near Fort Ransom State Park) meet or exceed recommended flows for approximately two-thirds of the open water season. Typically, flows are highest in the spring, and slowly decrease throughout the summer falling below the recommended value in mid-August through September. The flow in these areas is affected by Baldhill Dam releases managed by the Corps of Engineers.

Data show that canoeing conditions could be improved by an increase in flow near Cooperstown during most of the open water season. This stretch of the river is above Baldhill Dam and is unregulated. The reaches of the river below the dam tend to have flows that are more regular, but could be improved towards the latter part of the summer to accommodate canoeing. There are no minimum streamflows recommended for the Red River.

Public Access Generally, public access along the Sheyenne River is good. There are many roadside access points in addition to state and federal lands open to the public. However, improvements may be needed as the population of the Red River Valley increases through 2050. Examples of improvements are the removing stream hazards along many reaches of the river to facilitate canoeing; creating more campsites and stopovers for multi-day trips; adding potable water and restroom facilities; improving trails for hiking, biking, and horseback riding; and building more picnic and playground areas. Some of these improvements in public access may have consumptive demands, but it has been assumed that potable water and restroom facilities would be served by MR&I systems and are accounted for in that section of the needs assessment.

2.11 Needs Assessment Water Demands Summary

The objective of the Project is to meet the MR&I water needs through year 2050 and to optimize water resources in an attempt to meet identified water quality, aquatic environment, and recreation needs.

Scenario One: Reclamation's 2050 population projections x (per capita water demand – water conservation) + Bangsund and Leistritz (2004) intermediate future industrial water demands + recreation consumptive use.

Scenario Two: Water users' 2050 population projections x (per capita water demand – water conservation) + Bangsund and Leistritz (2004) high future industrial water demands + recreation consumptive use.

This section summarizes the results of various studies and analyses to estimate the future water demands with in the Red River Valley. Methods used to analyze and generate these demands are described in previous sections of this chapter. Based on the analysis completed, two water demand scenarios were developed. Scenario One included 2050 population numbers recommended by Reclamation (2003b/Revised 2005) and the intermediate future industrial water demand scenario from the Bangsund and Leistritz (2004) industrial report. Scenario Two includes 2050 population projections provided by the water users and the high scenario future industrial water demands from the same Bangsund and Leistritz (2004) report.

The water systems listed in the following tables comprise the Project service area which includes the 13 counties in North Dakota and the Minnesota cities of Breckenridge, East Grand Forks and Moorhead.

Water Demand Estimating Process

There are over 200 water systems in the Red River Valley service area in 2005. A process for determining how these water systems would be served through 2050 is described in section 2.1. Using this process Reclamation predicted 40 systems would remain in existence through 2050. This assumes that smaller systems would consolidate with existing rural water systems as the cost and complexity of operating water treatment plants increases.

Two key components are required to estimate future water demands for municipal and rural water systems. These are population projections and estimated per capita water demand. The population projections are described in Section 2.3 and the per capita water demands in section 2.4. Water conservation measures influence on estimating future per capita water demands is described in section 2.5. The methods used to estimate future water demands are described in section 2.2, and Fargo is used as an example.

Municipal and rural population projections and per capita water demand are used to estimate future demands in sections 2.6 and 2.7. Future industrial water demands are described in section 2.8 that address existing industrial facilities and future facilities predicted by three studies. Evaluation of water quality in section 2.10 reveals that none of the current water sources in the valley would have to be replaced because of SDWA compliance problems. Aquatic environment needs are addressed in that same section. Minor consumptive water use by future golf courses is a recreation water demand quantified in section 2.9.

Summary of Needs Assessment Results

Tables 2.11.1 and 2.11.2 summarize the consumptive use 2050 Red River Valley water demand estimates for water demand Scenarios One and Two. The tables show average annual water demand, maximum annual water demand and peak day all in ac-ft and cfs. The tables also subdivide water use into four demand categories: (1) municipal, (2) rural, (3) industrial, and (4) recreation.

Table 2.11.1 – Summary of Water Demand Estimates Scenario One.

Water Uses	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Peak Day Water Demand (ac-ft)	Peak Day Water Demand (cfs)
Municipal	57,053	79,442	503.0	253.6
Rural Water System	6,388	8,804	39.2	19.7
Industrial	22,566	25,039	95.8	48.3
Recreation	290	417	5.1	2.5
Total	**86,297**	**113,702**	**643.0**	**324.2**

The total average annual water demand is 86,297 ac-ft for Scenario One or 110,875 ac-ft for Scenario Two; a difference of 24,578 ac-ft. The total maximum annual water demand is 113,702 ac-ft for Scenario One or 142,380 ac-ft for Scenario Two. This is a difference of 28,678 ac-ft. The estimated peak day water demand is 643 ac-ft per day or 772 ac-ft per day for Scenario One or Two, respectively. The peak day water demand can also be expressed in million gallons per day at 209.5 mgd or 251.4 mgd for Scenario One or Two.

Table 2.11.2 – Summary of Water Demand Estimates Scenario Two.

Water Uses	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Peak Day Water Demand (ac-ft)	Peak Day Water Demand (cfs)
Municipal	65,944	91,806	583.0	294.0
Rural Water System	8,131	11,174	49.0	24.9
Industrial	36,510	38,983	134.0	67.5
Recreation	290	417	5.1	2.5
Total	**110,875**	**142,380**	**772.0**	**389.0**

The primary difference between Scenario One and Scenario Two water demands relates to municipal and industrial demands. For municipal water demands, the difference is related to population projections. For industrial water demands the difference can be traced to the use of intermediate as compared to high industrial demands estimated in Bangsund and Leistritz (2004). There are minor differences between rural water demands for either scenario, and the same recreation demands are used in both scenarios. Figures 2.11.1, 2.11.2, and 2.11.3 graph the difference between Scenario One and Scenario Two for average annual, maximum annual, and peak day water demands.

The difference between annual average and maximum annual water demands is not as large as might be expected. The maximum annual demand is 32% higher than the average annual demand under Scenario One and 29% higher under Scenario Two. The daily water demand equivalent of average annual water demand is 236.4 ac-ft (86,297 ac-ft / 365 days per year) for scenario one and 303.8 ac-ft under Scenario Two. The ratio between peak day water demand and average day water demand is 2.72 for Scenario One and 2.54 under Scenario Two. A peaking factor over 2.5 is considered high, but is typical of the Red River Valley because of the wide range of climatic conditions, particularly precipitation.

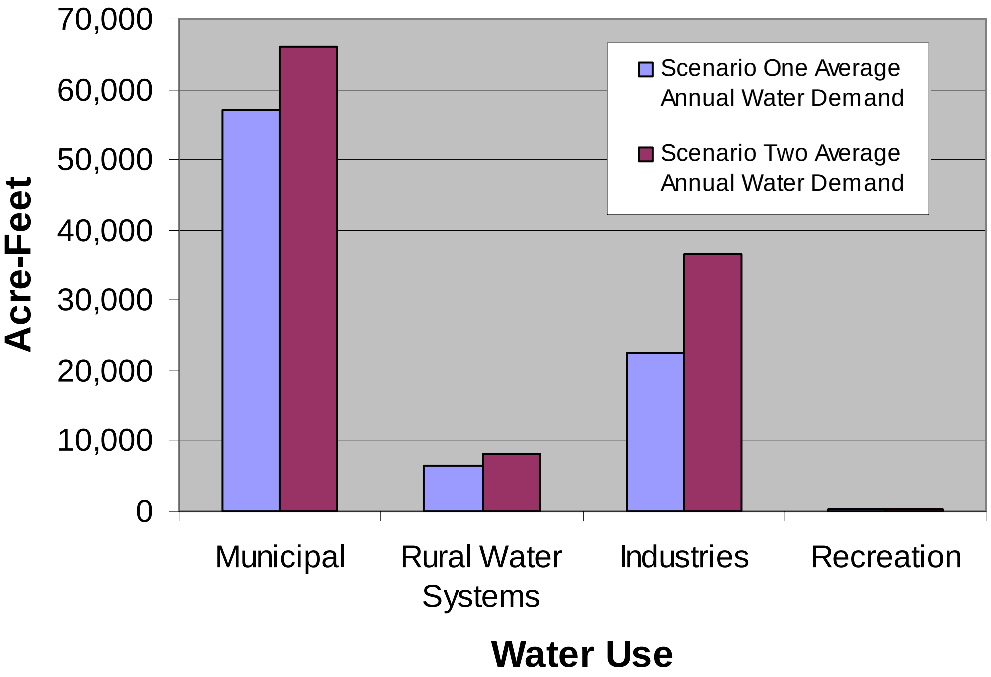


Figure 2.11.1 – Comparison of Average Annual Water Demand between Scenario One and Scenario Two.

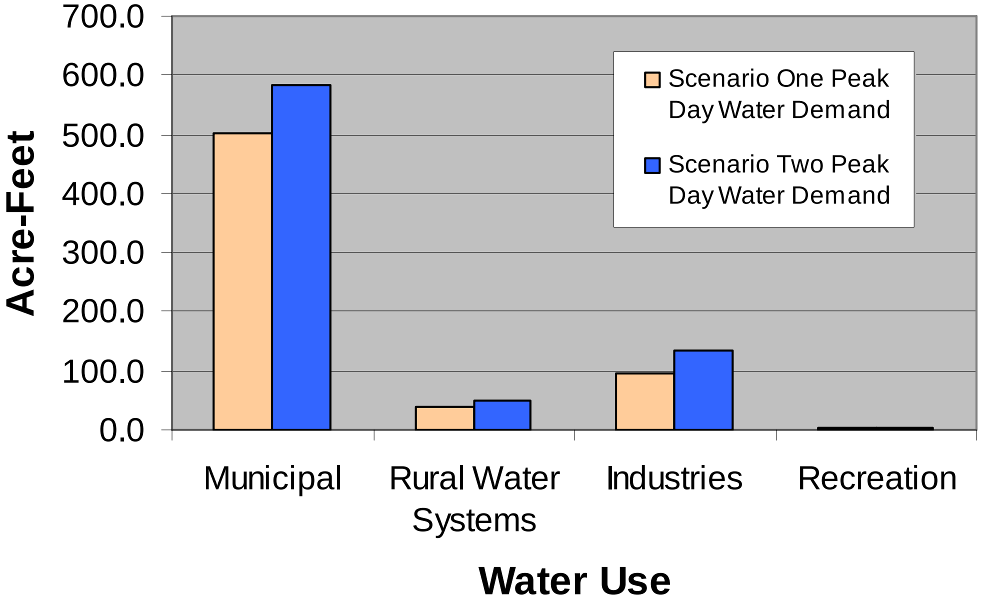


Figure 2.11.2 – Comparison of Maximum Annual Water Demand between Scenario One and Scenario Two.

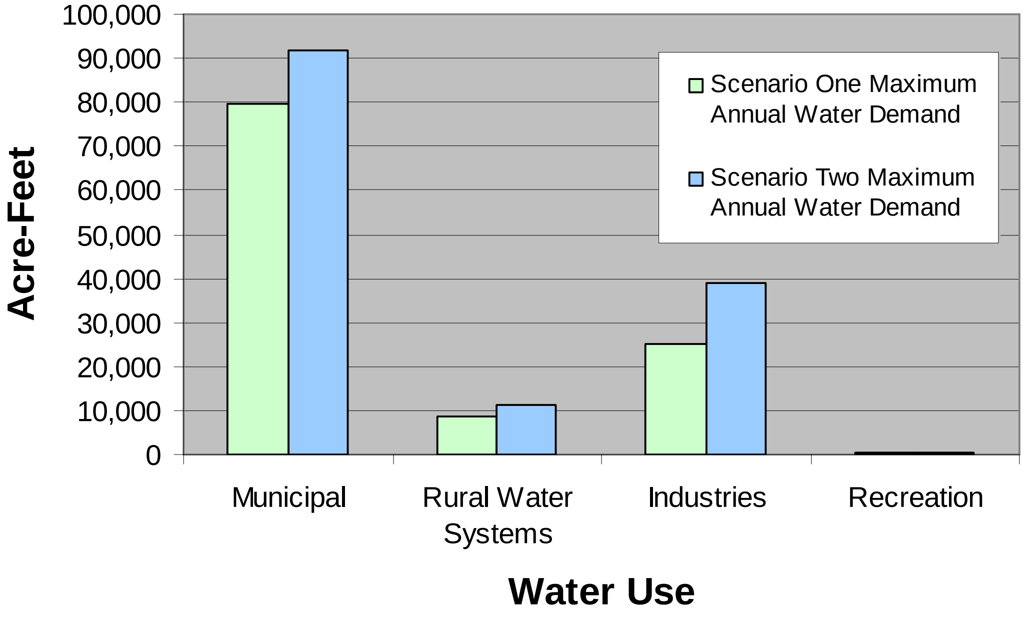


Figure 2.11.3 – Comparison of Peak Day Water Demand between Scenario One and Scenario Two.

Water treatment plant capacities are generally expressed in mgd (million of gallons per day).

To put the metrics of ac-ft (acre feet) and cfs (cubic feet per second) in perspective, a 10 mgd water treatment plant has an equivalent rated capacity of 15.5 cfs or produces 30.7 ac-ft of treated water per day.

Tables 2.11.3 and 2.11.4 show estimated water demands for each water system using a variety of metrics for Scenario One and Two. This includes average annual, maximum annual, and maximum month water demands in ac-ft. The average annual water demand represents the amount of water needed in a typical year, while maximum annual water demands represent the highest level of water use expected.

Maximum month water demand appears in cfs to reflect the flow rate required to provide a maximum month of water. Peak day water demand also is quantified in ac-ft and cfs. Peak day is an important metric because all water systems must have adequate water supplies in order to provide that volume or rate of water in a given peak day.

Tables 2.11.5 and 2.11.6 show the maximum annual water demands by month for municipal, rural, and industrial water systems for Scenario One or Two, respectively. Water demands by monthly values are listed because most water systems in the Red River Valley are served by surface water, and monthly demand input data are required for the monthly surface water hydrologic modeling described in chapter three.

Table 2.11.3 – Summary of 2050 Water Demands Scenario One.

Water System	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs)	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
North Dakota Municipalities:						
Drayton	281	607	67.8	1.1	3.07	1.55
Enderlin	761	793	70.4	1.2	4.02	2.03
Fargo	26,571	37,682	5,005.0	84.1	239.32	120.66
Grafton	706	927	101.3	1.7	4.31	2.17
Grand Forks	12,922	19,205	2,533.2	42.6	135.35	68.24
Gwinner	385	516	58.9	1.0	2.29	1.15
Langdon	272	577	65.7	1.1	3.56	1.79
Larimore	131	202	20.1	0.3	0.78	0.39
Lisbon	342	415	39.6	0.7	1.74	0.87
Park River	194	246	26.0	0.4	1.89	0.95
Valley City	685	894	116.5	2.0	6.92	3.49
Wahpeton	1,519	1,843	205.6	3.5	8.95	4.51
West Fargo	3,486	4,261	669.3	11.2	28.65	14.45
Minnesota Municipalities:						
Breckenridge	226	247	29.7	0.5	1.85	0.93
East Grand Forks	1,662	2,384	254.1	4.3	15.72	7.92
Moorhead	6,909	8,646	1,065.3	17.9	44.56	22.47
Rural Water System:						
Agassiz Water Users District	514	771	87.1	1.5	2.89	1.45
Barnes Rural Water District	320	447	46.9	0.8	2.12	1.07
Cass Rural Water Users District	1,489	1,852	212.3	3.6	7.68	3.87
Dakota Rural Water District	379	467	55.5	0.9	2.57	1.30

Water System	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs)	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
Grand Forks-Traill Water District	1,491	2,317	299.1	5.0	9.02	4.55
Langdon Rural Water District	100	143	17.1	0.3	0.99	0.50
North Valley Water District	479	625	71.1	1.2	3.24	1.63
Ransom-Sargent Water Users District	94	105	11.0	0.2	0.47	0.24
Southeast Water District	679	874	99.1	1.7	3.78	1.90
Traill Rural Water District	534	727	73.4	1.2	4.60	2.32
Tri-County Water District	186	312	40.8	0.7	1.04	0.53
Walsh Rural Water District	123	165	16.8	0.3	0.75	0.38
Existing Industry:						
ADM Corn Processing	214	481	40.1	0.7	2.20	1.11
American Crystal Sugar Co. – Drayton	378	1,156	518.6	8.7	16.95	8.54
American Crystal Sugar Co. – Hillsboro	269	733	319.2	5.4	9.51	4.80
American Crystal Sugar Co. – Moorhead	63	104	54.3	0.9	1.81	0.91
Cargill Corn Processing Plant	1,930	2,104	196.9	3.3	9.21	4.64
Cargill, Inc. - West Fargo	135	162	13.5	0.2	0.45	0.23
Cass-Clay Creameries, Inc.	119	151	12.6	0.2	0.42	0.21
Minn-Dak Farmers Coop	323	623	51.9	0.9	1.00	0.50
RDO Foods Co.	161	257	21.4	0.4	1.73	0.87
Central Livestock	66	361	30.0	0.5	0.71	0.36
Future Industry:						
Fargo/Cass County	7,282	7,282	618.5	10.4	19.95	10.06
Grand Forks/Grand Forks County	6,771	6,771	575.1	9.7	18.55	9.35
Moorhead/Clay County	1,150	1,150	97.7	1.6	3.15	1.59
Wahpeton/Richland County	3,705	3,705	314.7	5.3	10.15	5.12
Future Golf Courses:						
Cass County	201	288	76.9	1.3	3.49	1.76
Clay County	33	48	12.7	0.2	0.58	0.29
Grand Forks County	34	48	12.9	0.2	0.58	0.29
Otter Tail County	23	33	8.8	0.1	0.40	0.20
Totals:	**86,297**	**113,702**	**14,334.4**	**240.9**	**642.97**	**324.15**

Table 2.11.4 – Summary of 2050 Water Demands Scenario Two.

Water System	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs)	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
North Dakota Municipalities:						
Drayton	281	607	67.8	1.1	3.07	1.55
Enderlin	769	805	71.9	1.2	4.42	2.23
Fargo	31,613	44,833	5,954.9	100.1	284.73	143.55
Grafton	1,067	1,401	153.1	2.6	6.51	3.28
Grand Forks	13,727	20,348	2,685.8	45.1	144.77	72.99

Water System	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Maximum Month Water Demand (ac-ft)	Maximum Month Water Demand (cfs)	Peak Daily Water Demand (ac-ft)	Peak Daily Water Demand (cfs)
Gwinner	413	552	63.2	1.1	2.45	1.24
Langdon	272	577	65.7	1.1	3.56	1.79
Larimore	203	311	31.0	0.5	1.20	0.61
Lisbon	342	415	39.6	0.7	1.74	0.87
Park River	194	246	26.0	0.4	1.89	0.95
Valley City	880	1,148	149.6	2.5	8.89	4.48
Wahpeton	1,519	1,843	205.6	3.5	8.95	4.51
West Fargo	3,569	4,362	685.2	11.5	29.33	14.79
Minnesota Municipalities:						
Breckenridge	321	350	42.1	0.7	2.63	1.32
East Grand Forks	2,310	3,312	353.1	5.9	21.84	11.01
Moorhead	8,465	10,696	1,333.8	22.4	57.18	28.83
Rural Water System:						
Agassiz Water Users District	509	763	86.2	1.4	2.86	1.44
Barnes Rural Water District	691	966	101.4	1.7	4.59	2.31
Cass Rural Water Users District	1,929	2,399	275.1	4.6	9.95	5.02
Dakota Rural Water District	288	355	42.2	0.7	1.96	0.99
Grand Forks-Traill Water District	1,837	2,854	368.5	6.2	11.11	5.60
Langdon Rural Water District	184	264	31.5	0.5	1.84	0.93
North Valley Water District	835	1,090	124.0	2.1	5.66	2.85
Ransom-Sargent Water Users District	242	270	28.4	0.5	1.22	0.61
Southeast Water District	700	901	102.2	1.7	3.90	1.96
Traill Rural Water District	331	450	45.4	0.8	2.85	1.43
Tri-County Water District	238	400	52.3	0.9	1.34	0.67
Walsh Rural Water District	346	462	47.1	0.8	2.10	1.06
Existing Industry:						
ADM Corn Processing	214	481	40.1	0.7	2.20	1.11
American Crystal Sugar Co. – Drayton	378	1,156	518.6	8.7	16.95	8.54
American Crystal Sugar Co. – Hillsboro	269	733	319.2	5.4	9.51	4.80
American Crystal Sugar Co. – Moorhead	63	104	54.3	0.9	1.81	0.91
Cargill Corn Processing Plant	1,930	2,104	196.9	3.3	9.21	4.64
Cargill, Inc. - West Fargo	135	162	13.5	0.2	0.45	0.23
Cass-Clay Creameries, Inc.	119	151	12.6	0.2	0.42	0.21
Minn-Dak Farmers Coop	323	623	51.9	0.9	1.00	0.50
RDO Foods Co.	161	257	21.4	0.4	1.73	0.87
Central Livestock	66	361	30.0	0.5	0.71	0.36
Future Industry:						
Fargo/Cass County	12,850	12,850	1,091.4	18.3	35.21	17.75
Grand Forks/Grand Forks County	11,814	11,814	1,003.4	16.9	32.37	16.32
Moorhead/Clay County	1,740	1,740	147.8	2.5	4.77	2.40
Wahpeton/Richland County	6,448	6,448	547.6	9.2	17.67	8.91
Future Golf Courses:						
Cass County	201	288	76.9	1.3	3.49	1.76
Clay County	33	48	12.7	0.2	0.58	0.29
Grand Forks County	34	48	12.9	0.2	0.58	0.29
Otter Tail County	23	33	8.8	0.1	0.40	0.20
Totals:	**110,875**	**142,380**	**17,392.6**	**292.3**	**771.57**	**388.98**

Table 2.11.5 –Monthly Distribution of 2050 Maximum Year Water Demands (ac-ft) Scenario One.

Water System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
North Dakota Municipalities:													
Drayton	64	56	68	34	30	34	50	38	41	67	57	67	607
Enderlin	68	64	64	69	70	67	65	68	66	64	64	63	793
Fargo	2,408	2,144	2,513	2,619	3,502	4,549	5,005	3,812	3,099	2,540	2,838	2,652	37,682
Grafton	68	72	61	72	85	98	101	92	83	70	64	61	927
Grand Forks	1,249	1,217	1,314	1,286	1,565	2,108	2,533	1,999	1,559	1,537	1,507	1,329	19,205
Gwinner	33	35	38	37	45	57	59	53	46	50	33	30	516
Langdon	63	66	62	44	45	47	48	50	48	36	31	36	577
Larimore	17	19	20	14	16	18	20	15	12	15	18	18	202
Lisbon	36	35	29	32	37	40	39	38	36	32	30	31	415
Park River	19	19	20	18	20	24	26	23	19	18	18	20	246
Valley City	65	66	61	61	80	116	104	111	67	58	53	53	894
Wahpeton	124	123	125	135	149	203	206	203	172	143	130	131	1,843
West Fargo	257	240	266	275	345	446	669	505	339	318	341	261	4,261
Minnesota Municipalities:													
Breckenridge	17	15	17	18	21	25	27	30	22	20	17	17	247
East Grand Forks	185	158	173	150	224	219	244	254	220	190	189	178	2,384
Moorhead	560	608	646	661	711	953	1,065	846	798	621	599	576	8,646
Rural Water System:													
Agassiz Water Users District	54	59	52	63	85	87	76	78	60	52	46	59	771
Barnes Rural Water District	34	29	37	38	47	46	42	39	37	34	29	35	447
Cass Rural Water Users District	130	128	126	146	171	182	212	198	152	144	122	141	1,852
Dakota Rural Water District	37	46	34	31	36	44	46	56	44	32	30	31	467
Grand Forks-Traill Water District	169	169	140	299	226	284	184	217	148	175	169	136	2,317
Langdon Rural Water District	13	9	11	12	13	17	12	11	10	10	12	13	143
North Valley Water District	43	37	44	50	64	70	71	64	54	46	40	44	625
Ransom-Sargent Water Users District	8	7	8	9	10	11	11	10	9	8	8	8	105
Southeast Water District	60	56	60	63	92	99	97	89	68	64	64	62	874

Water System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
Traill Rural Water District	59	45	53	57	70	73	66	66	52	61	53	73	727
Tri-County Water District	21	22	23	22	26	29	41	23	20	37	26	23	312
Walsh Rural Water District	13	10	14	17	14	15	17	16	15	12	11	12	165
Existing Industry:													
ADM Corn Processing	15	15	15	15	15	15	15	15	15	15	15	15	184
ADM Corn Processing	25	25	25	25	25	25	25	25	25	25	25	25	298
American Crystal Sugar Co. – Drayton	0	0	0	0	0	0	0	7	508	519	122	0	1,156
American Crystal Sugar Co. – Hillsboro	0	0	319	285	128	0	0	0	0	0	0	0	733
American Crystal Sugar Co. – Moorhead	0	0	40	54	10	0	0	0	0	0	0	0	104
Cargill Corn Processing Plant	155	161	181	179	180	184	197	182	184	149	158	194	2,104
Cargill, Inc. - West Fargo	13	13	13	13	13	13	13	13	13	13	13	13	162
Cass-Clay Creameries, Inc.	13	13	13	13	13	13	13	13	13	13	13	13	151
Minn-Dak Farmers Coop	52	52	52	52	52	52	52	52	52	52	52	52	623
RDO Foods Co.	21	21	21	21	21	21	21	21	21	21	21	21	257
Central Livestock	30	30	30	30	30	30	30	30	30	30	30	30	361
Future Industry:													
Fargo/Cass County	618	559	618	599	618	599	618	618	599	618	599	618	7,282
Grand Forks/Grand Forks County	575	519	575	557	575	557	575	575	557	575	557	575	6,771
Moorhead/Clay County	98	88	98	95	98	95	98	98	95	98	95	98	1,150
Wahpeton/Richland County	315	284	315	305	315	305	315	315	305	315	305	315	3,705
Future Golf Course s:													
Cass County	0	0	0	3	31	59	71	77	35	13	0	0	288
Clay County	0	0	0	0	5	10	12	13	6	2	0	0	48
Grand Forks County	0	0	0	0	5	10	12	13	6	2	0	0	48
Otter Tail County	0	0	0	0	4	7	8	9	4	1	0	0	33
Totals:	**7,805**	**7,335**	**8,393**	**8,578**	**9,937**	**11,955**	**13,214**	**11,080**	**9,760**	**8,915**	**8,602**	**8,130**	**113,702**

Table 2.11.6 –Monthly Distribution of 2050 Maximum Year Water Demands (ac-ft) Scenario Two.

Water System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
North Dakota Municipalities:													
Drayton	64	56	68	34	30	34	50	38	41	67	57	67	607
Enderlin	70	65	65	70	72	68	66	70	67	65	64	64	805
Fargo	2,865	2,551	2,990	3,116	4,166	5,413	5,955	4,536	3,687	3,023	3,377	3,155	44,833
Grafton	103	109	92	109	129	148	153	139	125	105	97	92	1,401
Grand Forks	1,322	1,289	1,389	1,363	1,658	2,227	2,686	2,125	1,652	1,630	1,597	1,409	20,348
Gwinner	35	37	41	39	48	62	63	56	49	54	36	32	553
Langdon	63	66	62	44	45	47	48	50	48	36	31	36	577
Larimore	26	29	31	21	25	28	31	23	18	23	28	27	312
Lisbon	36	35	29	32	37	40	39	38	36	32	30	31	415
Park River	19	19	20	18	20	24	26	23	19	18	18	20	246
Valley City	83	85	78	78	102	150	133	142	86	74	68	68	1,148
Wahpeton	124	123	125	135	149	203	206	203	172	143	130	131	1,843
West Fargo	263	246	272	281	353	456	685	517	347	325	349	267	4,362
Minnesota Municipalities:													
Breckenridge	24	21	25	25	30	36	39	42	31	28	24	24	350
East Grand Forks	257	219	240	209	311	305	340	353	306	264	262	248	3,313
Moorhead	685	748	796	815	880	1,189	1,334	1,052	991	764	735	706	10,696
Rural Water System:													
Agassiz Water Users District	53	58	51	62	84	86	75	77	59	51	46	58	763
Barnes Rural Water District	73	62	80	82	101	100	92	84	80	73	62	76	966
Cass Rural Water Users District	168	166	163	189	222	236	275	256	196	186	158	183	2,399
Dakota Rural Water District	28	35	26	24	27	34	35	42	33	24	23	24	355
Grand Forks-Traill Water District	208	209	172	368	279	350	227	268	183	216	208	167	2,854
Langdon Rural Water District	24	16	20	22	23	32	23	20	18	18	23	25	264
North Valley Water District	75	64	76	87	112	122	124	111	93	80	69	76	1,090
Ransom-Sargent Water Users District	20	18	20	22	26	27	28	26	22	20	20	20	270
Southeast Water District	62	57	62	65	95	102	100	92	70	66	66	64	901

Water System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
Traill Rural Water District	37	28	33	35	43	45	41	41	32	38	33	45	450
Tri-County Water District	27	28	30	28	33	37	52	30	25	48	33	29	400
Walsh Rural Water District	37	29	39	47	38	42	47	44	41	33	31	34	462
Existing Industry:													
ADM Corn Processing	15	15	15	15	15	15	15	15	15	15	15	15	184
ADM Corn Processing	25	25	25	25	25	25	25	25	25	25	25	25	298
American Crystal Sugar Co. – Drayton	0	0	0	0	0	0	0	7	508	519	122	0	1,156
American Crystal Sugar Co. – Hillsboro	0	0	319	285	128	0	0	0	0	0	0	0	733
American Crystal Sugar Co. – Moorhead	0	0	40	54	10	0	0	0	0	0	0	0	104
Cargill Corn Processing Plant	155	161	181	179	180	184	197	182	184	149	158	194	2,104
Cargill, Inc. - West Fargo	13	13	13	13	13	13	13	13	13	13	13	13	162
Cass-Clay Creameries, Inc.	13	13	13	13	13	13	13	13	13	13	13	13	151
Minn-Dak Farmers Coop	52	52	52	52	52	52	52	52	52	52	52	52	623
RDO Foods Co.	21	21	21	21	21	21	21	21	21	21	21	21	257
Central Livestock	30	30	30	30	30	30	30	30	30	30	30	30	361
Future Industry:													
Fargo/Cass County	1,091	986	1,091	1,056	1,091	1,056	1,091	1,091	1,056	1,091	1,056	1,091	12,850
Grand Forks/Grand Forks County	1,003	906	1,003	971	1,003	971	1,003	1,003	971	1,003	971	1,003	11,814
Moorhead/Clay County	148	133	148	143	148	143	148	148	143	148	143	148	1,740
Wahpeton/Richland County	548	495	548	530	548	530	548	548	530	548	530	548	6,448
Future Golf Course s:													
Cass County	0	0	0	3	31	59	71	77	35	13	0	0	288
Clay County	0	0	0	0	5	10	12	13	6	2	0	0	48
Grand Forks County	0	0	0	0	5	10	12	13	6	2	0	0	48
Otter Tail County	0	0	0	0	4	7	8	9	4	1	0	0	33
Totals:	**9,967**	**9,319**	**10,594**	**10,817**	**12,462**	**14,780**	**16,232**	**13,760**	**12,142**	**11,151**	**10,825**	**10,334**	**142,381**

Comparison between Current (2005) and Future (2050) Water Demands

Table 2.11.7 compares the current maximum annual water demands to the total 2050 Scenario One and Two demands estimated in this chapter. The 2005 maximum municipal water demands reflect Reclamation population projections. Because Reclamation did not estimate 2005 rural populations, water user projections were used in column two. The water user population estimates generally assumed that rural population would remain stable through 2050. The 2005 industrial water demands are based on maximum historic water use. There are no new recreational water demands in column two.

Table 2.11.7 - Comparison of Current (2005) with Future (2050) Water Demands

Water Use	2005 Maximum Annual Water Demand (ac-ft)	2050 Scenario One Maximum Annual Water Demand (ac-ft)	2050 Scenario Two Maximum Annual Water Demand (ac-ft)
Municipal	48,359	79,441	91,806
Rural Water Systems	11,174	8,804	11,174
Industries	6,131	25,039	38,983
Recreation	0	417	417
Totals	**65,664**	**113,702**	**142,380**

Reclamation estimates that water demands will increase by 73.2% from the 2005 demand to the 2050 Scenario One demand estimate. The difference between current water demand and the 2050 Scenario One is 48,038 ac-ft, with a municipal increase of 31,082 ac-ft and industrial growth of 18,908 ac-ft. Rural water system water demand actually decreases by 2,370 ac-ft under Scenario One, because Reclamation assumes that populations served by these systems will decline in number. A minor amount of water (417 ac-ft) is estimated for future recreational demands from new golf courses.

The 6,131 ac-ft of current industrial water demand includes only industries that seek their own water source. A similar volume of industrial water demand is currently purchased from municipal and rural systems and is included in the municipal water demands. The industrial water demand estimates under Scenario One and Two include a current demand of 6,131 ac-ft plus all future estimated industrial demand estimated in the Bangsund and Leistritz (2004) industrial needs report.

The increase from current water demand to 2050 Scenario Two demand is 117.9%. The difference is 77,432 ac-ft which includes a municipal increase of 43,447 ac-ft and industrial growth of 32,852 ac-ft. There is no difference between the 2005 and 2050 Scenario Two rural water system water demands, because the same estimates were used.

Scenario Two is 25.9% or 28,678 ac-ft higher than Scenario One. The difference in total water demand includes 12,365 ac-ft for municipal use and 13,944 ac-ft for industrial use. The difference for rural water systems is 2,370 ac-ft, while there is no difference between the recreational water demand estimates. The difference in municipal water demand relates directly to the population projections used in the development of Scenario One and Two water demands. The same per capita per day demands were used in both water demand scenario estimates. The difference in industrial water demands is attributed to the use of intermediate industrial water demand estimated from Bangsund and Leistritz (2004) in Scenario One and use of the high projection in Scenario Two.

Chapter Three
Hydrology

3.1 Introduction

The previous chapter quantifies the future water demands of the Red River Valley service area through 2050. This chapter identifies existing Red River Valley water sources and determines which are adequate to meet the future demands. Where water shortages are predicted, the amount of water required to meet the future water demands is quantified.

3.1.1 Methods Used in Evaluating the Hydrology of the Red River Valley

Two types of water-needs analyses are performed in the Needs and Options Report: evaluation of water systems served by groundwater and evaluation of water systems served by surface water. To evaluate future water needs of a groundwater-supplied system, the maximum annual withdrawal in ac-ft (acre-feet) and maximum daily withdrawal in gpm (gallons per minute) are estimated and compared to the water systems' approved groundwater permit(s).

Evaluation of water systems supplied by surface water requires three steps. The first step is to evaluate the adequacy of the water systems' surface water permit(s) using estimated maximum annual withdrawal and maximum daily withdrawal water demand rates. The second step is to use a surface water model to estimate shortages. The third step is to perform peak day demand analysis to evaluate whether there would be adequate surface water flow to meet future water needs.

Historic and Naturalized Flow

Historic flow, also referred to as *regulated flow*, is the river flow recorded over the past at gaging sites.

Naturalized flow, also known as *unregulated flow*, is regressed from historic flow by removing human influence. Naturalized flow is used in watershed evaluations and in modeling as a baseline.

Monthly surface water hydrologic modeling was conducted to compare naturalized flow data with future water demand scenarios. Each water system had approximately 10 to 15 years of historic water use data that were updated to reflect future population and were used as water demand scenarios for modeling. The development of future water demand scenarios for hydrologic modeling is discussed in more detail later in this chapter. Daily time-step analysis was conducted using scenarios based on 31 days of daily water demand data that coincided with the historic maximum peak daily water demand.

3.1.2 Previous Red River Valley Hydrology Work

In 1994, Reclamation began a study to evaluate existing and future MR&I water use in the Red River Basin of North Dakota. The study used a surface water availability model to estimate existing and projected MR&I water needs. The study also evaluated options to identify existing and projected water shortages (Reclamation 1998). Providing information about viable water-supply options and enabling water users to make prudent decisions about future water needs for the Red River Basin were the study's main goals.

The current study expands on the results of the 1994 study and includes refinements such as updated information on water supplies, current and future water use, and explores additional viable water supply options. Numerous studies that investigated various hydrologic aspects in the Red River Basin were consulted for the current Project. Central to the current study and the more refined modeling effort were collection of water use data for the basin (Macek-Rowland et al. 2004), collection and estimation of historic and unregulated streamflows in the basin (Emerson 2005), estimation of evaporative losses from reservoirs in the basin (Vining 2003), investigation of river gains and losses (Williams-Sether 2004), and projection of the impacts of the Federal Devils Lake Outlet on the Sheyenne River (Corps 2003). Other studies that had an impact on the current investigation, especially with respect to hydrology, are in three extensive websites:

Red River Basin Decision Information Network website
http://www.rrbdin.org/do/communication/listFiles

U.S. Army Corps of Engineers St. Paul District website
http://www.mvp.usace.army.mil/finder

U.S. Geological Survey North Dakota District website
http://nd.water.usgs.gov/pubs/index.html

3.1.3 Surface Water and Groundwater Rights

The Red River Basin is under jurisdiction of North Dakota and Minnesota water law, which take two different approaches to water rights. For North Dakota, it is prior appropriations; for Minnesota, riparian. Each approach gives different, even contradictory, priorities for permitting and altering water uses. The hydrologic model must reflect the two states' approaches in allocating water rights. To model future water uses effectively, Reclamation developed a priority system for assessing which uses and changes would likely be permitted and how these uses would affect current and future water supplies.

Regulation of surface and groundwater rights determines who can use available water and how much can be used.

A clear understanding of the two different water rights also is required to evaluate groundwater use, development of new sources, and conversion. *Conversion* is the changing of a permitted use from one category to another, such as conversion from irrigation to municipal use.

Prior Appropriation Water Law – North Dakota

Article XI, section 3 of the North Dakota Constitution states, "all flowing streams and natural watercourses shall forever remain the property of the state for mining, irrigating and manufacturing purposes." By statute, appropriation of water in the State of North Dakota is the responsibility of the State Engineer. In North Dakota state law, NDCC *(North Dakota Century Code)* chapter 61-04 addresses appropriation of water. The State Engineer's rule-making authority is reflected in NDAC (North Dakota Administrative Code) § 89-03-01, § 89-03-02, and § 89-03-03. The Administrative Agencies Practice Act (NDCC chapter 28-32) binds the State

Engineer (as head of an administrative agency) to its provisions in conducting hearings on water permits, water appropriations, and related matters.

NDCC chapter 61-04 requires that an appropriation of water involve an actual diversion and works before a water permit may be perfected. North Dakota state law does not provide a mechanism for issuing water permits specifically to preserve a naturally occurring instream flow. However, under existing state law, a water permit *can* be issued for a project to divert or store water. The water released would be protected from appropriation by others. The existing water permit issued for the Garrison Diversion Project allows project water to be delivered to satisfy water demands, and the water is protected from downstream diversion under existing state law.

Listed in NDCC § 61-04-06 are the factors the State Engineer must consider in making a determination about whether to issue a water permit. That section provides, in part:

The state engineer shall issue a permit if the state engineer finds all of the following:

1. The rights of a prior appropriator will not be unduly affected.
2. The proposed means of diversion or construction are adequate.
3. The proposed use of water is beneficial.
4. The proposed appropriation is in the public interest. In determining the public interest, the state engineer shall consider all of the following:
    a. The benefit to the applicant resulting from the proposed appropriation.
    b. The effect of the economic activity resulting from the proposed appropriation.
    c. The effect on fish and game resources and public recreational opportunities.
    d. The effect of loss of alternate uses of water that might be made within a reasonable time if not precluded or hindered by the proposed appropriation.
    e. Harm to other persons resulting from the proposed appropriation.
    f. The intent and ability of the applicant to complete the appropriation.

When there are competing applications for water from the same source, and the source is insufficient to supply all applicants, the State Engineer is required to adhere to the following order of priority (NDCC § 61-04-06.1, Preference in Granting Permits):

1. Domestic use
2. Municipal use
3. Livestock use
4. Irrigation use
5. Industrial use
6. Fish, wildlife, and other outdoor recreational uses

Riparian Water Law - Minnesota

Minnesota Statutes § 103G.265 requires the MNDNR (Minnesota Department of Natural Resources) to manage water resources to ensure an adequate supply to meet long-range seasonal requirements for domestic, agricultural, fish and wildlife, recreational, power, navigation, and quality control purposes. The Water Appropriation Permit Program exists to balance competing management objectives that include both development and protection of Minnesota’s water

resources (see the MNDNR website:
http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/permits.html
for more information).

Water law in Minnesota is governed by riparian rights. Riparian water rights, or eastern water law, state that the owner of land containing a natural stream or abutting a stream is entitled to receive the natural flow of the stream limited only by the equal rights of the other riparian owners subject to reasonable use and public welfare. The riparian owner is protected against the diversion of water except for domestic purposes upstream from his property and from the diversion of excess flood flows toward his or her property.

The MNDNR has established minimum instream flows (i.e., 90% exceedence flow) using a hydrologic method as a guideline. The minimum instream flow for the Red River is 41 cfs at Moorhead, Minnesota.

3.1.4 Climatology Report

Reclamation contracted with Meridian Environmental Technology Inc. to conduct a study on drought frequency in the Red River Valley (Meridian Environmental Technology, Inc. 2004). The study estimated the probabilities that droughts of varying intensities would recur and recommended appropriate drought scenarios to use for hydrologic modeling.

Based on one- to five-year precipitation deficits, recurrence intervals for a 1930s-level drought ranged from less than 25 years to more than 100 years for North Dakota and the Red River Basin. Probable recurrence intervals for a drought of the intensity of the 1980s were significantly shorter than for the 1930s drought.

The study concluded that there is a strong probability that an extreme drought similar to the 1930s will occur in the Red River Valley before 2050. The study concluded that the 1930s drought typified the most extreme event anticipated until 2050, and that a drought of this magnitude and intensity was appropriate to use for water supply planning in the Red River Valley.

3.2 Groundwater Hydrology

ASR (Aquifer Storage and Recovery)

ASR is storage of water in a porous underground formation during times when excess surface water is available and recovery of water during times when it is needed.

Groundwater is a potential water supply source for the Project. This section provides an overview of groundwater in the Red River Valley. First, characteristics and current and potential uses of aquifers in North Dakota and Minnesota are described. Then, potential for additional groundwater development is analyzed. In North Dakota, future potential groundwater uses include proposals for conversion of existing use, reservation of known resources for future needs, and implementing ASR (aquifer storage and recovery) on selected aquifers. In Minnesota, future potential groundwater uses include ASR for the Moorhead Aquifer and potential development of selected Minnesota aquifers. Water quality, water quantity, and comparative merits of various aquifer development strategies are considered. Recommendations are made for those aquifers with the most promise for further development and use in the Project.

3.2.1 Groundwater Overview in Red River Valley

Water can often be found below the earth's surface. If water saturates the subsurface and can be retrieved via a well from a porous or fractured formation, this formation can be considered an aquifer. Many of the major aquifers in the Red River Valley were formed from glacial drainage channels and outwash, river deltas and beach deposits, and sand and gravel bodies embedded with till. Well yields from bedrock aquifers, such as the Dakota Sandstone Aquifer, are generally much lower in quantity and quality than well yields from aquifers derived from glacial events in the Red River Basin (Krenz and Leitch 1993).

Combinations of quantity, quality, and geographic location limited early exploration and development of groundwater throughout much of the Red River Valley. Future development will need to take advantage of advanced treatment and delivery technologies to make use of the limited groundwater available in the Red River Valley as described in the next section.

Aquifers in the Red River Valley can be classified as either surficial or buried. Surficial aquifers are in contact with the land surface and provide relatively direct infiltration of precipitation to the water table. Water quality of surficial aquifers can be negatively impacted by land-surface activities such as the application of agricultural chemicals, petroleum spills, and improperly built or maintained septic systems. Surficial aquifers also tend to exchange water with streams, lakes, and wetlands. In these exchanges, surficial aquifers can either gain or lose water.

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 is 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.

Conversely, buried aquifers are often confined by less permeable silt and clays, making it possible for buried aquifers to contain water under artesian pressure. One advantage confined aquifers have is the protection they receive from overlying clays and tills. Depending on local geology, several aquifers in the Red River Valley grade from confined to unconfined over their geographic extent.

Aquifers investigated in this Project are the West Fargo Aquifer System and the Sheyenne Delta, Hankinson, Milnor Channel, Brightwood, Spiritwood, Gwinner, and Wahpeton Buried Valley Aquifers in North Dakota; and the Moorhead, Buffalo, Pineland Sands, Ottertail, and Pelican River Sand-Plain aquifers in Minnesota (see figure 3.2.1).

Figure 3.2.1 – Aquifers Investigated in North Dakota and Minnesota. (Note: The Red River Basin, which is a surface water basin, is outlined in red. The Red River runs through the center of the basin.)

When looking at aquifer use between North Dakota and Minnesota, the difference in water laws and available data make comparisons somewhat difficult. North Dakota water permits show a maximum allowable value for annual withdrawals, where many Minnesota permits only use rates for permitting. For purposes of discussion, North Dakota aquifers are evaluated with respect to their permitted values, while Minnesota aquifers are best described using historical statistics regarding use of groundwater. Reclamation funded a study by the Minnesota Geological Survey to help determine the availability and suitability of various aquifers in Minnesota for MR&I needs (Thorleifson et al. 2005).

Water Quantity Terms

ac-ft (Acre-Feet) - An acre-foot is the volume of water that would cover 1 acre to a depth of 1 foot which equals 43,560 cubic feet of water or 325,851 gallons. At its normal summer operating level, Lake Ashtabula holds about 70,000 acre-feet of water. Ac-ft is also used to quantify the volume of groundwater held in storage within an aquifer or reservoir.

bgals (Billion Gallons) - This quantifies use of water or the amount of water in storage.

cfs (Cubic Feet per Second) - Represents the rate at which water flows in a river, pipeline, or from a well. A cubic foot of water is equal to 7.48 gallons. If 1,000 cfs of water from Baldhill Dam were released for an entire day, that would equal 86.4 million cubic feet of water or 1,983 acre-feet/day.

gpc/d (Gallons per Capita per Day) - The amount of water that a person uses in a day.

gpm (Gallons per Minute) - The number of gallons that flow per minute used to quantify well yields. For example, a typical municipal well may be able to produce 250 gpm or 0.557 cfs.

Mgals (Million Gallons) - This quantifies use of water or the amount of water in storage.

Conversion Factors

1 cfs = 724 ac-ft per year.
1 cubic foot = 7.48 gallons
1 ac-ft = 43,560 ft^3 or 1,232 m^3
1 m^3 = 35.3 ft^3

Water Quantity

Estimating the amount of water stored underground rarely can be done with great certainty. Lack of data on these heterogeneous groundwater systems makes estimating their properties very difficult. Further complicating the estimation process are the often incomplete historical data on past uses of an aquifer. Therefore, determining what constitutes sustainable use of the resource often is quite speculative until historical use and aquifer response can be analyzed in hindsight. Efforts to describe the current understanding of individual aquifers with respect to the Project are discussed in this section. Appraisals of Red River Valley aquifers by the NDSWC (North Dakota State Water Commission) are documented in correspondence included in Appendix B (NDSWC 1995; NDSWC 2005b).

Water Quality

Given the diversity in geologic settings, age of water, and natural recharge rates, water quality is as diverse as the setting. In general, all groundwater fell to the ground as precipitation and initially contained only a few milligrams per liter of TDS (total dissolved solids). Since water is often described as the universal solvent, it is no surprise that TDS tends to increase the longer water remains in contact with the geologic minerals present in the soil. Some groundwater, such as that present in the deep and older Dakota Sandstone Aquifer, initially fell to Earth millions of years ago. This water typically contains 2,000 to 5,000 mg/L (milligrams per liter) of TDS, with values in excess of 30,000 mg/L not uncommon.

Some of the moderately deep and confined aquifers (100 to 300 feet) contain water trapped during the Pleistocene Epoch over 10,000 years ago. This water is generally less saline than that in the Dakota Sandstone Formation. However, Pleistocene-Epoch waters typically exceed the secondary drinking water standard of 500 mg/L of TDS, with values up to 2,500 mg/L being common. The West Fargo Aquifer System and Spiritwood Aquifer are examples of this type of groundwater setting.

In the Red River Valley groundwater with the lowest values for TDS can generally be found in the shallow surficial aquifers. These aquifers tend to be recharged from precipitation on a regular basis. Total dissolved solids between 400 and 800 mg/L are common. Water quality impairments due to human activities are a concern in surficial aquifers, with agricultural chemicals, septic effluent, and trace metals causing the bulk of the impairments. Nitrate is a common contaminant associated with shallow aquifers, and naturally occurring trace elements such as arsenic also are of concern. Elk Valley, Sheyenne Delta, Brightwood, Milnor Channel, and Fordville aquifers typify Red River Valley shallow surficial aquifers.

As water quality differs between the different types of aquifers, so does the water quality within an aquifer. Significant variation in the water quality has been documented both horizontally and vertically within most of the aquifers in the Red River Valley. Table 3.2.1 summarizes water quality for selected aquifers on the North Dakota side of the Red River Valley.

North Dakota Aquifers

Aquifers in North Dakota are discussed individually, with descriptions of size, location, type of aquifer, water quality, current and pending permitted uses, and recommendations on future appropriations of water. ASR is evaluated for its potential as part of the future MR&I supply for the Red River Valley.

A number of the aquifers border one another, and that is reflected in the discussion. Selected aquifers from two aquifer systems (Wahpeton Aquifer System and West Fargo Aquifer System) and aquifers from one series of partially interconnected aquifers also are discussed. Within the Wahpeton Aquifer System, only the Wahpeton Buried Valley is discussed at length. Another aquifer system of interest is the West Fargo Aquifer System. Portions of West Fargo Aquifer System discussed in this section are West Fargo North, West Fargo South, and Horace aquifers. Another complex series of individual aquifers in close proximity to one another are Hankinson, Milnor Channel, Brightwood, and Sonora aquifers. Somewhat interconnected, they may exchange water between adjacent units and possibly with the Sheyenne Delta Aquifer to the north. Discussions of aquifers that are part of an aquifer system or that are interconnected may reference some nearby and interrelated aquifers.

The following descriptions of relevant aquifers in the Red River Valley of North Dakota are compiled from pertinent county groundwater studies, reports on individual aquifers, review of available well logs, and consultation with the NDSWC. While major withdrawals of groundwater are regulated by the permitting process of the NDSWC, domestic and stock wells do not require permits. These withdrawals are afforded the same protection as permitted withdrawals and are considered minor in comparison to permitted withdrawals. The major aquifers under consideration as Project groundwater sources - Brightwood, Elk Valley, Gwinner, Milnor Channel, a portion of Spiritwood, and West Fargo Aquifer System - have about 40,000 ac-ft of water permitted and an average annual withdrawal of almost 19,000 ac-ft.

Table 3.2.1 - Water Quality of Selected Aquifers in the Red River Valley in North Dakota.

Aquifer	Water Level below surface (ft)	Conductivity µS	pH	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	F mg/L	HCO3 mg/L	SO4 mg/L	Cl mg/L	NO3 mg/L	Fe mg/L	Mn mg/L	TDS mg/L	Hardness mg/L as CaCO3
Dakota	42.6	4977	8.1	113.9	58.5	26.8	1068.9	3.9	369.7	1054.8	1043	5.3	1.12	0.07	3564	516
Brightwood	47.8	1180	7.7	173.1	51.0	8.1	35.5	0.2	430.8	369.3	5.7	0.6	1.15	0.54	868	643
Elk Valley	17.1	764	7.5	105.6	31.1	4.4	23.5	0.3	328.4	154.4	13.9	6.7	0.88	0.72	512	392
Fordville	23.6	717	8.0	88.1	29.2	4.1	26.8	0.2	313.4	134.9	8.0	5.5	0.43	0.56	458	340
Gwinner**	103.2	2071	7.9	113.5	31.3	15.2	359.1	0.3	565.2	708.8	36.9	2.5	0.10	0.63	1565	412
Hankinson	13.5	1219	7.7	143.2	75.1	9.9	31.9	0.2	421.5	395.8	18.9	0.4	1.87	0.75	897	602
Horace	102.8	33.3	7.7	191.9	0.4	371.7	305.6	148	2.2	0.82	0.18	994	394	102.8	33.3	7.7
McVille	20.7	1040	7.9	110.6	30.9	8.0	148.9	0.3	405.6	309.7	50.5	13.0*	0.46	0.55	894	403
Milnor Channel	10.7	1026	7.9	109.0	37.3	8.2	77.6	0.2	398.6	239.1	28.2	2.4	0.87	0.55	707	426
Page/ Galesburg	21.4	916	7.6	134.1	41.8	8.7	44.1	0.2	379.4	272.0	9.7	5.7	0.8	0.91	718	506
Sheyenne Delta	14.0	1748	7.8	112.4	43.3	14.8	241.7	0.8	478.0	492.7	96.9	3.3	1.22	0.63	1304	455
Sonora**	24.8	1878	8.8	137.2	55.3	12.8	257.6	0.4	352.3	789.1	49.2	2.3	1.07	0.18	1492	531
Spiritwood	18.8	1462	7.5	110.6	32.5	11.8	166.7	0.3	457.2	347.6	36.3	1.8	1.91	0.53	960	409
Wahpeton Buried Valley	43.5	1063	5.7	107.4	41.0	8.3	80.2	0.6	490.6	171.8	26.2	1.6	1.07	0.18	716	444
West Fargo North	102.5	1466	8.0	48.7	18.1	8.5	267.4	0.6	406.8	106.9	250.6	2.0	0.32	0.08	918	196
West Fargo South	94.2	841	8.0	43.9	15.6	5.4	114.9	0.5	309.0	79.0	70.9	1.9	0.19	0.09	502	174

The above data are averaged from all chemical analyses and do not represent a statistical sampling of the water in the respective aquifers. This suggests that some areas of the aquifer may be over or under represented.

* McVille nitrate values are skewed by four very high sample results. Eliminating these anomalous measurements produces an aquifer average of 2.8 mg/L.

** These aquifers do not have very many samples from which these data are collected.

µS – microsiemens, Ca – Calcium, Mg – Magnesium, K – Potassium, Na – Sodium, F – Fluoride, HCO3 – Bicarbonate, SO4 – Sulfate, Cl – Chloride, NO3 – Nitrate, Fe – Iron, Mn – Manganese, TDS – Total Dissolved Solids, CaCO3 – Calcium Carbonate.

Elk Valley Aquifer The Elk Valley Aquifer has an area of about 200 square miles and is located in the north-central part of the Red River Valley. Water quality in the aquifer is fairly good, with some elevated levels of TDS. Irrigation is the primary use of the aquifer, and will continue to be under western water law doctrine of first-in-time appropriation of water rights. Grand Forks-Traill Water, Tri-County Water, and several small individual communities use the aquifer.

There are currently additional requests pending for irrigation appropriations from the Elk Valley Aquifer. These requests would be first in line for new appropriations. Any future additional appropriations would require extensive investigation for what must be described as modest volumes of water.

Due to the modest size of this aquifer and the amount of existing appropriation, this aquifer is not a good candidate for future increased withdrawals. This suggests that any future increase in MR&I demands on Elk Valley Aquifer must be offset by decreased use of the groundwater for irrigation. North Dakota law allows for conversion of a water right from an existing beneficial use to a higher beneficial use, as discussed later in the chapter.

Fordville Aquifer The Fordville Aquifer has an area of about 33 square miles and is located on the north end of the Elk Valley Aquifer. It is a much smaller aquifer than the Sheyenne Delta, Page-Galesburg, or Elk Valley aquifers. Water from the aquifer is quite good, with TDS typically between 400 and 600 mg/L. All but one of the existing observation wells show stable or slightly rising groundwater levels since 1990. It is fair to infer that existing uses, under the conditions since 1990, are not depleting the aquifer.

Walsh Rural Water and Minto currently use Fordville Aquifer for their water supplies. Due to the relatively small size of this aquifer and the amount of existing municipal use, new permits would require some site-specific investigations in order to protect existing users. It is unlikely that significant quantities of unallocated water would be discovered.

Gardar Aquifer The Gardar Aquifer is a small, shallow, unconfined aquifer in Pembina County. Due to the size and location of this aquifer, it would not be a suitable water source for the Project.

Gwinner Aquifer Armstrong (1982) describes the Gwinner Aquifer as a feature deposited in a depression of glacial till, approximately 22 miles long and 0.4 to 4 miles wide, with an average thickness of about 55 feet, ranging up to 109 feet. While not very large, this aquifer appears to receive recharge through the overlying glacial drift. The community of Gwinner holds rights to 500 ac-ft of water from the northwest portion of the Gwinner Aquifer for municipal use. There are no other major users of water from this aquifer (NDSWC 2004), and water levels suggest some ability for further use in the central and southeast portions of the aquifer. However, this aquifer is not large enough to be a major water-supply feature.

Grand Forks Aquifer The Grand Forks Aquifer is a small, deeply buried sand and gravel deposit in the vicinity of Grand Forks. The aquifer is poorly defined. Its depth is typically 200 feet and its thickness is probably less than 20 feet. Glacial till and lake clays overlie the deposit.

Water in the aquifer is highly mineralized, with dissolved solids concentrations often exceeding 5000 mg/L. For this reason, the aquifer has not been used as a potable water supply in the past. Its limited thickness and extent suggest that, even with advanced treatment technologies, this aquifer would be unable to serve as a major source of MR&I water in the future.

Hankinson Aquifer The Hankinson Aquifer is located south of the Sheyenne Delta Aquifer and east of the Milnor Channel. Distinctly separated from the Sheyenne Delta Aquifer by an area of till and lake clay, the Hankinson Aquifer forms a northwest-to-southeast deposit of beach sands and gravels of former Lake Agassiz. Aquifer deposits average about 40 feet in thickness, but range from more than 100 feet thick in the northwest portion of the aquifer in Ransom and Sargent Counties to only a few feet thick in southern Richland County near the South Dakota border. The surface area of the Hankinson Aquifer is about 100 square miles. Aquifer materials range from poorly sorted sandy gravel to well-sorted fine sand. The coarser deposits are near the south end of Richland County, and the material becomes finer grained toward the north. The aquifer is unconfined, and the water table is generally less than 10 feet below the ground surface.

Chemical analyses of water from the Hankinson Aquifer show the water is hard, but otherwise of generally good quality for drinking. As of 2004, the Hankinson Aquifer supported Hankinson and Southeast Water District with 1,035 ac-ft of municipal and rural water permits, four irrigation permits totaling 403.7 ac-ft, and 110 ac-ft of water between two industrial permits. Review of well logs for the area suggested that the high-yield area of the aquifer already was well developed, and earlier interpretations of the aquifer may have overestimated the aquifer’s extent. The Hankinson Aquifer itself is not suitable for use by the Project. The favorable-yield areas of the aquifer already are used by municipal and rural water appropriations. Any future development of the Hankinson Aquifer would require intensive field investigations to determine suitable locations, with a high likelihood of only a modest return on efforts.

Milnor Channel Aquifer The Milnor Channel Aquifer is a largely unconfined aquifer composed of terrace deposits, abandoned channel deposits, and surficial outwash in Ransom, Sargent, and Richland Counties. The aquifer formed after the Sheyenne River abandoned its former course prehistorically and established a new course to the southeast. The Milnor Channel Aquifer ranges from about one to two miles wide and underlies an area of about 45 square miles (Armstrong 1982). Deposits in the Milnor Channel consist of sand, sandy gravel, and sandy silt, with an estimated 150,000 ac-ft of water in available storage (Baker and Paulson 1967). The known range in thickness is from 8 to 66 feet, with average thickness of around 40 feet. Recharge to the Milnor Channel Aquifer is from direct precipitation on the aquifer and adjacent areas that drain to it; water moves through the aquifer from the north to west; and there is interaquifer movement from the Brightwood Aquifer. Some groundwater may move into the aquifer from the beach deposits near Hankinson, and small amounts may be contributed by the till adjacent to the channel. Discharges from the aquifer are an estimated 50,000 ac-ft per year and are assumed to roughly equal natural recharge (Baker and Paulson 1967). Water quality in the Milnor Channel is similar to the Hankinson Aquifer. Several small surface water features most likely are connected to groundwater within the aquifer, including Lake Elsie, Grass Lake, Willard Lake, Swan Lake, Salt Lake, Silver Lake, and Sand Lake. Lidgerwood maintains permits for 595.0 ac-ft of water for municipal use, with another 9,650.3 ac-ft of groundwater permitted for 56 irrigation permits. Review of available well logs, the aquifer’s size, and its balanced recharge rates suggests there may be some room for increased development in the central portion of the aquifer.

Overall water quality in the aquifer is fair to good, but the presence of elevated arsenic in some areas has concerned munnicipal water systems depending on the aquifer.

Brightwood Aquifer The Brightwood Aquifer is a thick deposit of glacial outwash that lies mostly south and west of the Milnor Channel and Hankinson Aquifers. The thickness of the outwash deposits ranges from 70 to 130 feet, and averages about 100 feet. The aquifer's surface area is approximately 13 square miles (Baker and Paulson 1967). However, the estimated aquifer area appears to have been ascertained by measuring surface features, not through extensive test drilling. Review of subsequent well log data suggests the aquifer or associated deposits extend farther north and west, encompassing features such as Star Lake and Moran Lake. Revised estimates would increase the aquifer's surface area and its associated sand and gravels to at least 60 square miles. The aquifer matrix consists of generally well-sorted sands and medium gravel. Much of the matrix is covered by glacial till, but the aquifer in general behaves as an unconfined aquifer. Recharge to the Brightwood Aquifer probably comes from direct infiltration of precipitation and ponded water in the numerous shallow depressions. Water moves eastward through the aquifer toward discharge areas, including Willard Lake, Lake Elsie, Grass Lake, and the Milnor Channel Aquifer. No active withdrawal permits have been identified for the Brightwood Aquifer. Water quality in the Brightwood Aquifer can best be called fair to good. Total dissolved solids range from around 500 mg/L to 1,300 mg/L.

While natural recharge and discharges remain unknown, the lack of active permits and the promise of high-capacity wells makes the Brightwood an attractive feature for a wellfield capable of producing large quantities of water for a short period of time, or much lesser amounts of water for a longer period of time.

Sonora Aquifer The Sonora Aquifer is very poorly defined in extent. It is a small buried channel with a northwest-to-southeast axis underlying the eastern edge of the Hankinson Aquifer. No permitted municipal, rural, industrial, or irrigation wells exist on this aquifer (NDSWC 2004). Very little information on characteristics and extent is available on this aquifer. However, anecdotal evidence suggests that a past attempt to use it for irrigation was abandoned due to degraded water quality under sustained use. This aquifer is believed to receive leakage from deep underlying Cretaceous bedrock, which may lead to degraded water quality over time and use.

Icelandic Aquifer The Icelandic Aquifer underlies about 82 square miles of Pembina County. The aquifer consists of very fine to medium sand with interbedded silt and clay. The aquifer's thickness ranges from 0 to 60 feet.

Recharge to the Icelandic Aquifer is mostly from precipitation, primarily snowmelt. Discharge from the aquifer is from underflow to other aquifers, flow into the Tongue River, and evapotranspiration.

Water from the aquifer is predominantly hard and contains calcium-magnesium bicarbonate. It has medium salinity and low sodium. Iron, sulfate, and chloride also occur in the water. The water is acceptable for most domestic and public uses.

Based on older statistics Hutchinson (1977) estimated that the aquifer could contain about 240,000 ac-ft of storage. Estimates from test wells indicated that flows around 50 gpm are to be expected. Due to the very low yields available and relatively long distances water would have to be conveyed from this aquifer, it is not a suitable candidate for MR&I development within the Project.

Inkster Aquifer This aquifer is fairly small and also is in the north-central Red River Valley. The size of the aquifer is 12 to 15 square miles, which is an area of approximately 8,300 acres. The average thickness is 20 to 50 feet. Water from the aquifer is generally good, with low concentrations of sodium.

Aquifer appropriations total 3,590 ac-ft for all irrigation and rural and municipal water. When compared to the aquifer area of about 8,300 acres, this corresponds to an average annual recharge of five inches of infiltration. This recharge rate is in the range of the annual recharge estimated for the Sheyenne Delta Aquifer (3 - 8 inches) and suggests this aquifer is fully developed. Agassiz Water Users have groundwater supply wells in the aquifer.

The aquifer's small size and the amount of existing annual appropriation make it a poor candidate for potential new permits.

McVille Aquifer The McVille Aquifer is a long, narrow aquifer that meanders for about 70 miles through portions of Ramsey, Nelson, Griggs, and Steele Counties. Rarely more than a mile in width, the aquifer consists mostly of fine sand, clayey sand, and sandy gravel, with lenses of clay and glacial till. The aquifer ranges in average thickness from about 160 to 300 feet.

Recharge in the aquifer is from precipitation and snowmelt. Discharge from the aquifer is mostly to the Sheyenne River and to Stump Lake.

Water in the aquifer is generally low in dissolved solids. The water varies from containing calcium bicarbonate, with relatively low salinity near recharge areas, to water containing sodium sulfate, with moderate salinity near discharge areas.

Yields from the McVille Aquifer were estimated in 1970 (Downey 1973) to be as much as 400 gpm in some locations. Total storage was estimated to be about 200,000 ac-ft. Lacking a centralized location for a large wellfield, this aquifer is much better suited for serving smaller communities in the Red River Valley, as it already does, than for providing an additional source of water for the larger metropolitan areas.

Page-Galesburg Aquifer The Page-Galesburg Aquifer has an area of about 400 square miles and is in parts of Cass, Steele, and Traill Counties. The aquifer's thickness ranges from 40 to 250 feet. Well yields from the aquifer can often be 500 gpm. This aquifer is located where it could be used by the larger municipal areas of Fargo and West Fargo. Currently, Traill Rural

Water District and Cass Rural Water Users District are using the aquifer for a water supply. Irrigation development has already taken advantage of the areas that are capable of high-yield wells.

During a drought period, some water level declines would be expected. However, subsequent wet years would be expected to refill the aquifer. Groundwater available in the aquifer can be estimated by comparing the annual recharge amount to the existing appropriations. Using a conservative estimate of 1 inch of recharge per year over the entire 400 square-mile surface area, the annual recharge would be 21,330 ac-ft. Existing appropriations are 16,385 ac-ft. The difference between estimated recharge and existing water appropriations is not an estimate of “safe yield,” but it does provide an estimated amount of annual aquifer recharge already consumed by human use (77%).

Currently there are 18 pending permits for an additional 6,500 ac-ft of irrigation water (NDSWC 2005b). Ripley (NDSWC 2005b) also suggests that some areas are capable of limited increases in development following site-specific investigations. However, any future large MR&I demands on the aquifer would need to include conversion of existing irrigation permits to MR&I permits. The aquifer is generally more suited to provide rural water systems with added water than it is for the larger metropolitan areas of the Red River Valley.

Sheyenne Delta Aquifer Located in Richland, Cass, Ransom, and Sargent Counties of North Dakota, the 750 square-mile Sheyenne Delta Aquifer is a deltaic deposit formed where the Sheyenne River discharged into former pro-glacial Lake Agassiz. As Lake Agassiz drained, the Sheyenne Delta remained behind, resting on a flat expanse of lakebed clay. Aeolian processes reworked much of the Sheyenne Delta, forming sand dunes up to 85 feet high and leaving depressions to a depth of 10 feet. The U.S. Forest Service acquired and designated over 70,000 acres as Sheyenne National Grasslands. The Sheyenne National Grasslands are associated with the Sheyenne Delta.

The typically sandy soils covering the Sheyenne Delta tend to allow rapid infiltration of snow meltwater and precipitation. Only the area immediately adjacent to the Sheyenne River has well developed surface drainage. Excess precipitation farther away from the river systems tends to form wetlands in low-lying areas. This leaves large areas of the Sheyenne Delta without well developed surface drainage and results in localized ponding of water before infiltration. The sand and silt of the Sheyenne Delta are as much as 200 feet thick. A notable exception to this thickness is near the Sheyenne River, where the stream has incised and reworked the deltaic deposits, with finer-grained sediment transported in from upstream areas.

The Sheyenne Delta Aquifer contains an estimated 4 million ac-ft of groundwater in storage and receives about 50,000 ac-ft of recharge during a year of average precipitation (Baker and Paulson 1967). Because much of the aquifer is overlain by the Sheyenne National Grasslands, the logical area for development would be external to the Grasslands to avoid unduly impacting a protected environment. Limited development might be possible at the southern extent of the aquifer.

Recharge to the Sheyenne Delta Aquifer takes place primarily during the spring. Evapotranspiration tends to exceed precipitation during the summer months. Only an occasional large rainfall event is sufficient to overcome soil moisture deficits and provide recharge to the groundwater. During the fall evapotranspiration diminishes, and precipitation may exceed combined evapotranspiration and soil moisture deficits and allow recharge. Even when recharge does not occur during the fall, soil moisture deficits generally are reduced, significantly affecting the magnitude of the following spring recharge event (Shaver 1998).

Groundwater is removed from the aquifer by evapotranspiration during the growing season and by flows to the Sheyenne River, which is a gaining stream through most of its reach in the Sheyenne Delta (Baker and Paulson 1967). Groundwater also is removed through irrigation and municipal wells tapped into the aquifer. As of 2004, Ransom-Sargent Water Users District and Cass Rural Water Users District are the only two municipal and rural water systems with permits on the Sheyenne Delta Aquifer, for a combined 1,300 ac-ft of water. The Sheyenne Delta Aquifer also supports 82 irrigation permits, for a total of 15,196.3 ac-ft of water, and one industrial permit for 4.0 ac-ft of water (NDSWC 2004).

The water in the Sheyenne Delta Aquifer is somewhat hard but is usable for most purposes (Baker and Paulson 1967). Additional water use from the aquifer is possible with maximum well yields of up to 250 gpm.

Spiritwood Aquifer The Spiritwood Aquifer is a large glacial drift aquifer occupying a buried-valley complex that crosses North Dakota from north to south. Approximately 175 square miles in Sargent County are under investigation for further development for this Project. The aquifer consists of sand and gravel interbedded with occasional silt and clay layers. With an average thickness of 33 feet, the Spiritwood Aquifer is overlain by up to 200 feet of till and is underlain by Cretaceous-age bedrock. Water moves into the aquifer both downward through the overlying drift and upward through the underlying bedrock formations. Recharge to this aquifer appears limited to leakage from adjacent formations and to small amounts of infiltration from overlying till. Although some areas appear to have appreciable vertical recharge, the Spiritwood Aquifer tends to be more characteristic of a confined aquifer. This portion of the aquifer retains approximately 850,000 ac-ft in storage, and wells produce between 500 to 1000 gpm, or 800 to 1600 ac-ft per year.

The variation in water chemistry from top to bottom of the aquifer can be quite dramatic. Generally, the water has high TDS, requiring mixing with water from other sources that have much lower TDS–or reverse osmosis–as treatment prior to use as a domestic supply.

Within the Spiritwood Aquifer segment in Sargent County, the cities of Rutland and Forman retain municipal water permits totaling 214.5 ac-ft. No industrial permits have been granted within this area of the Spiritwood, but there are 26 irrigation permits for 4,921.3 ac-ft of water (NDSWC 2004).

Given the hydraulic properties of this largely confined system and lack of significant recharge, this aquifer could produce large rates and volumes of water for use in times of drought, but should not be relied upon for extended periods of time.

Wahpeton Buried Valley Aquifer The three separate aquifers comprising the Wahpeton Aquifer System, in order of increasing depth, are Wahpeton Shallow Sand, Wahpeton Sand Plain, and Wahpeton Buried Valley (Schoenberg 1998). The highly saline Dakota Sandstone also underlies most of the area (Baker and Paulson 1967). In North Dakota, the Wahpeton Buried Valley Aquifer generally has a north-south axis on the eastern edge of Richland County, then extends under the Red River into Wilkin County, Minnesota. The Wahpeton Buried Valley Aquifer is fine-grained at the top to very coarse-grained at the bottom and covers about 8 square miles. It fills a steep-sided buried valley up to 125 feet thick cut into till and Cretaceous bedrock.

Potential sources of recharge to the Wahpeton aquifers include infiltration of the aquifer from the Red River and precipitation and inflow from adjacent confining units. The confining units are glacial Lake Agassiz sediments, till, and Cretaceous bedrock. Recharge from the Red River depends on two conditions: (1) the stage in the river must be higher than the hydraulic head in the aquifers and (2) the river must be hydraulically connected to the aquifer. Recharge from the Red River to the Wahpeton aquifers was not estimated. The texture of the riverbed sediments of the Red River and the degree of connectivity of the Red River to the Wahpeton Aquifers is unknown (Schoenberg 1998). Schoenberg (1998) also estimated that the upper limit for natural recharge to the Wahpeton aquifers as 1,780 ac-ft per year based upon withdrawals.

Current (2005) permitted use from the Wahpeton Buried Valley Aquifer includes 3,000 ac-ft of water in industrial permits for Cargill, which are held in abeyance for times of low flow in the Red River. Another 350 ac-ft of water is permitted for the Minn-Dak Farmers Cooperative and 2,130 ac-ft for Wahpeton. Breckinridge Minnesota also maintains a water permit for 1,680 ac-ft from the Wahpeton Buried Valley Aquifer, but typically withdraws less than 300 ac-ft per year from the aquifer. Total dissolved solids average 635 mg/L in Wahpeton Buried Valley Aquifer, with the underlying Dakota Sandstone Aquifer and overlying Colfax unit of the Wahpeton Sand-Plain Aquifer being higher at 938 and 1,611 mg/L, respectively (Froelich 1974).

The Wahpeton Buried Valley Aquifer is perhaps one of the better understood aquifers in the Red River Valley. It has no potential for increased permitting, given its limited natural recharge and existing development. However, Wahpeton Buried Valley may be a candidate for ASR. Using Wahpeton Buried Valley for ASR could replenish water removed from storage and allow surface waters to be stored in the aquifer for times when surface water is scarce.

West Fargo Aquifer System Underlying the communities of West Fargo and Fargo, and extending as far north as Harwood and as far south as Horace and Hickson in Cass County, is West Fargo Aquifer System. Several small aquifers make up West Fargo Aquifer System. Total storage in the aquifer system in 1995 was estimated at about 415 billion gallons (Ripley 2000). Declining water levels in this aquifer system indicate that, without appreciable recharge from infiltration, and no known connections to the Red River, the sustained yield for West Fargo Aquifer System is being exceeded. The portions of West Fargo Aquifer System discussed in this section are the West Fargo North, West Fargo South, and Horace aquifers.

West Fargo North Aquifer Part of the larger West Fargo Aquifer System is West Fargo North Aquifer, a buried, glacial drift aquifer in eastern Cass County, North Dakota. There are numerous aquifer units of various sizes within West Fargo Aquifer System. Of these, West Fargo North is one of the larger aquifers in the complex, with a surface area of approximately 27 square miles and average thickness of 79 feet (Ripley 2000).

Currently West Fargo North provides part of the water supply for West Fargo. Due to the confined nature of this aquifer, recharge due to infiltration of precipitation does not occur in any great amount; and existing withdrawals result in declining water tables (Ripley 2000). Limited interaquifer water movement may occur from adjacent units within West Fargo Aquifer System. Without appreciable recharge from infiltration, and no known connections to the Red River, all existing and proposed withdrawals from the aquifer system effectively remove water currently held in storage. Even continued use of West Fargo North Aquifer at existing rates would require an ASR feature to mitigate drawdown in the aquifer and prevent wells from having capture problems in the future.

Water quality is variable throughout the aquifer. Better-quality water in the West Fargo North Aquifer is along its southern edge, with salinity increasing in the aquifer’s northern reaches.

West Fargo South Aquifer Another aquifer in the West Fargo Aquifer System is West Fargo South. Its thickness averages about 90 feet over an area of about 14 square miles. Water levels in the aquifer have decreased about 2.3 feet per year during the past 15 years.

Water in the aquifer predominantly contains sodium bicarbonate, with TDS generally between 500 and 700 mg/L. Studies have indicated that recharge to this aquifer is insignificant. Discharge from this aquifer is mostly from pumping. Continued use of groundwater from West Fargo South Aquifer or others in West Fargo Aquifer System could result in deteriorating water quality as more, lower-quality water moves into the aquifer from surrounding aquitards and other West Fargo Aquifer units. An ASR program should be implemented that replenishes water in the West Fargo South Aquifer at about the same rate as it is withdrawn.

Aquitard is a layer of low permeability that can store groundwater and also transmit it slowly from one aquifer to another.

Horace Aquifer The Horace Aquifer is one of the larger units in West Fargo Aquifer System. This aquifer averages about 103 feet thick over an area of about 27 square miles. Water levels have declined about 1.3 feet per year during the last 15 years. Water in the aquifer ranges from calcium-sulfate-type water to sulfate with no dominant cation. Total dissolved solids range from 500 to 2,000 mg/L.

Other Aquifers in the Red River Valley of North Dakota Numerous other small sand and gravel bodies serve as aquifers. Some, such as the Fairmount, and Enderlin are named, while many others are not. These aquifers are of insignificant value to a large water supply project because they lack sufficient size, thickness, or transmissivity. This does not preclude them from being important sources of water for a finite number of water users. In fact they are often quite important as small communities, rural water systems, irrigation agriculture, livestock, and domestic users all benefit from these smaller aquifers.

Minnesota Aquifers

Beach ridge deposits and eight major surficial aquifers are located throughout and adjacent to the Minnesota portion of the Red River Basin. Information on these Minnesota aquifers and beach ridge deposits was collected to determine the quantity and quality of groundwater resources within the basin. The surficial aquifers and beach ridges generally are isolated deposits of sand and gravel, and typically are found near the surface. In 2003 total water withdrawal from the eight major surficial aquifers in the basin, not including groundwater withdrawn for private domestic use, was approximately 27,893 Mgals (85,600 ac-ft).

Much of the information in this section was extracted from two reports that address the availability and quality of Minnesota groundwater resources available in the Red River Valley. The first is a Minnesota Geological Survey report (Thorleifson et al. 2005), *Geological Mapping and 3D Model of Deposits That Host Ground-Water Systems in the Fargo-Moorhead Region, Minnesota and North Dakota.* The second is a USGS report, *Ground-Water Availability from Surficial Aquifers in the Red River of the North Basin, Minnesota* (Reppe 2005) written specifically for this Project. While the following information is generally consistent with the above reports, there are places where greater detail is available in the reports (see supporting documents). For more details the reader is directed to the original assessments, but water quality is listed in table 3.2.2 for selected Minnesota aquifers.

Moorhead Aquifer The Moorhead Aquifer is an elongated feature with a north-south axis underlying Moorhead in Clay County, Minnesota. The east-west boundaries of the aquifer tend to be well defined, in contrast to the north-south boundaries. The north-south boundaries grade into thin alternating layers of clay, sandy clay, and sand. At depth, alternating layers of clay, sandy clay, and sand are probably the result of glacial meltwater streams that preceded glacial Lake Agassiz leaving meandering channels and associated deposits. The Moorhead Aquifer is approximately 10 square miles in aereal extent. This aquifer receives virtually no vertical recharge, with only modest horizontal recharge from equivalent units.

Currently, hydrographs suggest that the aquifer is experiencing a decline in water level, making it a good candidate for ASR. With ASR, this aquifer could store water during the current period of excess surface water. Then during a drought, it could yield up to 724 ac-ft per year using ASR.

Wadena Aquifer The Wadena Aquifer is in portions of Douglas, Otter Tail, Todd, and Wadena Counties, and has an area of approximately 379 square miles. The aquifer consists of outwash sand and gravel deposits, and is part of the larger, more extensive Pineland Sands Area surficial outwash deposit. Aquifer thickness is up to 70 feet, with a mean thickness of 36 feet.

All streams in the aquifer area gain flow from the aquifer. During periods of little precipitation, streamflow in the area is composed almost entirely of discharge from the aquifer. Withdrawal of large volumes of groundwater from the aquifer would be likely to decrease local stream flows significantly, especially during drought conditions.

Table 3.2.2 – Water Quality of the Surficial Aquifers of the Red River Basin, Minnesota (adapted from Reppe 2005).

Aquifer	Date	TDS (mg/L)		Specific Conductance (µS/cm)		Ca (mg/L)		Mg (mg/L)		Fe (mg/L)		Na (mg/L)		Cl (mg/L)		N as NO2 & NO3 (mg/L)		SO4 (mg/L)	
		Max	Med	Max	Med	Max	Med	Max	Med	Max	Med	Max	Med	Max	Med	Max	Med	Max	Med
Beach Ridge Aquifers	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Bemidji-Bagley Surficial	1987-88	1,020	281	1,800	460	190	70	64	17	20	0.02	230	3.4	380	4.5	7.8	1.40	25	9.3
Buffalo	1957	1,190	490	1,500	789	181	84	83	33	4.6	0.73	159	21	39	3.5	--	--	545	108
Buffalo	1978	1,990	604	2,250	828	260	110	230	40	45	7.4	140	10	54	4.4	10	0	1,100	190
Middle River Surficial	1965	--	--	--	--	--	--	--	--	--	--	--	--	>600	--	--	--	--	--
Otter Tail Surficial	1965-68	655	271.5	1,020	436	150	50	42	25	0.22	0.22	19	3.3	42	3.9	24	3.8	37	20.5
Otter Tail Surficial	1964-68	680	238	570	353.50	108	47	31	22	5.9	0.07	9.6	2.8	14	2.7	80	19	51	16
Pelican River Sand-Plain	1965-73	708	298	1,270	542	93	75	28	23	1.7	0.05	140	2.7	170	5.7	0.02	0.02	32	17
Pineland Sands Surficial	1975-76	359	245	661	420	110	62	21	15	13	0.75	12	2.9	22	2.5	20	0.95	35	5.9
Pineland Sands Surficial	1988-89	330	252	790	389.5	120	66	34	20	--	--	18	3.7	57	4.8	35	3.5	34	6.4
Two Rivers Surficial	1969	<500	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

µS – microsiemens, TDS – Total Dissolved Solids, Ca – Calcium, Mg – Magnesium, Fe – Iron, Na - Sodium, Cl – Chloride, NO2 – Nitrite, NO3 – Nitrate, SO4 – sulfate.

Water in the Wadena Aquifer contains calcium bicarbonate and is considered very hard. The water has a low sodium hazard, and a medium to high salinity hazard. Nitrate concentration in groundwater was highly variable across the area. Locally high levels of nitrate were observed in shallow groundwater and attributed to human and agricultural activities, including septic tank effluent, fertilization, and livestock. In addition, elevated concentrations of iron and manganese were noted. As a result, domestic and industrial use of the untreated groundwater from this aquifer is not recommended.

In 2003, approximately 6,802 Mgals (20,875 ac-ft) of groundwater were removed from the Wadena Aquifer for industrial, commercial, and public water supply. Theoretical well yields indicated that more than 300 gpm could be produced from wells in approximately 60% of the Wadena Aquifer, and yields of 100 to 300 gpm were estimated in approximately 25% of the area. Hydrologic modeling of the aquifer indicated that no more than approximately 7.5 bgals/yr (billion gallons per year) of water could be withdrawn without significantly decreasing the water table. Continuous groundwater pumping would be likely to make local tributary streams dry; and larger streams, such as the Leaf and Crow Wing Rivers, most likely would have decreased flows during pumping. In addition, if maximum continuous pumping were performed, it is expected that water table levels would decline. Therefore, with limited saturated thickness and significant use of the known water budget already, the Wadena Aquifer is not recommended for development of a drought-based water supply.

Pineland Sands Area Aquifer The Pineland Sands Area Aquifer, located in Becker, Cass, Hubbard, and Wadena Counties, has an area of approximately 752 square miles and includes the smaller, Straight River Surficial outwash aquifer. Pineland Sands consists of surficial glacial outwash and very fine-grained sand to fine-grained gravel, with aquifer thickness averaging about 40 feet.

The aquifer is a steady-state system, with approximately equal inflow and outflow. Streams and lakes in the area of the aquifer receive most of the aquifer's discharge. Studies have indicated that withdrawals of 60 to 120 cfs would decrease the water table by as much as 12 feet in some areas of the aquifer, and such withdrawals would result in reduced streamflows and lower lake levels (Helgesen 1977).

Water from the Pineland Sands Area Aquifer, including the Straight River watershed portion, contains calcium bicarbonate and is considered moderately hard to very hard. Analyses of groundwater from the aquifer indicated a low sodium hazard and low to medium salinity hazard. Nitrate concentrations in water from selected shallow portions of the aquifer exceeded drinking water standards set by the MPCA (Minnesota Pollution Control Agency). In general, groundwater from the Pineland Sands Area Aquifer is acceptable for irrigation purposes. Groundwater from the Straight River Aquifer is suitable for irrigation, aquatic life, wildlife, and with treatment, domestic consumption.

In 2003, groundwater removed from the Pineland Sands Area Aquifer, excluding water withdrawn by private domestic supply wells, was approximately 8,179 Mgals (25,100 ac-ft). Theoretical well yields of 500 gpm were obtainable throughout most of the aquifer and exceeded 2,000 gpm in northern portions of the Pineland Sands Area. In 15% of the surficial outwash, theoretical well yields were expected to be at least 1,000 gpm; however, well yields less than 100 gpm were estimated in 30% of the aquifer. Groundwater model analyses of the Pineland Sands Area Aquifer demonstrated that much of the aquifer could support long-term, large-scale withdrawals. In addition, the results showed that groundwater withdrawals totaling approximately 3.3 cfs did not significantly affect the aquifer.

Although it holds a tremendous amount of water, its average saturated thickness of 40 feet makes this aquifer less attractive for water supply in a prolonged drought than aquifers of greater saturated thickness. Therefore, the Pinelands Sands Surficial Aquifer is not being considered for further development. However, this aquifer should be the first reconsidered if future investigations deem other preferred groundwater supplies insufficient or inaccessible.

Otter Tail Surficial Aquifer The Otter Tail Surficial Aquifer covers approximately 501 square miles in Becker and Otter Tail Counties and continues with the Pelican River Aquifer in portions of Becker County. The Otter Tail consists primarily of well-sorted sand, with varying areas of sand and gravel, and lenses of clay in some locations. The deposit is well sorted, and ranges from fine- to coarse-grained sand. The aquifer ranges in thickness from 0 to greater than 100 feet and is recharged largely by precipitation and underflow. Most groundwater is lost from the aquifer by evapotranspiration and direct discharge to streams.

Groundwater in the Otter Tail contains calcium bicarbonate and generally is very hard. Water from the aquifer has a low sodium hazard and a medium salinity hazard. Due to the varying use of pesticides and varying agricultural practices across the study area, local nitrate and chloride concentrations may exceed recommended levels. In addition, water hardness and dissolved concentrations of iron and manganese vary by location and may exceed recommended levels.

The total volume of groundwater pumped from the Otter Tail Surficial Aquifer in 2003, excluding water withdrawn for private water supply, was approximately 9,173 Mgals (28,151 ac-ft). In approximately 17% of the study area, sustained theoretical well yields from the aquifer were estimated to be 200 gpm or more; and in approximately 8% of the area, the theoretical yield was estimated to be 600 gpm. The maximum estimated well yield ranged from 1,200 to 1,500 gpm. Water held in storage within the Otter Tail Surficial Aquifer is estimated at 450 bgals (1.38 MAF [million ac-ft]). With an estimated 47,887 Mgals (150,000 ac-ft) of annual recharge, this aquifer must be considered a substantial source of water for the Project.

Pelican River Sand-Plain Aquifer The Pelican River Aquifer (Pelican River Sand-Plain Aquifer) is approximately 195 square miles in area and is in portions of Becker, Clay, and Otter Tail Counties. The aquifer is a surficial sand-plain deposit, ranging from fine- to coarse-grained sand. In general, the aquifer averages about 60 feet in saturated thickness.

Recharge of the Pelican River Aquifer is from precipitation and other groundwater discharge. Most of the groundwater in this aquifer is discharged through evapotranspiration. Discharge also occurs into nearby streams, lakes, and wetlands.

Groundwater in the Pelican River Sand-Plain Aquifer is very hard and is enriched with dissolved concentrations of calcium, magnesium, and bicarbonate. Water from the aquifer has a low sodium hazard and has a low risk to irrigation. Iron and manganese concentrations in groundwater collected from the aquifer generally may exceed drinking-water standards. The elevated iron and manganese levels had no apparent risks to vegetation; however, treating the water for domestic use would be necessary.

In 2003, approximately 1,872 Mgals (5,745 ac-ft) of groundwater were removed from the Pelican River Aquifer, excluding water withdrawn for private supply. There were no data and no permits for these private wells. Maximum values for well yields from the aquifer ranged from approximately 40 gpm to greater than 1,200 gpm, with a mean well yield of approximately 600 gpm. Under normal aquifer recharge conditions, long-term pumping was estimated to draw down portions of the aquifer water table by 2 to 8 feet. Hydrologic models indicated a hydraulic relation between the Pelican River Aquifer and the local surface-water bodies.

The Pelican River Sand-Plain Aquifer holds about 290 bgals (890,000 ac-ft) of water in storage, with annual recharge estimated up to 16,605 Mgals (50,960 ac-ft) of water. Given the location, water in storage, and annual recharge, this aquifer must be considered a good candidate for use as a water supply feature in the Project.

Buffalo Aquifer The Buffalo Aquifer is a narrow sand and gravel deposit located in northern Clay County that extends southward into southern Wilkin County. The Buffalo Aquifer is approximately 66 square miles. About 25 square miles of the aquifer are unconfined, with the remainder confined. The aquifer is a deposit of fine- to coarse-grained sand, cobbly gravel, silt, and clay that tends to be coarser at its axis and finer-grained toward the edges. Aquifer thickness varies from 10 to 220 feet.

Recharge of the Buffalo Aquifer occurs from precipitation, streamflow from the Buffalo River and its tributaries, and leakage from the overlying surrounding sediments. Discharges from the aquifer occur primarily through the adjacent glacial sediments and into the Buffalo River and the south branch of the Buffalo River. Evapotranspiration from the aquifer probably is negligible, since the water table is 5 to 40 feet below land surface.

Groundwater from the Buffalo Aquifer is very hard and contains calcium bicarbonate. Buffalo Aquifer water has a low sodium hazard and a medium to high salinity hazard. With adequate soil drainage and sufficient precipitation for flushing, accumulated salts and associated salinity hazards are minimized. However, because of steadily increasing pumping of the Buffalo Aquifer, upward-moving saline water has mixed with the calcium bicarbonate water, lowering water quality in some areas.

Approximately 408 Mgals (1,252 ac-ft) of groundwater were removed from the Buffalo Aquifer in 2003, excluding water withdrawn for private supply. Based on its saturated thickness and porosity, the Buffalo Aquifer’s storage volume was estimated at more than 250 bgals of water. Theoretical well yields from the Buffalo Aquifer could be between 200 and 10,000 gpm.

The Buffalo Aquifer already is a source of water for a few smaller communities, including Moorhead. Reppe (2005) suggests Buffalo Aquifer has potential for expanded development. However, potential development of Buffalo Aquifer should be limited to the Moorhead Public

Service Utility wellfields, rather than development of a large wellfield for supplying water to the Project.

Bemidji-Bagley Surficial Aquifer The Bemidji-Bagley Aquifer (Bemidji-Bagley Surficial Aquifer) has both confined and unconfined portions. Located in Beltrami, Cass, Clearwater, and Hubbard Counties, this unconfined sand-plain aquifer probably formed by glacial outwash and lake deposition. The total area of the unconfined portion of the Bemidji-Bagley Surficial Aquifer is approximately 622 square miles. The unconfined aquifer ranges in thickness from 0 feet to more than 80 feet The aquifer is composed of coarse-grained sand and gravel in the northern portion and finer-grained sand and gravel in the south.

Primary recharge of the Bemidji-Bagley Surficial Aquifer is through precipitation, and recharge is greatest where the unconfined aquifer is present at land surface. Main discharge points for the Bemidji-Bagley unconfined aquifer are the Mississippi and Clearwater Rivers. In addition, groundwater from the aquifer discharges to local streams, lakes, and wetlands, and through evapotranspiration.

Groundwater from the Bemidji-Bagley Aquifer is very hard and is calcium-bicarbonate-rich. The water has a low sodium hazard, and a medium to high salinity hazard. Concentrations of ammonia, boron, chromium, iron, manganese, phenols, and atrazine locally exceeded drinking water limits recommended by the MPCA; and concentrations of dissolved solids locally exceeded MPCA standards for agricultural and wildlife use. Elevated concentrations of ammonia, organic nitrogen, nitrate, nitrite, chloride, phosphorus, orthophosphorus, and phenols detected in the groundwater from the Bemidji-Bagley Surficial probably are related to local land-use practices.

In 2003, the total volume of groundwater removed from the Bemidji-Bagley Aquifer, not including water withdrawn for private supply, was approximately 994 Mgals (3,050 ac-ft). Theoretical well yields of several hundred gallons per minute are achievable in isolated portions of the unconfined Bemidji-Bagley Aquifer.

The Bemidji-Bagley Surficial Aquifer contains about 250 bgals (767,000 ac-ft) and could provide some water to the Project. Of the southern aquifers, it is the one most distant from the Fargo-Moorhead area (see figure 3.2.9). This aquifer would be more expensive to develop, because it would require approximately twice the pipeline than would the nearer aquifers and would result in higher construction and operation costs. Using this aquifer may be an option only if insufficient water supplies are available from similar, but closer, sources.

Middle River Surficial Aquifer The Middle River Aquifer (Middle River Surficial Aquifer) is in Marshall County, and has an area of approximately 22 square miles. The aquifer is composed primarily of sand and silt, with some clay and lenses of gravel. Aquifer thickness ranges from 0 to 60 feet.

Recharge of the Middle River Aquifer occurs primarily from precipitation and underflow. Discharge is predominantly through evapotranspiration.

Groundwater from the Middle River Surficial is hard, with a high iron concentration. Water from the aquifer is used for domestic and municipal supply, industrial and commercial uses, and for agricultural purposes.

In 2003, groundwater withdrawals, excluding water withdrawn for private supply, were approximately 26 Mgals (78 ac-ft). It was estimated that the Middle River Aquifer may be capable of storing approximately 4.6 billion gallons of water. In general, well yields from the Middle River Surficial are small to moderate. Theoretical well yields of 50 gpm or more could be produced from the thickest sections of the aquifer. Due to expected low yields for wells in this system, it would be unreasonable to expect this aquifer to yield significant volumes of water.

The Middle River Aquifer has insufficient potential yield per well and overall aquifer yield to warrant consideration as a feature in the Project.

Two Rivers Surficial Aquifer The Two Rivers Aquifer (Two Rivers Surficial Aquifer) has an area of about 146 square miles and is in the Two Rivers watershed and the northern portion of the Middle River watershed in Kittson and Marshall Counties. The aquifer consists mostly of sand, gravel, silt, and clay. Aquifer thickness ranges from 0 feet to greater than 280 feet within the Two Rivers watershed and from 0 to 130 feet in the Middle River watershed.

Recharge of the Two Rivers Aquifer is relatively rapid and is from precipitation and underflow. Discharge from the aquifer is predominantly through evapotranspiration. The water table generally is found less than 5 feet below the land surface. Water loss through discharge nearly equals water gain through recharge.

Water from the Two Rivers Surficial Aquifer contains bicarbonate and is very hard. This groundwater contains iron, with low concentrations of chloride and sulfate. The aquifer's groundwater is suitable for domestic and livestock consumption and for irrigation.

The total volume of groundwater pumped from the Two Rivers Aquifer in 2003, not including water withdrawn for private use, was approximately 439 Mgals (1,347 ac-ft). In general, well yields from the Two Rivers Surficial Aquifer are moderate to large. Theoretical well yields greater than 1,000 gpm could be produced from the thicker, coarser-material portions of the aquifer. Well yields of 50 gpm to greater than 100 gpm could be developed from other portions of the aquifer.

The Two Rivers Aquifer is a large aquifer with about 1,520 bgals (4.7 million ac-ft) in storage. The size implies that Two Rivers Aquifer could support additional groundwater development (Reppe 2005). However, developing this aquifer would incur not only the costs associated with the wellfield, but also the costs of pumping water uphill through the Red River Valley to the main consumers: Fargo and Grand Forks. These added costs suggest that developing the Two Rivers Aquifer would not be as cost effective as using groundwater in the southern Red River Valley. In the Fargo-Moorhead area, options are transferring groundwater, which would use gravity; or using surface water from Lake of the Woods, which would not require an extensive wellfield.

Beach Ridge Deposits Discontinuous beach ridge deposits of very fine- to medium-grained sand, with lenses of fine- to medium-grained gravel, are located throughout the Red River Basin. However, the horizontal and vertical extents of the beach ridges are highly variable. The beach ridge deposits range in length from one to tens of miles, and they range in width from a few hundred feet to several miles. The ridges can range in thickness from a few feet to 50 feet and may exceed 150 feet.

Groundwater recharge and discharge rates of the beach ridge deposits throughout the Red River Basin are unknown because of the variability of particle size, sediment sorting, geographic distribution, and hydraulic connectivity of the ridges.

Quantity and quality of groundwater from the deposits vary greatly within the Red River Basin and within individual deposits because the beach ridge deposits are discontinuous and variable. The quantity of usable groundwater from the ridges generally increases to the south in the basin. Groundwater from the beach ridge deposits most commonly is used for domestic water supply and secondarily for small-scale sand and gravel mining operations. Theoretical well yields from the beach ridge deposits are unknown.

3.2.2 Potential for Project Groundwater Development in North Dakota

Combinations of small quantity, poor quality, and geographic location at some distance from population centers limited early exploration and development of groundwater in much of the Red River Valley. Any future expansion of groundwater use from Red River Valley aquifers in North Dakota must take advantage of advanced treatment and delivery technologies. With respect to naturally replenished groundwater sources, increased development is quite limited and would be unable to meet the full demand of the Project. Only the Sheyenne Delta, Brightwood, Milnor Channel, Gwinner, and Page/Galesburg Aquifers appear to have any potential for increased withdrawals based upon natural recharge versus total withdrawals. Only extensive field investigations, and possibly groundwater modeling, will be able to quantify amounts available and the effects of increased use on other users and on the environment.

Aquifers including the Elk Valley, West Fargo North, West Fargo South, and Spiritwood may be able to supply portions of Project needs if their use patterns are modified or reserved for future use. Typically, irrigation commands the largest share of water use (approximately 85%) among Red River Valley aquifers in North Dakota. Two notable exceptions are Wahpeton Buried Valley Aquifer and West Fargo Aquifer System, as they are dominated by MR&I uses. Historical records reveal that the average irrigation use is about 50 to 65% of the permitted appropriation. During a prolonged drought, it is conceivable that irrigation users would rely more heavily upon groundwater, and their actual use would increase to values closer to the appropriated amounts.

Taking those assumptions into account, many groundwater sources could be considered over-permitted during an extended drought. In planning how to meet future water needs in normal times and in times of extended drought, it would be ill-advised to seek further dependence on aquifers for MR&I use that are nearly or fully appropriated. In such a case the Project would be using junior water permits, or appropriations later in time in these aquifers. Instead the Project proposes to develop groundwater features through the following: (1) conversion of existing uses;

(2) reservation of known resources for future need; and (3) implementation of ASR as described below.

The following discussion on the three proposed types of groundwater development concentrates on the physical availability of groundwater resources. Technical, socioeconomic, and legal issues regarding groundwater development will be discussed in greater detail within the Draft Environmental Impact Statement for the Project (Reclamation and Garrison Diversion 2005).

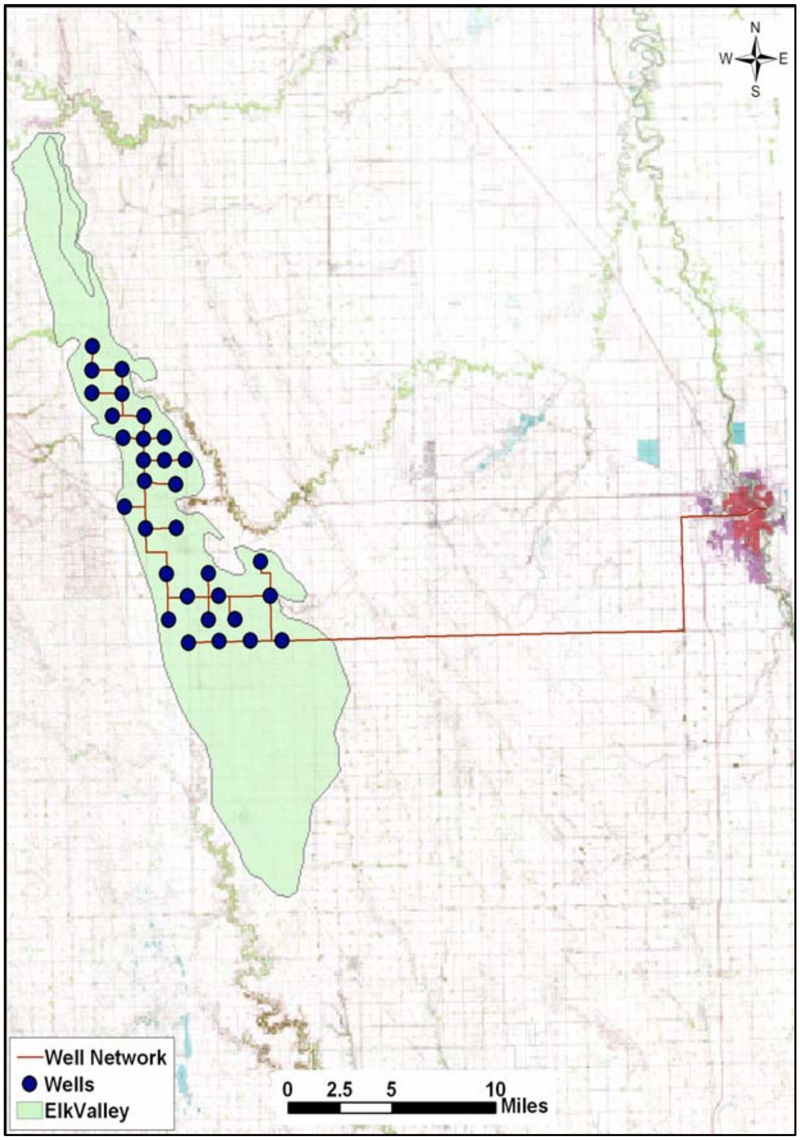


Figure 3.2.2 – Proposed Elk Valley Wellfield.

Conversion of Existing Use

Although irrigation is limited in the Red River Valley, it is the largest user of groundwater in the valley. It is the most obvious candidate for conversion to MR&I use. NDCC (*North Dakota Century Code*) § 61-04-01.1 provides for a change in purpose of use only for a superior use, as determined by the order of priorities specified in NDCC § 61-04-06.1 with approval of the State Engineer.

NDCC § 61-04-01.1 defines *beneficial use* as the "use of water for a purpose consistent with the best interests of the people of the state," and NDCC § 61-04-06.1 prioritizes beneficial uses as (1) domestic use, (2) municipal use, (3) livestock use, (4) irrigation use, (5) industrial use, and (6) fish, wildlife and other outdoor recreational uses. By policy of the NDSWC: "A change in purpose of use may only be granted for a use that has a higher priority than the use from which a change is sought" (NDAC § 89-03-02-01; also see NDCC § 61-04-15 and the internal policies section on the NDSWC website: http://www.swc.state.nd.us/waterlaws.html). Thus, irrigation use, the dominant groundwater use in the valley, is eligible for conversion to municipal use if willing sellers can be found in areas of interest to municipal water supply systems.

While all irrigation systems using groundwater are eligible for conversion under law, the proximity of an irrigation system to a municipal or rural water supply system also must be considered. The groundwater source most advantageous to meet peak day demands for Grand

Forks, as well as an anticipated increase in demand of Grand Forks-Traill Water District, is Elk Valley Aquifer (figure 3.2.2).

With respect to Grand Forks, groundwater from Elk Valley Aquifer is intended to serve only projected shortages in peak demands. Peak demand averages 6% of Grand Forks' use, as calculated from historical records, and volumes and rates of use may vary greatly from month to month and may vary slightly from one population projection to another. Grand Forks meets their basic water needs using either available surface waters or supplemental imports. However, these options are sized according to monthly demands and are not intended to fulfill all of the municipal needs for Grand Forks. Using Elk Valley Aquifer only to meet peak demand, Grand Forks would require between 27.1 cfs (12,163 gpm) and 28.7 cfs (12,8881 gpm), with annual withdrawals of 1,152 ac-ft (375 Mgals) to 1,221 ac-ft (398 Mgals).

Grand Forks-Traill Water District already uses Elk Valley Aquifer for its full demand. With future growth, it is anticipated that Grand Forks-Traill Water District will require an additional appropriation of water, something between 605 ac-ft (197 Mgals) and 1,142 ac-ft (372 Mgals) per year. Increasing the appropriation of water for Grand Forks-Traill Water District by converting irrigation purposes would entail increasing the geographic footprint of the district's wellfield. By doing this, Grand Forks-Traill Water District would expect to be able to meet peak demands merely by adding the wells required to increase their annual withdrawals.

Choosing Elk Valley Aquifer to serve Grand Forks and Grand Forks-Traill Water District leads to selecting an area that is geographically advantageous to both systems. As Grand Forks-Traill Water District already is located on Elk Valley Aquifer, logical transmission corridors to Grand Forks are either U.S. Highway 2 or Grand Forks County Road 4. Township 152 North, Range 55 West, and Township 151 North, Range 54 West are geographically advantageous for wellfield development and for transmission line placement adjacent to established rights of way (figure 3.2.2).

Because Grand Forks-Traill Water District and Grand Forks water supply systems would use relatively the same geographic area, it would be advantageous to combine the two into one system capable of supporting both Grand Forks-Traill Water District and Grand Forks in the future. To meet projected municipal and rural shortages effectively, something between 1,757 ac-ft (572 Mgals) and 2,363 ac-ft (770 Mgals) of water per year must be converted from irrigation uses in order to supply the two systems.

The conversion value for a specific water permit is not the appropriated amount listed on the permit but the historic average use associated with the permit. This conversion technique makes permits unequal in value with respect to conversion, and determining the exact number of permits required for conversion is difficult. After examining permits in the wellfield area, it was determined that average historic use for a diversion point assigned to a permit in this portion of Elk Valley Aquifer is around 87.5 ac-ft per year. Using this average, it would require conversion of 52% to 71% of the 38 diversion points in the wellfield area from irrigation to municipal use to meet anticipated shortages for Grand Forks-Traill Water District and Grand Forks through the year 2050.

To put irrigation versus municipal use of water into perspective, 120 gallons of water per day is the average requirement per person. Average annual use of 87.5 ac-ft of water on a typical irrigated field is equivalent to the water consumed by about 650 people in a year.

The peak day requirements for Grand Forks and increased needs for Grand Forks-Traill Water District are based on anticipated 2050 demand. Planners would have sufficient time to locate willing sellers before full capacity would be needed.

Reservation of Known Resources for Future Needs

North Dakota Century Code § 61-04-31 allows for the “reservation of waters.” It would be advantageous to identify areas of interest and to restrict development of aquifers suitable for Project use. As a feature of Project, groundwater could be reserved to serve as a future water supply to be used during the next drought. Groundwater availability is more likely to benefit from this type of reservation than is surface water, as groundwater sources are less prone to evapotranspiration than surface water reservoirs. Once water tables begin to fall in surficial aquifers, they become increasingly disconnected from plants’ root zones and other natural sources of discharge.

Within the Red River Valley of North Dakota, several aquifers could be reserved to benefit MR&I water users. One of the 2050 drought shortages that could best be met using reserved groundwater is the Wahpeton industrial demand. Table 3.2.3 shows projected groundwater use by industry in the Wahpeton area, as described in section 2.8.

Table 3.2.3 - Theoretical Groundwater Use by Wahpeton Industry, 1931-2001.

Demand Scenario	Total Projected Demand for Industry (ac-ft/yr)	Maximum Month ac-ft	Lowest One Year Use of Groundwater during 1930s-style Drought (ac-ft)	Highest One Year Use of Groundwater during 1930s-style drought (ac-ft)	Total Use of Groundwater during 1930s-style Drought (ac-ft)	71-year Average Use of Groundwater (ac-ft)	71-year Total Use of Groundwater (ac-ft)
Scenario One	5,814	512	3,739	5,330	46,150	758	53,818
Scenario Two	8,556	745	5,676	8,516	71,778	1,350	95,850

Table 3.2.3 shows two demand scenarios. The lower demand of 5,814 ac-ft per year in Scenario One is primarily a groundwater demand during the worst year of a 1930s style drought. About 91.7% of the total demand, or 5,330 ac-ft of water, would be required from groundwater. Some of this demand could be met by Cargill’s conditional water permit on the Wahpeton Buried Valley Aquifer. However, in order to ensure meeting the full demand during the later years of a lengthy drought, groundwater from another source would be required.

Under Scenario Two, about 99.5%, or 8,516 ac-ft, of the industrial demand would have to come from groundwater during the worst year of a 10-year drought scenario. Although these numbers reflect a major reliance on groundwater during a drought, the 71-year average is small enough under both scenarios to be absorbed in the long-term, if there are no other major users that prevent replenishment of the aquifer between major droughts.

As noted, two scenarios were used to determine a possible range of demands on groundwater that would need to be met. In table 3.2.4, these demands estimated for Scenario One and Two are translated into individual well specifications using a generic wellfield of 30 wells for each scenario.

Table 3.2.4 - Requirements for Individual Wells, Permits, and Aquifer Yields.

Demand Scenario	Maximum Annual Withdrawal from Each Well (ac-ft/yr)	Maximum Withdrawal in One Month (ac-ft)	Lowest One Year Use during 1930s-style Drought (ac-ft)	Highest One Year Use during 1930s-style Drought (ac-ft)	Total Use in 1930s-style Drought (ac-ft)	71-year Average Use (ac-ft)	71-year Total Use (ac-ft)
Scenario One	177.7	17.1	124.6	177.7	1,538.3	25.3	1,794
Scenario Two	283.9	24.8	189.2	283.9	2,392.6	45.0	3,195

Scenario One is the lower demand and uses the same wellfield, producing lower numbers throughout the table. Dispersing the wellfield over a broad geographic area and encompassing several aquifers should alleviate interference problems between wells and allow for short-term temporary exceedence of natural recharge. Similarly, spreading the wells over several aquifers produces advantages in mixing waters with different water-quality characteristics. The Spiritwood, Gwinner, Milnor Channel, and Brightwood Aquifers shown in figure 3.2.3 would all be used to meet such demands in times of drought. External to a drought scenario, Wahpeton industrial demands will be met using surface waters of the Red River that are locally available in Wahpeton. Further details are included in Appendix B.2.2.

Implementation of ASR

Aquifer storage and recovery is the storage of water in a porous underground formation during times when excess surface water is available and recovery of the water during times when it is needed. As water is removed from an aquifer in excess of natural recharge, the available pore space in the aquifer increases. This pore space can be used to store water for future use in an ASR system. Stored water can be either treated water or raw water. Recharge methods include injection wells, recharge shafts, and open pits. Choices among different recharge methods depend on the local geology and source water, whether the water is treated, and expected storage duration.

The major advantage of an ASR feature is that it could be built instead of a constructing a costly pipeline from a distant water source. The ASR feature would store locally available excess water when surface water is available and would eliminate the need to build ring dikes. Although ASR has its benefits, it does present difficulties and disadvantages not typically encountered by municipal water systems. One potential disadvantage to ASR is the loss of recharged water to adjacent aquifers or other sources of natural discharge. Any aquifer under consideration for ASR must be understood well enough to avoid losses of water that the managing entity has spent time and money to store.

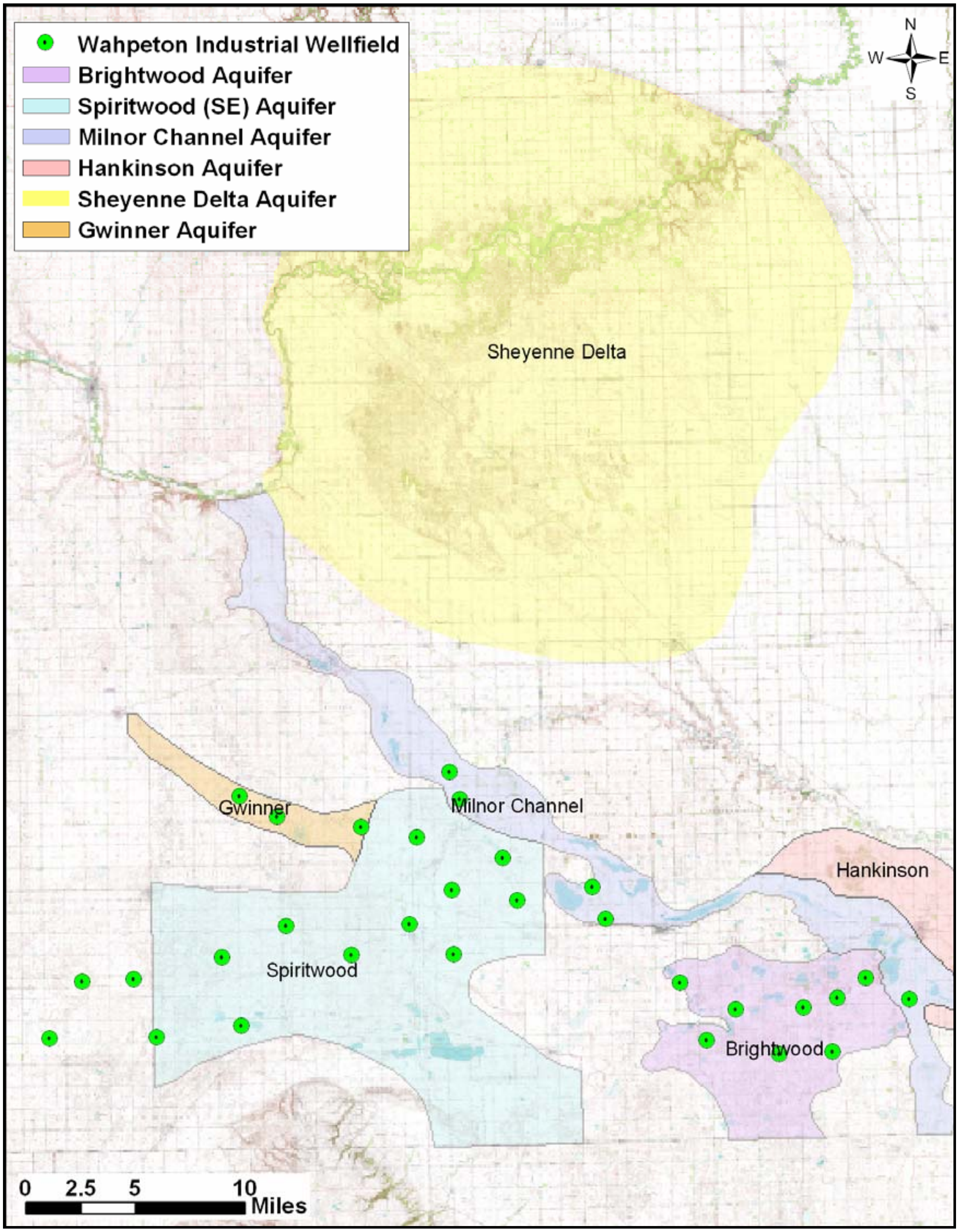


Figure 3.2.3 – Proposed Wellfield for Wahpeton Industrial Demand.

A second disadvantage is the much higher level of management that must be exerted over an ASR-based water supply than is needed for a typical wellfield or surface water intake. A well-managed ASR system requires ongoing attention to water supply options, water quality, and balancing aquifer recharge and withdrawal cycles.

A third disadvantage of ASR is the tendency for decreasing benefits over time from the system. This is typically related to physical, chemical, and biologic clogging of the well screen and aquifer, leading to reduced transmissivity of the aquifer immediately adjacent to the well. Physical clogging typically is caused by small particles in the recharge water that become lodged in the pore space of the aquifer. Chemical clogging results from precipitation of minerals in the aquifer pore spaces. Biologic clogging is also possible where microbes, both natural and introduced, form a biologic film on the well screen and within the aquifer pore spaces.

In order to prevent or minimize these types of adverse effects, recharge water would be filtered and possibly chemically modified in order to be compatible with the aquifer medium and the native groundwater. It is anticipated that recharge water would be modified to minimize these adverse effects. Even if efforts to prevent clogging are not completely successful, the well screen and formation can be remediated with varying degrees of success by chemical and physical treatment, or by replacing the well.

Despite difficulties and obstacles, ASR continues to gain momentum in the United States and the world as water demands grow. The Willow Water District in the Denver, Colorado, area evaluated ASR in the deep, confined Arapahoe Aquifer. While only a pilot study, this limestone, siltstone, sandstone and shale aquifer received 1,283 ac-ft of water through one well over cycles spread out over a period of five years. Although the system exhibited some of the previously described disadvantages, ASR into the Arapahoe Aquifer is economically feasible (Bloetscher et al. 2005).

A much larger ASR project was implemented in the Las Vegas Valley Water District’s wellfield in an alluvial filled valley. The Colorado River is the primary source of water for the district, but groundwater is used for peak demand during the summer months (Bloetscher et al. 2005). Using recharge cycles from October through May over ten years, 115,000 ac-ft of water was recharged through an extensive network of wells.

Perhaps the most applicable ASR project to the ASR systems proposed as features for this Project is the Huron, South Dakota pilot study (Reclamation 1999b). The study noted decreased transmissivity of the aquifer in the recharge and recovery well attributable to air entrainment and some initial physical clogging of the gravel pack around the well. Using treated surface water, about 27.6 ac-ft of water was recharged to the aquifer with no evidence of adverse chemical changes in the recharged water. The study concluded that it is hydraulically feasible to recharge buried glacial aquifers.

While not every aquifer is suited for ASR, West Fargo North, West Fargo South, and the Wahpeton Buried Valley aquifers all could be used for ASR as described below.

West Fargo North Aquifer West Fargo North Aquifer is a confined aquifer that receives little or no recharge. This confined aquifer system has only a finite quantity of water in storage, and all withdrawals should be considered one-time removals of a nonnaturally replenishable resource. Existing municipal and industrial wells in West Fargo North are shown in figure 3.2.4. Ripley (2000) estimated that about 33 bgals (101,000 ac-ft) of water had been removed from the West Fargo Aquifer System prior to 1995.

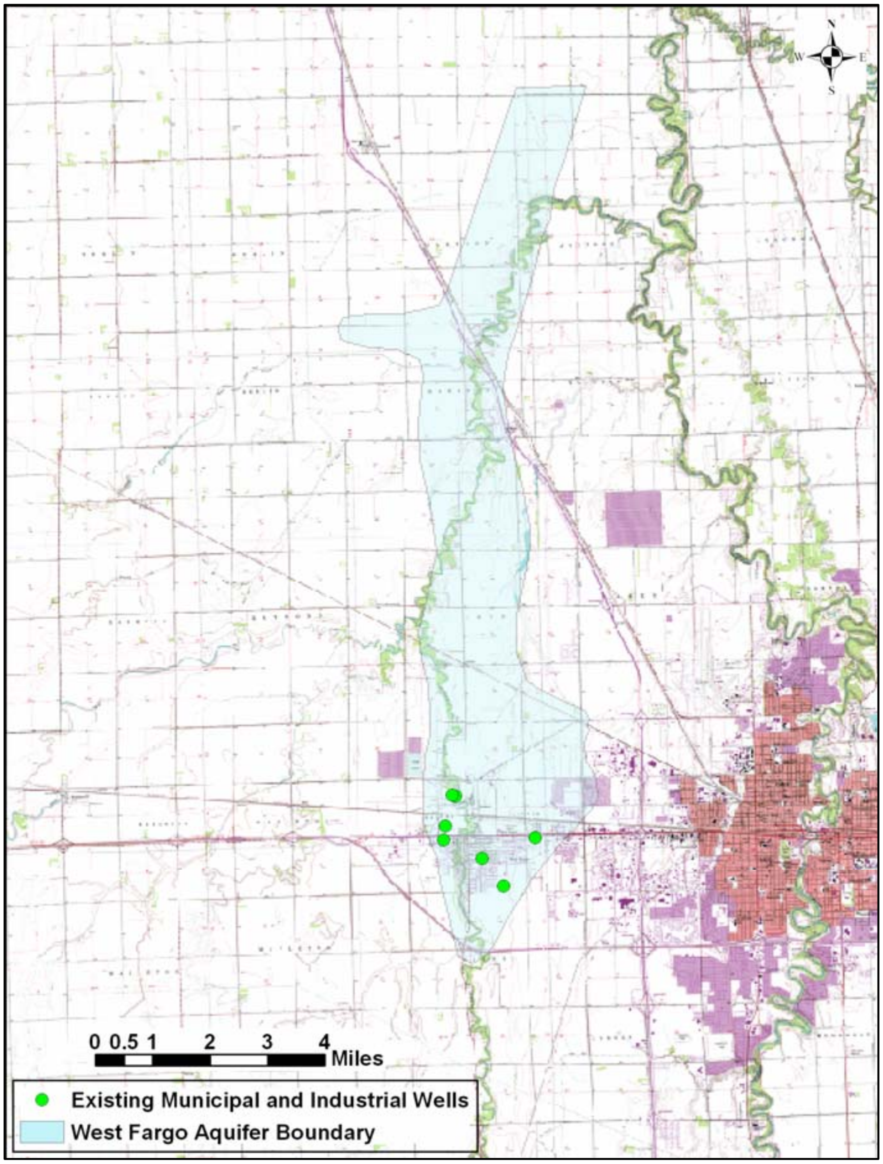


Figure 3.2.4 - Map of West Fargo North Aquifer, Existing Wells, and Associated Features. (Aquifer map and well locations are from NDSWC.)

Extrapolating this estimate to 2004, another 25,000 ac-ft have been removed, showing increasing reliance on a system undergoing long-term depletion. Ripley (2000) also discussed the high likelihood that the rate at which water could be drained from the surrounding aquitards would decrease as they became depleted. One certainty is that this drainage of a nonreplenishable resource will continue in the near future, and rates of decline in the aquifer are likely to increase.

Given the age of the existing infrastructure, all existing municipal wells would be gradually replaced by a new network of well sites, as shown in figure 3.2.5.

Using the spatial distribution of sites shown in figure 3.2.5 with the well site depiction in figure 3.2.6, a fully operational ASR system on West Fargo North Aquifer may require up to 45 wells. The proposed feature would have 15 dual-use wells capable of both recharge and recovery and 30 wells dedicated to injection of recharge water.

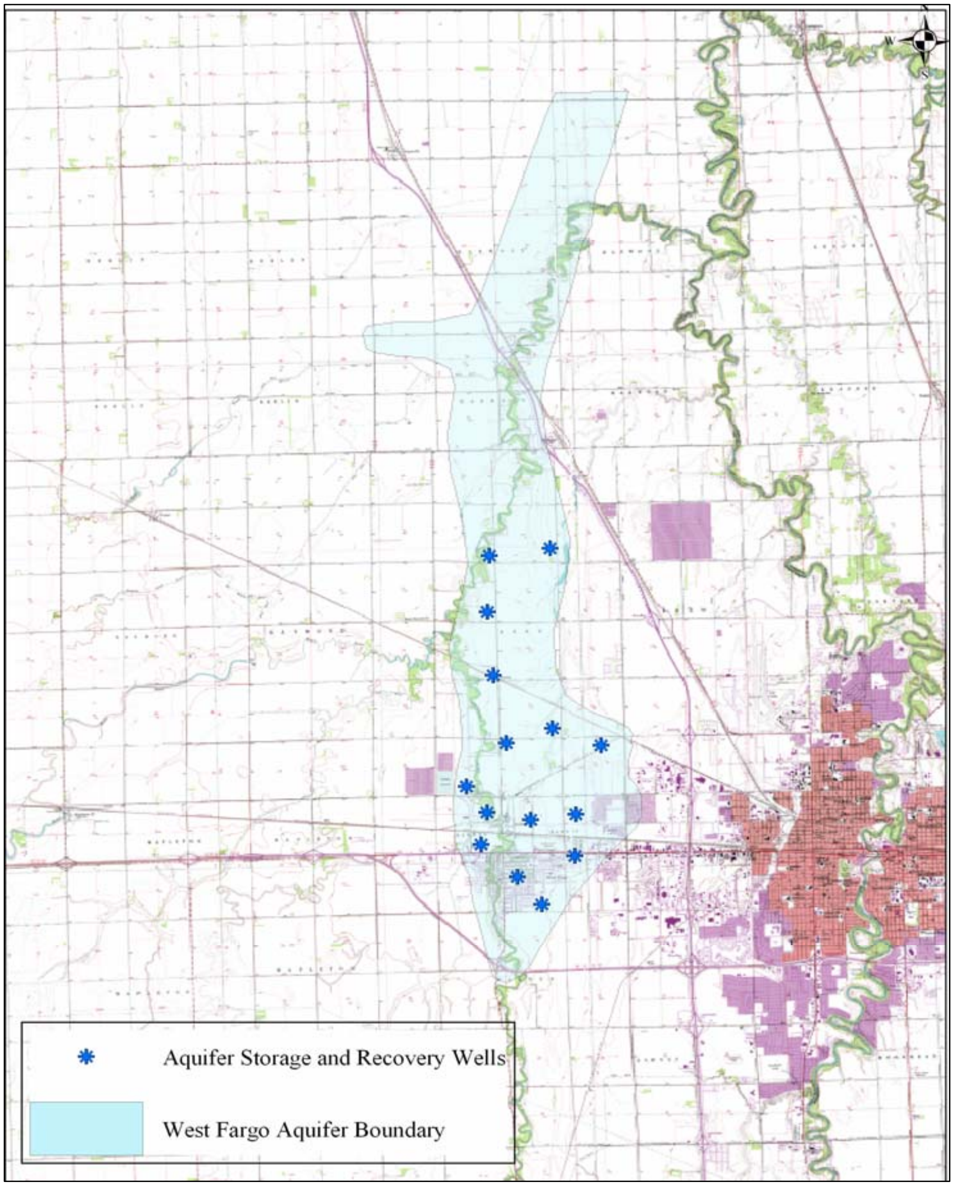


Figure 3.2.5 – Map of West Fargo North Aquifer and Associated ASR Well Sites.
Note: ASR wells shown above may contain more than one well site.

With continued use the West Fargo North Aquifer could be depleted in 25 years to such an extent that its utility during a drought would be questionable. Under such a scenario it would require a large number of additional wells to maintain existing withdrawals. Table 3.2.5 depicts water supply modeling of an ASR system on the West Fargo North Aquifer. Modeling suggests that during a 1930s drought there would be insufficient surface water to inject into the aquifer. Therefore, the total net change (columns four and seven) is the amount of water that would have to be stored prior to the drought to avoid a depletion.

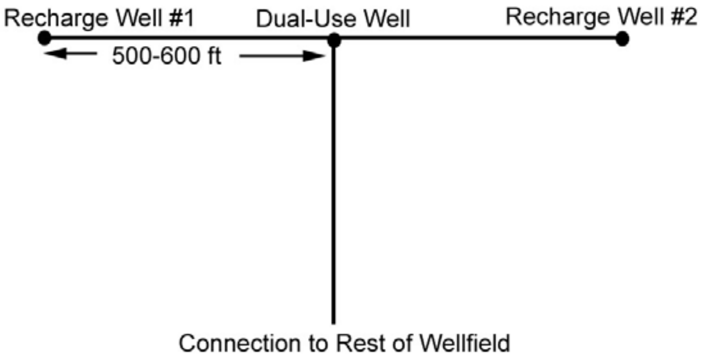


Figure 3.2.6 - Well Spacing at Individual Sites for ASR in the West Fargo North Aquifer.

Table 3.2.5 - Water Balance for ASR in the West Fargo North Aquifer During a 1930s Drought.

	North Dakota In-Basin Option Scenario One			North Dakota In-Basin Option Scenario Two		
Year	Recharge (ac-ft)	Withdrawal (ac-ft)	Net Change (ac-ft)	Recharge (ac-ft)	Withdrawal (ac-ft)	Net Change (ac-ft)
1	1707	2996	-1289	1139	3097	-1958
2	2176	2797	-621	2399	3129	-730
3	1825	3677	-1852	1825	3804	-1979
4	1210	3635	-2425	595	3720	-3125
5	3055	2757	298	1825	3237	-1412
6	1765	3682	-1917	1210	4168	-2958
7	2042	3785	-1743	1783	3886	-2103
8	3035	2864	171	2420	2949	-529
9	3977	2416	1561	2716	2723	-7
10	2360	2719	-359	2360	2820	-460
Totals	**23,152**	**31,328**	**-8,176**	**18,272**	**33,533**	**-15,261**

The two different demands, as discussed earlier, have a significant effect on the amount of water required from West Fargo North Aquifer. For the 10-year period, 23,152 ac-ft of water would be available from excess surface waters for recharge during a drought with a Scenario One demand placed on the surface water system. Under Scenario Two's higher demand requirements, only 18,272 ac-ft of water would be available for recharge during the same time period, concomitant with a higher demand for West Fargo. The difference between the recharge and withdrawal for a given year is the net change in the amount of water held in storage within West Fargo North Aquifer. The total net change under Scenario One is a negative 8,176 ac-ft, and negative 15,261 ac-ft under Scenario Two, respectively. This is the amount of water that must be recharged prior to a drought of the 1930s for the aquifer to have no net change in storage.

The goal of no net change in storage for West Fargo North can only be accomplished if future withdrawals from the aquifer do not remove recharged water prior to a drought. In surface water modeling Reclamation removed all major demands from West Fargo North until the beginning of a drought and placed those demands on surface waters. Included in these demands on surface waters are the recharge water for the aquifer during times of normal and high precipitation and normal and high Sheyenne River flows. One uncertainty is the efficiency of an ASR system in this aquifer. While the entire West Fargo Aquifer System is generally considered confined, with increased water levels in West Fargo North Aquifer, some leakage must be expected of recharged water to the adjacent aquitards and other units of the aquifer system.

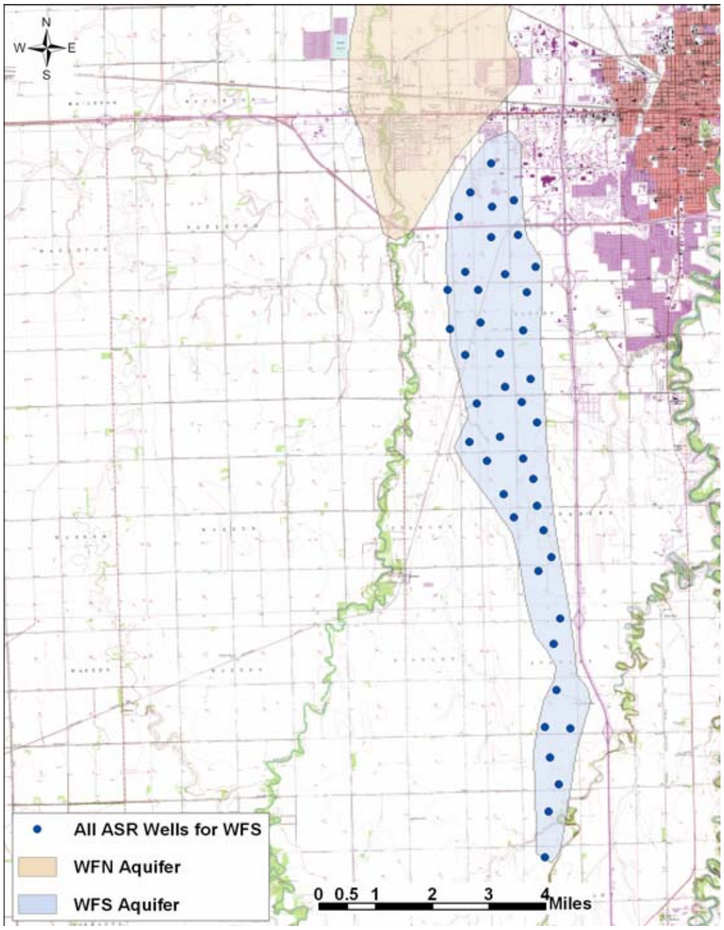


Figure 3.2.7 – Proposed Recovery Wellfield for West Fargo South Aquifer.

West Fargo South Aquifer Under many of the options Fargo will receive its maximum month water supply from surface waters or supplemental imports. The options that supply water under maximum month demand leave peak day demands unfulfilled unless local storage is developed. Above-ground storage would require immense water storage facilities. One alternative to the usual above-ground storage facilities is using a local aquifer to supply peak demands, as already discussed for Grand Forks (figure 3.2.7). One major difference for Fargo is the lack of a local aquifer that receives appreciable natural recharge. Without appreciable natural recharge, any withdrawals from the local West Fargo Aquifer System would be detrimental to the long-term viability of that aquifer. Short-term ASR might be a good candidate for meeting Fargo's peak demand requirements. A local aquifer with ASR potential is the West Fargo South Aquifer (figure 3.2.7).

Currently, only West Fargo and Cass Rural Water Users District have a combined allocation from West Fargo South Aquifer for about 1,525 ac-ft. Under the envisioned development plan, the primary demands of these water users would be removed from West Fargo South.

Calculating the peak demand for Fargo using the same methods used for Grand Forks, Fargo has a maximum annual peak demand of 2,261 ac-ft under Scenario One and 2,690 ac-ft under Scenario Two. Converting this into rates, the Scenario One peak demand would require water at

17,700 gpm (39.4 cfs) or 21,000 gpm (46.8 cfs) for Scenario Two. Although the rates at first glance appear to be very imposing numbers for a groundwater system, these are the worst one-year and worst one-day requirements to fulfill peak demand for Fargo. The average annual demand is expected to be considerably less for most years up to 2050. In fact, most years will require only minimal operation for maintenance of the system and replenishing already depleted groundwater levels.

In order to develop this capacity level in West Fargo South Aquifer, approximately 36 to 42 production wells, capable of 500 gpm (1.11 cfs) each, would be required to meet the single-day peak demand of 17,700 to 21,000 gpm, as shown in figure 3.2.7. These delivery requirements would be applied to an aquifer of limited geometry. Nontraditional wells could be considered for increasing individual well yields while decreasing the wellfield footprint. Horizontal wells or wells drilled at an angle will have longer screen lengths that would likely have higher production capacity. Use of these non-traditional wells could lessen the total number of wells required by this feature. However, horizontal wells are more expensive per well, and a thorough investigation of specific sites is required to achieve a less costly system overall.

Data suggest that excess water treatment plant capacity and West Fargo South Aquifer would not be used as a water supply for about 16 days per month even during the worst year. If all 16 days were used each month for placing ASR water into West Fargo South Aquifer, only about 8.1 cfs (3,635 gpm) of capacity would be needed for injection wells to ensure a zero net change in water stored within the aquifer throughout the year. Eighteen wells capable of dual use, able to recharge and recover injected waters, with the ability to recharge at about 200 gpm (0.45 cfs) per well would provide good spatial distribution over the aquifer, as shown in figure 3.2.8. Adequate spatial distribution of the dual-use wells would help minimize problems from groundwater mounding and excessive lowering of water levels throughout the aquifer.

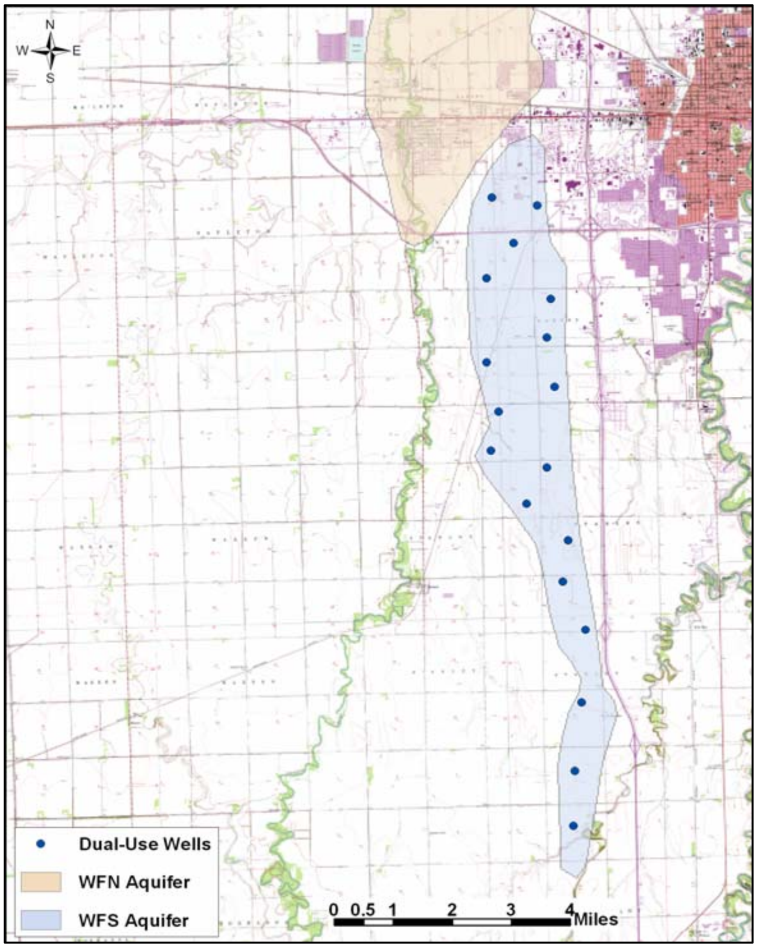


Figure 3.2.8 – Dual-Use Wells for ASR in West Fargo South Aquifer.

One advantage this ASR system would have over other methods of supplying peak demand water would be that development could be phased in as system requirements increase. A second advantage is that using the system for ASR prior to a drought would improve the overall health of the aquifer and would increase the amount of stored water for future needs. The third advantage in this system is that when it is fully operational, it could provide Fargo with a redundant, albeit very temporary, water supply in case of interruptions in its main water supply. A couple of disadvantages must also be considered.

One disadvantage is potential water loss to other aquifers in West Fargo Aquifer System. Water loss to other aquifers could be minimized if coupled with ASR in West Fargo North. By balancing water discharge and recharge levels in both aquifers with ASR, exchanges between these two aquifers would be minimized. The second disadvantage is the level of management that must be exerted over the water supply. A well-managed ASR system requires ongoing attention to water supply options, water quality, and balancing cycles of aquifer recharge and withdrawal. For both West Fargo Aquifers where ASR has been proposed, surface water from the Sheyenne River would be the likely source for recharge water. It is anticipated that recharge water would be modified to minimize or avoid adverse effects.

Wahpeton Buried Valley Aquifer Providing the city and industries of Wahpeton with a large share of their water needs is the Wahpeton Buried Valley Aquifer. During a drought Wahpeton's estimated water needs for municipal and industrial uses will exceed the aquifer's natural recharge. Projected needs for groundwater for industrial use (table 3.2.3) might be less if ASR on Wahpeton Buried Valley were able to increase the aquifer's natural recharge rate and hold more water in storage for use in times of need. ASR has been discussed as a mechanism for increasing the utility of two aquifers in another aquifer system, the West Fargo Aquifer System. Geologically, Wahpeton Buried Valley may be better suited to ASR than West Fargo North and West Fargo South Aquifers in the West Fargo Aquifer System. The Wahpteon Buried Valley and Wahpeton Sand-Plain Aquifers have shallow sands and gravels that could be recharged using surface infiltration methods. In practical terms, however, Wahpeton Buried Valley and overlying sands of the Wahpeton Sand-Plain and Wahpeton Shallow Sand units do not appear to have sufficient depletions to warrant ASR for future needs.

Current aquifer depletions in the Wahpeton Sand-Plain and Wahpeton Shallow Sand units appear related to withdrawals from the Wahpeton Buried Valley Aquifer. Several well logs depict good to excellent hydraulic connections between these units. Furthermore, there is reason to believe that these overlying sands are hydraulically connected to the Red River and provide a conduit for recharge from Red River to Wahpeton Buried Valley through a slightly circuitous pathway.

One method of increasing recharge to Wahpeton Buried Valley is increasing the natural recharge of water from the Red River. If a low-head dam were properly placed on the Red River north of Wahpeton, it would increase the gravitational driving force of dh/dl behind groundwater flow by raising the river over the sands and gravels adjacent to the Red River and maintaining its hydraulic conductivity[1].

---

[1] Darcy's Law of $q = -k(dh/dl)$, dictates that q (flow) increases if dh/dl (change in head over a given distance) increases while k (hydraulic conductivity) is held constant.

Conceptually, a low-head dam is a workable, low-maintenance mechanism for increasing recharge to Wahpeton Buried Valley and overlying aquifers. Realistically, the value of a low-head dam to the Wahpeton Buried Valley Aquifer is nearly impossible to quantify without knowing the full extent of contact between the Red River and surrounding permeable formations.

3.2.3 Potential for Project Groundwater Development in Minnesota

Minnesota groundwater resources that are most likely to have value for a Project are discussed in this section. The groundwater resources of Minnesota are described in section 3.2.1, and all Minnesota aquifers considered in that discussion are shown on the map in figure 3.2.9. Recommendations in this section will focus on the Moorhead Aquifer, the Otter Tail Surficial Aquifer, the Pelican River Sand-Plain Aquifer, and the Buffalo Aquifer.

Several aquifers and other groundwater resources were eliminated from further consideration, for reasons based on each resource's individual characteristics. Associated with glacial Lake Agassiz are numerous other sand and gravel deposits, including many beach ridge deposits. These deposits and the water they hold are often of great importance to individual users, but their lack of size and their broad distribution remove them from consideration as water supply features for the Project.

For example, the Middle River Aquifer in the northern Red River Valley of Minnesota is a major aquifer, but its insufficient potential yield per well and overall aquifer yield would require approximately 285 individual wells to fulfill Grand Forks' peak day demand. Such a major investment in infrastructure is enough to remove the Middle River Aquifer from further consideration.

To the south and east, the Wadena Surficial Aquifer has sizeable use of its known water budget, so it is not a good candidate for future development by the Project. The Bemidji-Bagley and Two Rivers aquifers also are far from where their water might be needed. Transporting Bemidji-Bagley Aquifer water to Fargo-Moorhead would require construction of a long pipeline; other sources are nearer the point of need. Using water from the Two Rivers Aquifer would have higher costs than other potential sources. A wellfield would have to be constructed, and water to main consumers in Fargo and Grand Forks would be pumped uphill, making this a higher-cost feature than others under consideration in the Project.

The aquifers that are good candidates for development include the Moorhead Aquifer with ASR, the Pelican River Sand-Plain Aquifer and the Otter Tail Surficial Aquifer through increased development, and the Buffalo Aquifer with expansion of existing Moorhead municipal wells. The Pineland Sands Surficial Aquifer also is a fair candidate for further development. However, this resource is located at significantly greater distance that the previously mentioned aquifers, but it should be reconsidered if the other resources would not adequately provide the desired supply.

Aquifer Storage and Recovery for the Moorhead Aquifer

Moorhead receives its water from aquifer and surface water supplies. The Moorhead Aquifer is one part of the city's current water supply system. The Moorhead ASR feature would store excess water during times of sufficient surface water supplies. Excess water stored in the Moorhead Aquifer would, in effect, be banked for use during a drought. Detailed discussion of

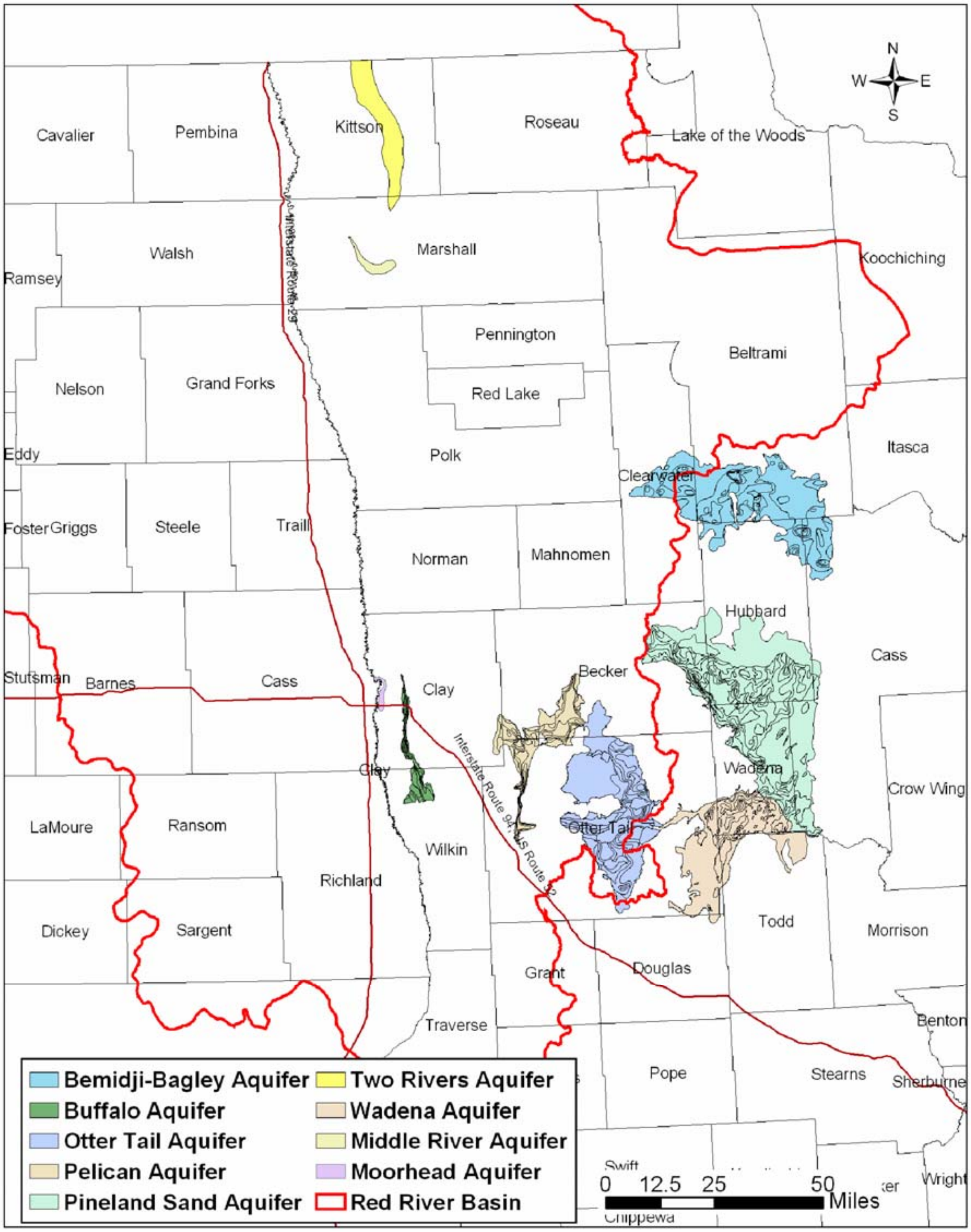


Figure 3.2.9 – Minnesota Aquifers Considered as Water Supply Features.

Moorhead Aquifer's potential for ASR is in Appendix B. Current evidence suggests that the aquifer receives some inflow from adjacent sands and gravels, but no vertical recharge from precipitation. A somewhat generous interpretation of Moorhead Aquifer's extent is shown in figure 3.2.10. The proposed ASR program for the Moorhead Aquifer would have three wells. One well would be strictly an injection well 1/4 mile from Moorhead city wells as shown in figure 3.2.10. The second well would be one of Moorhead's existing wells and would be used only for production. The third well would be installed by redrilling the other Moorhead city well and connecting it as a dual-use well capable of injection and production.

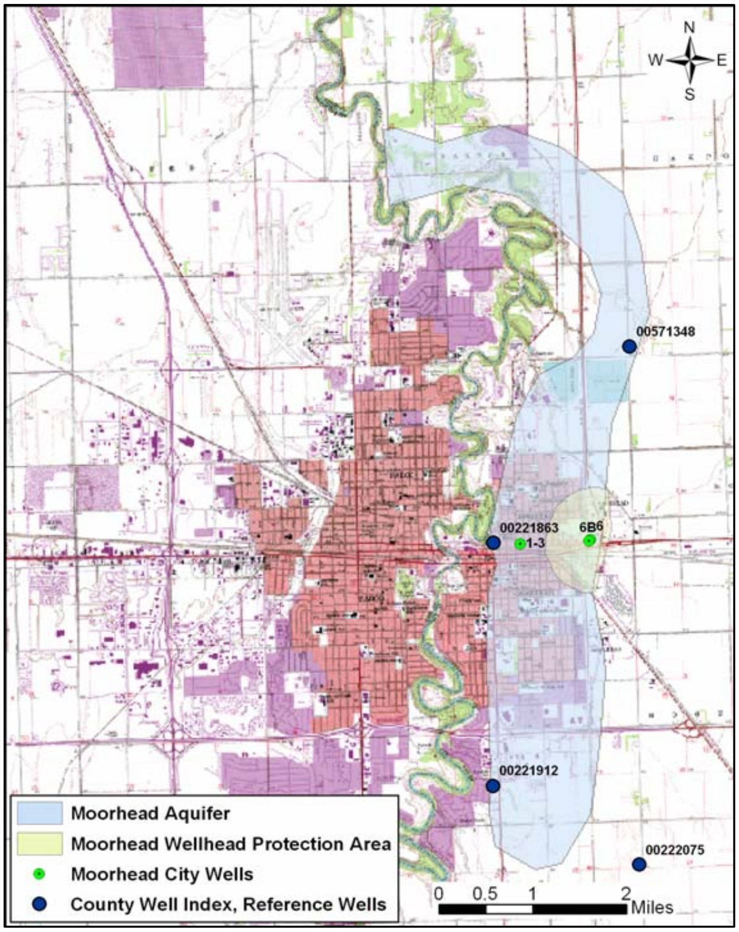


Figure 3.2.10 – The Moorhead Aquifer and Associated Features. (Aquifer and wellhead protection definitions were provided by the Minnesota Department of Health.)

Reclamation used a surface water supply model to quantify the amount of water that would be used from and stored in the Moorhead Aquifer during a 1930s-style drought (see table 3.2.6). Under the two demand scenarios, aquifer withdrawals were limited to times when insufficient surface water was available. Similarly, recharge to the aquifer was limited to times when excess surface water was available in the Red River. In Scenario One, aquifer withdrawals would be nearly balanced, exceeding aquifer recharge by only 1 ac-ft. In Scenario Two, aquifer withdrawals would exceed recharge by 50 ac-ft. This demonstrates that a properly managed ASR system on the Moorhead Aquifer would not deplete the aquifer even during a lengthy drought.

If a 1930s drought occurred today, it is possible that the Moorhead Aquifer could provide the water amounts shown in table 3.2.6, even with current water systems in use. However, if historic patterns of aquifer withdrawals continue into the future, this aquifer may not be able to provide water at the rate or volumes projected. The only way to ensure the aquifer's continuing utility is to take advantage of about 3,840 ac-ft of available pore space for storing water. Storage of about 3,000 ac-ft of water against the coming years of a drought will provide Moorhead greater flexibility and assurance of a reliable water supply.

Table 3.2.6 – Water Balance for Required ASR Use of the Moorhead Aquifer during a 1930s Drought.

	ND In-Basin Scenario One			ND In-Basin Scenario Two		
Drought Year	**Moorhead Aquifer Recharge (ac-ft)**	**Moorhead Aquifer Withdrawal (ac-ft)**	**Net Change (ac-ft)**	**Moorhead Aquifer Recharge (ac-ft)**	**Moorhead Aquifer Withdrawal (ac-ft)**	**Net Change (ac-ft)**
1	0	60	-60	0	91	-91
2	60	303	-243	91	303	-212
3	303	60	243	179	60	119
4	60	61	-1	179	61	118
5	179	179	0	184	179	5
6	61	365	-304	61	389	-328
7	543	179	364	547	182	365
8	0	0	0	23	0	23
9	0	0	0	0	0	0
10	0	0	0	20	69	-49
Totals	**1,206**	**1,207**	**-1**	**1,284**	**1,334**	**-50**

Aquifer Development of the Buffalo Aquifer

The Buffalo Aquifer already provides water to Moorhead. Potential for increased development has been suggested by Reppe (2005). Further development of this aquifer can be done by adding two wells to the Moorhead wellfield and taking advantage of existing infrastructure pathways to replace connecting pipelines, as shown in figure 3.2.11. The goal for further development of Moorhead wellfield on the Buffalo Aquifer is to increase the wellfield to a capacity of 7.0 cfs under Scenario One and 8.3. cfs under Scenario Two. These capacities were developed based upon peak demands for Moorhead and do not represent continuous withdrawals. Averaged over a year, withdrawals would amount to about 1.9 cfs, or 114 ac-ft per month for a total of 1,368 ac-ft (446 Mgals)

The development of Minnesota groundwater is intended to serve the Project from the Pelican River Sand-Plain and Otter Tail

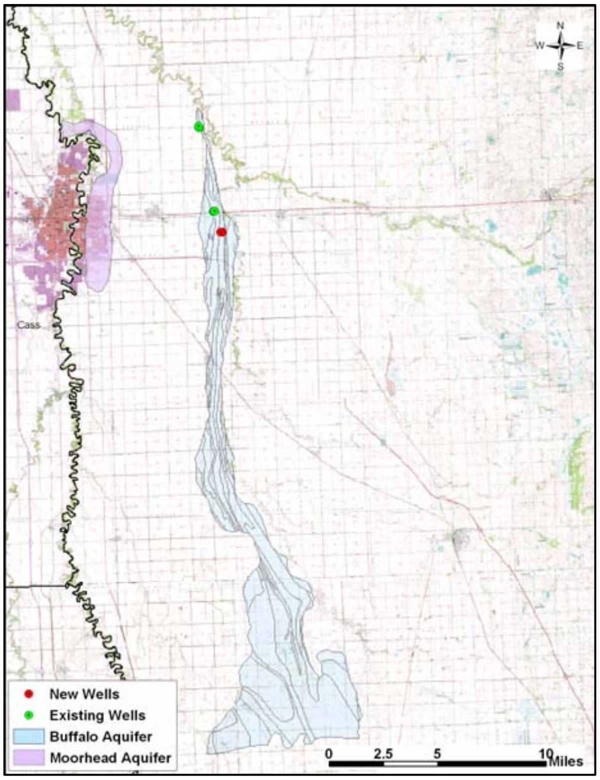


Figure 3.2.11 – Buffalo Aquifer, Existing Well, Proposed Wells and Surrounding Features.

Surficial aquifers. A Minnesota groundwater feature must be able to meet the demands shown in table 3.2.7. Scenario One and Scenario Two requirements are quite different using the Minnesota features as modeled. Under Scenario One, the maximum rate required is 45 cfs from a total of 81 wells at an average of 0.56 cfs (250 gpm) per well for instantaneous rates. The individual wells do not run continuously, only as needed. Using the wells as needed suggests that each well would average about 302 ac-ft withdrawals during the worst year of a 1930s-intensity drought. During the 11-year period of a 1930s drought where Minnesota groundwater would be required, the aquifers must be capable of producing an average of 16,443 ac-ft per year. While this is not a trivial amount of water from these aquifers, the long-term effect is much less. By restricting groundwater use to times of drought and insufficient surface water supplies, the proposed Minnesota groundwater feature would have a mean annual use of about 2,644 ac-ft under Scenario One over the modeled 71-year record of surface water availability.

Table 3.2.7 – Minnesota Groundwater Required as a Supplement to the Project.

Demand Scenario	Rate (cfs)	Rate (gpm)	Well Quantity	Individual Well Requirements* (ac-ft/month)	Maximum Year Demand for Average Well* (ac-ft)	Average Year Demand* during Major Drought (ac-ft)	Average Year Demand during 71-year. Historic Record (ac-ft)
One	45	20,197	81	33.2	302	16,443	2,644
Two	72	32,316	129	34.0	310	27,669	4,567

* Reflects 5% above actual MR&I demand to allow for losses in transmission.

Scenario Two in table 3.2.7 has a considerably larger rate of 72 cfs. This requires more wells, with approximately the same requirements as Scenario One for individual wells. Hence, the geographic footprint of Scenario Two also is correspondingly larger than for Scenario One (figures 3.2.12 and 3.2.13). If groundwater would be restricted to use only during drought and water supply insufficiencies, the Minnesota groundwater features would have a mean annual use of about 4,567 ac-ft under Scenario Two over the modeled 71-year record of surface water availability.

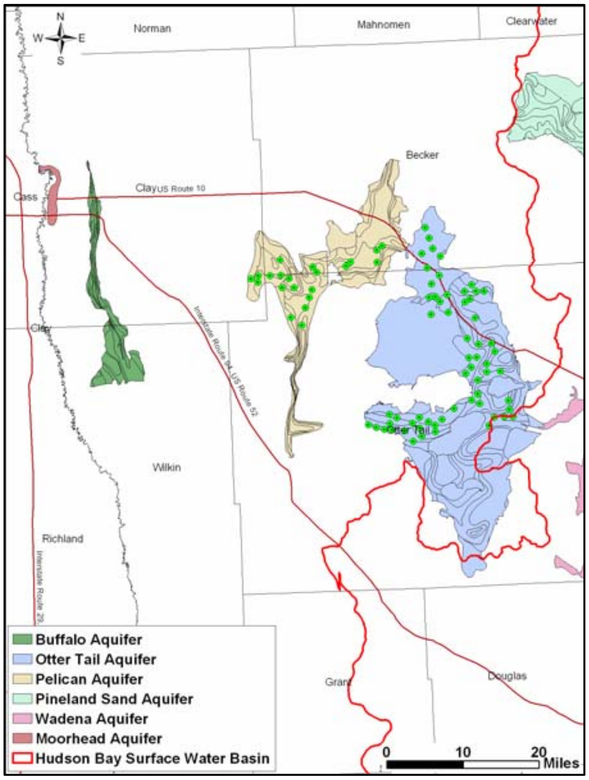


Figure 3.2.12 – Proposed Wellfield for Pelican River Sand-Plain and Otter Tail Surficial aquifers under Scenario One.

Although both the Pelican Sand-Plain and Otter Tail aquifers tend to be surficial aquifers, evidence suggests the presence of deeper sands and gravels that may be less well connected to local surface waters. When possible wells would be completed in the deeper, more isolated portions of the aquifers. By doing this, water table drawdown and surface water impacts would be minimized during a drought. Along with these benefits, the more wells placed in the aquifers'

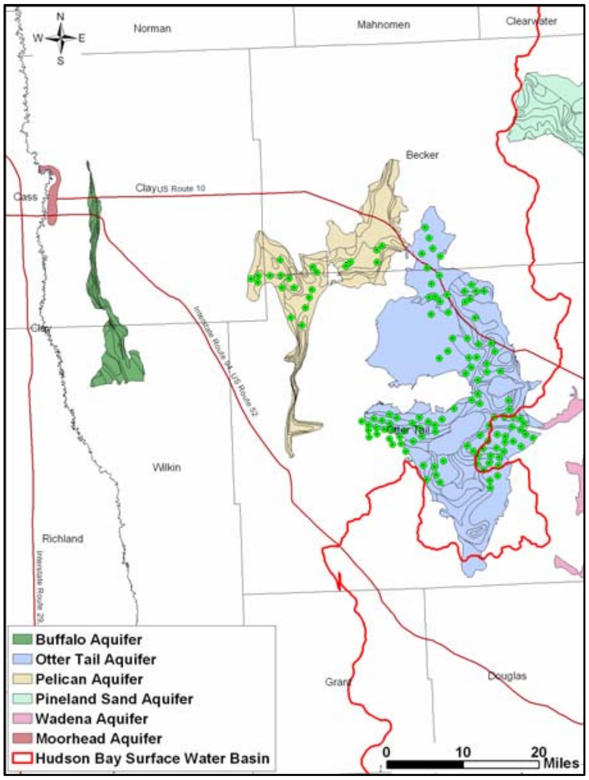


Figure 3.2.13 – Proposed Wellfield on the Pelican River Sand-Plain and Otter Tail Surficial aquifers under Scenario Two.

deeper portions, the greater the saturated thickness of the aquifers and the greater the viability of the wellfields.

Regrettably, as sufficient well yields typically are found at relatively shallow depths, there are very little data that delineate the aquifers' deeper sands and gravels. Similarly, the accepted definition of the Otter Tail Aquifer depicted in figures 3.2.12 and 3.2.13 does not appear to capture the aquifer's full extent.

Specifically, along the Otter Tail's southwestern edge the saturated thickness is substantial up to the aquifer's border in the two figures. Accordingly, the approximate well placement shown in figure 3.2.12 used existing well logs for determining the suitability of placing some wells adjacent to the aquifer boundaries.

To help meet Scenario Two demands, in figure 3.2.13 correspondingly more wells were sited in the aquifer to take advantage of any opportunity to use deeper sands and gravels. These are approximate locations. Some of the wells appear external to the accepted definition of the aquifer, but are based upon existing well logs depicting acceptable locations.

3.3 Water Demands vs. Water Supplies

Section 3.2 provides an overview of surface and groundwater sources in the Red River Valley and their potential to serve future water needs. The section discusses the water budget or sustainability of each aquifer and identifies some limited opportunities for expansion of water withdrawals.

This section compares future water demands developed in chapter two with each water system's permitted water supply allocations. The discussion of aquifers established the viability of each groundwater source. Given that discussion, this section evaluates each water system permit to determine if there would be adequate groundwater capacity through 2050. No matter the reason, those water systems that have inadequate groundwater sources will need to seek additional supplies. Any water system with the potential to use surface water must be included in hydrologic modeling to determine if surface water source would be adequate during a drought.

Those water systems with surface water permits also are evaluated to determine their capacity to meet their future needs. Systems that fall short on capacity will need to procure additional permit(s). Additional permits would be junior to other existing permits in North Dakota under western water law. The lower-use priority on junior permits could seriously jeopardize the water systems' likelihood of having a reliable future water source during a drought.

3.3.1 Water Demands to be Evaluated by Surface Water Model

This section evaluates all future water demands in the Red River Valley quantified in chapter two and determines which water system demands must be simulated in the surface water model. The surface water model identifies which water systems will have adequate future water supplies and which will have shortages.

The first step in that process is to determine which water systems that currently use groundwater would have adequate future supplies and which would have inadequate supplies. Groundwater-dependent water systems' anticipated water deficiencies are incorporated in the surface water model. The second step is to determine which water systems that currently use surface water have adequate permit allocations and which systems have inadequate permit allocation. Surface-water-dependent systems' current and anticipated needs are incorporated in the surface water model, as well. The evaluation is described in this section.

Water Demands Analysis of MR&I Water System Water Permits

Chapter two quantifies the future MR&I water demands of the Red River Valley service area. This chapter estimates how much water is available, compares it to future water demands, and identifies the magnitude of any future water shortages. These shortages are met by the options described in chapter four of this report.

The first step in evaluating the adequacy of the future water supplies is to analyze existing MR&I water system permits. If an existing permitted water withdrawal is too small, a determination is made if an additional permitted amount of water is available. Just because an MR&I system has a permit does not guarantee the water is available. This is true for groundwater and surface water sources, particularly surface water.

Two types of water supply analyses are conducted in the Needs and Options Report: groundwater-dependent system supplies and surface-water-dependent system supplies. To evaluate future water supplies of groundwater-dependent systems, the maximum annual withdrawal in ac-ft and maximum daily withdrawal in gpm (which are estimated in chapter two) are compared to groundwater permit(s) approved for each MR&I water system.

Evaluation of water systems supplied by surface water requires three steps. The first step is to evaluate the adequacy of each system's surface water permit(s) using estimated maximum annual withdrawal and maximum daily withdrawal water demand rates as a basis of comparison. The second step is to conduct monthly surface water modeling to determine water supply adequacy under different streamflow conditions. Monthly surface water analysis uses a hydrologic model to compare historic stream flows against future water demands. The third step is to evaluate whether the daily surface water supply is adequate to meet estimated peak day MR&I water demands. Methods used to conduct monthly and peak day surface water analysis will be discussed later in this chapter.

Monthly surface water hydrologic modeling uses StateMod software. The software compares historic natural streamflow data, discussed later in this chapter, against maximum month water demand data developed in chapter two for each surface-water-dependent system. Each water system has 10 to 15 years of historic water use data, which were updated to reflect future population and used as a water demand scenario for modeling. Daily time-step water demand analysis was conducted using a spreadsheet. The analysis is based on a 31-day water demand scenario, which coincides with the maximum historic water use month for each water system.

Two water demand scenarios are developed in chapter two. Scenario One uses Reclamation population projections and the intermediate water demands results from the NDSU Industrial Water Needs Report (Bangsund and Leistritz 2004). Scenario Two uses the water-user-provided population projections and the high water demand results from the NDSU Industrial Water Needs Report (Bangsund and Leistritz 2004). All of the analysis is conducted for both water demand scenarios in the following sections.

Municipal Water System Permit Analysis Future water demands are analyzed in this section for the municipal water systems listed in table 3.3.1. The water source and permit information for each system also are listed in table 3.3.1. The present water supply or permitted volume is compared to the future water needs of each system to determine if there would be an adequate permitted quantity of water through 2050. This analysis includes annual water demand in ac-ft and peak daily water demands in gpm.

Analyzing future water supply of groundwater-dependent water systems is relatively straightforward. The permitted or allocated amount of groundwater is compared to the estimated future water demand, and a determination is made whether the water system has an adequate future supply of water. Groundwater is the primary water source for eight of the 16 municipal systems evaluated. The study assumes that state agencies responsible for approving groundwater permits are doing so in a manner that assures these water sources will be available as permitted through 2050 under a variety of climatic conditions.

Evaluating surface water supplies is more difficult. Generally, municipalities served by surface water have generous surface water permits well in excess of their future water demands; however, there is no guarantee that these permitted volumes of water will be available in a drought.

Six water systems hold both surface and groundwater permits (table 3.3.1). Moorhead is the only system of the six capable of treating both surface and groundwater. It is assumed that the cities of Breckenridge, Lisbon, and Park River will use their groundwater permits; and it is assumed Valley City and West Fargo will use their surface water permits as their primary water sources. The assumptions are that eight systems will use surface water; seven systems will use groundwater; and one, Moorhead, will use both types of sources. Each community's annual permit allocations are analyzed only for the water source (ground, surface, or both) that they are capable of treating.

Scenario One and Scenario Two Future Municipal Water Demand Analysis Table 3.3.2 shows the average, maximum annual, and peak day per capita water demand estimates for each of the municipal water systems. These per capita demands are developed in chapter two. The municipalities with groundwater supplies are shaded in the table. The per capita water demands include water conservation and water losses.

Tables 3.3.3 and 3.3.4 show the average annual water demand analysis of the 16 municipal water systems under Scenario One and Scenario Two water demands, respectively. Column three shows the average per capita water demand taken from table 3.3.2, and column four shows the estimated annual water demand in ac-ft. Column five shows the annual permitted allocation in ac-ft taken from table 3.3.1. Column six shows the annual surpluses or shortages of water for each system. Column seven shows the relative percentage of the surplus or shortage.

Table 3.3.1 – Municipal Water System Water Sources and Permitted Allocation.

Municipal Water System	Water Source	Permit #(s)	Annual Permitted Allocation (ac-ft)	Maximum Permitted Daily Withdrawal Rate (gpm)
North Dakota:				
Drayton			2,000	1,000
	Red River	Permit #00669	1,000	1,000
	Red River	Permit #1244	1,000	NA
Enderlin			850	1478
	Enderlin Aquifer	Permit #734	300	350
	Enderlin Aquifer	Permit #3594	350	753
	Enderlin Aquifer	Permit #4962	200	375
Fargo			152,575	127,040
	Red River	Permit # 749	109,500	67,320
	Red River	Permit #5250	162	0
	Red River	Permit #5415	32.8	0
	Sheyenne River	Permit #1091	35,880	48,470
	Sheyenne River	Permit #4718	7,000	11,250
Grafton			1,754	6,300
	Park River	Permit #00679	389	2,100
	Park River	Permit #04039	68.67	2,100
	Red River	Permit #00893	1,296.6	2,100
Grand Forks			69,373	39,800
	Red River	Permit #00835	33,600	33,600
	Red River	Permit 0835A	20,023	0
	Red River	Permit #04354	5,250	0
	Red Lake River	Permit #63-449	10,500	6,200
Gwinner			500	1,250
	Unnamed Aquifer	Permit #2894	275	900
	Unnamed Aquifer	Permit #4053	225	350
Langdon			795	1,760
	Mulberry Creek	Permit #00920	138	660
	Mt. Carmel Dam	Permit #01609A	299	600
	Mt. Carmel Dam	Permit #04832	358	500
Larimore	Elk Valley	Permit #01212P	500	500
Lisbon			873	1,200
	Unnamed Aquifer	Permit #3446	500	600
	Sheyenne River	Permit #3588	373	600
Park River			1,220	1,950
	Homme Reservoir	Permit #697	610	1,350
	Fordville Aquifer	Permit #1679	200	NA
	Fordville Aquifer	Permit #05081	410	600

Municipal Water System	Water Source	Permit #(s)	Annual Permitted Allocation (ac-ft)	Maximum Permitted Daily Withdrawal Rate (gpm)
Valley City	Sheyenne River	Permit #1096	6,686	13,464
Wahpeton			2,130	4,200
	Wahpeton Buried Valley Wahpeton Buried Valley	Permit #1822 Permit #1898	1,420 710	2,100 2,100
West Fargo			4,984	6,115
	Sheyenne River Sheyenne River Sheyenne River West Fargo Aquifer West Fargo Aquifer West Fargo Aquifer West Fargo Aquifer	Permit #127 Permit #921 Permit #00921A Permit #00921B Permit #1103 Permit #1900 Permit #3585	200 954 1,460 895 60 565 850	450 700 700 1,500 700 565 1,500
Minnesota:				
Breckenridge			2,325	NA
	Wahpeton Buried Valley Ottertail River	Permit #771670 Permit #751162	1,680 645	NA NA
East Grand Forks	Red Lake River	Permit 75-1150	1,990	NA
Moorhead			28,630	9,150
	Buffalo Aquifer Moorhead Aquifer Red River Buffalo River Buffalo Aquifer	Permit #470014 Permit #871243 Permit #771852 Permit #771851 Permit #721850	2,240 690 11,200 7,250 7,250	1,750 950 5,000 0 1,450

Table 3.3.2 – Municipal Per Capita Water Demand Estimates.

Municipality	Average Per Capita Water Use (gpc/d)	Annual Maximum Per Capita Water Demand (gpc/d)	Peak Daily Water Demand Used in Analysis (gpc/d)
North Dakota Municipalities:			
Drayton	272.8	588.5	1087.8
Enderlin	790.0	823.2	1522.1
Fargo	116.1	164.7	381.7
Grafton	152.5	200.3	339.7
Grand Forks	137.7	204.6	526.3
Gwinner	293.7	393.3	637.6
Langdon	115.7	245.3	552.4
Larimore	98.6	151.2	213.3

Municipality	Average Per Capita Water Use (gpc/d)	Annual Maximum Per Capita Water Demand (gpc/d)	Peak Daily Water Demand Used in Analysis (gpc/d)
Lisbon	120.8	146.4	223.5
Park River	112.3	142.4	399.3
Valley City	104.7	136.6	386.2
Wahpeton	111.7	135.5	240.1
West Fargo	91.8	112.2	275.4
Minnesota Municipalities:			
Breckenridge	79.5	86.8	237.7
East Grand Forks	151.4	217.1	522.6
Moorhead	122.8	153.7	289.2

Table 3.3.3 – Average Year Water Demand Analysis – Scenario One.

Municipality	2050 Reclamation Population Projection	Average Year Per Capita Water Demand (gpc/d)	Estimated Annual Water Demand (ac-ft)	Annual Permitted Allocation (ac-ft)	Annual Water Surplus or Shortage (ac-ft)	Percent Surplus or Shortage of Water Supply (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
North Dakota Municipalities:						
Drayton	920	272.8	281	2,000	1,719	611%
Enderlin	860	790.0	761	850	89	12%
Fargo	204,300	116.1	26,571	152,575	126,004	474%
Grafton	4,130	152.5	706	1,754	1,048	149%
Grand Forks	83,800	137.7	12,922	69,373	56,451	437%
Gwinner	1,170	293.7	385	500	115	30%
Langdon	2,100	115.7	272	795	523	192%
Larimore	1,190	98.6	131	500	369	280%
Lisbon	2,530	120.8	342	500	158	46%
Park River	1,540	112.3	194	610	416	215%
Valley City	5,840	104.7	685	6,686	6,001	876%
Wahpeton	12,140	111.7	1,519	2,130	611	40%
West Fargo	33,900	91.8	3,486	2,614	-872	-25%

Municipality	2050 Reclamation Population Projection	Average Year Per Capita Water Demand (gpc/d)	Estimated Annual Water Demand (ac-ft)	Annual Permitted Allocation (ac-ft)	Annual Water Surplus or Shortage (ac-ft)	Percent Surplus or Shortage of Water Supply (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
Minnesota Municipalities:						
Breckenridge	2,540	79.5	226	1,680	1,454	643%
East Grand Forks	9,800	151.4	1,662	1,990	328	20%
Moorhead	50,211	122.8	6,909	28,630	21,721	314%

Note: Blue shading denotes use of groundwater. Tan shading highlights shortages.

Table 3.3.4 – Average Year Water Demand Analysis – Scenario Two.

Municipality	2050 Water User Population Projection	Average Year Per Capita Water Demand (gpc/d)	Estimated Annual Water Demand (ac-ft)	Annual Permitted Allocation (ac-ft)	Annual Water Surplus or Shortage (ac-ft)	Percent Surplus or Shortage of Water Supply (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
North Dakota Municipalities:						
Drayton	920	272.8	281	2,000	1,719	611%
Enderlin	947	724.9	769	850	81	11%
Fargo	243,073	116.1	31,613	152,575	120,962	383%
Grafton	6,244	152.5	1,067	1,754	687	64%
Grand Forks	89,631	136.7	13,727	69,373	55,646	405%
Gwinner	1,254	293.7	413	500	87	21%
Langdon	2,100	115.7	272	795	523	192%
Larimore	1,839	98.6	203	500	297	146%
Lisbon	2,530	120.8	342	500	158	46%
Park River	1,540	112.3	194	610	416	215%
Valley City	7,500	104.7	880	6,686	5,806	660%
Wahpeton	12,140	111.7	1,519	2,130	611	40%
West Fargo	34,705	91.8	3,569	2,614	-955	-27%
Minnesota Municipalities:						
Breckenridge	3,601	79.5	321	1,680	1,359	424%
East Grand Forks	13,619	151.4	2,310	1,990	-320	-14%
Moorhead	64,432	117.3	8,465	28,630	20,165	238%

Note: Blue shading denotes use of groundwater. Tan shading highlights shortages.

West Fargo is the only municipality that has a shortage for both scenarios when compared to their permitted allocation in an average water use year (see chapter two). In 2000 the NDSWC completed a study of the West Fargo Aquifer System entitled, *Water Resource Characteristics of the West Fargo Aquifer System, Cass and Richland Counties, North Dakota*. The report concludes that the West Fargo South Aquifer is not a reliable water source through 2050. Therefore, the permitted allocations from the West Fargo Aquifer for Cass Rural Water Users District are not used in the analysis. West Fargo's future water needs would be met using the Sheyenne River as their future primary source (in the Project) to replace their current groundwater source.

For Scenario Two only, East Grand Forks also has a shortage when compared to its permitted allocation in an average water year. Whether East Grand Forks has enough surface water in the future is addressed in hydrologic modeling. If adequate surface water is available for East Grand Forks in the future, it is recommended that the city consider increasing its surface water permit allocation.

Tables 3.3.3 and 3.3.4 also show that all the cities using groundwater (shaded in table) have adequate annual permitted water allocations in an average water demand year. Because Moorhead will continue to use both its groundwater and its surface water sources in the future, Moorhead is not shaded in the table.

Tables 3.3.5 and 3.3.6 are similar to tables 3.3.3 and 3.3.4, except that these show the annual maximum water demand analysis of the 16 municipal water systems under Scenario One and Scenario Two water demands. The groundwater-dependent cities are shaded. The method for developing annual maximum month water demands is discussed in chapter two.

With the exception of Gwinner, all groundwater-dependent cities have adequate permitted water supplies to meet their maximum annual water demands through 2050. Gwinner has a 3% (15 ac-ft per year) shortage under Scenario One and a 10% (52 ac-ft per year) shortage under Scenario Two. Given that the shortages are minor and Gwinner has a rather high water loss rate at 27.5%, Reclamation assumes that Gwinner will pursue conservation measures to address their future shortages.

West Fargo and East Grand Forks also have shortages when compared to their permitted allocation in a maximum month water use year for both scenarios. West Fargo and East Grand Forks water shortages were discussed earlier and were further analyzed with the other surface-dependent systems, including Moorhead, to determine if they would have adequate water supplies for the future.

Tables 3.3.7 and 3.3.8 show the peak day water demand analysis of the 16 municipal water systems under Scenario One and Scenario Two water demands, respectively. This analysis is similar to the previous analysis, except these tables compare the estimated system withdrawal rate with the permitted withdrawal rate. The analysis assumes that wells or intake pumps could run for 20 hours in a 24-hour period. Columns six and seven in the two tables show the difference in ac-ft and relative percentage of surplus or shortage in withdrawal capacity. All but two municipal systems have adequate annual permitted withdrawal capacity. Only West Fargo and Moorhead appear to need more withdrawal capacity. Permitted daily withdrawal rate data were not available for Breckenridge and East Grand Forks, so analysis could not be conducted on those water systems.

Table 3.3.5 – Annual Maximum Month Water Demand Analysis – Scenario One.

Municipality	2050 Reclamation Population Projection	Annual Maximum Month Per Capita Water Demand (gpc/d)	Estimated Annual Water Demand (ac-ft)	Annual Permitted Allocation (ac-ft)	Annual Water Surplus or Shortage (ac-ft)	Percent Surplus or Shortage of Water Supply (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
North Dakota Municipalities:						
Drayton	920	588.5	607	2,000	1,393	230%
Enderlin	860	823.2	793	850	57	7%
Fargo	204,300	164.7	37,682	152,575	114,893	305%
Grafton	4,130	200.3	927	1,754	827	89%
Grand Forks	83,800	204.6	19,205	69,373	50,168	261%
Gwinner	1,170	393.3	515	500	-15	-3%
Langdon	2,100	245.3	577	795	218	38%
Larimore	1,190	151.2	202	500	298	148%
Lisbon	2,530	146.4	415	500	85	21%
Park River	1,540	142.4	246	610	364	148%
Valley City	5,840	136.6	894	6,686	5,792	648%
Wahpeton	12,140	135.5	1,843	2,130	287	16%
West Fargo	33,900	112.2	4,261	2,614	-1,647	-39%
Minnesota Municipalities:						
Breckenridge	2,540	86.8	247	1,680	1,433	580%
East Grand Forks	9,800	217.1	2,383	1,990	-393	-17%
Moorhead	50,211	153.7	8,646	28,630	19,984	231%

Note: Blue shading denotes use of groundwater. Tan shading highlights shortages.

Table 3.3.6 – Annual Maximum Month Water Demand Analysis – Scenario Two.

Municipality	2050 Water User Population Projection	Annual Maximum Month Per Capita Water Demand (gpc/d)	Estimated Annual Water Demand (ac-ft)	Annual Permitted Allocation (ac-ft)	Annual Water Surplus or Shortage (ac-ft)	Percent Surplus or Shortage of Water Supply (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
North Dakota Municipalities:						
Drayton	920	588.5	607	2,000	1,393	230%
Enderlin	947	758.8	805	850	45	6%
Fargo	243,073	164.7	44,833	152,575	107,742	240%
Grafton	6,244	200.3	1,401	1,754	353	25%
Grand Forks	89,631	202.7	20,348	69,373	49,025	241%
Gwinner	1,254	393.3	552	500	-52	-10%
Langdon	2,100	245.3	577	795	218	38%
Larimore	1,839	151.2	311	500	189	61%
Lisbon	2,530	146.4	415	500	85	21%
Park River	1,540	142.4	246	610	364	148%
Valley City	7,500	136.6	1,148	6,686	5,538	483%
Wahpeton	12,140	135.5	1,843	2,130	287	16%
West Fargo	34,705	112.2	4,362	2,614	-1,748	-40%
Minnesota Municipalities:						
Breckenridge	3,601	86.8	350	1,680	1,330	380%
East Grand Forks	13,619	217.1	3,312	1,990	-1,322	-40%
Moorhead	64,432	148.2	10,696	28,630	17,934	168%

Note: Blue shading denotes use of groundwater. Tan shading highlights shortages.

Table 3.3.7 – Maximum Peak Day Water Demand Analysis – Scenario One.

Municipality	2050 Reclamation Population Projection	Maximum Peak Daily Water Demand (gpc/d)	Estimated Daily Withdrawal Rate @ 20 Hour/day Operation (gpm)	Maximum Daily Withdrawal Rate (gpm)	Withdrawal Rate Surplus or Shortage (gpm)	Percent Surplus or Shortage (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
North Dakota Municipalities:						
Drayton	920	1,087.8	834	1,000	166	17%
Enderlin	860	1,522.1	1,091	1,478	387	26%
Fargo	204,300	381.7	64,984	127,040	62,056	49%
Grafton	4,130	339.7	1,169	6,300	5,131	81%
Grand Forks	83,800	526.3	36,753	39,800	3,047	8%
Gwinner	1,170	637.6	622	1,250	628	50%
Langdon	2,100	552.4	967	1,760	793	45%
Larimore	1,190	213.3	211	500	289	58%
Lisbon	2,530	223.5	471	600	129	21%
Park River	1,540	399.3	512	600	88	15%
Valley City	5,840	386.2	1,880	13,464	11,584	86%
Wahpeton	12,140	240.1	2,429	4,200	1,771	42%
West Fargo	33,900	275.4	7,780	1,850	-5,930	-321%
Minnesota Municipalities:						
Breckenridge	2,540	237.7	503	NA	NA	NA
East Grand Forks	9,800	522.6	4,268	NA	NA	NA
Moorhead	50,211	289.2	12,101	9150	-2,951	-32%

Note: Blue shading denotes use of groundwater. Tan shading highlights shortages.

Table 3.3.8 – Maximum Peak Day Water Demand Analysis – Scenario Two.

Municipality	2050 Water User Population Projection	Maximum Peak Daily Water Demand (gpc/d)	Estimated Daily Withdrawal Rate @ 20 Hour/day Operation (gpm)	Maximum Daily Withdrawal Rate (gpm)	Withdrawal Rate Surplus or Shortage (gpm)	Percent Surplus or Shortage (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
North Dakota Municipalities:						
Drayton	920	1,087.8	834	1,000	166	17%
Enderlin	947	1,522.1	1,201	1,478	277	19%
Fargo	243,073	381.7	77,317	127,040	49,723	39%
Grafton	6,244	339.7	1,768	6,300	4,532	72%
Grand Forks	89,631	526.3	39,311	39,800	489	1%
Gwinner	1,254	637.6	666	1,250	584	47%
Langdon	2,100	552.4	967	1,760	793	45%
Larimore	1,839	213.3	327	500	173	35%
Lisbon	2,530	223.5	471	600	129	21%
Park River	1,540	399.3	512	600	88	15%
Valley City	7,500	386.2	2,414	13,464	11,050	82%
Wahpeton	12,140	240.1	2,429	4,200	1,771	42%
West Fargo	34,705	275.4	7,965	1,850	-6,115	-331%
Minnesota Municipalities:						
Breckenridge	3,601	237.7	713	NA	NA	NA
East Grand Forks	13,619	522.6	5,931	NA	NA	NA
Moorhead	64,432	289.2	15,528	9150	-6,378	-70%

Note: Blue shading denotes use of groundwater. Tan shading highlights shortages.

Municipal Water Demand Conclusions Of the 16 municipal water systems, 13 have adequate annual permitted allocations to meet their annual maximum month water demands through 2050 for both scenarios. In both scenarios, West Fargo exceeds their annual permitted allocation for both average and annual maximum water demands through 2050. East Grand Forks, under Scenario Two water demands, exceeds their annual permitted allocation under average or annual maximum month water demands through 2050.

Fourteen of the 16 water systems have adequate permitted daily withdrawal rates to meet their maximum peak daily demands through 2050, under both scenarios. Moorhead and West Fargo do not have sufficient daily withdrawal capacity. West Fargo also shows an inadequate permitted withdrawal rate, but more importantly, NDSWC (2000) has determined that the West Fargo Aquifer is not a reliable water source for the city through 2050.

Comparing future water demands against water permits does not adequately evaluate surface water sources. Surface water sources also must be evaluated for their expected reliability during a drought. Therefore, surface water hydrologic modeling was required for the nine municipal water systems using surface water as their primary water sources through 2050. The nine municipalities are Drayton, Fargo, Grafton, Grand Forks, Langdon, Valley City, West Fargo, East Grand Forks, and Moorhead.

Rural Water System Permit Analysis   Twelve rural water systems in the Red River Valley were analyzed to determine if they have adequate water supplies to meet projected water demands through 2050. These systems are listed in Table 3.3.9, along with their current water source and permit information. Permit data were compared to future water demands of each system to determine if there would be adequate water quantity through 2050. Analysis included annual water demand in ac-ft and peak daily water demands in gpm.

Table 3.3.9 – Rural Water System Water Sources and Permitted Allocation.

Rural Water System	Water Source	Annual Permitted Allocation (ac-ft)	Maximum Permitted Daily Withdrawal Rate (gpm)
Agassiz Water Users District	Inkster Aquifer	800	1,650
Barnes Rural Water District	Spiritwood Aquifer	1,100	1,800
Cass Rural Water Users District	**Cass Rural Total =**	**1,825**	**2,400**
	Page Aquifer	400	600
	Sheyenne Delta Aquifer	750	900
	West Fargo South Aquifer	675 [1]	900
Dakota Rural Water District	**Dakota Rural Total =**	**575**	**1,050**
	McVille Aquifer	225	500
	Spiritwood Aquifer	350	550
Grand Forks-Traill Water District	Elk Valley Aquifer	1,712	2,755
Langdon Rural Water District	Pembina River	481	800
North Valley Water District	**North Valley Total =**	**1,430**	**2,105**
	Gardar Aquifer	110	200
	Icelandic Aquifer	1,320	1,905
Ransom-Sargent Water Users District	Sheyenne Delta Aquifer	275	700
Southeast Water District	Hankinson Aquifer	750	1,800
Traill Rural Water District	Galesburg Aquifer	644	1,070
Tri-County Water District	Elk Valley Aquifer	392	700
Walsh Rural Water District	Fordville Aquifer	804	1,670

[1] 200 ac-ft of the permitted allocation is conditional and has a sunset clause of 2010. The NDSWC has determined that the West Fargo South Aquifer will not be a reliable source of water through 2050.

Eleven of the 12 rural water systems use one or more groundwater sources as their water supply. Only Langdon Rural Water District which is highlighted in table 3.3.9, and other tables uses a surface water source (Pembina River) as their water supply. The analysis determined which water systems needed further evaluation as surface water demands in hydrologic modeling. Langdon Rural Water District had to be modeled, as did other water systems within the service area that showed a shortage.

Scenarios One and Two Future Rural Water System Water Demand Analysis Table 3.3.10 shows the Reclamation- and water-user-developed population projections through 2050. The Reclamation population projection was used to develop Scenario One water demands, and the water user population projections were used to development Scenario Two water demands. A detailed discussion of rural water system service-area population projections is in section 2.7 and Appendix A.

Table 3.3.10 – Reclamation and Water User 2050 Population Projections.

Rural Water System	Reclamation 2050 Population Projection	Water User 2050 Population Projection
Agassiz Water Users District	5,355	5,300
Barnes Rural Water District	2,266	4,897
Cass Rural Water Users District	16,244	21,048
Dakota Rural Water District	3,421	2,600
Grand Forks-Traill Water District	12,176	15,000
Langdon Rural Water District	1,568	2,900
North Valley Water District	5,101	8,900
Ransom-Sargent Water Users District	1,036	2,673
Southeast Water District	7,273	7,500
Traill Rural Water District	4,527	2,800
Tri-County Water District	2,185	2,800
Walsh Rural Water District	1,129	3,160
Totals	**62,281**	**79,578**

Table 3.3.11 shows the average, maximum annual, and peak day per capita water demand estimates for each of the municipal water systems. Refer to section 2.4 for a more detailed discussion of how these per capita water demands were estimated. The per capita water demands include water conservation and water losses.

Tables 3.3.12 and 3.3.13 show the average annual water demands of the 12 rural water systems under Scenario One and Scenario Two water demands, respectively. Column three shows the average per capita water demand taken from table 3.3.11, and column four shows the estimated annual water demand in ac-ft. Column five shows the annual permitted allocation in ac-ft taken from table 3.3.9. Column six shows the annual surpluses or shortages of water for each system. Column seven shows the relative percentage of the surplus or shortage.

Table 3.3.11 – Rural Water System Per Capita Water Demands.

Rural Water System	Average Per Capita Water Demand w/Cities (gpc/d)	Maximum Year Per Capita Water Demand w/Cities (gpc/d)	Rural Water System Peak Daily Water Demand w/ Cities (gpc/d)
Agassiz Water Users District	85.7	128.5	175.6
Barnes Rural Water District	125.9	176.1	305.5
Cass Rural Water Users District	81.9	101.8	154.1
Dakota Rural Water District	98.9	121.9	245.2
Grand Forks-Traill Water District	109.3	169.9	241.3
Langdon Rural Water District	56.7	81.3	206.3
North Valley Water District	83.8	109.3	207.0
Ransom-Sargent Water Users District	80.9	90.3	148.3
Southeast Water District	83.3	107.2	169.2
Traill Rural Water District	105.4	143.4	331.2
Tri-County Water District	75.9	127.5	155.6
Walsh Rural Water District	97.6	130.4	216.6

Under Scenario One water demands, Cass Rural Water Users District has a shortage of 340 ac-ft in the worst year. Under Scenario Two water demands, both Cass Rural Water Users District and Grand Forks-Traill Water District have shortages of 780 ac-ft and 125 ac-ft in the worst year, respectively. All other rural water systems have adequate annual permitted capacity to meet their future annual average water demands.

Tables 3.3.14 and 3.3.15 are similar to tables 3.3.12 and 3.3.13, except that these show annual maximum water demand analysis of the 12 rural water systems under Scenario One or Scenario Two water demands. The method for developing annual maximum month water demands is discussed in chapter two.

Four rural water systems have shortages under both demand scenarios. Under Scenario One water demands, the systems with shortages in the worst year are: Cass Rural Water Users District with a shortage of 702 ac-ft; Grand Forks-Traill Water District with a shortage of 605 ac-ft; Southeast Water District with a shortage of 123 ac-ft; and Traill Rural Water District with a shortage of 83 ac-ft. Under Scenario Two water demands, systems with shortages in the worst year are: Cass Rural Water Users District with a shortage of 1,250 ac-ft; Grand Forks-Traill Water District with a shortage of 1,143 ac-ft; Southeast Water District with a shortage of 151 ac-ft; and Tri-County Water District with a shortage of 8 ac-ft. All other rural water systems have adequate annual permitted capacity to meet their future annual maximum water demands.

Table 3.3.12 – Average Annual Water Demand Analysis – Scenario One.

Rural Water System	2050 Reclamation Population Projection	Average Per Capita Water Demand w/Cities (gpc/d)	Estimated Annual Water Demand (ac-ft)	Annual Permitted Allocation (ac-ft)	Annual Water Surplus or Shortage (ac-ft)	Percent Surplus or Shortage of Water Supply (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
Agassiz Water Users District	5,355	85.7	514	800	286	56%
Barnes Rural Water District	2,266	125.9	320	1,100	780	244%
Cass Rural Water Users District	16,244	81.9	1,490	1,150	-340	-23%
Dakota Rural Water District	3,421	98.9	379	575	196	52%
Grand Forks-Traill Water District	12,176	109.3	1,491	1,712	221	15%
Langdon Rural Water District	1,568	56.7	100	481	381	383%
North Valley Water District	5,101	83.8	479	1,430	951	199%
Ransom-Sargent Water Users District	1,036	80.9	94	275	181	193%
Southeast Water District	7,273	83.3	679	750	71	10%
Traill Rural Water District	4,527	105.4	534	644	110	21%
Tri-County Water District	2,185	75.9	186	392	206	111%
Walsh Rural Water District	1,129	97.6	123	804	681	551%

Note: Tan shading highlights shortages.

Traill Rural Water District has a shortage under Scenario One but not Scenario Two because Reclamation estimates a higher future water demand than do the water users. Reclamation includes the communities of Hillsboro, Mayville, and Galesburg in future population estimates, but the rural water system does not. Tri-County Water District also has a small shortage of 8 ac-ft under Scenario Two water demands. Since the shortages are relatively small, Reclamation assumes Tri-County will have adequate annual permitted groundwater allocation in the future.

Tables 3.3.16 and 3.3.17 show the maximum peak day water demand analysis of the 12 rural water systems under Scenario One or Scenario Two water demands, respectively. This analysis is similar to that in the previous four tables, except that the next two tables compare the estimated system withdrawal rate with the permitted withdrawal rate. The analysis assumes that wells or intake pumps could run for 20 hours in a 24-hour period. Columns six and seven in the two tables show the difference in ac-ft and relative percentage of surplus or shortage in withdrawal capacity.

Table 3.3.13 – Average Annual Water Demand Analysis – Scenario Two.

Rural Water System	2050 Water User Population Projection	Average Per Capita Water Demand w/Cities (gpc/d)	Estimated Annual Water Demand (ac-ft)	Annual Permitted Allocation (ac-ft)	Annual Water Surplus or Shortage (ac-ft)	Percent Surplus or Shortage of Water Supply (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
Agassiz Water Users District	5,300	85.7	509	800	291	57%
Barnes Rural Water District	4,897	125.9	691	1,100	409	59%
Cass Rural Water Users District	21,048	81.9	1,930	1,150	-780	-40%
Dakota Rural Water District	2,600	98.9	288	575	287	100%
Grand Forks-Traill Water District	15,000	109.3	1,837	1,712	-125	-7%
Langdon Rural Water District	2,900	56.7	184	481	297	161%
North Valley Water District	8,900	83.8	835	1,430	595	71%
Ransom-Sargent Water Users District	2,673	80.9	242	275	33	14%
Southeast Water District	7,500	83.3	700	750	50	7%
Traill Rural Water District	2,800	105.4	330	644	314	95%
Tri-County Water District	2,800	75.9	238	392	154	65%
Walsh Rural Water District	3,160	97.6	345	804	459	133%

Note: Tan shading highlights shortages.

Table 3.3.14 – Maximum Annual Water Demand Analysis – Scenario One.

Rural Water System	2050 Reclamation Population Projection	Maximum Annual Per Capita Water Demand w/Cities (gpc/d)	Estimated Annual Water Demand (ac-ft)	Annual Permitted Allocation (ac-ft)	Annual Water Surplus or Shortage (ac-ft)	Percent Surplus or Shortage of Water Supply (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
Agassiz Water Users District	5,355	128.5	771	800	29	4%
Barnes Rural Water District	2,266	176.1	447	1,100	653	146%
Cass Rural Water Users District	16,244	101.8	1,852	1,150	-702	-38%
Dakota Rural Water District	3,421	121.9	467	575	108	23%
Grand Forks-Traill Water District	12,176	169.9	2,317	1,712	-605	-26%
Langdon Rural Water District	1,568	81.3	143	481	338	237%

Rural Water System	2050 Reclamation Population Projection	Maximum Annual Per Capita Water Demand w/Cities (gpc/d)	Estimated Annual Water Demand (ac-ft)	Annual Permitted Allocation (ac-ft)	Annual Water Surplus or Shortage (ac-ft)	Percent Surplus or Shortage of Water Supply (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
North Valley Water District	5,101	109.3	625	1,430	805	129%
Ransom-Sargent Water Users District	1,036	90.3	105	275	170	162%
Southeast Water District	7,273	107.2	873	750	-123	-14%
Traill Rural Water District	4,527	143.4	727	644	-83	-11%
Tri-County Water District	2,185	127.5	312	392	80	26%
Walsh Rural Water District	1,129	130.4	165	804	639	388%

Note: Tan shading highlights shortages.

Table 3.3.15 – Maximum Annual Water Demand Analysis – Scenario Two.

Rural Water System	2050 Water User Population Projection	Maximum Annual Per Capita Water Demand w/Cities (gpc/d)	Estimated Annual Water Demand (ac-ft)	Annual Permitted Allocation (ac-ft)	Annual Water Surplus or Shortage (ac-ft)	Percent Surplus or Shortage of Water Supply (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
Agassiz Water Users District	5,300	128.5	763	800	37	5%
Barnes Rural Water District	4,897	176.1	966	1,100	134	14%
Cass Rural Water Users District	21,048	101.8	2,400	1,150	-1,250	-52%
Dakota Rural Water District	2,600	121.9	355	575	220	62%
Grand Forks-Traill Water District	15,000	169.9	2,855	1,712	-1,143	-40%
Langdon Rural Water District	2,900	81.3	264	481	217	82%
North Valley Water District	8,900	109.3	1,090	1,430	340	31%
Ransom-Sargent Water Users District	2,673	90.3	270	275	5	2%
Southeast Water District	7,500	107.2	901	750	-151	-17%
Traill Rural Water District	2,800	143.4	450	644	194	43%
Tri-County Water District	2,800	127.5	400	392	-8	-2%
Walsh Rural Water District	3,160	130.4	462	804	342	74%

Note: Tan shading highlights shortages.

Table 3.3.16 – Peak Day Water Demand Analysis – Sceario One.

Rural Water System	2050 Reclamation Population Projection	Maximum Peak Daily Water Demand (gpc/d)	Estimated Daily Withdrawal Rate @ 20 Hour/day Operation (gpm)	Maximum Daily Permitted Withdrawal Rate (gpm)	Withdrawal Rate Surplus or Shortage (gpm)	Percent Surplus or Shortage (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
Agassiz Water Users District	5,355	175.6	784	1,650	866	53%
Barnes Rural Water District	2,266	305.5	577	1,800	1,223	212%
Cass Rural Water Users District	16,244	154.1	2,086	1,500	-586	-28%
Dakota Rural Water District	3,421	245.2	699	1,050	351	50%
Grand Forks-Traill Water District	12,176	241.3	2,448	2,755	307	13%
Langdon Rural Water District	1,568	206.3	270	800	530	197%
North Valley Water District	5,101	207.0	880	2,105	1,225	139%
Ransom-Sargent Water Users District	1,036	148.3	128	700	572	447%
Southeast Water District	7,273	169.2	1,025	1,800	775	76%
Traill Rural Water District	4,527	331.2	1,249	1,070	-179	-14%
Tri-County Water District	2,185	155.6	283	700	417	147%
Walsh Rural Water District	1,129	216.6	204	1,670	1,466	719%

Note: Tan shading highlights shortages.

Table 3.3.17 – Peak Day Water Demand Analysis – Scenario Two.

Rural Water System	2050 Water User Population Projection	Maximum Peak Daily Water Demand (gpc/d)	Estimated Daily Withdrawal Rate @ 20 hour/day Operation (gpm)	Maximum Daily Permitted Withdrawal Rate (gpm)	Withdrawal Rate Surplus or Shortage (gpm)	Percent Surplus or Shortage (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
Agassiz Water Users District	5,300	175.6	776	1,650	874	53%
Barnes Rural Water District	4,897	305.5	1,247	1,800	553	44%
Cass Rural Water Users District	21,048	154.1	2,703	1,500	-1,203	-45%
Dakota Rural Water District	2,600	245.2	531	1,050	519	98%
Grand Forks-Traill Water District	15,000	241.3	3,016	2,755	-261	-9%

Rural Water System	2050 Water User Population Projection	Maximum Peak Daily Water Demand (gpc/d)	Estimated Daily Withdrawal Rate @ 20 hour/day Operation (gpm)	Maximum Daily Permitted Withdrawal Rate (gpm)	Withdrawal Rate Surplus or Shortage (gpm)	Percent Surplus or Shortage (%)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
Langdon Rural Water District	2,900	206.3	499	800	301	60%
North Valley Water District	8,900	207.0	1,535	2,105	570	37%
Ransom-Sargent Water Users District	2,673	148.3	330	700	370	112%
Southeast Water District	7,500	169.2	1,058	1,800	743	70%
Traill Rural Water District	2,800	331.2	773	1,070	297	38%
Tri-County Water District	2,800	155.6	363	700	337	93%
Walsh Rural Water District	3,160	216.6	570	1,670	1,100	193%

Note: Tan shading highlights shortages.

Under Scenario One, Cass Rural Water Users District has a withdrawal shortage of 586 gpm, and Traill Rural Water District has a shortage of 179 gpm. Under Scenario Two, Cass Rural Water Users District has a withdrawal shortage of 1,203 gpm, and Grand Forks-Traill Water District has a shortage of 261 gpm. Under Scenario One, Traill Rural Water District has a withdrawal shortage, but is has no shortage under Scenario Two. Reclamation includes the communities of Hillsboro, Mayville, and Galesburg in the future population estimates used in Scenario One, but the rural water system projections do not include these cities.

Further Analysis of Selected Rural Water Systems The evaluation of average and maximum annual water demands and peak day water demands identifies five rural water systems that have one or more shortages under water demand Scenario One or Scenario Two. The water systems and their respective shortages are listed in table 3.3.18. Based on their unique water system characteristics, each of the rural water systems were evaluated to determine the adequacy of their water supplies through 2050. Only the maximum annual and peak day water shortages are addressed in the following analysis. Average annual shortages are obviously less than maximum annual shortages, so there is no need to analyze average annual shortages. Tri-County Water District has a very minor shortage, so no further investigation of that water system is required.

Cass Rural Water Users District Demand Analysis Table 3.3.19 shows that Cass Rural Water Users District has an estimated future maximum annual water demand deficit of 702 ac-ft under Scenario One or 1,250 ac-ft under Scenario Two. Under Scenario One, Cass Rural Water Users District has an estimated peak day withdrawal rate deficiency of 586 gpm, and it has a deficiency of 1,203 gpm under Scenario Two. These estimates take into account the 675 ac-ft West Fargo South Aquifer permitted allocation which was not included in the analysis, because Ripley (2000) has determined it not to be a reliable water source through 2050.

Historically, Cass Rural Water Users District has a high water loss averaging 23.1%, so the reduction of future water demands by improved efficiencies is possible. However, Cass Rural Water Users District reports that approximately 5% to 10% of these losses are attributable to system flushing and treatment waste stream. That leaves 13.1% to 18.1% as unaccounted-for water losses, which is reasonable when compared to the acceptable level of water losses of 15% as discussed in chapter two. Therefore, no water demand reduction is estimated for improved unaccounted-for water loss.

Table 3.3.18 – Rural Water Systems with Identified Future Water Shortages.

Rural Water System	Scenario One Average Annual Shortage (ac-ft)	Scenario Two Average Annual Shortage (ac-ft)	Scenario One Maximum Annual Shortage (ac-ft)	Scenario Two Maximum Annual Shortage (ac-ft)	Scenario One Peak Day Shortage (gpm)	Scenario Two Peak Day Shortage (gpm)
Cass Rural Water Users District	340	780	702	1,250	1,304	2,113
Grand Forks-Traill Water District		125	605	1,143	536	1,300
Southeast Water District			123	151		
Traill Rural Water District			83		610	
Tri-County Water District				8		

Note: Tan shading highlights shortages.

Table 3.3.19 – Cass Rural Water Users District Annual Maximum Month and Peak Day Water Demands/Shortages.

Water Demand Scenario	2050 Population Projection	Annual Permitted Allocation (ac-ft)	Estimated Annual Maximum 2050 Water Demand (ac-ft)	Annual Maximum 2050 Water Demand Shortage or Surplus (ac-ft)	Maximum Daily Permitted Withdrawal Rate (gpm)	Estimated Peak Daily Withdrawal Rate @ 20 hour/day Operation (gpm)	Peak Daily Withdrawal Rate Surplus or Shortage (gpm)
Scenario One	16,244	1,150	1,852	-702	1,500	2,086	-586
Scenario Two	21,048	1,150	2,400	-1,250	1,500	2,703	-1,203

Cass Rural Water Users District commissioned a study titled *Report on Phase I Water Supply, Bartlett and West Engineers Inc. 2003*. This report briefly covers all three phases of Cass Rural Water Users District's service areas but concentrates on finding alternative water sources for the Phase I service area, which is supplied by the West Fargo Aquifer. Bartlett and West (2003) estimates Cass Rural Water Users District's 2050 water demand at 2,875 ac-ft annually, using a linear historic projection of the past 20 years of water use.

Bartlett and West (2003) concludes that Phase II and III have adequate water supplies through 2050, contingent on NDSWC's approval of increased groundwater permit allocations, which the study concludes is likely. The report also concludes that future 2050 Phase I water needs (1,175 ac-ft annually) will be met by (1) purchasing water from Fargo (approximately 807 ac-ft, based on current contract), (2) securing more groundwater from the Sheyenne Delta Aquifer (present Phase II source), and (3) making very limited future use of the West Fargo Aquifer. Given these conclusions, Cass Rural Water Users District contracted with Fargo for water service and is planning system distribution and storage facilities to receive water from Fargo.

Based on Bartlett and West (2003)," it appears that the Phase II and III areas of Cass Rural Water Users District probably have adequate future water supplies, assuming additional groundwater permits can be obtained. However, serving the Phase I area of Cass Rural Water Users District from groundwater does not appear viable. Since the district already is planning on purchasing water from Fargo, Reclamation assumes that the annual shortage of 702 ac-ft under Scenario One and the shortage of 1,250 ac-ft under Scenario Two would be served from Fargo. Fargo uses the Red and Sheyenne Rivers for their water supply, so any water purchased from Fargo creates an additional Fargo surface water demand that was incorporated in surface water modeling. The water contract with Fargo will meet the district's peak day shortage of 586 gpm under Scenario One or the shortage of 1,203 gpm under Scenario Two.

Grand Forks-Traill Water District Water Demand Analysis Table 3.3.20 shows that Grand Forks-Traill Water District has an estimated shortage of 605 ac-ft under Scenario One or a shortage of 1,143 ac-ft under Scenario Two. There is a peak day withdrawal rate deficiency of 307 gpm under Scenario One or a shortage of 261 gpm under Scenario Two.

Table 3.3.20 – Grand Forks-Traill Water District Annual Maximum Month and Peak Day Water Demands/Shortages.

Water Demand Scenario	2050 Population Projection	Annual Permitted Allocation (ac-ft)	Estimated Annual Maximum 2050 Water Demand (ac-ft)	Annual Maximum 2050 Water Demand Shortage or Surplus (ac-ft)	Maximum Daily Permitted Withdrawal Rate (gpm)	Estimated Peak Daily Withdrawal Rate @ 20 Hour/day Operation (gpm)	Peak Daily Withdrawal Rate Surplus or Shortage (gpm)
Scenario One	12,176	1,712	2,317	-605	2,755	2,448	307
Scenario Two	15,000	1,712	2,855	-1,143	2,755	3,106	-261

The Grand Forks-Traill Water District has two options to meet its future estimated shortages: (1) interconnect Grand Forks-Traill Water District with Grand Forks water system, or (2) purchase existing groundwater rights in the Elk Valley Aquifer. Both options are considered in the options presented in chapter four.

Southeast Water District Water Demand Analysis Table 3.3.21 shows the estimated maximum annual water demand deficiency of 123 ac-ft under Scenario One or 151 ac-ft water demand deficiency under Scenario Two. Southeast Water District has a surplus of 775 gpm in daily withdrawal rate under Scenario One or a surplus of 743 gpm under Scenario Two.

Table 3.3.21 – Southeast Water District Future Water Demands and Surpluses/Shortages.

Water Demand Scenario	2050 Population Projection	Annual Permitted Allocation (ac-ft)	Estimated Annual Maximum 2050 Water Demand (ac-ft)	Annual Maximum 2050 Water Demand Shortage or Surplus (ac-ft)	Maximum Daily Permitted Withdrawal Rate (gpm)	Estimated Peak Daily Withdrawal Rate @ 20 Hour/day Operation (gpm)	Peak Daily Withdrawal Rate Surplus or Shortage (gpm)
Scenario One	7,273	750	873	-123	1,800	1,025	775
Scenario Two	7,500	750	901	-151	1,800	1,058	743

Because Southeast Water District seems to be addressing their future water needs, there appears to be no reason to further investigate alternative water sources. Therefore, no surface water demand from the Red River is included in hydrologic modeling for Southeast Water District.

Traill Rural Water District Water Demand Analysis The future water demand analysis for this district assumes that the cities of Hillsboro, Mayville, and Galesburg will be served by Traill Rural Water District in the future. If these additional cities are not served by the rural water district, Traill Rural Water District will have adequate capacity to meet their future water demands.

Table 3.3.22 shows estimated maximum annual water demand deficiency of 83 ac-ft under Scenario One or a surplus of 194 ac-ft under Scenario Two. The water system has a daily withdrawal rate deficiency of 179 gpm under Scenario One or a surplus of 297 gpm under Scenario Two. The major difference is because the Scenario One water demand assumes that the cities of Hillsboro, Mayville, and Galesburg will be served by Traill Rural Water District in the future.

Table 3.3.22 – Traill Rural Water District Future Water Demands and Surpluses/Shortages.

Water Demand Scenario	2050 Population Projection	Annual Permitted Allocation (ac-ft)	Estimated Annual Maximum 2050 Water Demand (ac-ft)	Annual Maximum 2050 Water Demand Shortage or Surplus (ac-ft)	Maximum Daily Permitted Withdrawal Rate (gpm)	Estimated Peak Daily Withdrawal Rate @ 20 Hour/day Operation (gpm)	Peak Daily Withdrawal Rate Surplus or Shortage (gpm)
Scenario One	4,527	644	727	-83	1,070	1,249	-179
Scenario Two	2,800	644	450	194	1,070	773	297

Traill Rural Water District had high water losses at 37% in 2002. This included 25% for filter backwash, 10% for water system leaks and breaks, and 2% for system flushing. The 10% for water system leaks and breaks is reasonable when compared to the target level of 15% (see chapter two).

Traill Rural Water District is investigating additional groundwater sources and estimating the cost of interconnecting the cities of Hillsboro, Mayville, and Galesburg. Traill Rural Water has identified an area in the Galesburg Aquifer that the NDSWC verbally has agreed would be an allowable water permit source of additional groundwater for future development. Because Traill Rural Water District has a tentative agreement with NDSWC to increase their groundwater allocation, no surface water demand from the Red River is included in hydrologic modeling for Traill Rural Water District.

Rural Water Systems Water Demand Analysis Conclusions Two rural water systems, Cass Rural Water Users District and Grand Forks-Traill Water District, have shortages in groundwater supplies that only can be addressed by tapping surface water supplies. Langdon Rural Water District currently is served by surface water, so its current and future water supply is modeled using surface water supplies. In addition, Southeast Water District and Traill Rural Water District also have shortages, but currently they are addressing their future water needs by securing additional groundwater sources. Monthly water demands for Cass Rural Water Users District and Grand Forks-Traill Water District surface water modeling are specified at the end of this section. These demands were used in hydrologic modeling to determine adequacy of future water supplies.

Industrial Water System Permit Analysis The existing industrial facilities in the Red River Valley service area are listed in table 3.3.23. These include industrial facilities which use over 12.5 ac-ft (North Dakota permit requirement) of water annually and require a permit. Also listed in the table are water sources and permit information for each facility. The industrial water system permit analysis compares the present water supply or permitted volume to the future water demand to determine if there is an adequate quantity of water available through 2050. This analysis includes annual water demand in ac-ft and peak daily water demands in gpm.

Table 3.3.24 compares the average and annual maximum month water demands with the annual permitted allocation, in ac-ft, for each industrial facility. Column five shows that all of the industrial facilities have an adequate annual permitted allocation of water as compared to the average historic water use. Column seven shows that all except American Crystal Sugar Company in Hillsboro and Minn-Dak Farmers Cooperative in Wahpeton have an adequate annual permitted allocation of water, as compared to the maximum historic water use. American Crystal Sugar Company in Hillsboro is short 283 ac-ft, and Minn-Dak Farmers Cooperative is short 273 ac-ft of water permit allocation.

American Crystal Sugar Company will need to increase their annual withdrawal permit if they expect their water need to equal or exceed their historic annual maximum month of 733 ac-ft. Minn-Dak Farmers Cooperative in Wahpeton's shortage of 273 ac-ft occurred in 1991 based on a demand of 623 ac-ft. No other year exceeds their annual permitted allocation of 350 ac-ft. If Minn-Dak Farmers Cooperative believes a repeat of the 623 ac-ft water demand is possible, they should seek an additional allocation from the Wahpeton Buried Valley Aquifer. If the aquifer cannot support the additional yield, then Minn-Dak Farmers Cooperative should consider the Red River as a future source. Since Minn-Dak Farmers Cooperative was short only one year in 15, and no other years are estimated at even close to the 623 ac-ft demand, it seems reasonable to conclude that they will have adequate groundwater into the future.

Table 3.3.23 – Existing Industrial Facility Water Sources and Permitted Allocation.

Industrial Facility	Water Source	Permit #(s)	Annual Permitted Allocation (ac-ft)	Maximum Permitted Daily Withdrawal Rate (gpm)
ADM Corn Processing – Walhalla			1,800	1,500
	Icelandic Aquifer	3662	900	750
	Pembina River Aquifer	3662	900	750
American Crystal Sugar Company – Drayton	Red River	1076	2,250	6,600
American Crystal Sugar Company – Hillsboro	Goose River	1917	450	9,000
American Crystal Sugar Company – Moorhead	Red River	251	1,841	3,456
Cargill Corn Processing Plant			9,000	7,000
	Red River	4861	6,000	4,000
	Wahpeton Buried Valley Aquifer	4862	3,000	3,000
Cargill, Inc. – West Fargo	West Fargo Aquifer	3170	175	140
Cass-Clay Creameries, Inc.	Fargo Aquifer	3457	200	400
Central Livestock	West Fargo Aquifer	01298P	1,077	6,300
Minn-Dak Farmers Coop 1			350	2,400
	Wahpeton Buried Valley Aquifer	3898	215	1,200
	Wahpeton Buried Valley Aquifer	4121	135	1,200
RDO Foods Company	Grand Forks Aquifer	5041	400	400

The analysis in table 3.3.24 compares only permitted capacity with historic water use. The analysis does not address whether there will be adequate water in the hydrologic system, particularly in a drought situation. Seven of the 11 industrial permits evaluated use groundwater as a source. However, three of the five groundwater permits draw from the West Fargo Aquifer, which Ripley (2000) has identified as a water source which cannot be relied on through 2050. Therefore, Reclamation assumes that Cargill, Inc., in West Fargo, Cass-Clay Creameries, Inc., in Fargo, and Central Livestock in Fargo need to purchase water from Fargo or West Fargo in the future. Such industrial purchases from municipal water systems will, in effect, increase the demand on the Sheyenne River, the Red River, or both.

Four of the 11 industrial water permits evaluated use surface water sources. Three of the four appear to have an adequate permitted allocation of water, but this analysis does not guarantee adequate water supplies under all situations, such as a drought. Monthly water demands for existing industrial water systems that depend on surface water sources are listed at the end of this section.

Table 3.3.24 – Annual Average and Maximum Month Water Demand Analysis.

Industrial Facility	Water Source	Annual Permitted Allocation (ac-ft)	Average Annual Water Demand for Withdrawal Years (ac-ft)	Average Annual Water Demand Surplus or Shortage (ac-ft)	Annual Maximum Water Demand (ac-ft)	Annual Maximum Water Demand Surplus or Shortage (ac-ft)
Column No.	**2**	**3**	**4**	**5**	**6**	**7**
ADM Corn Processing – Walhalla ND	Icelandic Aquifer	900	85.8	814	183.6	716
ADM Corn Processing – Walhalla ND	Pembina River Aquifer	900	128.4	772	297.8	602
American Crystal Sugar Company – Drayton ND	Red River	2,250	377.5	1,873	1155.8	1,094
American Crystal Sugar Company – Hillsboro ND	Goose River	450	269	181	732.6	-283
American Crystal Sugar Company – Moorhead MN	Red River	1,841	63.4	1,778	104.3	1,737
Cargill Corn Processing Plant - ND	Red River	9,000	1929.5	7,071	2,104	6,896
Cargill, Inc. – West Fargo ND	West Fargo Aquifer	175	134.8	40	161.9	13
Cass-Clay Creameries, Inc. - ND	West Fargo Aquifer	200	118.6	81	150.8	49
Central Livestock - ND	West Fargo Aquifer	1,077	66.3	1,011	360.5	717
Minn-Dak Farmers Coop - ND	Wahpeton Buried Valley Aquifer	350	323.4	27	622.8	-273
RDO Foods Company - ND	Grand Forks Aquifer	400	161.2	239	256.9	143

Table 3.3.25 shows the comparison between maximum permitted peak daily water withdrawal rates and estimated peak daily withdrawal rates. Most of the industries did not provide historic peak day water use, so the peak daily water demand was estimated based on historic maximum month data.

All 11 permits evaluated have adequately permitted allocations to meet the estimated peak daily demands. However, three of the 11 industries use the West Fargo Aquifer, which is not a reliable future water source. Six of the 11 industries use surface water sources, which were evaluated in the surface water hydrologic model to determine reliability.

New Future Industrial Water Demands Future industrial water demands were evaluated by comparing existing industrial water demands and water permits to determine any potential shortages. Future water demands for new industries also are estimated in section 2.8, but the estimates could not compare uses allocated in water permits against projected demands. These future industrial water demands are assumed to be in the Grand Forks, Fargo, Moorhead, and Wahpeton areas. There is little additional groundwater that can serve these needs. Reclamation assumes that these facilities will be served by surface water sources. Monthly water demands for these future industrial facilities that will use surface water are discussed in surface water modeling at the end of this section.

Table 3.3.25 – Peak Daily Water Demand Analysis.

Industrial Facility	Water Source	Maximum Permitted Daily Withdrawal Rate (gpm)	Estimated Peak Daily Withdrawal Rate (gpm)	Peak Daily Water Demand Surplus or Shortage (gpm)
ADM Corn Processing – Walhalla ND	Icelandic Aquifer	750	250	500
ADM Corn Processing – Walhalla ND	Pembina River Aquifer	750	250	500
American Crystal Sugar Company – Drayton ND [1]	Red River	6,600	3,835	2,765
American Crystal Sugar Company – Hillsboro ND [1]	Goose River	9,000	2,153	6,847
American Crystal Sugar Company – Moorhead MN [1]	Red River	3,456	409	3,047
Cargill Corn Processing Plant - ND	Red River	7,000	2,083	4,917
Cargill, Inc. – West Fargo ND [1]	West Fargo Aquifer	140	102	38
Cass-Clay Creameries, Inc. - ND [1]	West Fargo Aquifer	400	95	305
Central Livestock - ND[1]	West Fargo Aquifer	6,300	227	6,073
Minn-Dak Farmers Coop - ND [1]	Wahpeton Buried Valley Aquifer	2,400	391	2,009
RDO Foods Company - ND [1]	Grand Forks Aquifer	400	161	239

[1] Daily withdrawal rate was estimated by using maximum monthly water demand divided by 30 days/month.

New Future Recreational Water Demands As with future industrial water demands, no permits were available to analyze future recreational water demands, which are estimated in chapter two, section 2.9. The projected recreational water demands are relatively small and only include some expansion of golf courses in the Red River Valley. There is little available groundwater in the valley, so Reclamation assumes that these water demands will be met from surface water sources. Monthly water demands for these future recreational facilities will be used in surface water modeling as discussed at the end of this section.

Summary of MR&I and Other Water Demands to be Modeled

Tables 3.3.26 and 3.3.27 show the monthly water demands estimated for MR&I and recreational water systems for Scenario One and Scenario Two, respectively. The table includes all water systems that will require surface water. This includes water systems which currently use surface water, water systems which currently use groundwater but will need to switch to surface water, and water systems which do not have enough groundwater and will need to turn to surface water to meet their shortages. Refer to Appendix A for more detail on how the monthly water demands were developed for each water system.

Table 3.3.26 – Monthly Water Demands – Scenario One.

Water System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
North Dakota Municipalities:													
Drayton	64	56	68	34	30	34	50	38	41	67	57	67	607
Fargo	2,408	2,144	2,513	2,619	3,502	4,549	5,005	3,812	3,099	2,540	2,838	2,652	37,682
Grafton	68	72	61	72	85	98	101	92	83	70	64	61	927
Grand Forks	1,249	1,217	1,314	1,286	1,565	2,108	2,533	1,999	1,559	1,537	1,507	1,329	19,205
Langdon	63	66	62	44	45	47	48	50	48	36	31	36	577
Valley City	65	66	61	61	80	116	104	111	67	58	53	53	894
West Fargo	257	240	266	275	345	446	669	505	339	318	341	261	4,261
Minnesota Municipalities:													
East Grand Forks	185	158	173	150	224	219	244	254	220	190	189	178	2,384
Moorhead	560	608	646	661	711	953	1,065	846	798	621	599	576	8,646
Rural Water System:													
Cass Rural Water Users District	34	32	30	50	76	87	116	102	56	48	26	45	702
Grand Forks-Traill Water District	25	26	0	155	83	141	41	74	5	32	25	0	605
Langdon Rural Water District	13	9	11	12	13	17	12	11	10	10	12	13	143
Industrial Users													
ADM Corn Processing	25	25	25	25	25	25	25	25	25	25	25	25	298
American Crystal Sugar Co. – Drayton	0	0	0	0	0	0	0	7	508	519	122	0	1,156
American Crystal Sugar Co. – Hillsboro	0	0	319	285	128	0	0	0	0	0	0	0	733
American Crystal Sugar Co. - Moorhead	0	0	40	54	10	0	0	0	0	0	0	0	104
Cargill Corn Processing Plant	155	161	181	179	180	184	197	182	184	149	158	194	2,104
Cargill, Inc. - West Fargo	13	13	13	13	13	13	13	13	13	13	13	13	162
Cass-Clay Creameries, Inc.	13	13	13	13	13	13	13	13	13	13	13	13	151
Central Livestock	30	30	30	30	30	30	30	30	30	30	30	30	361
Future Industrial Water Demands													
Fargo/Cass County	618	559	618	599	618	599	618	618	599	618	599	618	7,282
Grand Forks/Grand Forks County	575	519	575	557	575	557	575	575	557	575	557	575	6,771
Moorhead/Clay County	98	88	98	95	98	95	98	98	95	98	95	98	1,150
Wahpeton/Richland County	315	284	315	305	315	305	315	315	305	315	305	315	3,705
Future Golf Course Water Demands													
Cass County	0	0	0	3	31	59	71	77	35	13	0	0	288
Clay County	0	0	0	0	5	10	12	13	6	2	0	0	48

Water System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
Grand Forks County	0	0	0	0	5	10	12	13	6	2	0	0	48
Otter Tail County	0	0	0	0	4	7	8	9	4	1	0	0	33
Total	6,833	6,387	7,431	7,579	8,808	10,718	11,976	9,881	8,702	7,899	7,656	7,153	101,023

Table 3.3.27 – Monthly Water Demands – Scenario Two.

Water System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
North Dakota Municipalities:													
Drayton	64	56	68	34	30	34	50	38	41	67	57	67	607
Fargo	2,865	2,551	2,990	3,116	4,166	5,413	5,955	4,536	3,687	3,023	3,377	3,155	44,833
Grafton	103	109	92	109	129	148	153	139	125	105	97	92	1,401
Grand Forks	1,322	1,289	1,389	1,363	1,658	2,227	2,686	2,125	1,652	1,630	1,597	1,409	20,348
Langdon	63	66	62	44	45	47	48	50	48	36	31	36	577
Valley City	83	85	78	78	102	150	133	142	86	74	68	68	1,148
West Fargo	263	246	272	281	353	456	685	517	347	325	349	267	4,362
Minnesota Municipalities:													
East Grand Forks	257	219	240	209	311	305	340	353	306	264	262	248	3,313
Moorhead	685	748	796	815	880	1,189	1,334	1,052	991	764	735	706	10,696
Rural Water System:													
Cass Rural Water Users District	72	69	67	93	126	140	179	160	100	90	62	87	1,244
Grand Forks-Traill Water District	66	66	29	226	136	208	85	125	40	73	65	25	1,142
Langdon Rural Water District	24	16	20	22	23	32	23	20	18	18	23	25	264
Industrial Users													
ADM Corn Processing	25	25	25	25	25	25	25	25	25	25	25	25	298
American Crystal Sugar Co. - Drayton	0	0	0	0	0	0	0	7	508	519	122	0	1,156
American Crystal Sugar Co. - Hillsboro	0	0	319	285	128	0	0	0	0	0	0	0	733
American Crystal Sugar Co. - Moorhead	0	0	40	54	10	0	0	0	0	0	0	0	104
Cargill Corn Processing Plant	155	161	181	179	180	184	197	182	184	149	158	194	2,104
Cargill, Inc. - West Fargo	13	13	13	13	13	13	13	13	13	13	13	13	162
Cass-Clay Creameries, Inc.	13	13	13	13	13	13	13	13	13	13	13	13	151
Central Livestock	30	30	30	30	30	30	30	30	30	30	30	30	361
Future Industrial Water Demands													
Fargo/Cass County	1,091	986	1,091	1,056	1,091	1,056	1,091	1,091	1,056	1,091	1,056	1,091	12,850
Grand Forks/Grand Forks County	1,003	906	1,003	971	1,003	971	1,003	1,003	971	1,003	971	1,003	11,814
Moorhead/Clay County	148	133	148	143	148	143	148	148	143	148	143	148	1,740

Water System	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total (ac-ft)
Wahpeton/Richland County	548	495	548	530	548	530	548	548	530	548	530	548	6,448
Future Golf Course Water Demands													
Cass County	0	0	0	3	31	59	71	77	35	13	0	0	288
Clay County	0	0	0	0	5	10	12	13	6	2	0	0	48
Grand Forks County	0	0	0	0	5	10	12	13	6	2	0	0	48
Otter Tail County	0	0	0	0	4	7	8	9	4	1	0	0	33
Total	8,893	8,283	9,515	9,695	11,194	13,396	14,840	12,430	10,966	10,027	9,784	9,250	128,272

3.3.2 Development of Water Demands for GDU Import to Sheyenne River Alternative

The water demand methods for the GDU Import to Sheyenne River Alternative differ from the water demand methods of the other options. The GDU Import to Sheyenne River Alternative needs to account not only for maximum month demands, but also for peak day demands of selected water systems in the Red River Valley that depend on surface water.

Two methods were used to develop the water demands for this alternative. The first method used maximum month and peak day demand estimates from each water system. The second method used maximum month demand estimates and Grand Forks daily water use data.

Maximum Monthly and Peak Day Method

This method modified maximum monthly demands and monthly demands using a daily peaking factor to develop monthly water demand scenarios that addressed peak day water demands for each water system. For each water system, the water system's 12 maximum monthly water demands were multiplied by the ratio of the monthly demand to meet peak day for that system by the estimated overall maximum monthly demand for the system. The advantage of this method was that these estimates were developed for each water system. The disadvantage was that the ratio might be too high for the winter months. Generally, peaking ratios are lower in the winter and higher in the summer. This method assumed that the peaking ratio would be the same for the whole year. A full discussion of the method and tables that show all water system estimates is in Appendix B.

Maximum Month and Grand Forks Data Method

Historic daily water use data from Grand Forks for the years 1987-2001 were used to determine peaking ratios for all 180 months of the 15-year period. Monthly peak day water use was divided by monthly average water use to obtain monthly peaking ratios.

Three different monthly summary peaking ratios were calculated: (1) the average monthly peaking ratio, (2) the monthly peaking ratio during the month with maximum water use, and (3) the maximum monthly peaking ratio. The largest summary peaking ratios generally occurred during summer. Elevated maximum monthly peaking ratios occurred in April and May because of the very large volumes of water used for cleaning sanitary systems and flushing distribution lines in 1997 after the spring flood.

Using either the monthly peaking ratio during the month with maximum water use or using the maximum monthly peaking ratio is suitable for the objectives of this Project. The peaking ratio during the month with maximum water use is the most conservative approach, yields lower water demand results, and probably represents the lower end of the range. Using the maximum monthly peaking ratio results in higher water demand and represents the high end of the range.

The two methods for determining monthly peaking ratios have advantages and disadvantages. The maximum monthly and peak day method uses data specific to the water system, but may overestimate winter month water demand, because the same peaking ratio is used throughout the year. The maximum month and Grand Forks data method determines two likely seasonally distributed peaking ratios from Grand Forks, but these ratios may not be directly related to Fargo or other cities. One ratio may underestimate summer month water demand, while the other may estimate high demands, as did the maximum monthly and peak day method; but using high demands lowers the risk of being short on capacity. Because the three different peaking ratios have advantages and disadvantages, the most reasonable approach was to average the three ratios and use the averaged ratio as the adjusted maximum month peak day water demand for the GDU Import to Sheyenne River Alternative.

A full discussion of how the daily peaking ratios were determined and tables showing data and results are in Appendix B.

3.4 Surface Water Hydrology

The amount of water in a stream is related to the size of its watershed and climate. Surface water consists of all water naturally open to the atmosphere, and includes rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, and wetlands. Rivers are organized into networks, each with its own recharge area upstream and mouth downstream. Networks are ordered from a main river to secondary rivers, to streams, which correspond to river basins, subbasins, sub-subbasins, and so forth. A *watershed* is an area where all surface water shares the same drainage outlet. A *drainage divide* is the boundary of a watershed.

The remainder of this section focuses on the analysis of the surface water resources within the Red River Valley of North Dakota, South Dakota, and Minnesota. The discussion covers the surface water resources and the data that was collected to analyze them for modeling purposes.

3.4.1 Surface Water Quantity Overview in Red River Valley

The USGS has numerous stream gaging stations (gages) along rivers and streams throughout the United States. Data reviewed from this study are from gages located at various points in the Red River Basin. Figure 3.4.1 shows locations of some of the current gages along the Sheyenne and Red Rivers that are used by the USGS to evaluate water quantity.

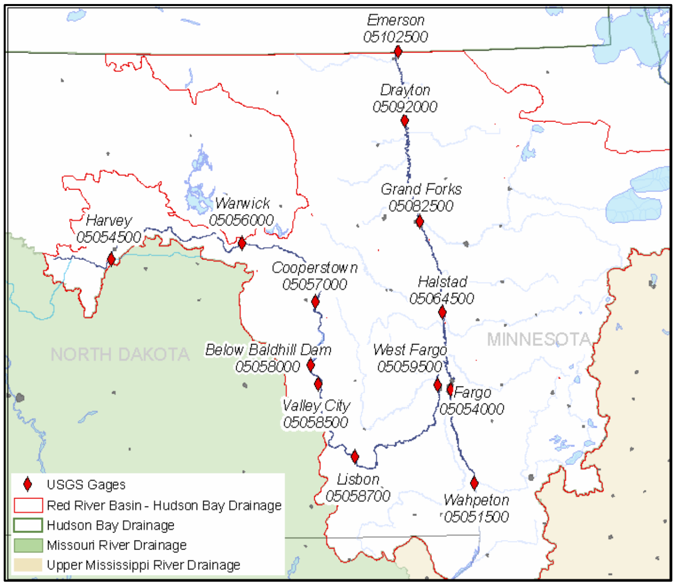


Figure 3.4.1 USGS Gage Stations along the Sheyenne River and Red River.

Surface water quantity is the amount of water available at a given point in a watershed, and is a function of stream stage and stream discharge. *Stage* is the height of the water surface above a specified elevation in a river and is commonly measured in feet. *Stream discharge* is the amount of water flowing in a stream at a particular stage, usually expressed as cubic feet of water flowing by each second (cfs). Typically, the higher the stream stage, the higher the discharge.

To measure the available water quantity, water allocations must be accounted for. Under North Dakota law, all the waters of the state belong to the public. Individuals, farms, businesses, and cities are granted the right to take water out of rivers (or pump it from the ground) for agricultural, industrial, domestic, or municipal uses. A water right must be obtained from the NDSWC to use water from any source in North Dakota. Water allocations in Minnesota are administered under riparian water law, as noted in section 3.1.

A water permit specifies the amount of water that can be taken, where the water must be withdrawn (also referred to as the diversion point), where it can be used, and for what purpose. The terms of the water permit cannot be changed without approval of the State Engineer. What is not limited, however, is the life of the water permit. Once granted, a perfected water permit continues indefinitely unless it is abandoned or forfeited for lack of use. Water permits have been required in North Dakota since 1905, as discussed in section 3.1.3 of this chapter.

Water quantity was evaluated for the Red River, Sheyenne River, Missouri River, and Lake of the Woods. The Red River and Sheyenne River were evaluated with StateMod modeling software, while a depletion analysis on the Missouri River and Lake of the Woods was performed separately to be used as part of the draft environmental impact statement (Reclamation and Garrison Diversion 2005). In addition to the Red and Sheyenne Rivers, there are other waterways in the Red River Basin; however, the two rivers serve as a main source of water and are most likely to be affected by at least one option. Changes to other water regimes are not proposed in this Project and, therefore, were not evaluated.

Red River

The Red River begins where the Otter Tail River and Bois de Sioux River join at Wahpeton, North Dakota, and Breckenridge, Minnesota, and flows northward 394 miles to the United States-Canadian boundary. From the international boundary, the Red River flows north another 155 miles and discharges into Lake Winnipeg. The slope of the river is extremely flat and falls only about 200 feet in its 394-mile course from Wahpeton to the international boundary (Miller and Frink 1984). The Red River is the centerpiece of the Red River Basin.

Parts of South Dakota, North Dakota, and Minnesota in the United States, and parts of Saskatchewan and Manitoba in Canada are drained by the Red River. Drainage area of the Red River at Emerson, Manitoba (USGS gage 05102500), is approximately 36,400 square miles, excluding closed basins such as Devils Lake (see figure 3.4.1. and http://nd.water.usgs.gov/pubs/wdr/wdrnd001/htdocs/d.05102500sw00.html).

The Red River receives most of its flow from its eastern tributaries because of regional patterns in precipitation, evapotranspiration, soils, and topography. Stream discharge increases from south to north. The banks of the Red River also have increasing capacity from south to north. Bankfull channel capacities on the mainstem of the Red River are 3,100 cfs at Wahpeton-Breckenridge, 7,000 cfs at Fargo-Moorhead, 27,000 cfs at Grand Forks, and 35,000 cfs at Emerson. Channel widths range from 200 to 500 feet, and depths at bankfull stage range from 10 to 30 feet (Miller and Frink 1984).

Because of climatic variability, flooding can be a major problem, which is aggravated by the flat slope of the Red River and the flatness of the over-bank areas. In contrast to flooding, there were several instances of zero flow during the 1930s and the summer of 1988. To provide some perspective, figure 3.4.2 shows the extreme variability of flow on the Red River.

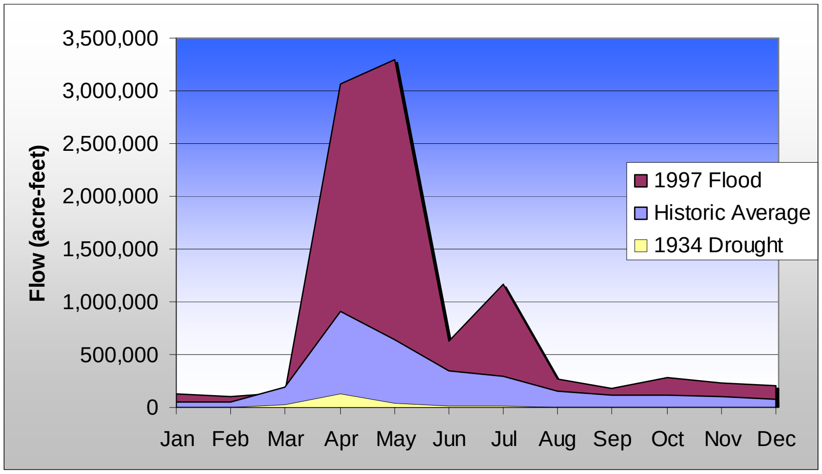


Figure 3.4.2 – Natural Flow on Red River.

The Red River is a source of drinking water for cities such as Moorhead, Minnesota, and Fargo, Grand Forks, Grafton, and Drayton, North Dakota. The river also supplies irrigators and industries with water throughout the valley. Currently, there are 119 municipal, industrial, and irrigation permits on the Red River, allocating 254,955 ac-ft of water. North Dakota permit data can be accessed on NDSWC’s website: http://www.swc.state.nd.us/permits.html. Minnesota permit data can be obtained from MNDNR.

Sheyenne River

The Sheyenne River originates in Sheridan County in central North Dakota and winds its way through south-central North Dakota, ultimately emptying into the Red River north of Fargo. In its course, the Sheyenne River traverses a variety of North Dakota terrains, including flat plains, rolling sand hills, wide bottomland, tall-grass prairie, and hardwood forests. Like the Red River, the Sheyenne's slope is fairly flat and falls about 846 feet over approximately 542 miles, for an average slope of 1.6 feet per mile (WEST Consultants 2001).

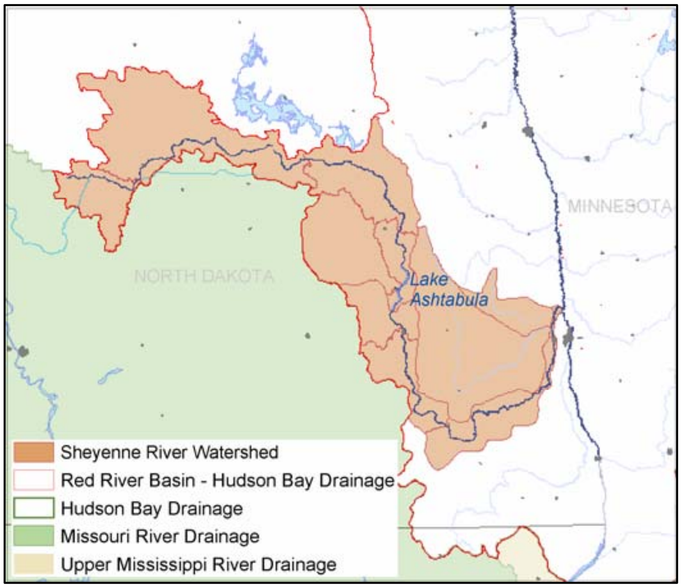


Figure 3.4.3 - The Sheyenne River Watershed within the Red River Basin.

The watershed for the Sheyenne River is approximately 7,200 square miles, excluding the Devils Lake Basin, and is shown in figure 3.4.3. The Sheyenne River drains parts of 16 counties in North Dakota. The Sheyenne River is divided into twelve subbasins for modeling purposes.

From its headwaters in Sheridan County to the top of Lake Ashtabula, the Sheyenne River is considered a free-flowing river, although there is a culvert control structure at Harvey, North Dakota, and a low-head dam near Warwick, North Dakota. This reach of the river has records of past instances of no flow. Flow in the lower reaches of the river is regulated by releases from Baldhill Dam.

Baldhill Dam was constructed by the Corps (U.S. Army Corps of Engineers) and began operating in 1950. The dam, located approximately 16 miles north of Valley City, North Dakota, backs up water from the upper Sheyenne into a reservoir called Lake Ashtabula. Lake Ashtabula's purpose is to augment low flow to meet downstream water supply and pollution abatement objectives and to reduce flooding in the Sheyenne River Valley. Recreation and fish and wildlife enhancement are secondary objectives of the dam operation plan. The dam recently was raised to provide increased flood control. The capacity of the reservoir at maximum pool elevation of 1273.2 feet is 116,500 ac-ft.

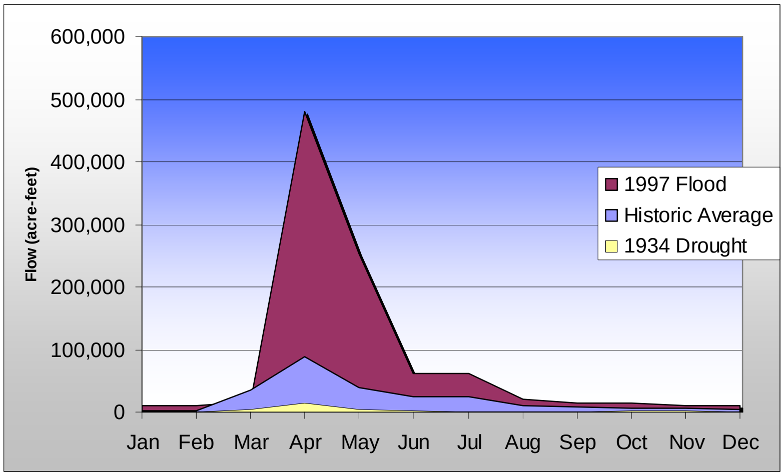


Figure 3.4.4 – Natural Flow on Sheyenne River.

Figure 3.4.4 shows the natural flow on the Sheyenne River. The extreme flow variability trends are the same as those shown for the Red River in figure 3.4.2. Flow patterns for the Red River and Sheyenne River are typical of northern prairie rivers that receive a majority of their water from snowmelt and spring precipitation, as shown by peak discharges that occur each year in March and April.

Cities such as Valley City, Lisbon, West Fargo, and Fargo use the Sheyenne River as a source of drinking water. The river also supplies water for irrigation and industrial uses. Currently, there are 77 municipal, industrial, and irrigation permits on the Sheyenne River allocating 70,215 ac-ft of water.

Missouri River

The Missouri River extends 2,619 miles from its source at Hell Roaring Creek and 2,321 miles from Three Forks, Montana, where the Jefferson, Madison, and Gallatin Rivers converge. The Missouri River is the longest river in the United States, draining one-sixth of the country. The system (Missouri River system) consists of six dams and reservoirs located in Montana, North Dakota, South Dakota, and Nebraska. Its storage capacity is 73.4 MAF of water, which makes it the largest reservoir system in North America. The system is operated by Corps to serve congressionally authorized project purposes of flood control, navigation, irrigation, hydropower, water supply, water quality, recreation, and fish and wildlife. Water is released from the system as needed for downstream purposes. Released water from the lowest dam in the system, Gavins Point Dam, flows down the lower river, which includes Corps's Bank Stabilization and Navigation Project from Sioux City, Iowa, to St. Louis, Missouri (for more information, see http://www.nwo.usace.army.mil/html/Lake_Proj/missouririver/stabilization.html)

The Master Manual (Missouri River Master Water Control Manual) records the basic water control plan and objectives for the integrated operation of the mainstem reservoirs and guides the operation of the Corps's Mainstem Reservoir System (Corps 2004).

Lake of the Woods

Lake of the Woods lies on the border between the United States and Canada and is located in Minnesota, Ontario, and Manitoba. The lake covers nearly 1,500 square miles, including islands. Lake of the Woods is in the Rainy River Basin, which has a total area of 27,114 square miles. Of the total basin area, 11,244 square miles (41%) are in Minnesota, and 15,870 square miles (59%) are in Canada (MPCA 2001). The Lake of the Woods portion of the basin has extensive wetlands and is located on the glacial Lake Agassiz lakebed.

Other than spring melt and precipitation, the main source of inflow to the lake is the Rainy River, which on average comprises 65% to 70% of the river inflows (Walden 2004). At the northeast portion of the lake, there are two outlets: the Kenora generating station and the Norman generating station (Kopechanski 2005). These two hydropower facilities are used to regulate lake levels by the Canadian Lake of the Woods Control Board , in compliance with the 1925 Lake of the Woods Convention and Protocol, established by the International Joint Commission. The two outlets are the headwater source for the Winnipeg River, which travels northwest into Lake Winnipeg in Manitoba. Originally there were three natural outlets on the northern portion of the lake. These outlets were dammed to allow the water in the lake to rise (MPCA 2001).

3.4.2 Purpose and Scope of Modeling Effort

During wet years, there are adequate water sources to meet future water demands in the Red River Valley, but during a drought there will be water shortages. Water shortages were estimated for the service area using a hydrologic model called StateMod. StateMod is a computer modeling program used to evaluate timing of river flows, water withdrawals, return flows, precipitation, and evaporation at many locations throughout the Red River Basin. The model is a water appropriation tool that was used to evaluate water supply options for the Project. Specific modeling objectives were to:

- Examine surface water supply conditions to estimate 2005 and 2050 water supply shortages.
- Develop water supply options to meet future water needs.

The modelling effort was applied to the entire U.S. portion of the Red River Basin, from the headwaters to the international border at Emerson, Manitoba, Canada. Historic data from many sources for the period 1931-2001 were used. Water demands from chapter two were used for modeling Scenarios One and Two.

3.4.3 Hydrologic Data Collection and Sources

Hydrologic modeling relies on past studies (described in section 3.1.2) and expands upon them. Hydrologic data collection and sources include permitted historic water use data; USGS gaging station flow data; evaporation and precipitation data; and analysis of reservoir characteristics of several reservoirs within the Red River Basin, including Lake Ashtabula, Lake Traverse (including Mud Lake) and Orwell Lake, and Upper and Lower Red Lakes. Data characteristics and the uses of these data in building the hydrologic model are described in the next sections.

Permitted Historic Water Use Data

Permitted historic withdrawal and return flow data for the Red River Basin were obtained from databases of the NDSWC, MNDNR, the South Dakota Department of Environmental and Natural Resources, and the Environmental Protection Agency.

Monthly totals of withdrawal and return flow data were required for modeling. Withdrawal data are typically reported as either monthly or annual totals in the databases, and monthly totals were compiled directly from the databases. Annual totals were divided evenly among 12 months if no additional determining data are available. If a correlation was determined between similar users with corresponding monthly and annual totals, then an annual total was distributed as monthly totals. Return flows are often reported as the number of days flow was discharged from a facility rather than as monthly totals. The number of days of discharge were used to compile monthly totals.

Withdrawal data are categorized by their permits as municipal, industrial, irrigation, or other. *Municipal water use* describes water used by public or private suppliers and delivered to urban users. *Industrial water use* is water used for industrial purposes by industries that hold individual water permits. *Irrigation water use* supplies water for crops to supplement rainfall. If irrigation water use was reported as an annual total, then monthly irrigation totals were derived from monthly usage percentages based on irrigation type as supplied by NDSWC. This method was applied to irrigation permits valley-wide. Other water use incorporated a variety of uses including recreation, fish, and wildlife.

All permitted water use databases undergo constant review and revision; therefore, information presented here may not be completely current. A full discussion of permitted historic water use is in Macek-Rowland (et al. 2004). Figure 3.4.5 shows the withdrawal node locations used by StateMod.

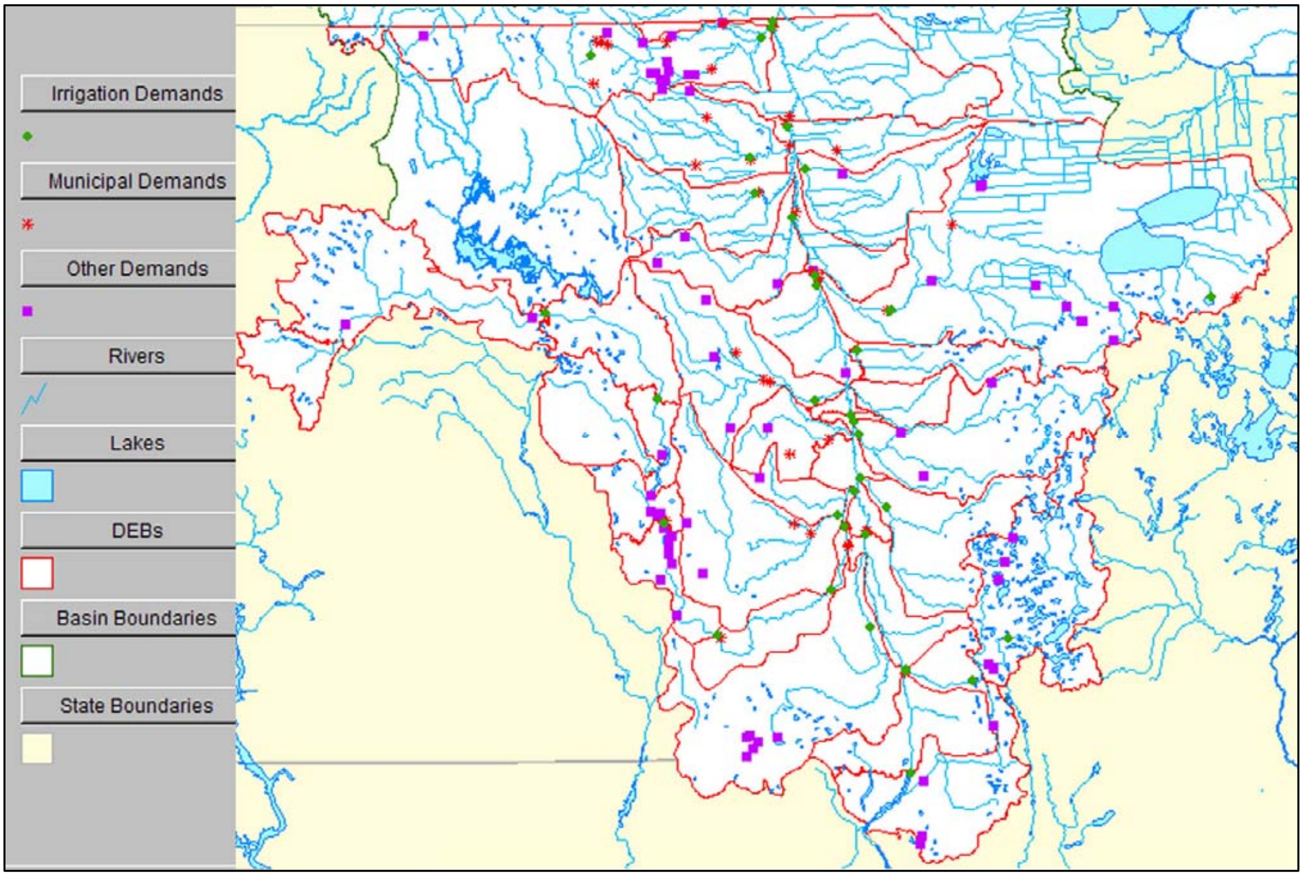


Figure 3.4.5 – Withdrawal Nodes Used in Modeling.

USGS Gaging Station Flow Data

Historic and estimated monthly streamflow data for 1931-2001 were compiled for 35 gaged and ungaged sites (figure 3.4.5) in the Red River Basin (Emerson 2005). These 35 sites are similar to the sites used in an earlier modeling effort (Reclamation 1998). The period 1931-2001 was chosen because nine streamflow gaging stations in the basin had complete monthly data for those years. Streamflow data compiled for the 35 sites included four sites that had monthly streamflow data for 1931-2001. Of the remaining 31 sites, 10 had monthly streamflow gage data for part of the 1931-2001 period, and 21 had no monthly streamflow data gaged data. Gaged data for 27 other gaging stations were used to estimate missing streamflow data for 31 of the 35 sites.

A modified drainage-area ratio method was used to estimate missing 1931-2001 monthly streamflow data for gaged sites with incomplete records and for ungaged sites located near gaged sites on the same stream. Modified drainage-area ratios for ungaged sites were computed using historic and estimated gaged data. The ratio of the drainage area of the site of interest was divided by the drainage area of a base station; that ratio was multiplied by the streamflow at the base station to estimate streamflow at the site of interest. Usually, the base station is a gaging station nearest the site of interest. This method can produce varying results because there are variations in contributing drainage areas from wet to dry years. A water-balance method was also used to estimate missing streamflow data when a sufficient amount of data were available. Complete discussions of the methods are in Emerson (2005).

Evaporation and Precipitation Data

Adequate estimates of evaporative losses from three reservoirs, Lake Ashtabula in North Dakota, Orwell Lake in Minnesota, and Lake Traverse in Minnesota and South Dakota are needed to determine the total water supply in the Red River Basin for future water quantity and quality needs. The energy budget method gives the most rigorous estimate of evaporation. This method relies on the optimum placement of sensors in and around a reservoir. However, the energy budget method requires measurements of atmospheric and environmental variables not commonly obtained at most meteorological stations. Therefore, a combination of (1) air temperature data from several meteorological stations near the reservoirs and (2) evaporation data from USGS energy budget sites in North Dakota and Minnesota were used to estimate monthly evaporation from the three reservoirs for 1931-2001. A full explanation of the method is in Vining (2003).

Monthly precipitation data and monthly evaporation data for the reservoirs were used to provide a better estimate of water balance for each reservoir. Net evaporation is the value of monthly evaporation minus monthly precipitation. Monthly precipitation data were calculated using data from meteorological stations near each reservoir for the period 1931-2001. Lake Ashtabula monthly precipitation data were calculated from Valley City and Cooperstown data, Orwell Lake data were calculated from Campbell and Fergus Falls data, and Lake Traverse data were calculated from Wheaton and Victor data. If the two meteorological stations used for calculating reservoir precipitation had data missing for the same month, then the 1971-2000 normal values for the two stations were used to calculate reservoir precipitation.

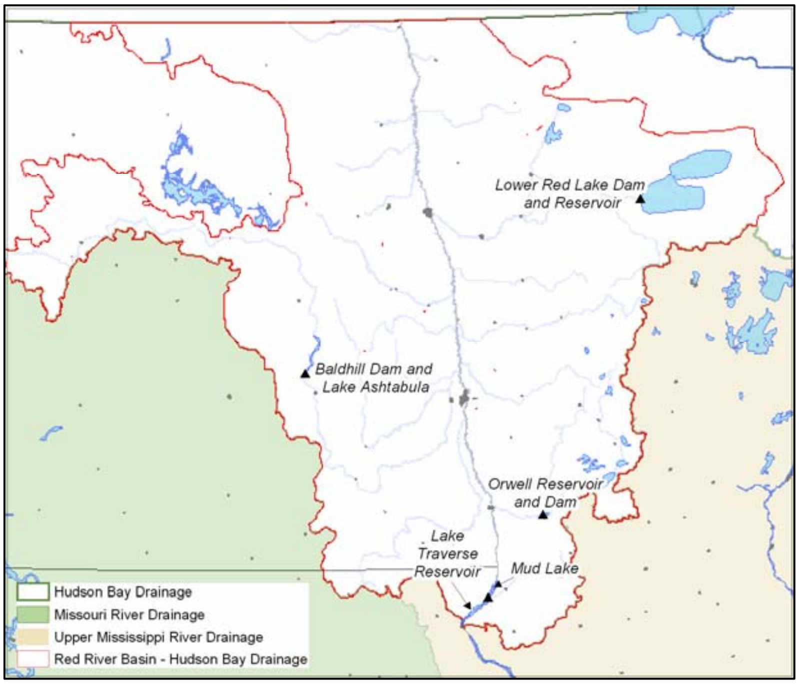


Figure – 3.4.6 – Reservoir Systems within the Red River Basin.

Reservoir Characteristics

Four reservoir systems in the Red River Basin (Lake Ashtabula, Lake Traverse [including Mud Lake], Orwell Lake, and Upper and Lower Red Lakes) are considered water-supply contributors for this study (figure 3.4.6). Mount Carmel Dam and Reservoir also was considered as a water supply source, but it only benefits Langdon and the Langdon Rural Water District. Other smaller reservoirs and impoundments are considered too small to provide any substantial water supply, especially during drought conditions. All end-of-month reservoir content data and area capacity curve data are from Corps. Additional reservoir surface area data are from USGS.

Lake Ashtabula Lake Ashtabula is the primary surface water-supply reservoir in the Red River Basin. Baldhill Dam and Lake Ashtabula were constructed in the 1950s and authorized to serve for water supply and flood control. The original capacity of Lake Ashtabula was 70,700 ac-ft at the top of the conservation pool. Capacity was reduced by 5,000 ac-ft in simulating future options to account for an estimated amount of sediment deposition by 2050. End-of-month reservoir content was calculated as the sum of the inflow, less bypasses, M&I (municipal and industrial) releases, and evaporation. For the year 2050 condition, Lake Ashtabula contents were limited to 65,700 ac-ft from March through September. To accommodate spring flood control, reservoir releases were simulated, starting in October, to lower the reservoir content to 52,250 ac-ft by the first of March. Lake Ashtabula design characteristics are shown in table 3.4.1.

Table 3.4.1 – Lake Ashtabula Characteristics.

Description	Elevation (feet above sea level)	Content (ac-ft)	Area (Acres)
Dam Height	61.0	-	-
Top of Dam Elevation	1278.5	158,000*	8,400*
Top of Flood Pool (feet)	1273.2	120,000*	7,150*
Top of Overflow Spillway Crest	1271.0	105,000*	6,600*
Top of Gates (proposed)	1271.0	105,000*	6,600*
Top of Gates (present)	1267.0	80,000*	5,700*
Top of Conservation Pool	1266.0	67,5600	5,300
Top of Desired Fish and Wildlife Pool	1257.0	28,000	1,500
Top of Service Spillway Crest	1252.0	18,000*	2,250*
Top of Dead Pool and Outlet Works	1238.0	1,200	350*

Outlet Works Capacity
@ 1266.0 feet = 22,000 cfs
@ 1273.2 feet = 43,100 cfs

Downstream Channel Capacity = 2,400 cfs

* Estimated from original area-capacity curve

Releases were made on a straight-line basis to accommodate monthly decrease in reservoir content. For October through February, reservoir content was allowed to be drawn down for flood control purposes. Although the dead pool is 1,200 ac-ft, a minimum capacity of 28,000 ac-ft (elevation 1257 feet) was selected as a point to stop withdrawals (Corps 1983). At elevation 1257 feet, the reservoir still has a surface area of about 1,500 acres. Maintaining a minimum pool is desired for recreation and fish and wildlife (Corps 1983). The surface area drops off very rapidly below this level. Lake Ashtabula has no formal drought operation plan. Rather, during dry periods, the users and the State can modify operations in cooperation with Corps on an as-needed basis.

Monthly net evaporation was figured by using the computed net evaporation rate and the reservoir surface area, based on the capacity at the end of the previous month. The end-of-month surface area was estimated using an equation of area as a function of capacity. Capacity was derived from an area capacity table obtained from Corps. Free water surface evaporation minus normal monthly precipitation gave an estimated average net evaporation rate for Lake Ashtabula of about 22 inches annually.

The state of North Dakota recognizes city storage allocations as part of the Thompson-Acker Plan, described in a NDSWC Office Memo of November 27, 1992, from Craig Odenbach, Water Resource Engineer, to Milton Lindvig, Director Hydrology Division, on Lake Ashtabula Allocations (NDSWC [1992]; see also NDSWC [2005a]). Based on the memo, municipalities with storage rights from Lake Ashtabula are assumed to be entitled to their permitted amounts without regard to a priority or permit date. The total Thompson-Acker distribution of reservoir volume is as follows:

Fargo	56.1%
Grand Forks	31.3%
Valley City	10.5%
West Fargo	1.5%
Lisbon	0.6%

In addition to the Thompson-Acker M&I distribution on Lake Ashtabula, there is a 13 cfs “minimum downstream flow requirement” (Corps 2005), which is part of the basic aquatic environment need used in modeling the options.

Lake Traverse (including Mud Lake) and Orwell Lake Lake Traverse is formed from Reservation Dam and a dike at its uppermost extent. Water from Lake Traverse flows north into Mud Lake. White Rock Dam, which forms Mud Lake, is located north of Lake Traverse and controls water flowing into the Bois de Sioux River. Together, Lake Traverse and Mud Lake have a surface area of about 15,000 acres. Orwell Lake is formed by Orwell Dam and has a surface area of about 1,540 acres.

Details regarding the operation of Lake Traverse (including Mud Lake) on the upper Red River (Bois de Sioux River) between South Dakota and Minnesota and operation of Orwell Lake on the Otter Tail River in Minnesota are not fully developed here. Instead of detailed operations of the reservoir, only depleted outflows resulting from operations are used as inflow in the upper reaches of the Red River. The depleted flows entering the Red River from these reservoir systems are assumed to account for operational releases, spills, evaporation, and flood control. It also is assumed that any net changes in the water budgets of these reservoirs are insignificant.

Upper and Lower Red Lakes The lakes are composed of an upper and lower portion and are operated by Corps. Upper Red Lake has a surface area of 168.5 square miles, a maximum depth of 20 feet, and an average depth of 3 feet. Lower Red Lake has a surface area of 245.6 square miles, a maximum depth of 35 feet, and an average depth of 18 feet.

Until the early 1930s, the outflow from the Red Lakes was uncontrolled. The BIA (Bureau of Indian Affairs) constructed the original control structure on Lower Red Lake in 1931. Modifications to the structure in the river channel downstream came later and were completed in 1951. At this time, BIA turned control over to Corps. Currently, the operation of the Red Lakes is in accordance with an agreement between the Red Lake Band of Chippewa Indians and the

Corps. When the level of the Red Lakes is between 1173.5 and 1172.0, the outflow is regulated not to exceed 50,000 ac-ft annually. When the lake level is below the minimum conservation pool elevation of 1171.0, the maximum release from the reservoir is 15 cfs and the minimum is 5 cfs.

DEBS

The Red River Basin was divided into 35 subbasins based on locations of USGS streamflow-gaging stations and locations of specific reaches on the Red River and its tributaries. Subbasin boundaries were delineated using GIS (Geographical Information Systems) software and the National Hydrography Dataset for North Dakota, Minnesota, and South Dakota. These subbasins were used to identify surface withdrawal and return flow points that were used to estimate naturalized streamflows for the 35 gaged and ungaged sites in the basin. These contributing areas were called Doug Emerson Basins, or DEBs. The DEBs locations and the 35 gaged and ungaged sites are shown in figure 3.4.7. The associated watershed names are listed just after the figure in table 3.4.2.

Gage Locations

Gage locations currently used by USGS to evaluate water quantity in the Red River Basin are shown in figure 3.4.1. To enhance surface water modeling and to incorporate into USGS's naturalized flow database (Emerson 2005), Reclamation required USGS to develop historic and naturalized flow data at additional nodes. Additional flow nodes were located at the confluence of the Sheyenne and Red Rivers and at the mouths of all major tributaries to these rivers. To complete this effort, data were collected from multiple gages and flow points within the basin (figure 3.4.8). Flow nodes used in the surface water model are shown in figure 3.4.9.

Historic vs. Naturalized Flow

Reclamation entered into an interagency agreement with USGS to develop both historic and naturalized flow data sets for the Red River Basin (Emerson 2005). *Historic flow*, also referred to as *regulated flow*, is recognized as the flow recorded over the past at a gaging site(s). No attempt has been made to remove the effect humans have imposed on flow through regulation. *Naturalized flow*, also known as *unregulated flow*, is regressed from the historic flow by removing humans' influence. Naturalized flow is used in watershed evaluations and modeling as a baseline. Working from the naturalized flow baseline, variations of demands, return flows, and operational considerations can be applied to simulate options that are analyzed in planning.

Historic monthly streamflow data for 1931-2001 were compiled for 35 gaged and ungaged sites in the Red River Basin (Emerson 2005). Naturalized streamflows were determined by adjusting historic streamflow to reflect the absence of water resource developments. The adjustments eliminated the hydrologic effects of Orwell Dam, Reservation Dam, White Rock Dam, Baldhill Dam, surface-water withdrawals, and return flows. The hydrologic effects of small ponds and reservoirs constructed during the 1931-2001 period were not considered in estimating naturalized streamflows.

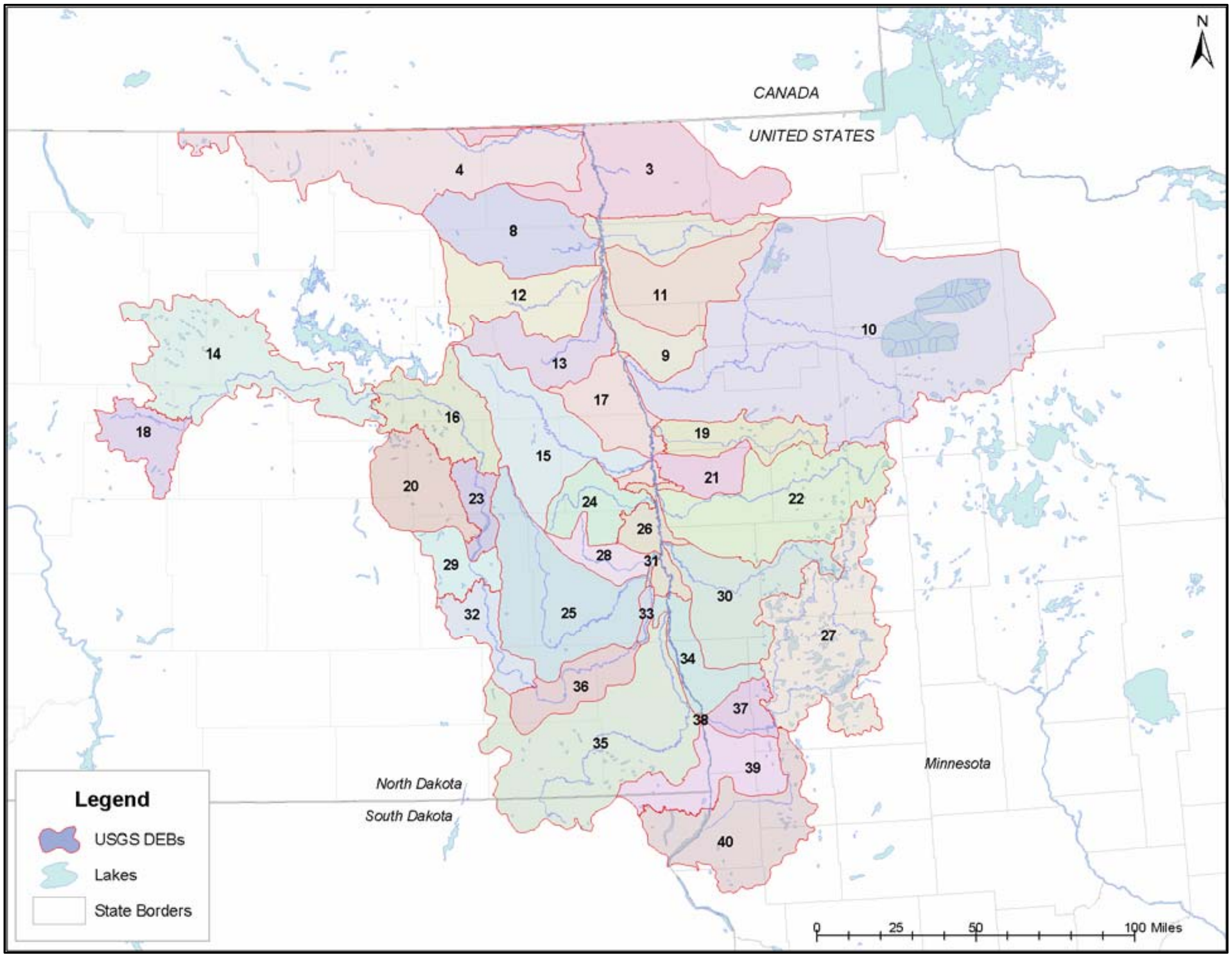


Figure 3.4.7 – USGS DEB Watersheds of the Red River Basin.

Table 3.4.2 – USGS DEB Watershed Names.

DEB	Watershed	DEB	Watershed
3	Red River at Emerson	24	Maple River
4	Pembina River	25	Elm River
8	Park River	26	Red River at Halstad
9	Red River at Drayton	27	Otter Tail River above Orwell
10	Red Lake River	28	Rush River
11	Snake River	29	Sheyenne River at Valley City
12	Forest River	30	Buffalo River
13	Turtle River	31	Sheyenne River at Mouth
14	Sheyenne River near Warwick	32	Sheyenne River at Lisbon
15	Goose River	33	Sheyenne River at West Fargo
16	Sheyenne River near Cooperstown	34	Red River at Fargo
17	Red River at Grand Forks	35	Wild Rice River, ND
18	Sheyenne River above Harvey	36	Sheyenne River at Kindred
19	Sand Hill River	37	Otter Tail River
20	Baldhill Creek	38	Red River at Wahpeton
21	Marsh River	39	Bois de Sioux River at Mouth
22	Wild Rice River, MN	40	Bois de Sioux River above Lake Traverse
23	Sheyenne River below Baldhill Dam		

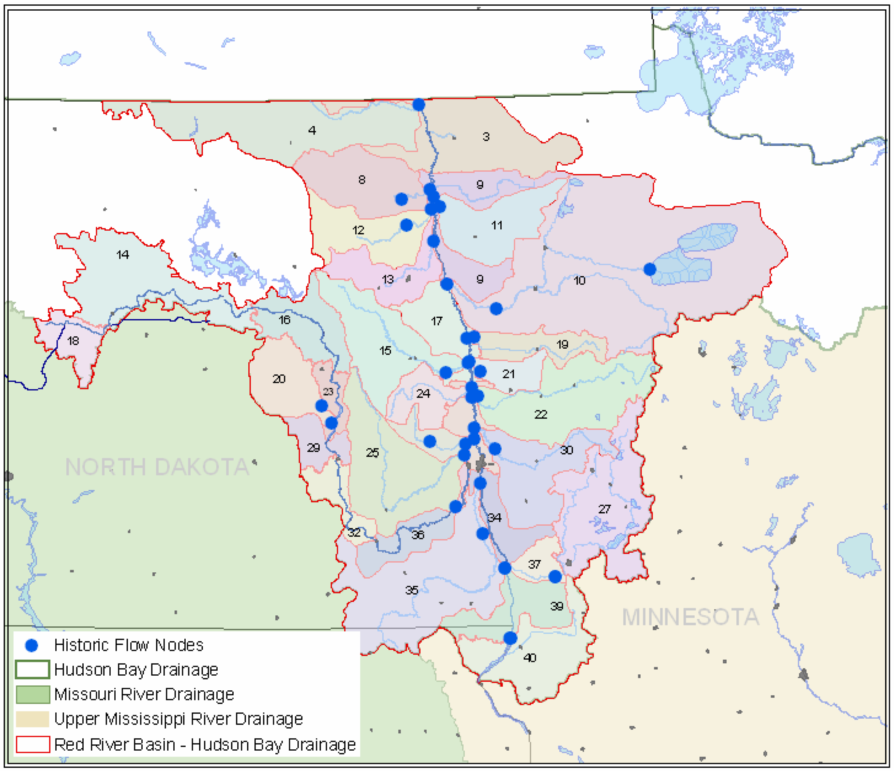


Figure 3.4.8 – Additional Flow Nodes Used by USGS.

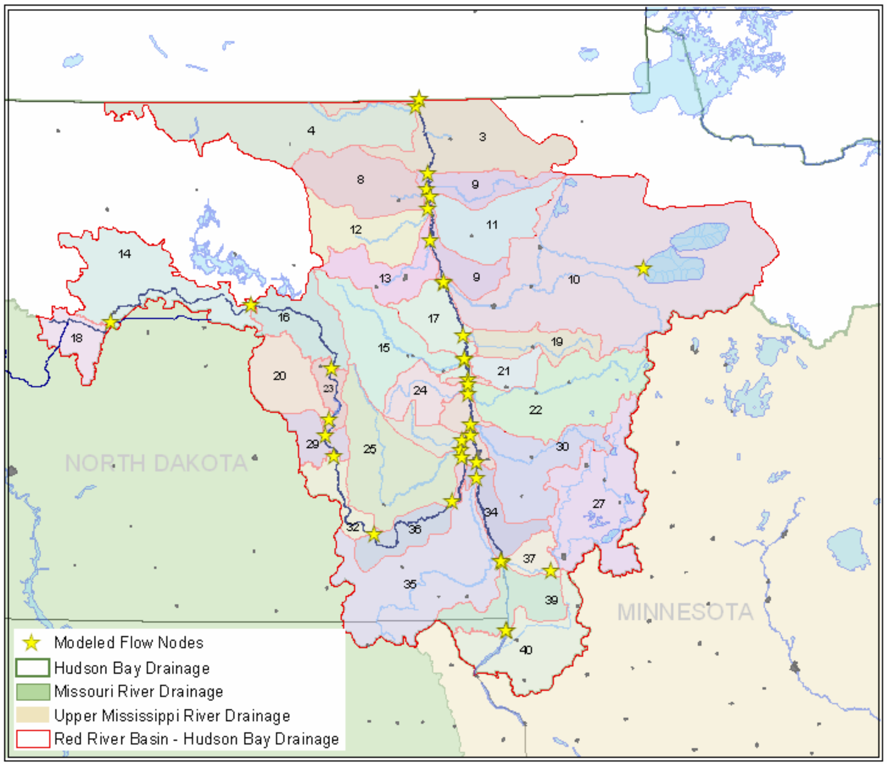


Figure 3.4.9 – Flow Nodes Developed for Modeling.

At most of the selected sites, naturalized streamflows were estimated by adding surface-water withdrawals to and subtracting return flows from the gaged and estimated historic streamflows at the sites. At other sites, naturalized streamflows were estimated in a series of calculations: (1) determining the difference between the naturalized and the gaged and estimated historic streamflows for the site immediately upstream from the site of interest (2) adding the gaged and estimated historic streamflows for the site of interest, and (3) adding the surface withdrawals that occurred between the site of interest and the site immediately upstream, (4) then subtracting the return flows that occurred between the site of interest and the site immediately upstream, and (5) subtracting the difference between the naturalized and the gaged and estimated streamflow for tributary inflow between the site of interest and the site immediately upstream. A complete discussion on estimating naturalized monthly streamflows at the 35 sites is in Emerson (2005).

3.4.4 Surface Water Quality Overview

Reclamation contracted with USGS to evaluate water quality needs in the Red River Valley. The resulting report (Tornes 2005) summarized water quality data collected by USGS in the Red River Basin in Minnesota, North Dakota, and South Dakota, and analyzed those data to determine whether the water quality of streams in the basin is adequate to meet future needs. The following discussion is excerpted from the report’s summary and conclusions.

> For the Red River at Emerson, Manitoba, site, pH values, water temperatures, and dissolved oxygen concentrations generally were within the criteria established for the protection of aquatic life. Dissolved solids concentrations ranged from 245 to 1,100 milligrams per liter. Maximum sulfate and chloride concentrations were near, but did not exceed, the established secondary maximum contaminant level. Nutrient concentrations generally were less than those for smaller streams that drain agricultural areas, possibly because of the integrating effect of the stream system at Emerson. The trace elements considered potentially harmful generally were at concentrations that were less than the established guidelines, standards, and criteria. When lead was detected, the concentrations were 11 micrograms per liter or less. The concentrations that were detected may have occurred as a result of sample contamination.
>
> For the Red River upstream from Emerson, Manitoba, sites, pH values rarely exceeded the criterion established for the protection of aquatic life, and water temperatures occasionally exceeded the criterion. Dissolved oxygen concentrations occasionally exceeded the criterion during the 1970’s. Many constituent concentrations for the Red River below Fargo, North Dakota, site exceeded water quality guidelines, standards, and criteria. However, the trace element exceedances could be natural or could be related to pollution or sample contamination.
>
> For the Sheyenne River sites, pH values rarely exceeded the criterion established for the protection of aquatic life. Water temperatures and dissolved oxygen concentrations generally were within the criterion. Sodium concentrations generally were much less than 100 milligrams per liter for sites downstream from the Sheyenne River above Harvey, North Dakota, site. At many sites, the sulfate

concentrations occasionally exceeded the established drinking water standard of 250 milligrams per liter. Median arsenic concentrations typically were 4 micrograms per liter or less, and maximum concentrations occasionally exceeded the 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.

Many of the tributaries in the western part of the Red River Basin had median specific conductance values that were greater than 1,000 microsiemens per centimeter. Sulfate concentrations occasionally exceeded the established drinking water standard. Median arsenic concentrations were 6 micrograms per liter or less, and maximum concentrations rarely exceeded the 10 microgram per liter drinking water standard that is scheduled to take effect in 2006. The small concentrations of lead, mercury, and selenium that occasionally were detected may have been a result of sample contamination or other factors.

The tributaries in the eastern part of the Red River Basin had median specific conductance values that were less than 1,000 microsiemens per centimeter. For the Bois de Sioux River near Doran, Minnesota, site (which was included with the tributaries in the eastern part of the basin), one-fourth of the samples had specific conductance values that were greater than 1,340 microsiemens per centimeter. The sulfate concentrations for the Doran site often exceeded the established drinking water standard of 250 milligrams per liter. All other measurements for the Doran site indicated the concentrations were within established water quality guidelines, standards, and criteria. Data reviewed for the Otter Tail River indicated no exceedances of water quality guidelines, standards, and criteria. The dissolved oxygen concentration for the Wild Rice River at Hendrum, Minnesota, site was less than 1 milligram per liter during low flow. The minimum concentration for the Wild Rice River at Twin Valley, Minnesota, site was 3.1 milligrams per liter. All constituent concentrations for the Red Lake River at Crookston, Minnesota, site were within established guidelines, standards, and criteria.

Concentrations of pesticides that were detected and that had regulatory limits were less than the cited water quality guidelines, standards, and criteria. Concentrations of compounds that were detected generally were less than the sediment quality standards and criteria.

The data considered in this report generally provide a good baseline from which to evaluate changes in water quality conditions. However, because many of the trace elements detected, including lead and mercury, may have been the result of sample contamination, additional data are needed to confirm that trace element concentrations generally are low. Concentrations of major ions, including sulfate, and specific conductance may continue to approach drinking water standards during periods of low flow because the streams, particularly those in the western part of the basin, are sustained mostly by groundwater discharge that generally has large dissolved solids concentrations.

3.5 Surface Water Modeling

3.5.1 Model Selection Process

While previous modeling efforts for the Red River provided valuable information, they were not considered to be feasibility-level efforts. During this phase, Reclamation worked to improve modeling accuracy by enlisting the help of members of a Technical Team to develop criteria and to select modeling software which would best achieve the goal.

Model Capabilities and Constraints

The first capability considered was the type of model that would be used for this analysis. With differing types of models available, it was agreed that a water availability model would be used for this effort. A *water availability model* is a computer program that calculates the amount of water in a river basin using hydrologic principles and measurements taken at stream gages.

Evaluation criteria developed by the Texas Natural Resource Conservation Commission (known after September 2002 as TCEQ [Texas Commission on Environmental Quality]) were used as a template for selecting models. With the template and input from Technical Team Hydrology Subgroup breakout sessions, a list of capabilities and constraints was identified. This process led to developing a matrix of 58 criteria that were used to rank various models. This matrix, and the data used to develop it, are in Appendix B. Each criterion was associated with a level of importance and with whether it was a desired or required aspect of the modeling to be performed. Finally a scoring system was applied.

Data Requirements

For this Project surface water modeling data are required for both the historic record and for the predicted future. The following is a basic checklist of the required historic and predicted future data sets:

Model Development

- River Network (geographic location of nodes)
- Water Use (demands)
- Water Rights
- Return Flow
- Stream Flow
- Evaporation
- Precipitation
- Reservoir Characteristics

Simulation of Options

- Future Water Use of Existing and Future Demands
- Return Flows Associated with Future Demands
- New Water Rights Covering New Users
- Operational Changes to Reservoirs

These data were required for any water availability model selected. To save time, collection of model development data sets began before selection of the model was completed.

Model Assessments

Upon development of the matrix for the criteria for selecting a model, the following list was developed and implemented:

1. Identify expert users of each model (table 3.5.1)
2. Distribute questionnaires to expert users.
3. Receive completed questionnaires.
4. Review answers to each question and fill in matrix in relation to other models.
5. Contact model reviewers about inconsistent answers.
6. Update matrix based on new information.
7. Calculate scores based on importance level.
8. Total score for each model.
9. Review data requirements for each model.
10. Add data requirement rating to matrix and recalculate score.
11. Complete model evaluation report.

Table 3.5.1 – Sources Used to Review Water Availability Models and the Resulting Scores.

Model	Reviewer	Agency	Score
StateMod	Ray Bennett	State of Colorado	1620
MODSIM-DSS	Nancy Parker	Reclamation	1554
HYDROSS	Thomas Bellinger	Reclamation	1458
RiverWare	Don Frevert	Reclamation	1452
HEC-5	Marilyn Hurst	Corps	1410
WRAP	Lann Bookout	Texas Natural Resource Conservation Commission	1380
MIKE BASIN	Carter Border	Danish Hydraulic Institution	1332

The top three models were chosen for further investigation. An evaluation of the pros and cons (Appendix B) was performed to determine the best fit for each of these software packages to the hydrologic modeling requirements of the Red River Basin.

3.5.2 Selection of Model StateMod Development and Calibration

StateMod was chosen to perform the surface water modeling for the Red River Valley. Primarily, State Mod software was chosen because it scored the highest on the evaluation matrix. Reclamation was confident in the process used to develop the matrix and its results and in the process of investigating and evaluating additional pros and cons.

Additionally, StateMod is capable of calculating Baseflow. *Baseflow* is the name used by this software to denote a more recognized term, *naturalized flow*. Since USGS had already created a naturalized flow database for the same flow nodes that StateMod used, the output from baseflow was compared with the USGS natural flow results and was part of the calibration process.

Incorporating Data into the Model

StateMod requires that historic information be formatted and fit into a series of data sets. Data gaps exist, as water use and return flow records are not very complete prior to 1979. To avoid error that could be introduced into the model from an incomplete historic record, Reclamation decided to develop the model based on data gathered for the period spanning January 1979 through December 2001.

The data gathered for this model is monthly time-step based. This means the data are only end of the month data in the period of record analyzed. No attempt was made to develop the model further to handle daily data for a couple of reasons. First, it is important to build a model at a monthly time step and to make sure that it is working properly before moving to a more data-intensive daily version. Additionally, the model output, baseflow, was to be compared to the naturalized flow database developed by USGS (Emerson 2005), which existed only in monthly time-step form.

These data were collected by Reclamation and USGS from a number of sources. There are numerous data sets associated with the model; however, the following data sets are required to achieve baseflow:

- **Control File:** in general this file contains the units used, the time frame analyzed, and the time step preferred.
    - This model is set up to work in ac-ft of water on a monthly time step for the period 1979-2001.
- **River Network:** lists all water structures including intakes, discharge lines, reservoirs, and gaging stations that are located on the rivers in the system in the correct geographical order.
    - All known structures for which data were available are listed here.
- **Reservoir Station:** lists all modeled reservoirs, their location on the river network, and characteristics of each, such as size. It specifies which net evaporation data to use.
    - The five reservoirs included in this model are Lake Ashtabula, Lake Traverse, Mud Lake, Lake Orwell, and Red Lake.
- **Direct Diversion Station**: contains permit numbers, owners, and locations of all water users in the system.
    - All water users having a permit after 1979 in the states of Minnesota, North Dakota, and South Dakota are included.
- **River Station:** lists the node location for which river flow data are assigned.
    - Thirty-seven flow nodes were entered into the model, including 14 existing USGS gaging sites.
- **Instream Flow Station:** provides the location of all known segments of rivers that have a minimum instream flow requirement.
    - This file contains seven minimum instream flows, known as Q90, as monitored by the State of Minnesota on both the Otter Tail and Red Lake rivers. It also contains a 13 cfs downstream flow requirement release from Baldhill Dam to account for the Corps operating plan parameter.
- **Instream Flow Rights:** shows the priority date and flow requirements for each listing in the instream flow station file.
    - Priority dates were set to predate more senior water rights, and flow requirements are those provided by the State of Minnesota and Corps.

- **Reservoir Rights:** shows the date when the reservoir began holding water and the volume it is limited to withhold from the system on an annual basis.
    - Construction dates of the associated five reservoirs in this model were entered, and volumes were set to full capacity for each; these were not used during the calibration process.
- **Direct Diversion Rights:** lists all permits for water withdrawals and their owners.
    - Existing permit dates were entered for North Dakota permits. Due to differences in water law between North Dakota and Minnesota, the Minnesota water permits were modeled as senior rights, listed on or before the year 1800.
- **Precipitation:** provides all data associated with precipitation at each reservoir within the system.
- **Evaporation:** like precipitation, this file provides all data associated with evaporation at each reservoir within the system.
    - To facilitate the model, precipitation and evaporation are combined into a net evaporation file. Individual values are included for all five reservoirs.
- **Streamflow:** This file contains all of baseflow information associated with the river station file.
    - This data set contains naturalized flow data from USGS. Though not used by the model to determine baseflow, these data can be used in the model for comparison purposes.
- **Direct Diversion Demand:** provides water use data associated with what the modeler is modeling. This can be used to model future demands.
    - This data set is a direct copy of the historic diversions file; a copy was made in order to avoid confusion regarding which data are historic and which are desired demands.
- **Delay Table:** lists delays associated with return flows.
    - This file contains general delays associated with municipal and irrigation returns to the system. However, this file is left blank, because the delays used by StateMod were not required when Reclamation modified its approach to modeling return flows. Return flows as used by Reclamation are modeled as imports to the system and come directly from historic record in which delays have already been accounted.
- **Reservoir End of Month Contents:** contains monthly volumes associated with each reservoir in the system.
    - The values for Lake Ashtabula were entered into this file to account for lake operation. The remainder of the reservoirs are operated as if they are pass-through systems due to lack of information and in lieu of flow data available just downstream of reservoirs.
- **Historic Streamflow:** contains all of historically recorded flow data available for each river station in the system.
    - These data were provided by USGS for all flow points within the system. Data are directly available for all existing gaging locations. The remainder of the flow data were derived by USGS as part of the naturalized flow database.
- **Historic Diversions:** provides all of water use data for each permit or demand in the model. These values are from historic record.

  - These data were entered in the system based on water use records from the NDSWC and MNDNR.

Further detail and discussion on these datasets is in Appendix B.

Development of Baseflow Data (1979 – 2001)

To achieve baseflow, the model was set up and historic data were entered into the appropriate files. The model was run to determine warnings or errors. All inconsistencies within the model were printed in a reviewable log file. With assistance from the software developer, CDSS (Colorado Decision Support Systems), Reclamation tracked all trouble spots within the data. Most errors were related to data formatting. The model was run and errors were fixed until all error messages were eliminated from the log file and all warnings were accounted for. This produced an output file that was representative of a naturalized flow for the period 1979-2001.

It is important to describe what actually occurs in the model when it is run. All too often, those who are not directly involved in the modeling process are left to believe that a model is a "black box" that generates output in some mysterious way. As a means to open that black box and to help the reader understand what StateMod is doing when it calculates baseflow (or naturalized flow), figure 3.5.1 shows the equation used in the model.

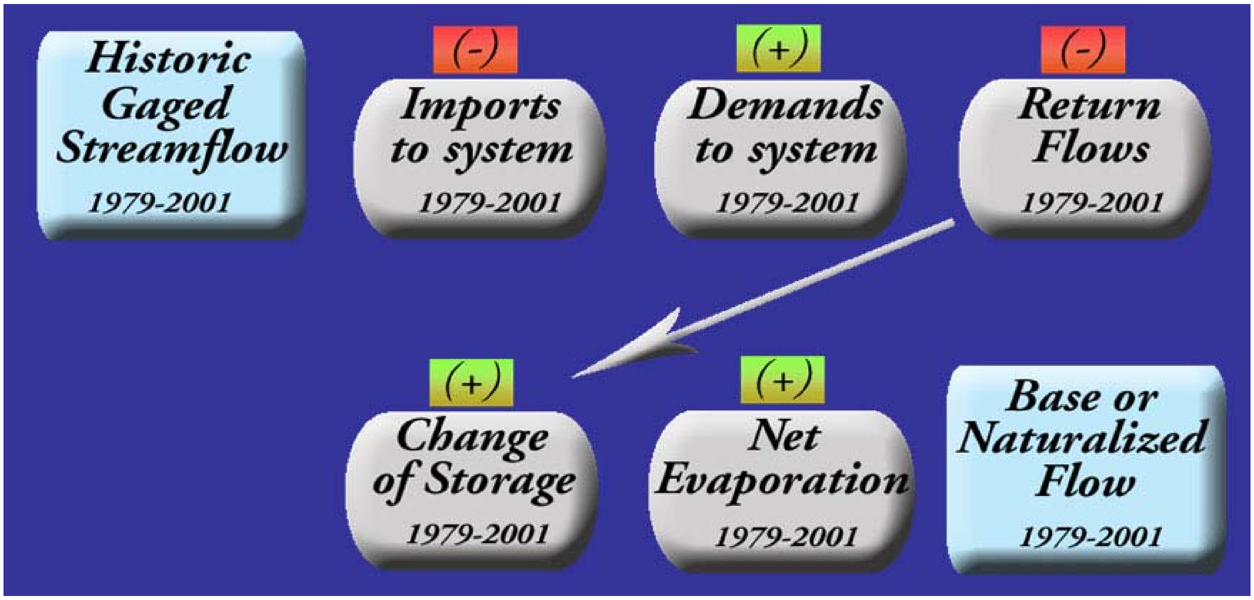


Figure 3.5.1 – StateMod Equation for Calculating Baseflow.

Comparison of Baseflow Data and USGS Naturalized Flow Database

The question might arise why Reclamation did not use the baseflow from StateMod to perform further modeling. The response is that baseflow calculated by StateMod only covers the 1979-2001 period, and the naturalized flow database developed by USGS covers a 71 period of record from 1931-2001. Since the climatology report (Meridian Environmental Technology, Inc. 2004) recommends that the 1930s drought to be an appropriate drought to model to plan for droughts, the USGS database is the only one capable of providing the corresponding flow data.

To determine the accuracy of the model and to verify output results, baseflow data were compared to the USGS naturalized database. The data were compared month to month and at each river node. The results showed only minor differences between the two datasets for the entire system over the 1979-2001 period of overlapping data. This difference was well within acceptable limits and verified that the model was properly developed. All modeling of Project options used the USGS database in lieu of the baseflow calculated by StateMod.

3.5.3 Modeling Assumptions

Reclamation used StateMod software for surface water modeling of the Red River Basin in North Dakota and Minnesota as part of the Project. To assist the reader in understanding how data were used, this section contains both assumptions used while building the model and some of the general parameters that were set. It is important to understand that modeling software is not designed to address the issues of every watershed. Thus, data are sometimes manipulated to more closely approximate conditions that exist in the watershed that is being analyzed. Manipulation occurs when data were not available or when it was necessary to simulate conditions beyond what was considered normal. The next portions of this section pertain to monthly time-step modeling using StateMod unless otherwise noted. Daily modeling is discussed separately in section 3.5.6 of this report.

Historic Flow Database

A historic flow database consists of the flows recorded at gaging stations. Historic flow data were obtained from USGS (Emerson 2005). All streamflow measurements potentially may be skewed by small percentages of error, depending on site conditions and methods used during data collection. However, all data were assumed to be accurate and were used as is.

Naturalized Flow Database

Naturalized flow is the flow within a channel without human influences. The naturalized flow database is used by the surface flow model as a baseline to which demands, return flows, and other operational considerations are applied. USGS developed a naturalized flow database for the period 1931 - 2001 (Emerson 2005). The Red River Basin was divided into DEBs (figure 3.4.7), allowing for water withdrawal and return flows to be correctly associated with the data locations used to develop the naturalized flow database. All assumptions and methods used by USGS are documented (Emerson 2005). Reclamation has reviewed and agreed with the methods USGS used for their calculations.

During development of the naturalized flow database, precipitation variations within each DEB and channel slope were examined. The results indicated that neither precipitation nor channel slope contributed enough variation to require altering regression equations originally used to develop the naturalized flow database.

Baseflow Database

As described earlier, StateMod is capable of generating its own “natural flow” database. This natural flow database is called “baseflow” by the model and is calculated using the equation shown in figure 3.5.1. With the exception of imports, all variables used historically recorded data as a base. However, to more closely approximate historic return flows, these were entered into the model as a negative import. This is further explained in the return flow portion of this section.

Calibration/Simulation

To verify that the model was constructed properly, the output from StateMod's baseflow was compared to the naturalized flow data base created by USGS. This effort was the calibration process.

To perform calibration, the period 1985 through 1995 of both the naturalized flow database from USGS and the baseflow from StateMod were compared. The time frame was chosen because it represented a period of low flow conditions where all required data for the model were readily available in the historic record. Using the equation (A-B)/(A+B)*100, the results of the comparison showed an average of 0.5% difference in flow over the entire period analyzed. Reclamation conferred with USGS, and they agreed that the resultant difference was insignificant to the model's resolution and that the model was properly constructed.

Based on the recommendation by Meridian Environmental Technology, Inc. (2004), Reclamation designed the options (see chapter four) to meet water demands during a 1930s-style drought. Since the baseflow created in StateMod was created for the period where demands and return flows were available (1979-2001) and did not cover time period of interest, Reclamation turned to the USGS naturalized flow database. The USGS database was confirmed to be within 0.5% of the baseflow database and was considered interchangeable. The USGS naturalized flow database that included data from 1931 - 2001 replaced the baseflow database within StateMod for running model simulations on options.

Simulation efforts used the naturalized flow database developed by USGS. All projected 2050 demands, return flows, and operational rights data were placed directly over the time period 1931 through 2001. The time frame analyzed was 1931 - 1941 (1941 reflects the return of normal spring runoff to the watershed). This was done to simulate a 1930s drought in the projected future. Ultimately, all options were run for the full 71 years to show patterns of water shortages.

Water Permits

Withdrawals exceeding 12.5 ac-ft per year for North Dakota and 1 Mgals (3.07 ac-ft) per year for Minnesota require a permit. All available demand and discharge permit data were entered into the model according to documented location, administration date, and decreed amount. Permit data were included for all mainstem and tributary locations in the basin. Withdrawals not requiring a permit were not included within the model and are assumed to be covered within the streamflow gaged data.

Withdrawal and discharge permits were entered in the model as river stations in the appropriate DEB. Though river stations were placed in the correct DEB, their order within that DEB may not reflect actual physical location. Exact location was deemed inconsequential because the model is "priority driven." *Priority driven* means that permits are served by their priority dates rather than by their physical locations.

Priority dates are used by the model to determine the order in which water is served to users through their permit(s). Priority is defined in North Dakota water law as the date when the State Engineer receives the water permit application. Priority dates were entered into the model from the NDSWC database. Due to the difference in water law between North Dakota and Minnesota, the administrative priority on all demand permits on Minnesota tributaries was set to predate any existing permits from North Dakota. This was done to reflect Minnesota's riparian water law, where location is more important than the date of issue of a permit. Priority dates for larger Minnesota municipal users on the Red River were set to match the most senior water right of counterpart municipalities across the river. This was done to provide equal priority to communities on both sides of a river to water that is regulated by differing water laws and to reflect how the system currently is being managed.

Minnesota places minimum instream flow requirements on their watersheds. These minimum instream flows govern water use and are referred to as Q90; these are discussed later in this section. Q90 requires that permits be shut off when flow at a given point falls below a specified level. Since this action has priority over all other water use, all Q90 minimum instream flow points were given a senior priority date to all water withdrawal or discharge permits in the model. With Q90 requirements given first priority, Reclamation assumed that municipalities on Minnesota tributaries still would be served, even when flows drop below Q90. Thus, the administrative priority dates of those Minnesota municipalities were set to be one year more senior than the minimum instream flow administrative dates.

Permits required to serve an anticipated increase in either domestic or industrial use were included in simulation model runs and were entered with a priority date junior to all others.

All permits have a "decreed amount" associated with them. This is the amount of water that can be used by the permit holder, and it is given either as the total amount for a year or as a maximum pumping rate in gpm. The total amount for each existing and future permit was used as the decreed amount in modeling. Those permits without a clearly defined decreed amount had a value set to match their peak annual use from historic record.

Reclamation consulted with NDSWC about estimating the amount of water used by illegal or unmeasured diversions and found that there were no available estimates. Reclamation assumed that historic illegal or unmeasured diversions are accounted for by gaged data.

Diversions/Demands

Diversion/demand data were compiled for all known permits by USGS and Reclamation. These data were collected for the Sheyenne and Red Rivers and included all major tributaries. The demand data for each permit used in the calibration effort came directly from the historic record.

The simulation of options required changes to the demand database. All projected MR&I maximum month demands developed in section 3.3.1 replaced historic values for those permits in the database. These projected maximum month demands were entered into the database and held constant for every year of record. Those demands not covered under section 3.3.1 were recalculated to reflect the maximum month approach. However, these recalculated demands were based solely on the historic record and were not adjusted to reflect an increase in demand over time. Demands on certain permits were set to zero when it was assumed that the water user would be served by a bulk water user in the future.

Irrigation demands were handled differently during simulation. Based on recommendations from NDSWC and on previous modeling practices used by Reclamation, all irrigation demands were entered into the model at their full decreed amount, for every year of the simulation. Since the majority of irrigation permits in the valley are generally junior in standing to MR&I permits, whether historic values or decreed amounts are used in modeling had little influence on results.

Demands for irrigation and golf courses were combined into one withdrawal point for each DEB, which minimized the number of river nodes in the model. In modeling, each permit retained its identity through priority date and decreed amount.

Operational Limitations

A surface water model uses input data to account for use and storage of water in a system. The naturalized flow database includes average delays and losses. But most accounting models, including StateMod, do not recognize lag times between storage and delivery points. Similarly, the models do not account for most water systems' inability to draw down surface water supply to zero. To bypass these operational limitations during modeling, the demand data for MR&I and irrigation were set to maximum month, as outlined in section 3.3.1.

Operational Rights

Surface water models use operational rights as a tool to more closely simulate actual conditions within a system. For instance, the model recognizes that Fargo has multiple water permits, but it does not know the limitations or operational considerations placed on them. To account for this, an operational right is entered into the model that allows Fargo to divert water from its Sheyenne River permit when the supply on the Red River is exhausted. This operational right transports water to Fargo by pipeline from the intake on the Sheyenne.

No operational rights were entered into the model for calibration, as all calculations to achieve baseflow are based directly on the historic record. However, multiple operational rights were added to simulate current and future conditions for modeling. Operational rights include but are not limited to the following:

- Operational rights for water users with multiple water permits allow the model to access water from the correct structure based on priority.

- The No Action Alternative is the future [2050] without the proposed Project, which is evaluated in the DEIS (Reclamation and Garrison Diversion 2005). In modeling No Action the 2050 water demands were placed on the system and only water sources currently in use were depleted by water users. The Thompson-Acker Plan (plan for apportioning water in Lake Ashtabula) was applied. The cities with rights to storage in Lake Ashtabula (Fargo, Grand Forks, West Fargo, Valley City, and Lisbon) each were given an operational right that allowed them to call for stored water when their river supplies were exhausted.

- In modeling the options, the water allocations in Thompson-Acker Plan were modified from their existing parameters. When the options were modeled, the Thompson-Acker Plan apportionments were ignored, and instead the city with the largest need was allowed to use the most stored water. The system was optimized by sizing the features in each option until each was large enough to maintain the 28,000 ac-ft pool and the continual 13 cfs minimum release from Baldhill Dam, while meeting the water needs of the five communities.

- An additional modification of the Thompson-Acker Plan was made for individual MR&I permit holders in the service area downstream of Lake Ashtabula. These water users were given an water allocation right to Lake Ashtabula to meet their water shortage. The system was optimized by sizing the features in each option until each was large enough to maintain the 28,000 ac-ft pool and the continual 13 cfs minimum release from Baldhill Dam, while meeting the water needs of the MR&I individual permit holders.

- Those permits that are served by a pipeline in some options were given operational rights that allowed them to pull water directly from that pipeline when their surface water sources were depleted.

- A minimum instream flow point was placed just below Lake Ashtabula to simulate the Corps's operational release requirement of 13 cfs. An operational right was placed on this point to release water from storage when the natural flow or operational release for Thompson-Acker fell below 13 cfs.

- The minimum instream (Q90) flow point just below Lake Orwell has an operational right that allows that reservoir to release water from storage to meet the minimum instream flow when natural flows are inadequate.

Return Flows

Because of the complexities involved with modeling return flows and their appropriate locations within the system, Reclamation combined the return flows volumes for each DEB and returned them to the very end of each DEB, just before its gaging station. This approach was considered conservative, as it does not allow other users within the same DEB to reuse the water before it leaves the DEB. This approach was considered reasonable because most major users are located in differing DEBs.

During the calibration effort, the model's return flows were based directly on the historic record. StateMod requires that return flows be modeled as a percent of demand; however, the historic trend in the valley shows that return flows sometimes exceed demands. This situation is caused when water quality restriction on the discharge permit prevents discharge to surface water during some months, while this discharge is increased during other months when surface water flows are adequate for mixing. In the model, return flows in excess of demand are calculated as a negative percentage that the model does not allow. To account mathematically for this, return flow values were modeled as imports during calibration. Based upon a recommendation from the StateMod software developer (CDSS), imports were placed in the demand file as negative numbers. StateMod recognizes these values as an import and properly runs them through the equation to develop baseflow.

This method accurately accounts for return flows during calibration. However, this method cannot be used during the simulation effort. To account for return flows during simulation, consumptive use of demands was set to 100%, meaning that all water taken from the system was used and no water was returned. Next, return flow wells were added to the system. These wells simulate the volume of water that would be returned to the system. The return volume is simulated as a value taken from groundwater and placed back into surface water at the end of each DEB. These wells have a 0% consumptive use, and all water is returned to surface water.

Values used for return flows during simulation of options were calculated by averaging each month of the historic record. These averages were then increased as a direct percent increase as compared to the increase in water demand for the same DEB.

The No Action Alternative model runs provided valuable information on the location of shortages in the system. No Action was the foundation from which all other options were developed. When water demands were not met during the No Action runs, return flows were reduced to account for consumptive use differences.

Minnesota Minimum Instream Flow Q90

The MNDNR established minimum instream flows (Q90) for all watersheds within the state using a hydrologic method (i.e., 90% exceedence flow) as a guideline. Using this method they set minimum instream flows at various points along the Red River and on its major tributaries. When flows fall below Q90, water users are prohibited from withdrawing water, and irrigators are cut off before municipalities. There is no minimum instream flow requirement in North Dakota.

MNDNR Q90 Values

Watershed	Location	Q90 (cfs)
Red Lake River	High Landing Crookston	37 119
Otter Tail River	Fergus Falls	36
Wild Rice River	Twin Valley	16
Sandhill River	Climax	9
Buffalo	Dilworth	9.8
Bioux de Sioux	Doran	0.3
Red River (Not modeled – not enforced)	Fargo Halstad Grand Forks Drayton	41 225 281 486

Q90 values were set in the model at points on tributaries above the Red River on the Minnesota side. Q90 flow limitations for Minnesota cities on the Red River were not incorporated into the model because these are not enforced due to the complexity of water laws dividing the river.

Reservoirs All impoundments in the Red River Valley were initially examined for inclusion in the modeling effort. Ultimately, smaller reservoirs or impoundments were not included as part of this model. Where more information is needed, an individual reservoir and its storage potential may be analyzed outside of the overall modeling effort.

Lake Ashtabula During development of No Action, the effects of Thompson-Acker Plan were handled as separate accounts to the main reservoir. These accounts subdivide the reservoir into seven areas, including (1) dead pool (1240 ac-ft), (2) fish and wildlife conservation (28,000 ac-ft), and the remaining storage based on the Thompson-Acker Plan: (3) Fargo 56.1%, (4) Grand Forks 31.3%, (5) Valley City 10.5%, (6) West Fargo 1.5%, and (7) Lisbon 0.6%.

While reviewing calibration results, it became apparent that the percentages established for each municipal water system in the Thompson-Acker Plan were well thought out. However, the cities in the plan historically have made few calls for water from Thompson-Acker. Results of the No Action Alternative modeling also revealed some gaps in demand and fulfillment. Modeling showed large volumes of water left in the reservoir when Fargo was out of water. The lowest volume of water available for use from Lake Ashtabula for No Action Alternative Scenario One is 31,043 ac-ft during the 1930s. Based on the results of the No Action modeling, it was apparent that the plan could be improved. To optimize the system and any features that may be used during simulation, Thompson-Acker Plan allocations were modified for all Project options. Additionally, the following parameters were set:

- The starting volume was assumed to be at 54,400 ac-ft, which is the operational plan drawdown target less 5,000 ac-ft for sedimentation.
- A minimum pool of 28,000 ac-ft for fish and wildlife conservation was set as a target to maintain when optimizing options and their features. This pool volume cannot be met under either No Action Alternative (the future without the Project) or the North Dakota In-Basin Alternative.
- Sedimentation/dead pool is discussed in the sedimentation section of this chapter (see below).
- The filling and net evaporation of the reservoir is shared evenly in all accounts.
- Drawdowns to meet target volumes for flooding from spring runoff were set based on the new operational plan from Corps that includes a five-foot dam raise for flood protection.
- Winter drawdown targets remained at elevation 1264.0 throughout model simulation.

Lake Orwell No operational plan for this reservoir was found. This reservoir was designed as a spill-only reservoir (the reservoir only lets out water when the dam is overtopped), with an operational right to supply the Q90 structure downstream with required flows. The starting volume was set to 4,035 ac-ft, the lowest recorded volume in January from 1985 through 1994.

Red Lake Reservoir There were no data available for inflows to Red Lake Reservoir. Reclamation turned this reservoir off in the model in lieu of using 1930s flow data for the area just below the outlet structure. This flow was entered into the model as natural flow, and all demands above this point were moved just downstream in order to properly account for them.

Lake Traverse & Mud Lake There are no operational plans available for either of these reservoirs. These reservoirs have no operational water rights associated with them. It appears that they operate primarily for flood purposes and only supply water to the system when they spill over. Releases are constrained by water quality issues. However, during a 1930s drought, the net evaporation on both reservoirs is approximately equal to their inflow. Historic gage data below Mud Lake show outflow as zero during much of the 1930s.

Lake Sakakawea Review of the Corps' Missouri River water control manual (Corps 2004a; Corps 2004b) shows no operational limitations in respect to the current use of this body of water or being available as a future water supply. Further, Lake Sakakawea would drop to an elevation of 1792 feet msl during a 1930s drought. That corresponds to a volume of approximately 7.5 million acre-feet. By contrast, the largest annual depletion under any of the options would be approximately 140,000 acre-feet.

Precipitation/Evaporation

Precipitation and evaporation data gathered by USGS (Vining 2003) were used for computing monthly net evaporation from the reservoirs. No attempt was made to determine precipitation or evaporation outside these reservoirs, as these are assumed to be accounted for by gaged data.

Sedimentation

Future sedimentation was calculated for Lake Ashtabula based on historic patterns. This value was calculated as approximately 100 ac-ft per year, which is 5,000 ac-ft over the period of study and matches previous results. Future sedimentation was subtracted from storage capacity during simulation of options, leaving the reservoir with a total volume of 65,700 ac-ft. The 28,000 ac-ft fish and wildlife conservation pool was left intact. Sedimentation acts only on the storage above that volume. Sedimentation rates for other reservoirs in the basin were assumed to be negligible; no accounting for sedimentation is included in the model for reservoirs other than Lake Ashtabula. Reclamation and Corps predict sedimentation at less than 100 ac-ft through the year 2050 for each reservoir.

River Gains and Losses

Due to varying technical opinions about Sheyenne River losses, Reclamation contracted with USGS to compile river gains and losses for the Red River Basin in North Dakota and Minnesota (Williams-Sether 2004***)***. This report gathered data from all known studies and reports on gains and losses on the Sheyenne and Red Rivers. A large range of values were associated with losses on the Sheyenne River.

Upon further development of the surface water model, Reclamation determined that the average gains and losses were tracked by the model, based on their values in the gage data. Reclamation recognized that the model did not account for losses associated with Project flows (losses greater than those occurring from natural flows). Since losses identified in previous study efforts (Williams-Sether 2004) do not distinguish natural losses from Project losses, Reclamation asked USGS to develop a value for additional losses that would result from adding Project water.

Reclamation assumed the Project water flows to be approximately 100 cfs, based on appraisal-level results. Based on the assumed Project flow, USGS analysis showed a Project water loss of 3.5 cfs on the Sheyenne River and 3.5 cfs on the Red River from West Fargo to Grand Forks. These losses were composed of (1) evaporation, increased because of the additional surface water width; (2) bank storage; and (3) transpiration. The additional losses from Project water flows are accounted for in the model.

Devils Lake Outlet

Reclamation also consulted with the NDSWC and North Dakota Department of Health about the proposed state outlet to determine how it should be modeled. Based on those discussions, Reclamation assumed that water available from the proposed Devils Lake Outlet would not be available to the system during a drought. Prior to the onset and during initial years of a 1930s-type drought, evaporation on Devils Lake could drop lake elevation below the level the outlet would operate. Water quality also would decline, so that even if releases were possible, they would not be allowed under the proposed outlet's water quality permit. Further analysis of the effects of an outlet in evaluating the proposed options is in the DEIS (Reclamation and Garrison Diversion 2005).

Daily Modeling

Though StateMod is capable of simulating flows on a daily time step, the data required for this analysis is very incomplete. Reclamation was concerned that developing the model further to perform this daily time step would introduce unacceptable levels of error in the model. Monthly volumes at any given node in the system are the same as when all of the daily data for that same node are added together. The difference between monthly and daily modeling is that daily modeling shows peaks and valleys within the data that can show more precisely when stream flow goes to zero within the month. Since the system encountered full months of zero flow at numerous points during simulation, it was clear that daily modeling would not show any new or deepened shortages. Reclamation performed daily modeling outside StateMod using a spreadsheet analysis, as explained in section 3.5.6.

Quality Assurance/ Quality Control

Quality of the StateMod modeling effort was assured by a peer review of the model's operation in June 2004 by Ray R. Bennett of CDSS. Bennett's complete comments are in Appendix B. All suggestions by Bennett were incorporated in operating the model. Control of modeling operations relied on guidance from the Phase II modeling effort, and where appropriate, improvements were made. Complete documentation comparing the two modeling efforts is in Appendix B.

3.5.4 Modeling Approach

This section describes the approach taken after the model was developed to simulate the options described earlier. Model runs discussed in this section were performed at a monthly time step. Further discussion of daily modeling is in section 3.5.6.

To assist the reader in understanding what the model does during simulation, figure 3.5.2 shows the general equation used to calculate flow results. The equation in figure 3.5.2 is the same equation, worked backwards, as that used in figure 3.5.1 for calculating baseflow or naturalized flow. Figure 3.5.2 shows the results as future flow results; but once naturalized flow is entered in the model, any past, present, or future period can be calculated, as long as the time scales for the other data line up or are accounted for.

To begin, the model needs a foundation that all the options and features are added to for simulation. The baseflow model, named "Calibr8," uses the flow data from 1931 - 2001. Using Calibr8 as the foundation not only provides a platform that has been reviewed and calibrated, it provides differing time frames to be reviewed for specific purposes. When future demands and alternative operational considerations were imposed on the base model, the 1930s drought period was used to quantify how much additional water is required within the system. The entire period 1931-2001 was used to determine total depletions from storage, import supplies, groundwater, and ASR. The period 1990-2001 was used to determine each option's impact in conjunction with a proposed Devils Lake Outlet. Finally, each option was run twice, once with Scenario One demands and once with Scenario Two demands, as discussed in this chapter and in chapter two.

Although the model simulates meeting the shortages of each option, it is not configured to meet every shortage. As required by DWRA (Dakota Water Resources Act), each option provides water supplies to offset shortages for MR&I systems in the service area. In modeling no attempt was made to supply water to offset shortages for North Dakota irrigators unless their water rights were senior to those MR&I systems being served. Minnesota irrigators have riparian water rights; however, no additional Project water sources were made available to them.

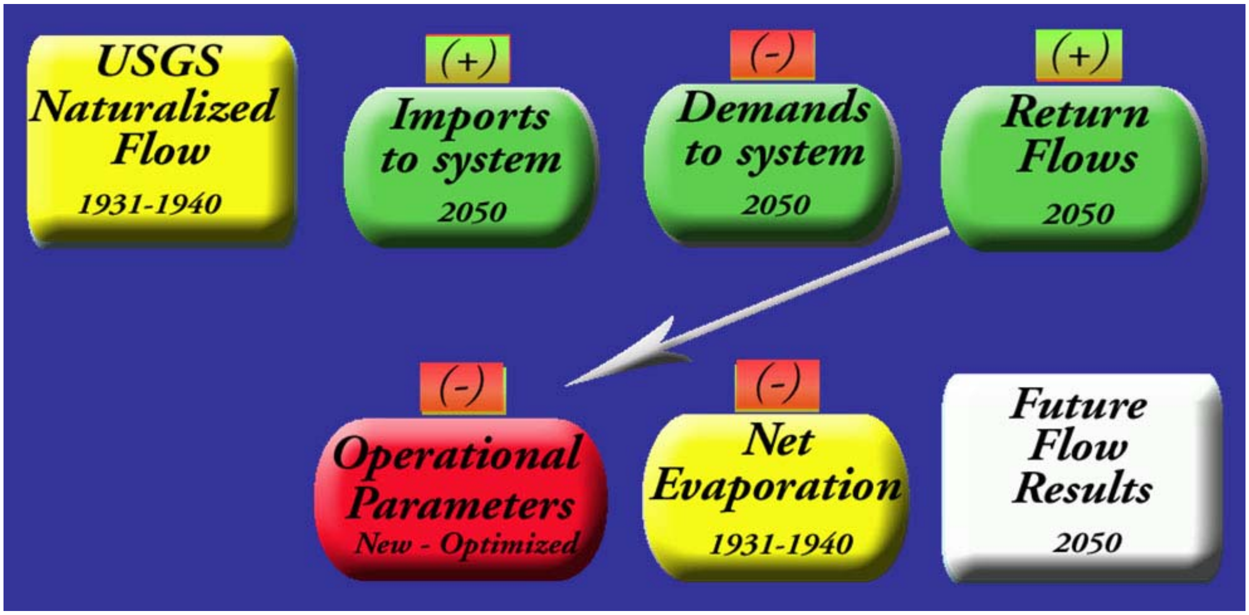


Figure 3.5.2 - StateMod Equation for Future Flow Results.

Each of the following model runs has a general description of its unique configurations. Further detail on features is in chapter four of this report, and additional technical modeling details are in Appendix B.

Current (2005) Water Demand Analysis – Base171

This model run is not for an option to meet the future needs of the Red River Valley. Rather, modeling was used as a tool to evaluate existing conditions and consider the current need for the Project. It answers the question of whether there would be a water shortage in the service area in 2005 if a 1930s drought were to occur. Could the valley endure a 1930s drought at current levels of development, with the available water supply?

This model run uses the Calibr8 files developed during the calibration process. Demands are constant for every year in the model and are set to reflect 2005 population projections. No additional industry or irrigation demands are included. Return flows are averaged over the last 10 years and remain constant for the modeling period. All other aspects of the model, including system configurations, minimum instream flows, and operational plans, are consistent with those used in the Calibr8 model. The model run optimizes water use only to the extent allowed by operational plans while allowing the results to show shortages. The Thompson-Acker Plan water allocations from Lake Ashtabula were used, as was the 28,000 ac-ft fish and wildlife conservation pool.

No Action – Red River without Project - NA1ID71 / NA2ID71

These No Action model runs were not part of the options design analysis for the Needs and Options Report. They were included because they will be required for further analysis as part of the DEIS (Reclamation and Garrison Diversion 2005). The No Action runs were the first modeling effort after the calibration process. Along with the calibration data used to determine baseflow, the system configurations and operational rights used in the No Action runs were the foundation for all other modeling in this report.

Knowing that the No Action runs were the foundation for all other modeling, Reclamation enlisted the StateMod software developer to review the model configuration and to assist in explaining output files. Ray Bennett from CDSS was consulted on many occasions to ensure that the model was working properly and that all warnings and errors were either accounted for or fixed before further modeling was attempted. A peer review of the model performed by Ray Bennett is in Appendix B.

The following is a list of the data changes made in the original Calibr8 datasets:

- **River Network:** Additional nodes were added to account for new industry.
- **Reservoir Station:** Lake Ashtabula's area capacity curve was altered to account for 5,000 ac-ft of sedimentation that may result by 2050. Starting volumes for all reservoirs were set to the lowest recorded volume, once filled after construction, between 1941 and 2001.
- **Direct Diversion Station**: New permits with junior water rights were added to account for new industry.
- **Reservoir Rights:** Changes were made to reflect the assumptions for reservoirs in section 3.4.3 of this chapter.
- **Direct Diversion Rights:** New permits for industry added with junior rights to all existing permits.
- **Streamflow:** Replaced with the naturalized flow data provided by the USGS.
- **Direct Diversion Demand:** Updated to reflect 2050 water demands for MR&I systems. Irrigation demands were set to the full decreed amount.

Modeling the Options

This section discusses the approach to modeling used in this Project and the results achieved when simulating various options. The primary focus of this modeling was to size the engineering features included in the options. Each option was modeled separately and associated features were optimized and sized only to meet the demand requirements, so that MR&I systems would not encounter shortages during a 1930s drought event. To better understand configuration of the options, see chapter four, section 4.3.

Using the No Action (NA1ID71 and NA2ID71) model runs as a foundation, each model run of an option added on the engineering features used in the option to meet the valley's future water demands within the service area. These runs were performed multiple times until each option was considered generally optimized. *General optimization* means that the model runs were performed with features of varying sizes until the system as a whole met the water shortage in the service area and the basic aquatic environmental need (maintaining the 28,000 ac-ft fish and wildlife conservation pool in Lake Ashtabula and a 13 cfs minimum instream flow below Baldhill Dam).

After No Action was completed, but during initial optimization model runs, it was determined that even though water was available in Lake Ashtabula storage at an elevation above the fish and wildlife conservation pool, a number of MR&I users were running out of water. Therefore, when the options were modeled, the Thompson-Acker Plan apportionments were modified, and those cities included in the plan were allowed to withdraw as much water as required to overcome their shortages. No attempt was made to deliver additional water to non-MR&I users, such as irrigators, unless they had senior water rights to natural flows in the river.

In general, all options were modeled using similar operations, i.e., the order in which water sources were used. In general, operations used in modeling are as follows:

- **Fargo:** Fargo withdrew water from the Red River under its senior water permit, then used available natural flows from the Sheyenne River intake, and finally drew upon Project flows released into the Sheyenne River from its storage allocation in Lake Ashtabula. Included in Fargo's demands were existing and new industries near Fargo and Cass Rural Water Use District.

- **Moorhead:** Moorhead withdrew a monthly average of 114 ac-ft from the Buffalo Aquifer all year, followed by withdrawal from the Red River using a permit with the same seniority as Fargo's permit. Included in this water demand was future industry in Minnesota that would be located near Moorhead. ASR was also used in some options.

- **Grand Forks:** Grand Forks withdrew water from the Red and Red Lake Rivers using multiple permits, and then used Project water, which had been released into the Sheyenne and Red Rivers from Lake Ashtabula.

- **West Fargo:** In the model West Fargo no longer relied upon its primary water source, the West Fargo Aquifer. Instead West Fargo withdrew water from the Sheyenne River using a junior surface water permit for natural flows. After that, the city used Project water on the Sheyenne River from its Lake Ashtabula storage allocation. ASR on the West Fargo North Aquifer was also available for use in some options. The ASR system was recharged from available natural flows in the Sheyenne River.

- **Other Communities on Red River Tributaries:** The other communities used water under existing permits from tributaries.

- **Irrigation:** Each irrigator used their existing surface water permit, based upon seniority, to withdraw natural flow in the stream at the full decreed amount. The model did not supply water for future irrigation.

- **Lake Ashtabula:** During model runs StateMod attempted to maintain a basic aquatic environmental need of a 28,000 ac-ft fish and wildlife conservation pool in Lake Ashtabula and a 13 cfs minimum release from Baldhill Dam. In order to optimize the system, the Thompson-Acker Plan apportionments were modified, and those cities included in the plan were allowed to withdraw as much water as required to overcome their shortages.

- **Return Flows:** In the model, return flows were increased to a 2050 level by multiplying the average historic return flow of a given system by the percent increase in demand for Scenario One. For No Action, return flows for some of the MR&I systems were decreased in direct relation to their water shortage.

North Dakota In-Basin Alternative – Loop171 / Loop271 Some operations were specific to certain options. This option is in-basin because it does not propose to import water from outside the Hudson Bay Basin. The major feature is the Grand Forks to Lake Ashtabula Pipeline, a carrier pipeline that originates downstream of the confluence of the Red and Red Lake Rivers (just north of Grand Forks) and is designed to return available natural flows from the Red River back to Lake Ashtabula for storage and release.

Option-specific operations used in the model runs include:

- **Moorhead:** The city withdrew water from Moorhead Aquifer ASR feature before turning to the Buffalo Aquifer, and finally to local surface Red River water. Once its local water supplies were depleted and withdrawals from ASR reached maximum target, a junior water right supplemented its water supply through Fargo’s rights to Lake Ashtabula.

- **West Fargo**: During a drought, withdrawals from the West Fargo Aquifer ASR feature were used before turning to surface water rights and allocation in Lake Ashtabula.

- **Other Communities on Red River Tributaries:** Communities were each given a water allocation right to use water from Lake Ashtabula. After depleting their local water supplies, these communities called for water from Lake Ashtabula and withdrew it from a point nearest them on the Red River.

- **Return Flows:** Return flows were released to the rivers based upon Scenario One demands, without the reduction used in No Action for MR&I systems with shortages. Both scenarios used the same return flow values.

The optimization of the model runs Loop171 and Loop271 reached critical points where increasing the size of the Grand Forks to Lake Ashtabula Pipeline no longer benefited the system. Meanwhile, both water demand scenarios needed too much water to maintain the Lake Ashtabula fish and wildlife conservation pool for short periods during a 1930s drought, which could not be overcome by increasing the size of Baldhill Dam. Although, the basic aquatic environmental need was not always met during the drought, no MR& demands ran short.

Red River Basin Alternative – BF1NGF71 / BF2NGF71 This in-basin alternative proposes to transfer groundwater directly to the Fargo/Moorhead area to be used as a supplemental supply only during the time of a drought or during extreme low flow events.

Option-specific operations used in the model runs include:

- **Fargo:** After its other water supplies were depleted, Fargo was supplied supplemental water via a pipeline from Minnesota groundwater.
- **Moorhead:** After withdrawals from the Moorhead Aquifer ASR feature reached a maximum target and other local water supplies were depleted, a junior water right was given to supplement Moorhead's water supply through Fargo's rights to Lake Ashtabula storage. Finally, Moorhead was supplied supplemental water via a pipeline from Minnesota groundwater when all other withdrawal targets were reached.
- **West Fargo:** After its existing water supplies were depleted and withdrawals from ASR maximized, West Fargo was supplied supplemental water via a pipeline from Minnesota groundwater.
- **Other Communities on Red River Tributaries:** Other communities were given senior water rights to Lake Ashtabula to withdraw water from a point nearest them on the Red River. This prevented the larger communities, which have storage allocation rights to the reservoir, from depleting it before switching to supplemental Minnesota groundwater and effectively leaving the other communities short of water.
- **Return Flows:** Return flows were released to the rivers based upon Scenario One demands, without the reduction used in No Action for MR&I systems with shortages. Both scenarios used the same return flow values.

Lake of the Woods Alternative – BF1W71 / BF2W71 These model runs mirror those done for the Red River Basin, except that the Lake of the Woods is used as a supplemental water source instead of Minnesota groundwater; however, a 20 cfs supplemental flow also is provided continuously to Grand Forks from the lake. Grand Forks requested the supplemental flow to mix with Red and Red Lake River flows to improve raw water quality.

Option-specific operations used in the model runs include:

- **Fargo:** Once its existing water supplies have been depleted, Fargo was supplied supplemental water via a pipeline from Lake of the Woods.
- **Moorhead:** After its existing water supplies have been depleted, Moorhead is supplied supplemental water via a pipeline from Lake of the Woods through Fargo.
- **Grand Forks**: The city was given a senior water right to use a continuous 20 cfs water supply from Lake of the Woods before turning to its existing water permits.

- **West Fargo:** Following depletion of its existing water supplies, West Fargo is supplied supplemental water via a pipeline from Lake of the Woods.

- **Other Communities on Red River Tributaries:** Other communities were given senior water rights to Lake Ashtabula water to withdraw water from a point nearest each on the Red River. This prevented the more senior appropriators from emptying Lake Ashtabula before switching to the water supply pipeline from Lake of the Woods.

- **Return Flows:** Return flows were released to the rivers based upon Scenario One demands, without the reduction used in No Action for MR&I systems with shortages. Both scenarios used the same return flow values.

GDU Import to Sheyenne River Alternative – I1NAWPOP / I2NAWPOP These model runs simulate supplementing existing surface water supplies with water piped from the Missouri River. Water was drawn from the Missouri River through the McClusky Canal, where it would be treated for biota and then conveyed by pipeline and released into Lake Ashtabula. This option would supply water to meet the peak day demands of all the major MR&I systems in the service area.

Option-specific operations used in the model runs include:

- **Major MR&I Users (Fargo, Moorhead, West Fargo, Grand Forks, East Grand Forks, Drayton, Grafton, Langdon, and Valley City):** These entities requested water at the rate of peak day demand at all times. Their demands were increased to account for sufficient water in the system for them to draw peak day demand any day of the month. When peak day demands were not needed, the additional flow was available for use by downstream permit holders.

- **Moorhead:** Once its existing water supplies were depleted, Moorhead was supplied supplemental water via a pipeline from Lake Ashtabula through Fargo.

- **Other Communities on Red River Tributaries:** Communities were each given a water allocation right to use water from Lake Ashtabula. After depleting their local water supplies, these communities called for water from Lake Ashtabula and withdrew it from a point nearest them on the Red River.

- **Lake Ashtabula:** Recharge of the reservoir occurred continuously, as all water imported to the system was routed through Lake Ashtabula.

- **Return Flows:** Return flows were released to the rivers based upon Scenario One demands, without the reduction used in No Action for MR&I systems with shortages. Both scenarios used the same return flow values.

GDU Import Pipeline Alternative – BF1NAW71 / BF2NAW71 This import alternative would provide peak day water demand in a pipeline from the McClusky Canal to major MR&I users in the Red River Valley using the McClusky Canal to Fargo and Grand Forks Pipeline.

The option is configured like the Lake of the Woods alternative with respect to delivery points used in monthly modeling.

Option-specific operations used in the model runs include:

- **Major MR&I users:** In the model water users were connected to the import pipeline and used it to supplement existing water sources that were meeting maximum month demands. Pipe size was increased mathematically outside the model to allow users to receive instantaneous peak day demands from the pipeline.
- **Fargo:** After its local surface water supply and allocation from Lake Ashtabula was exhausted, Fargo turned to direct pipeline import of water from the Missouri River via the McClusky Canal.
- **Moorhead**: After its existing water supplies were depleted, Moorhead was supplied supplemental water via a pipeline from Lake Ashtabula through Fargo.
- **Grand Forks**: The city was given a senior water right to use a continous 20 cfs water supply from the import pipeline before using its existing water permits.
- **West Fargo:** Once its local surface water supply and allocation from Lake Ashtabula were exhausted, West Fargo turns to the direct pipeline import of water from the Missouri River via the McClusky Canal.
- **Other Communities on Red River tributaries:** Communities were each given a water allocation right to use water from Lake Ashtabula. After depleting their local water supplies, these communities called for water from Lake Ashtabula and withdrew it from a point nearest them on the Red River.
- **Return Flows:** Return flows were released to the rivers based upon Scenario One demands, without the reduction used in No Action for MR&I systems with shortages. Both scenarios used the same return flow values.

Missouri River to Red River Valley Import – I1D71 / I2D71 Operation of this alternative mirrored Lake of the Woods, with the addition of a spur pipeline feeding water to Lake Ashtabula where water was stored. When flows in the river were adequate to meet MR&I demands, the spur stored water in Lake Ashtabula, and the model delivered it to users when river water supplies and the pipeline did not meet system needs.

Option-specific operations used in the model runs include:

- **Fargo:** Fargo withdrew water from local surface water sources, then from the Bismarck to Fargo pipeline, and finally from its allocation on Lake Ashtabula that had been recharged by the pipeline spur.
- **Moorhead:** After Moorhead’s existing water supplies were depleted, Moorhead was supplied supplemental water via a pipeline from Lake Ashtabula through Fargo.

- **Grand Forks**: The city was given a senior water right to continuously use water at 20 cfs from the import pipeline before drawing upon its existing water permits.

- **West Fargo:** The city withdrew water from local surface water, then from the Bismarck to Fargo Pipeline, and finally from its allocation on Lake Ashtabula that had been recharged by the pipeline spur.

- **Other Communities on Red River tributaries:** Communities were each given a water allocation right to use water from Lake Ashtabula. This water was withdrawn from a point nearest them on the Red River, after depleting their local surface water supplies.

- **Lake Ashtabula:** When water was available, the pipeline spur from the Bismarck to Fargo Pipeline recharged the reservoir with Project water.

- **Return Flows:** Return flows were released to the rivers based upon Scenario One demands, without the reduction used in No Action for MR&I systems with shortages. Both scenarios used the same return flow values.

GDU Water Supply Replacement Pipeline Alternative – Repl71 This model run differs from the others, because it is a replacement water supply. This option uses the Replacement Pipeline to import Missouri River to supply the entire MR&I water demand of the service area. Remaining water in the system is available to water users outside the service area, irrigation permits, recreation, and other aquatic environmental needs. The pipe was sized to meet all of the water demands (see chapter two, section 2.11).

Option-specific operations used in the model runs include:

Major MR&I Water Users: Water users were removed from their surface and groundwater supplies and given priority to draw water from the Replacement Pipeline.

Other Communities on Red River Tributaries: Other communities in the service area were also given priority to draw water from the Replacement Pipeline.

- **Lake Ashtabula:** The Thompson-Acker Plan allocations were not used, because the cities with rights to the water were delivered water by the Replacement Pipeline. The only releases from the reservoir were to meet the 13 cfs aquatic environment release or to avoid overtopping the reservoir.

- **Return Flows:** Return flows were released to the rivers based upon Scenario One demands, without the reduction used in No Action for MR&I systems with shortages. Both scenarios used the same return flow values.

- **Peak Day Demand:** The Replacement Pipeline carried sufficient water to meet all MR&I peak day demands in the service area.

3.5.5 Results of Surface Water Hydrologic Modeling

For the purposes of this report, the discussion of results pertains to estimating shortages, sizing pipelines, and discussing some hydrologic aspects of the system. Additional data and analyses are in Appendix B.

Water Shortage

This report defines *shortage* as the amount of water that MR&I users within the service area would require, in addition to their existing water sources, to meet their water demand in 2050 (see chapter two). Shortages can occur either when water supplies are insufficient or do not arrive when needed. Shortages discussed in this section are limited to surface water systems and to those systems that would be served from the Project. Modeling shows times during extreme low flow conditions when water shortages are offset by return flows from upstream users.

Shortages include irrigators along the Sheyenne River, who were included only to quantify impacts to non-Project demands for evaluation in the DEIS (Reclamation and Garrison Diversion 2005). In modeling, irrigators have permits restricted to natural flows based on seniority and were not served by Project water. *Project water* is water that augments natural flows in the river and is intended for delivery to a permit holder downstream with a more senior water right. If one of the options that would augment streamflow with Project water would be constructed, inappropriate withdrawals of Project water would have to be marshaled appropriately to prevent undue releases from storage. Although there are other irrigators in the Red River Valley, they are supplied by groundwater or rely on tributaries regulated by Q90 minimum instream flows by the state of Minnesota; these uses would not affect Project flows.

Current (2005) Water Demand Analysis A current water demand model run is not typically included in an engineering document; however, the shortage estimated by this model run shows that water users in the Red River Valley would not have enough water to meet their current needs if a 1930s drought were to begin today. Even if demand in the Red River Valley does not increase over time, current water sources are insufficient to meet existing demands.

Table 3.5.2 shows composite shortages of almost 14,000 ac-ft at current development levels during the worst year of a 1930s drought. The worst year corresponds to 1936. The worst drought year, then, could be encountered by the sixth year of a 1930s drought. If a 1930s drought began in 2005, the Red River Valley would encounter its worst-year shortage by the year 2010. Note too that, based on projected population growth, by 2010 water demand is expected to grow, so the corresponding water shortage also would be greater than 2005 levels.

Figure 3.5.3 shows the annual shortages for the service area over the 71-year period of record. The shortages are broken out into three main groups. Irrigation shortages on the Sheyenne River appear in yellow. Industrial shortages for those independent industries, which are currently not part of a municipal supply system, are graphed in red. Municipal shortages, including other industries and rural water systems that would be served by a municipal system, are shown in blue.

Table 3.5.2 - Predicted No Action MR&I Water Shortages in 2005 and 2050 during a 1930s Drought

Locality or System	Current (2005) Water Demand			Projected (2050) Water Demand					
				Scenario One			Scenario Two		
	"1936" Shortage (ac-ft)	Maximum Individual Year Shortage (ac-ft)	Maximum Year	"1934" Shortage (ac-ft)	Maximum Individual Year Shortage (ac-ft)	Maximum Year	"1934" Shortage (ac-ft)	Maximum Individual Year Shortage (ac-ft)	Maximum Year
Fargo	0	0	1931	24,152	24,152	1934	37,456	37,456	1934
West Fargo	540	570	1934	3,363	3,544	1936	3,680	3,797	1936
Moorhead	2,765	2,765	1936	874	4,543	1936	1,050	5,007	1936
Grand Forks	0	0	1931	0	0	1931	0	1,927	1937
Valley City	0	0	1931	0	0	1931	0	0	1931
Grafton	5	66	1937	0	0	1931	0	0	1931
Drayton	0	90	1937	0	90	1937	0	90	1937
Pembina	Part of Rural Water			Part of Rural Water			Part of Rural Water		
East Grand Forks	0	0	1931	0	0	1931	0	0	1931
Langdon	149	340	1940	137	340	1940	137	392	1939
Agassiz Water Users District	No Shortage to model			No Shortage to model			No Shortage to model		
Cass Rural Water Users District	Represented within shortage for Fargo			Represented within shortage for Fargo			Represented within shortage for Fargo		
Dakota Rural Water District	No Shortage to model			No Shortage to model			No Shortage to model		
Grand Forks-Traill Water District	Represented within shortage for Grand Forks			Represented within shortage for Grand Forks			Represented within shortage for Grand Forks		
Langdon Rural Water District	33	101	1939	65	101	1939	123	190	1939
Ransom-Sargent Water Users District	No Shortage to model			No Shortage to model			No Shortage to model		
Southeast Water District	No Shortage to model			No Shortage to model			No Shortage to model		
Traill County Water District	No Shortage to model			No Shortage to model			No Shortage to model		
Tri-County Water District	No Shortage to model			No Shortage to model			No Shortage to model		
Walsh Rural Water Distict	No Shortage to model			No Shortage to model			No Shortage to model		
Existing Cargill Industry	1,746	1,746	1936	1,926	1,926	1931	1,926	2,105	1931
Other Existing Industry									
American Crystal, Permit 251	0	15	1937	0	0	1931	0	0	1931
American Crystal, Permit 1076	0	0	1931	0	0	1931	0	0	1931
American Crystal, MN Permit 450008	495	495	1936	53	495	1936	53	464	1936
American Crystal, Permit 1917	319	447	1934	447	447	1934	447	447	1934
New Industry									
New ADM Corn Processing	84	225	1939	150	225	1939	150	225	1939
New Industry at Wahpeton	0	0	1931	3,404	3,404	1931	6,060	6,451	1931
New Cass County Golf	0	0	1931	286	286	1931	289	289	1931
New Grand Forks County Golf	0	0	1931	13	27	1932	15	33	1932
New Clay County Golf	0	0	1931	33	33	1931	33	33	1931
New Otter Tail County Golf	0	0	1931	49	49	1931	49	49	1931
Other Project Shortages	1,281	2,129		1,472	2,235		1,547	2,327	
TOTAL (ac-ft)	**7,417**			**36,424**			**53,015**		

No Action Alternative No Action Alternative model runs typically are associated only with an EIS. However, the model runs were included in this discussion, because these were the base from which all other proposed options were constructed. They also forewarn of future water shortages. Tables 3.5.2, 3.5.3, and 3.5.4 show composite water shortages for the No Action Alternative in 2005 and 2050.

The worst year for the No Action Alternative corresponds to 1934. This year differs from the 2005 water demand analysis worst year of 1936, because the system dynamic changed when additional demands were subtracted from it. The change in timing of the worst drought year means that the worst year could come by the fourth year of a 1930s drought, rather than the sixth year. These shortages are what the proposed options were developed to overcome.

Figures 3.5.4 and 3.5.5 show the annual shortages for No Action Alternative with Scenario One or Scenario Two water demands for the service area over the 71-year period of record. The shortages are broken out into three main groups. First, irrigation shortages on the Sheyenne River that could impact Project shortages are graphed in yellow. Second, industrial shortages for independent industries with their own water permit(s) are illustrated in red. Third, municipal shortages, including industries and rural water systems that would be served by a municipal supply system, are shown in blue.

Table 3.5.3 - Predicted Scenario One MR&I Water Shortages in 2050 by Year during a 1930s Drought.

Locality or System	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Fargo	0	0	4,271	24,152	5,330	16,929	14,364	15,628	10,204	21,291
West Fargo	1,133	1,587	2,526	3,363	1,885	3,544	3,114	2,236	1,591	2,130
Moorhead	872	2,867	691	874	1,483	4,543	2,344	0	0	624
Grand Forks	0	0	0	0	0	0	0	0	0	0
Valley City	0	0	0	0	0	0	0	0	0	0
Grafton	0	0	0	0	0	0	0	0	0	0
Drayton	0	0	0	0	0	0	90	0	0	0
Pembina	Part of Rural Water System									
East Grand Forks	0	0	0	0	0	0	0	0	0	0
Langdon	21	54	129	137	129	149	242	326	330	340
Agassiz Water Users District	No Shortage									
Cass Rural Water Users District	Part of Fargo									
Dakota Rural Water District	No Shortage									
Grand Forks-Traill Water District	Part of Grand Forks									
Langdon Rural Water District	44	45	22	65	35	33	78	78	101	90
Ransom-Sargent Water Users District	No Shortage									
Southeast Water District	No Shortage									
Traill County Water District	No Shortage									
Tri-County Water District	No Shortage									
Walsh Rural Water Distict	No Shortage									
Existing Cargill Industry	1,926	1,745	1,926	1,926	1,565	1,926	1,596	1,381	1,343	1,562
Other Existing Industry										
American Crystal, Permit 251	0	0	0	0	0	0	0	0	0	0
American Crystal, Permit 1076	0	0	0	0	0	0	0	0	0	0
American Crystal, MN Permit 450008	0	53	0	53	23	495	31	0	0	0
American Crystal, Permit 1917	128	0	0	447	0	319	319	178	128	319
New Industry										
New ADM Corn Processing	100	125	50	150	75	84	175	175	225	225
New Industry at Wahpeton	3,404	3,089	3,404	3,404	2,774	3,404	2,774	2,469	2,583	2,784
New Cass County Golf	286	286	286	286	263	286	242	196	255	196
New Grand Forks County Golf	0	27	25	13	13	25	0	13	0	13
New Clay County Golf	33	33	33	33	33	33	28	22	29	22
New Otter Tail County Golf	49	48	48	49	49	49	47	34	43	35
Other Project Shortages	1,064	1,151	1,217	1,472	1,060	1,397	1,517	1,571	1,771	1,930
TOTAL (ac-ft)	**9,060**	**11,110**	**14,628**	**36,424**	**14,717**	**33,216**	**26,961**	**24,307**	**18,603**	**31,561**

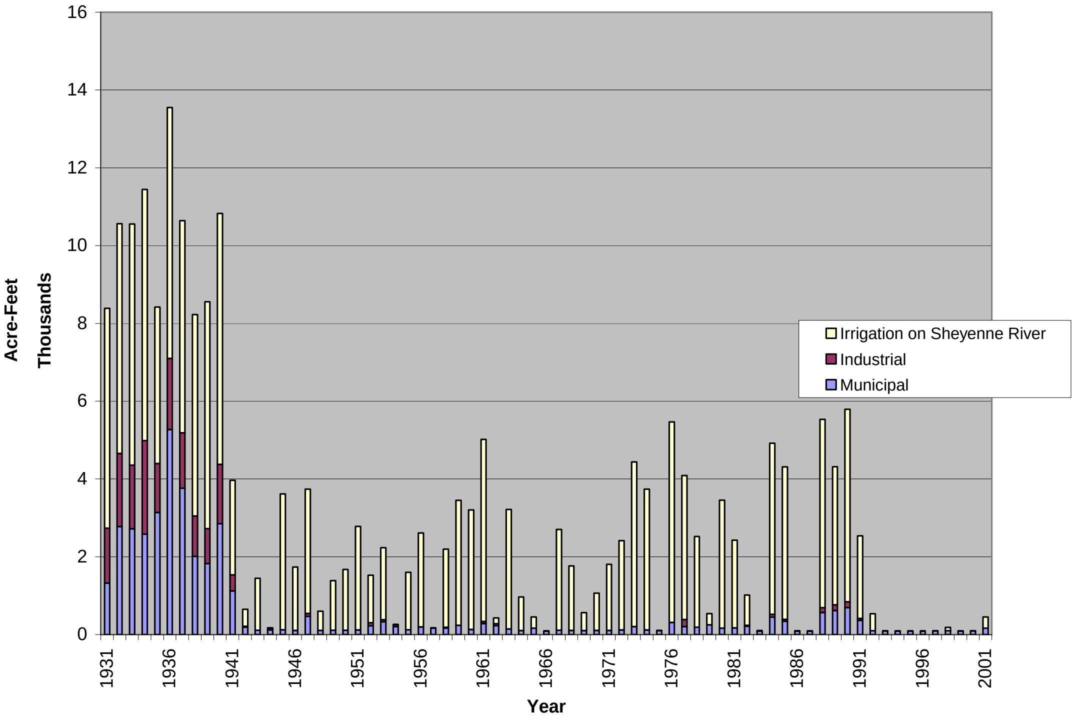


Figure 3.5.3 - Current (2005) Water Demand Shortages during a 1930s Drought.

Table 3.5.4 - Predicted Scenario Two MR&I Water Shortages by year during a 1930s Drought.

Locality or System	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Fargo	1,066	9,662	16,063	37,456	14,417	32,797	26,602	26,585	18,062	32,014
West Fargo	1,235	1,917	2,743	3,680	2,473	3,797	3,321	2,196	1,970	2,405
Moorhead	981	3,156	859	1,050	1,654	5,007	2,574	7	49	850
Grand Forks	0	0	0	0	0	0	1,927	0	0	0
Valley City	0	0	0	0	0	0	0	0	0	0
Grafton	0	0	0	0	0	0	0	0	0	0
Drayton	0	0	0	0	0	0	90	0	0	0
Pembina	Part of Rural Water System									
East Grand Forks	0	0	0	0	0	0	0	0	0	0
Langdon	21	54	129	137	129	149	242	326	392	340
Agassiz Water Users District	No Shortage									
Cass Rural Water Users District	Part of Fargo									
Dakota Rural Water District	No Shortage									
Grand Forks-Traill Water District	Part of Grand Forks									
Langdon Rural Water District	84	86	43	123	68	63	147	147	190	170
Ransom-Sargent Water Users District	No Shortage									
Southeast Water District	No Shortage									
Traill County Water District	No Shortage									
Tri-County Water District	No Shortage									
Walsh Rural Water Distict	No Shortage									
Existing Cargill Industry	2,105	1,745	1,926	1,926	1,745	1,926	1,746	1,381	1,585	1,562
Other Existing Industry										
American Crystal, Permit 251	0	0	0	0	0	0	0	0	0	0
American Crystal, Permit 1076	0	0	0	0	0	0	0	0	0	0
American Crystal, MN Permit 450008	0	53	0	53	23	464	31	0	0	0
American Crystal, Permit 1917	128	0	0	447	0	319	319	178	447	319
New Industry										
New ADM Corn Processing	100	125	50	150	75	96	175	175	225	225
New Industry at Wahpeton	6,451	5,373	5,921	6,060	5,373	5,921	5,373	4,295	4,878	4,843
New Cass County Golf	289	286	286	289	286	286	255	196	255	196
New Grand Forks County Golf	25	33	27	15	13	27	0	13	0	13
New Clay County Golf	33	33	33	33	33	33	29	22	29	22
New Otter Tail County Golf	49	48	48	49	49	49	49	34	43	35
Other Project Shortages	1,245	1,257	1,224	1,547	1,060	1,409	1,517	1,570	1,847	1,908
TOTAL (ac-ft)	**13,812**	**23,828**	**29,352**	**53,015**	**27,398**	**52,343**	**44,397**	**37,125**	**29,972**	**44,902**

Sizing Options

For those options that propose importing water, the capacity of the import pipeline combined with storage are the controlling factors in model outcomes. Each pipeline has a capacity requirement. The capacity requirement is reached when the model run is optimized, resulting in a pipe capacity that is used in designing the options. The pipe capacities shown in table 3.5.5 are those that satisfy the parameters of the model; these capacities do not include pipe or system losses, which are addressed in chapter four.

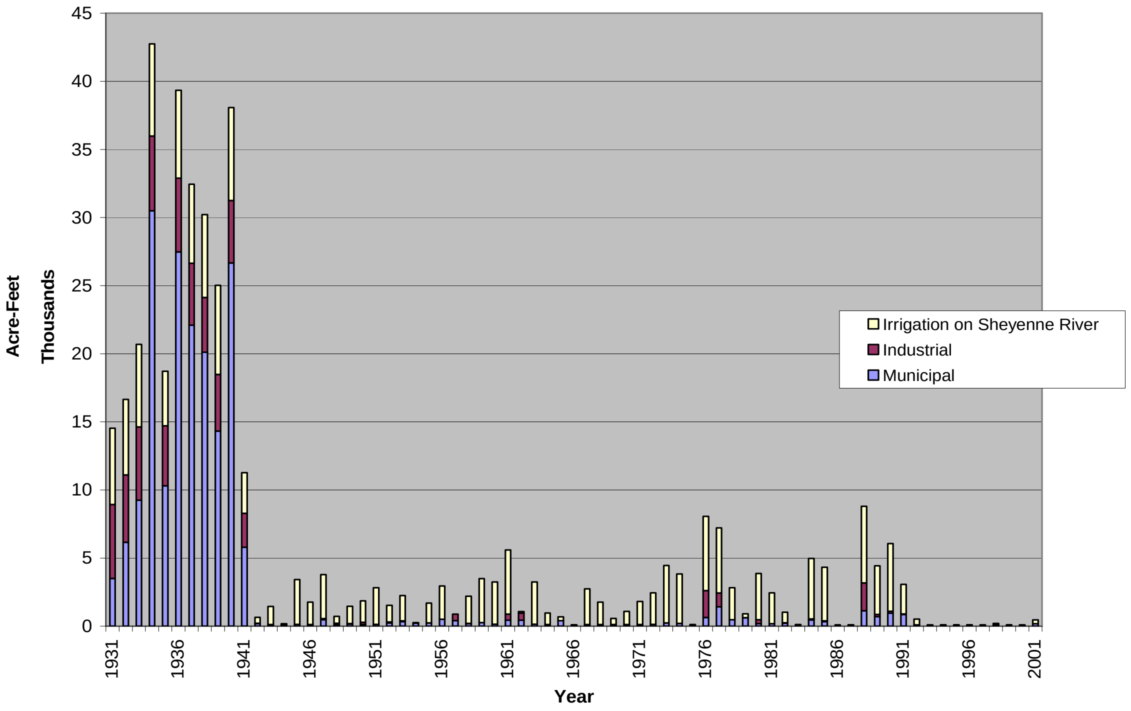


Figure 3.5.4 – No Action Alternative Shortages - Scenario One.

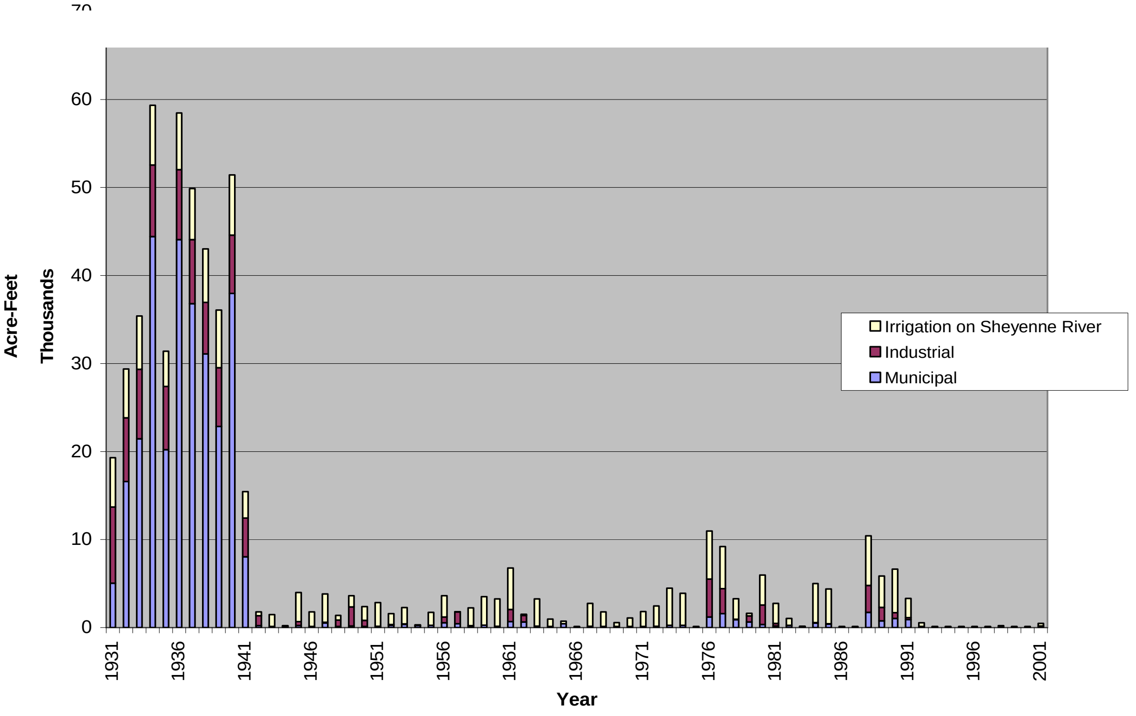


Figure 3.5.5 – No Action Alternative Shortages - Scenario Two.

Table 3.5.5- Pipe Sizing by Project Option.

Option	Scenario One Sizing (cfs)	Scenario Two Sizing (cfs)
North Dakota In-Basin	50	67
Red River Basin	42	68
Lake of the Woods	66	93
GDU Import to Sheyenne River - Peak Day in Pipe	59	92
GDU Import to Red River Valley Import - Peak Day in Pipe	*160**	*202**
Missouri River to Red River Valley Import	42	60
GDU Water Supply Replacement Pipeline	*341**	*411**

*These values are directly from chapter four, section 4.2, which included pipe losses. Actual values were supplied to the model for major users.

3.5.6 Daily Water Modeling

The previous section described the results of surface water hydrologic modeling using StateMod on a monthly time step for the No Action Alternative (future without the Project) and proposed options (chapter four). For each Project option, two models runs (Scenarios One and Two water demands) specific to each option were developed and the capacity requirements of water supply features were determined.

Daily modeling is required to help understand the water demand and flow variability that is not perceivable from monthly surface water modeling. While monthly modeling assures that demands are met on average over a month, flows may not be adequate on individual days to supply enough water to meet peaking requirements. Daily modeling shows the status of available flow and the ability of daily flows to meet peaking demands.

Evaluating peak day demands for water systems using groundwater is relatively straightforward, assuming the aquifers in question have been adequately assessed prior to issuing water permits. The maximum permitted daily withdrawal was compared to the estimated peak day water demand to determine if the current permit is adequate. Evaluating surface-water-dependent systems is more complicated than evaluating groundwater-dependent systems and requires hydrologic modeling to determine the adequacy of future supplies.

StateMod is capable of performing daily time-step modeling; however, the results from any modeling are only as good as the available input data. There is very little daily 1930s flow data for key locations in the model. Additionally, historic demand data for daily peaking are not readily available for the majority of MR&I systems in the area.

Although StateMod is capable of filling in data gaps by interpolating flow data from nearby gages, monthly modeling results showed zero flow available for nearly all major water users at some point during the modeling period. Adding peaking demands to the system will not provide greater resolution to the model, since the available flow is still zero. This means that an alternative water source must be used not only to meet monthly demand, but also to meet the full requirements of daily peaking demands.

Through consultation with USGS it was agreed that daily modeling in StateMod would not give a higher level of flow resolution and ultimately would introduce an unacceptable level of error into the model. Instead of modeling, it was agreed that spreadsheet analysis of daily peaking requirements for individual water demands would provide answers.

Peak Day Water Demand Analysis Method

Section 2.2 (Water Demand Calculation Methods) describes methods used to evaluate peak day water demand in this report. Three basic methods were investigated for each Red River Valley water system that fully or partially depends on surface water sources and has daily peaking factors that must be met by the options. These methods are additional groundwater capacity, additional storage, or additional capacity of imported water sources. Some water systems have access to groundwater sources that can be used to meet short-term peaking demands if there is adequate withdrawal capacity. All water systems have the potential to develop storage to meet all or part of their daily peaking requirements. Finally, some options proposed in the Needs and Options Report propose to import new water sources. The capacity of this imported conveyance feature could be increased to meet peak day demand requirements. Table 3.5.6 lists the water systems evaluated and which of the available peaking methods were analyzed for each system to meet daily peaking requirements.

Table 3.5.6 – Water Systems to be Evaluated for Peak Day Water Demand.

Water Systems	Groundwater	Storage	Import[1]
Cass Rural Water Users District	Yes	Yes	Yes
Drayton	No	Yes	Yes
East Grand Forks	No	Yes	Yes
Fargo	Yes	Yes	Yes
Grafton	No	Yes	Yes
Grand Forks	Yes	Yes	Yes
Grand Forks-Traill Water District	Yes	Yes	Yes
Langdon (City and RWD)	No	Yes	Yes
Moorhead	Yes	Yes	Yes
Valley City	Yes	Yes	Yes
West Fargo	Yes	Yes	Yes

[1] Not all water systems are served via pipeline in the options, but additional pipeline capacity can be considered for these systems to meet their increased surface water flow needs.

Groundwater – Peak Day Water Demand Method

Groundwater can be used to meet peak day water demand requirements if sources of groundwater are available. Seven out of the 11 water systems listed in table 3.5.7 have the potential to tap local groundwater sources. The water systems and their potential groundwater sources are listed in table 3.5.7. The concept is to increase existing groundwater withdrawal capacity or to develop new groundwater sources to meet peak day demands. The added groundwater is intended for short-term intensive withdrawals, not day-to-day use.

The 31-day scenario for modeling peak day is based on estimated peak day, maximum month, and a 31-day water demand distribution curve. Following are two examples that show how the peak day and maximum month analysis was conducted.

An analysis of Grand Forks historic water use revealed annual groundwater withdrawals to meet peak day averaged about 6% of the annual maximum water demand. This analysis is in Appendix B.

Table 3.5.7 – Water Systems with Potential Groundwater Sources.

Water Systems	Groundwater Source Description
Cass Rural Water Users District	Cass Rural Water Users District currently has wells in the West Fargo North Aquifer, but this study assumes that it will purchase water from Fargo as its primary source of water in the future. There is adequate capacity in the aquifer to meet short-term peaking needs.
Fargo	The West Fargo South Aquifer is located approximately 6 miles south of Fargo. Although the aquifer is not a good water source for continuous withdrawals, it is relatively untapped and could serve Fargo's periodic peak day water demands in the future (see section 3.2).
Grand Forks	The Elk Valley Aquifer is located approximately 17 miles west of Grand Forks. The aquifer is heavily permitted, but there is potential to purchase or contract for irrigation water rights to meet peak day water needs.
Grand Forks-Traill Water District	Grand Forks-Traill Water District currently uses the Elk Valley Aquifer as a water source. The aquifer is heavily permitted, but there is potential to purchase or contract for irrigation water rights to meet peak day water needs.
Moorhead	Moorhead currently uses the Buffalo Aquifer as a water source. There is potential to expand their well capacity in the aquifer to meet peak day demands.
Valley City	Valley City currently uses surface water from the Sheyenne River to recharge groundwater via a pond adjacent to the water treatment plant. Its actual water supply comes from wells adjacent to the recharge pond. Well capacity to meet peak day demands would also be included.
West Fargo	An ASR system is proposed as a water source for West Fargo in a drought using the West Fargo North Aquifer. The ASR system would be designed for peak day capacity.

An analysis of Fargo maximum month water demand revealed a water demand of 5,005 ac-ft under Scenario One. Column 8 in table 3.5.8 shows Fargo's daily water shortage and surplus storage for their maximum month under Scenario One demands. The total shortage is 449.1 ac-ft or 146.3 Mgals. That is the amount of water that would be withdrawn from groundwater in the maximum month. The largest daily shortage occurs on the twenty-first day of the month at 77.9 ac-ft (25.4 Mgals) or an equivalent flow capacity of 39.3 cfs. Additional well capacity of 39.3 cfs would be required to meet the peak day water demand for Fargo under Scenario One.

Storage - Peak Day Water Demand Method

Table 3.5.8 shows a 31-day maximum month water demand scenario developed for each water system evaluated for peak day water demand (table 3.5.6). The Scenario One water demand for Fargo is used as an example in the following discussion. The 31-day scenario was developed based on historic daily water use by Grand Forks, because Grand Forks had historic data that other systems lacked.

Table 3.5.8 shows the estimated water demand in cfs and ac-ft (columns 3 and 4), the daily water delivery in 161.5 ac-ft (column 5), and storage required, which is the difference between the water needed and delivered in ac-ft and Mgals (columns 8 and 9) and net storage (column 10). The net storage is the day-by-day storage volume simulation for the water system. In this example, Fargo's peak daily water demand could be met with 125.3 Mgals of storage.

Table 3.5.8 – Water Demand and Storage Analysis – Fargo – Scenario One.

Day of Maximum Month	Daily Water Demand Distribution (%)	Daily Water Demand (cfs)	Daily Water Demand (ac-ft)	Daily Water Delivery (ac-ft)	Accum. Water Demand (ac-ft)	Accum. System Deliver (ac-ft)	Storage Required (ac-ft)	Storage Required (10^6 gallons)	Storage (10^6 gallons)
Column #	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	3.37%	84.9	168.5	161.5	168.5	161.5	-7.0	-2.3	57.7
2	2.76%	69.6	138.0	161.5	306.5	322.9	23.5	7.6	65.3
3	2.24%	56.6	112.2	161.5	418.7	484.4	49.3	16.1	81.4
4	2.29%	57.7	114.5	161.5	533.2	645.8	46.9	15.3	96.7
5	3.76%	94.8	188.1	161.5	721.3	807.3	-26.6	-8.7	88.0
6	3.93%	99.1	196.6	161.5	917.9	968.7	-35.2	-11.5	76.5
7	3.28%	82.8	164.2	161.5	1,082.1	1,130.2	-2.7	-0.9	75.7
8	2.99%	75.5	149.7	161.5	1,231.8	1,291.6	11.7	3.8	79.5
9	2.37%	59.7	118.4	161.5	1,350.3	1,453.1	43.0	14.0	93.5
10	2.41%	60.9	120.8	161.5	1,471.1	1,614.5	40.7	13.2	106.7
11	2.99%	75.5	149.7	161.5	1,620.8	1,776.0	11.7	3.8	110.6
12	2.99%	75.5	149.7	161.5	1,770.5	1,937.4	11.7	3.8	114.4
13	2.99%	75.5	149.7	161.5	1,920.3	2,098.9	11.7	3.8	118.2
14	2.99%	75.5	149.7	161.5	2,070.0	2,260.3	11.7	3.8	122.0
15	3.02%	76.3	151.4	161.5	2,221.4	2,421.8	10.1	3.3	125.3
16	3.50%	88.3	175.1	161.5	2,396.4	2,583.2	-13.6	-4.4	120.9
17	3.59%	90.6	179.8	161.5	2,576.2	2,744.7	-18.3	-6.0	114.9
18	3.59%	90.6	179.8	161.5	2,755.9	2,906.1	-18.3	-6.0	108.9
19	3.59%	90.6	179.8	161.5	2,935.7	3,067.6	-18.3	-6.0	103.0
20	3.63%	91.7	181.9	161.5	3,117.6	3,229.0	-20.4	-6.7	96.3
21	4.78%	120.7	239.3	161.5	3,356.9	3,390.5	-77.9	-25.4	70.9
22	4.20%	106.1	210.4	161.5	3,567.3	3,551.9	-48.9	-15.9	55.0
23	3.77%	95.2	188.8	161.5	3,756.1	3,713.4	-27.4	-8.9	46.1
24	3.34%	84.4	167.3	161.5	3,923.4	3,874.8	-5.9	-1.9	44.2
25	3.58%	90.3	179.1	161.5	4,102.5	4,036.3	-17.6	-5.7	38.4
26	4.42%	111.6	221.3	161.5	4,323.8	4,197.7	-59.8	-19.5	18.9
27	4.25%	107.1	212.5	161.5	4,536.3	4,359.2	-51.0	-16.6	2.3
28	2.44%	61.7	122.4	161.5	4,658.6	4,520.6	39.1	12.7	15.0
29	1.38%	34.9	69.2	161.5	4,727.8	4,682.1	92.3	30.1	45.1
30	2.36%	59.5	118.1	161.5	4,845.9	4,843.5	43.4	14.1	59.2
31	3.18%	80.2	159.1	161.5	5,005.0	5,005.0	2.3	0.8	60.0
Totals			5,005.0	5,005.0					

Note: Blue highlighted numbers are discussed in the text.

Figure 3.5.6 below shows the water demand curve for Fargo under Scenario One in ac-ft. The peak day occurs on the twenty-first day of the month at a demand of 239.3 ac-ft or 120.7 cfs. Figure 3.5.7 shows the storage simulation for Fargo. A total storage of 125.3 Mgals (385 ac-ft) is required to meet peak day water demands during the maximum water demand month. In this simulation, the maximum volume of water required for peaking is achieved on the fifteenth day of the month at 125.3 Mgals, as shown in column 10 of table 3.5.8.

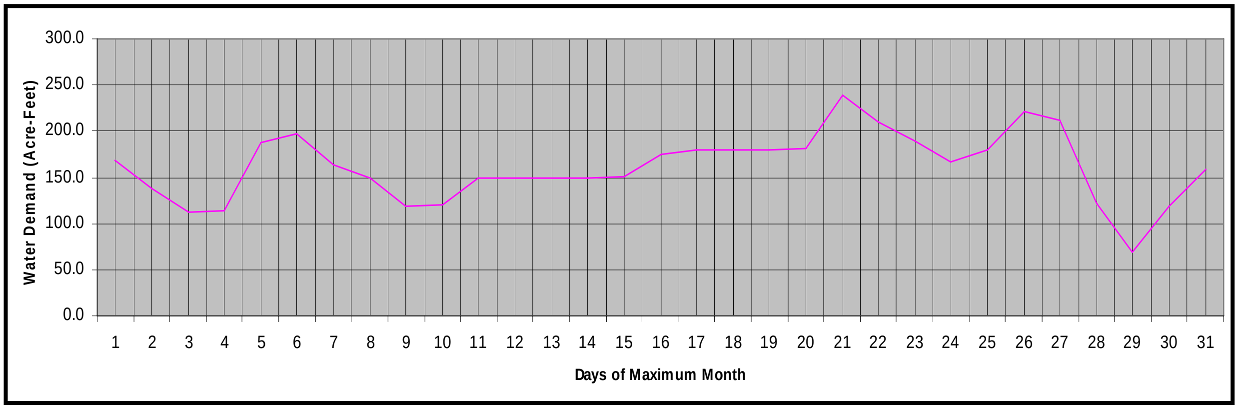


Figure 3.5.6 – Maximum Month Water Demand Curve – Fargo under Scenario One.

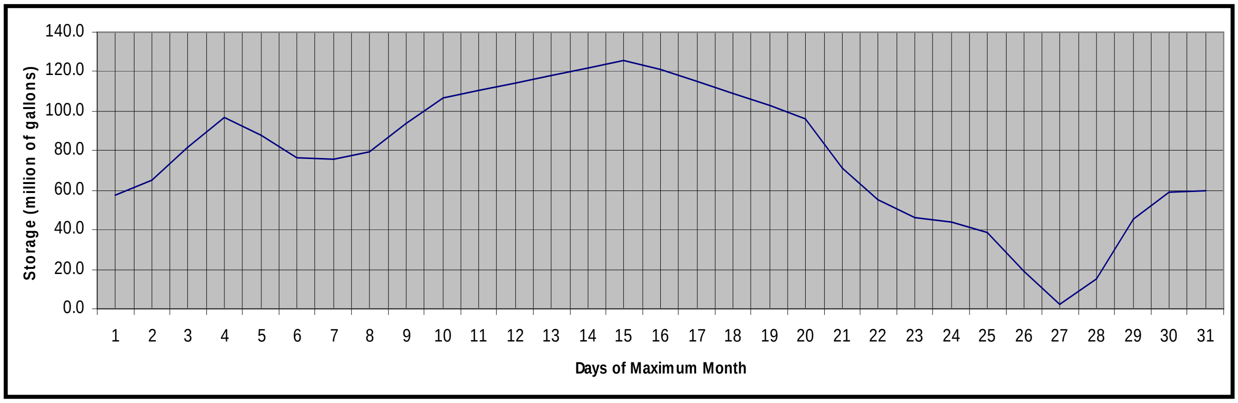


Figure 3.5.7 – Storage Simulation – Fargo under Scenario One.

This storage method captures excess flows from Lake Ashtabula when its releases are higher than needed during the maximum month. Water is withdrawn from storage on days where river flows (releases from Ashtabula and natural flows) are not adequate to meet peak day demands. Column 5 of table 3.5.8 shows the average volume of water (161.5 ac-ft) allocated for Fargo's use during the maximum month scenario. In 16 of the 31 days, the water demand is higher than what is available, based on hydrologic modeling. Approximately 125.3 Mgals of storage has to be drawn during these 16 days to meet peaking demands. The other 15 days require less than average maximum month demand (< 161.5 ac-ft) and excess allocated flows to Fargo can be used to recharge the storage reservoir(s).

Additional Pipeline Capacity - Peak Day Water Demand Method

Some options involve importing water from outside the Red River Valley. Water imports include water from the Missouri River, Lake of the Woods and Minnesota groundwater. The conveyance pipeline system's capacity from each of these water sources can be increased to meet peak day requirements. For example, for Fargo under Scenario One, the difference between average water allocation during the maximum month (161.5 ac-ft) and Fargo's peak day water demand (239.3 ac-ft) is 77.9 ac-ft or 25.4 Mgals. That is equivalent to 39.3 cfs flow over a one-day period. Therefore, the import feature to serve Fargo can be increased in capacity by 39.3 cfs to meet peak day water demands. The results are the same capacity requirements as discussed for groundwater. These values are highlighted in table 3.5.8.

Peak Day Water Demand Analysis Results

Tables 3.5.9 and 3.5.10 show the results of peak day water demand analysis for water demand Scenario One or Scenario Two. The tables show the required increase in capacity in cfs from groundwater sources, storage in millions of gallons, and added pipeline capacity in cfs for imports. Groundwater capacity in the table represents the added capacity required above what is needed to meet average day demand during a maximum month. Storage volume in the table represents the volume in Mgals required to meet peak day above a water system's requirements for normal operational flows and fire flows. Added pipeline capacity in cfs is the added capacity required above results generated in the monthly hydrologic model that are based on maximum month. Detailed analysis for each of the water systems appears in Appendix A.

Table 3.5.9 – Peak Day Water Demand Results - Scenario One.

Water Systems	Scenario One Well Capacity (cfs)	Scenario One Storage Capacity (millions of gallons)	Scenario One Added Pipeline Capacity (cfs)
Cass Rural Water Users District	0.56	2.78	0.56
Drayton	NA	1.86	0.45
East Grand Forks	NA	7.90	3.79
Fargo	39.26	125.30	39.26
Grafton	NA	2.69	0.52
Grand Forks	27.05	65.37	27.05
Grand Forks-Traill Water District	1.29	4.12	1.29
Langdon (City and Rural Water System)	NA	2.45	0.92
Moorhead	5.12	24.01	5.12
Valley City	1.53	3.36	1.53
West Fargo	3.56	15.99	3.56

NA - This method of meeting peak day demand is not available

A combination of two or all three of these peak day demand methods can be employed by a water system to meet peak day. For example, Moorhead has all three methods available, so some combination may be preferable to using one method exclusively. Table 3.5.6 identifies the peak day methods available to individual systems. If one method is more cost effective than the other two, the full capability of that method may be used before the other two are considered.

Table 3.5.10 – Peak Day Water Demand Results - Scenario Two.

Water Systems	Scenario Two Well Capacity (cfs)	Scenario Two Storage Capacity (millions of gallons)	Scenario Two Added Pipeline Capacity (cfs)
Cass Rural Water Users District	0.85	4.27	0.85
Drayton	NA	1.86	0.45
East Grand Forks	NA	10.41	5.27
Fargo	46.72	147.69	46.72
Grafton	NA	3.81	0.79
Grand Forks	28.67	69.50	28.67
Grand Forks-Traill Water District	1.86	5.85	1.86
Langdon (City and Rural Water System)	NA	2.75	1.08
Moorhead	6.42	30.04	6.42
Valley City	1.97	4.26	1.97
West Fargo	3.64	16.18	3.64

NA - This method of meeting peak day demand is not available

Peak Day Results for Options

All Project options need to meet peak day water demands in order to meet the comprehensive water needs of the Red River Valley. Table 3.5.11 lists each option and the peak day method or methods employed for that option. Tables 3.5.12 and 3.5.13 show the peak day water demand methods used and results for each of the Project options under Scenario One and Scenario Two, respectively. The GDU Water Supply Replacement Pipeline Alternative is not listed in the tables because it was originally designed to meet peak day demands, so no additional capacity was added to this option.

Table 3.5.11 – Options and Peak Day Water Demand Methods Used.

Option	Peaking Factor Method(s)
North Dakota In-Basin	Groundwater and Storage
Red River Basin	Groundwater and Storage
Lake of the Woods	Groundwater and Storage
GDU Import to Sheyenne River	Peak day releases from Lake Ashtabula to meet downstream peak day demands
GDU Import Pipeline	Import pipeline capacity increased
Missouri River Import to RRV	Groundwater and Storage

Each water system has a peaking method shown with the associated capacity requirement for each of the six supplement options. Capacity values for groundwater and pipelines are in cfs units, while capacity requirements for storage are in Mgals.

Table 3.5.12 – Alternative Peak Day Method and Capacity Requirement – Scenario One.

Water Systems	Options					
	ND In-Basin	**Red River Basin**	**Lake of the Woods**	**GDU Import to Sheyenne River**	**GDU Import Pipeline**	**Missouri River to RRV Import**
Cass Rural Water Users District	Groundwater	Groundwater	Groundwater	Purchased [1]	Purchased [1]	Groundwater
	0.56 cfs	0.56 cfs	0.56 cfs	0.56 cfs	0.56 cfs	0.56 cfs
Drayton	Storage	Storage	Storage	In River [2]	In River [2]	Storage
	1.86 Mgals	1.86 Mgals	1.86 Mgals	0.45 cfs	0.45 cfs	1.86 Mgals
East Grand Forks	Storage	Storage	Storage	In River [2]	Pipeline	Storage
	7.90 Mgals	7.90 Mgals	7.90 Mgals	3.79 cfs	3.79 cfs	7.90 Mgals
Fargo	Groundwater	Groundwater	Groundwater	In River [2]	Pipeline	Groundwater
	39.26 cfs	39.26 cfs	39.26 cfs	39.26 cfs	39.26 cfs	39.26 cfs
Grafton	Storage	Storage	Storage	In River [2]	In River [2]	Storage
	2.69 Mgals	2.69 Mgals	2.69 Mgals	0.52 cfs	0.52 cfs	2.69 Mgals
Grand Forks	Groundwater	Groundwater	Groundwater	In River [2]	Pipeline	Groundwater
	27.05 cfs	27.05 cfs	27.05 cfs	27.05 cfs	27.05 cfs	27.05 cfs
Grand Forks-Traill Water District	Groundwater	Groundwater	Groundwater	Purchased [1]	Purchased [1]	Groundwater
	1.29 cfs	1.29 cfs	1.29 cfs	1.29 cfs	1.29 cfs	1.29 cfs
Langdon (City and Rural)	Storage	Storage	Storage	In River [2]	In River [2]	Storage
	2.45 Mgals	2.45 Mgals	2.45 Mgals	0.92 cfs	0.92 cfs	2.45 Mgals
Moorhead	Groundwater	Groundwater	Groundwater	In River [2]	Pipeline	Groundwater
	5.12 cfs	5.12 cfs	5.12 cfs	5.12 cfs	5.12 cfs	5.12 cfs
Valley City	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater
	1.53 cfs	1.53 cfs	1.53 cfs	1.53 cfs	1.53 cfs	1.53 cfs
West Fargo	Groundwater	Groundwater	Groundwater	In River [2]	Pipeline	Groundwater
	3.56 cfs	3.56 cfs	3.56 cfs	3.56 cfs	3.56 cfs	3.56 cfs
Groundwater Capacity (cfs)	78.4 cfs	78.4 cfs	78.4 cfs	1.5 cfs	1.5 cfs	78.4 cfs
Storage Capacity (Mgals)	14.9 Mgals	14.9 Mgals	14.9 Mgals	0.0 Mgals	0.0 Mgals	14.9 Mgals
Pipeline Capacity (cfs)	0.0 cfs	0.0 cfs	0.0 cfs	82.5 cfs	82.5 cfs	0.0 cfs

[1] The water to meet peak day demands would be actually purchased from Fargo or Grand Forks for these rural systems.

[2] Peak day demand met by additional flows in river.

Table 3.5.13 - Alternative Peak Day Method and Capacity Requirement – Scenario Two.

Water Systems	Options					
	ND In-Basin	Red River Basin	Lake of the Woods	GDU Import to Sheyenne River	GDU Import Pipeline	Missouri River to RRV Import
Cass Rural Water Users District	Groundwater	Groundwater	Groundwater	Purchased [1]	Purchased [1]	Groundwater
	0.85 cfs	0.85 cfs	0.85 cfs	0.85 cfs	0.85 cfs	0.85 cfs
Drayton	Storage	Storage	Storage	In River [2]	In River [2]	Storage
	1.86 Mgals	1.86 Mgals	1.86 Mgals	0.45 cfs	0.45 cfs	1.86 Mgals
East Grand Forks	Storage	Storage	Storage	In River [2]	Pipeline	Storage
	10.41 Mgals	10.41 Mgals	10.41 Mgals	5.27 cfs	5.27 cfs	10.41 Mgals
Fargo	Groundwater	Groundwater	Groundwater	In River [2]	Pipeline	Groundwater
	46.72 cfs	46.72 cfs	46.72 cfs	46.72 cfs	46.72 cfs	46.72 cfs
Grafton	Storage	Storage	Storage	In River [2]	In River [2]	Storage
	3.81 Mgals	3.81 Mgals	3.81 Mgals	0.79 cfs	0.79 cfs	3.81 Mgals
Grand Forks	Groundwater	Groundwater	Groundwater	In River [2]	Pipeline	Groundwater
	28.67 cfs	28.67 cfs	28.67 cfs	28.67 cfs	28.67 cfs	28.67 cfs
Grand Forks-Traill Water District	Groundwater	Groundwater	Groundwater	Purchased [1]	Purchased [1]	Groundwater
	1.86 cfs	1.86 cfs	1.86 cfs	1.86 cfs	1.86 cfs	1.86 cfs
Langdon (City and Rural)	Storage	Storage	Storage	In River [2]	In River [2]	Storage
	2.75 Mgals	2.75 Mgals	2.75 Mgals	1.08 cfs	1.08 cfs	2.75 Mgals
Moorhead	Groundwater	Groundwater	Groundwater	In River [2]	Pipeline	Groundwater
	6.42 cfs	6.42 cfs	6.42 cfs	6.42 cfs	6.42 cfs	6.42 cfs
Valley City	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater
	1.97 cfs	1.97 cfs	1.97 cfs	1.97 cfs	1.97 cfs	1.97 cfs
West Fargo	Groundwater	Groundwater	Groundwater	In River [2]	Pipeline	Groundwater
	3.64 cfs	3.64 cfs	3.64 cfs	3.64 cfs	3.64 cfs	3.64 cfs
Groundwater Capacity (cfs)	90.1 cfs	90.1 cfs	90.1 cfs	2.0 cfs	2.0 cfs	90.1 cfs
Storage Capacity (Mgals)	18.8 Mgals	18.8 Mgals	18.8 Mgals	0.0 Mgals	0.0 Mgals	18.8 Mgals
Pipeline Capacity (cfs)	0.0 cfs	0.0 cfs	0.0 cfs	95.7 cfs	95.7 cfs	0.0 cfs

[1] The water to meet peak day demands would be actually purchased from Fargo or Grand Forks for these rural systems.

[2] Peak day demand met by additional flows in river.

Four of the six options primarily use groundwater, with some storage to meet their peak day demands. The GDU Import Pipeline Alternative uses increased import pipeline capacity and some limited storage to meet peak day. The GDU Import to Sheyenne River Alternative also has increased pipeline capacity as its primary method of meeting peak day demands, but this is somewhat misleading. Rather than adding 82.5 cfs (Scenario One) or 95.7 cfs (Scenario Two) increased pipeline capacity, the increase was smaller because of efficiencies associated with using Lake Ashtabula as a re-regulating reservoir. Storage was used to meet peak day demands in some options for Drayton, Grafton, Langdon (city and rural water system), and East Grand Forks.

3.6 Hydrology Summary

3.6.1 Groundwater

Available scientific literature concerning groundwater distribution, quantity, and quality available to the Red River Valley and northwestern Minnesota have been examined and summarized. All large groundwater resources that could supply significant amounts of water were evaluated for their potential contribution to the Project; however, it was not feasible to consider every sand and gravel body that could theoretically fit the definition of an aquifer.

When looking for sustainable production from aquifers, many questions concerning the utility of a specific aquifer had to be addressed. While not all questions are applicable to all aquifers or situations, the questions key to making recommendations are as follows:

- What are the physical properties of the aquifer?
    - Saturated thickness
    - Areal extent
    - Individual well yield (instantaneous and annual)
    - Confined versus unconfined
    - Amount and types of natural recharge
- Is water quality suitable for use as a MR&I source?
- What is the geographic relationship between wellfield and consumer?
    - Distance between wellfield and user
    - Terrain and right-of-way for connecting pipeline
- Are there obvious negative impacts associated with the proposed use of the resource with respect to existing users or the environment? (Addressed in the DEIS)
- What is land use above the aquifer and its recharge area?
    - Municipal and residential
    - Agriculture
    - Wetlands
    - Parks, grasslands, and wildlife
- What are the existing demands on the aquifer?
    - MR&I
    - Irrigation
    - Natural discharge
- What type of development, or redevelopment is reasonable for the aquifer?
    - Increased development
    - Conversion of existing uses
    - Reservation of water for future use
    - Aquifer storage and recovery

Using these questions for guidance, several groundwater sources in or near the Red River Valley were identified as a potential water source for the Project. Aquifers with potential for development in eastern North Dakota are the Brightwood, Milnor Channel, Gwinner, Spiritwood, Elk Valley, West Fargo North, and West Fargo South (table 3.6.1).

Table 3.6.1 lists general advantages and disadvantages of aquifers as water supply features, identifies which options include the aquifers as a feature, type of proposed development by the Project, and the entity which would benefit from the feature.

The Brightwood, Milnor Channel, and Gwinner aquifers along with a portion of the Spiritwood Aquifer in Sargent County could be reserved for future use during a drought. Given a drought of duration and intensity similar to that experienced during the 1930s, these aquifers should be able to augment water supplies that normally use surface water in the Wahpeton area. Securing the use of these aquifers would require limiting future development of these aquifers to only Project features.

The Elk Valley Aquifer is geographically well suited to supply water to Grand Forks and Grand Forks-Traill Rural Water Users District. Grand Forks would require water to meet peak day demands during a drought while Grand Forks-Traill Water Users District needs between 605 and 1,142 ac-ft of additional water on an annual basis. The combined annual demand for groundwater for these systems during a drought is between 1,757 and 2,363 ac-ft. Since the Elk Valley Aquifer is already considered to be permitted near capacity, obtaining new permits for groundwater withdrawals is unlikely. An analysis of irrigation on the Elk Valley Aquifer shows that for every average irrigation plot converted to municipal or rural use, a year supply of water for 650 people could be obtained. The conversion of permitted use has not been attempted in North Dakota on a scale this large, but it may be advantageous because of the geographic suitability of this water supply.

Aquifer storage and recovery within the West Fargo Aquifer System has several advantages. The biggest advantage is the close proximity of the West Fargo Aquifer System to the Fargo and West Fargo communities that would benefit from the ASR systems. The West Fargo North and West Fargo South Aquifers are the two aquifer units of the aquifer system proposed for ASR as part of the Project. The ASR system for West Fargo North would serve West Fargo and would augment surface water from the Sheyenne River.

Aquifer storage and recovery in the West Fargo South Aquifer constitutes a peak day supply of water to augment surface water supplied as part of the Project. While the West Fargo Aquifer System has other units, only the West Fargo North and West Fargo South are being proposed for ASR due to limited supply of surface water for recharge during a drought. Given the lack of natural recharge, continuation use at current levels, and persistent water table declines, all major West Fargo Aquifer System aquifers will eventually have reduced value for water supply without ASR.

There are several large aquifers within or adjacent to the Red River Valley in Minnesota. Aquifers considered suitable for development in western Minnesota include the Buffalo, Moorhead, Pelican River Sand-Plain, and Otter Tail Surficial Aquifers. Options to develop these aquifers into features for the Project include increasing withdrawals by expansion of development, ASR, and new development (table 3.6.2).

Table 3.6.1 - Summary of Proposed Use of North Dakota Aquifers for the Project.

Aquifer	Advantages	Disadvantages	Options with Aquifer as a Feature	Proposed Type of Use	Water User
Brightwood	Good recharge	Thin formations Connected to surface waters	▪ North Dakota In-Basin ▪ Red River Basin ▪ Lake of the Woods ▪ Missouri River Import to Red River Valley	Reservation	Wahpeton Industrial
Milnor Channel	Good recharge	Thin formations Connected to surface waters			
Gwinner	Good recharge	Small aquifer			
Spiritwood	High-yield wells	Poor water quality Little or no natural recharge			
Elk Valley	Location Good recharge Good water quality	Heavily appropriated	▪ North Dakota In-Basin ▪ Red River Basin ▪ Lake of the Woods ▪ Missouri River to Red River Valley Import	Conversion of use	Grand Forks Grand Forks-Traill Water District
Fordville	None	Small aquifer Heavily appropriated	None	Existing	
Gardar	None	Small aquifer Geographically isolated	None	Existing	
Grand Forks	Location	Poor water quality Very small aquifer No recharge	None	Existing	
Icelandic	None	Small aquifer Heavily appropriated	None	Existing	
Inkster	None	Small aquifer Heavily appropriated	None	Existing	
McVille	None	Small aquifer Geographically isolated from population centers	None	Existing	
Page-Galesburg	Large aquifer	Heavily appropriated Unknown recharge Many pending permits	None	Existing	

Table 3.6.1 continued - Summary of Proposed Use of North Dakota Aquifers for the Project.

Aquifer	Advantages	Disadvantages	Options with Aquifer as a Feature	Proposed Type of Use	Water User
Sheyenne Delta	Large aquifer	Fine-grained Physically difficult to develop Underlies National Grasslands	None	Existing	
Sonora	None	Very small Poor water quality	None	None	
Wahpeton Buried Valley	Location Good water quality	Small aquifer Heavily appropriated	None	Existing	
West Fargo North	Location	Relatively small Rapidly depleting	▪ North Dakota In-Basin ▪ Red River Basin ▪ Lake of the Woods ▪ Missouri River Import to Red River Valley	ASR	West Fargo
West Fargo South	Location	Relatively small Rapidly depleting	▪ North Dakota In-Basin ▪ Red River Basin ▪ Lake of the Woods ▪ Missouri River Import to Red River Valley	ASR	Fargo
Other West Fargo Aquifers	Location	Relatively small Undergoing depletion	None	Existing	

The Buffalo Aquifer is currently being used by Moorhead. Analysis shows that groundwater resources may be available for increased withdrawals by expanding the Moorhead wellfield in the Buffalo Aquifer.

Another aquifer available to Moorhead is the Moorhead Aquifer. This aquifer's usefulness has steadily declined as water levels have continued to decrease; however, this aquifer is ideally located and potentially well suited for ASR. While ASR cannot provide the entire future water supply for Moorhead, the aquifer can be stabilized using ASR and developed into a dependable, limited source of water during a drought.

The Pelican River Sand-Plain Aquifer is located approximately 40 miles southeast of the Fargo-Moorhead area in Minnesota. It has potential for increased development. Combining it with the Otter Tail Surficial Aquifer, located about 65 miles southeast of Fargo-Moorhead, would provide sufficient groundwater resources to augment water supplies in the Fargo-Moorhead area during a drought.

Analysis shows there are several aquifers of suitable size in the Red River Valley of North Dakota that do not have sufficient potential for expanded development. These aquifers are the Page-Galesburg, Sheyenne Delta, and Wahpeton Buried Valley aquifers. The Page-Galesburg Aquifer is heavily used for irrigation. While limited potential exists in portions of the aquifer, it is unlikely the aquifer could support significant increased development to warrant inclusion as a feature. The Sheyenne Delta Aquifer has potential for limited development along its southern edge, but it is highly unlikely that significant quantities of water could be obtained without adversely impacting the Sheyenne National Grasslands. The Wahpeton Buried Valley Aquifer is considered permitted to its limit primarily due to a large permit held in abeyance for use only during a drought.

Several aquifers in the Red River Valley of Minnesota are not suitable for development by the Project. These include the Middle River and Two Rivers Surficial aquifers in the northern part of the Red River Valley, the Pineland Sands Surficial Aquifer, and the Wadena and Bemidji-Bagley Surficial aquifers. The Two Rivers Surficial Aquifer would be a suitable candidate for future development based upon existing use and size of the aquifer; however, its geographic location is a disadvantage because there are suitable groundwater supplies closer in proximity to the communities being served. The Pineland Sands Surficial Aquifer is not currently proposed for future development as a feature in the Project. It should be noted that if water supplies of more suitable aquifers prove insufficient with further testing, this aquifer is the next likely candidate for development. Other aquifers not suitable for development have attributes ranging from thin saturated zones, heavy use, or remote location. Depending on these aquifers in times of extended drought may not provide a reliable water supply.

Table 3.6.2 - Summary of Proposed Use of Minnesota Aquifers for the Project.

Aquifer	Advantages	Disadvantages	Options with Aquifer as a Feature	Proposed Type of Use	Water User
Beach Ridges	None	Small discrete aquifers Unknown water quality Typically low yield potential	None	None	
Buffalo	Location Good recharge	None	▪ North Dakota In-Basin ▪ Red River Basin ▪ Lake of the Woods ▪ Missouri River Import to Red River Valley	Expansion	Moorhead
Bemidji-Bagley	Large aquifer High recharge	Agricultural chemicals Geographically distant compared to other aquifers	None	None	
Moorhead	Location	No recharge Undergoing depletion	▪ North Dakota In-Basin ▪ Red River Basin ▪ Lake of the Woods ▪ Missouri River Import to Red River Valley	ASR	Moorhead
Otter Tail Surficial	Large aquifer Good water quality High recharge	Potential impact to surface waters	Red River Basin	Expansion	Fargo Metro Area
Middle River Surficial	None	Geographically isolated Low yield potential Small aquifer	None	None	
Pelican River Sand-Plain	Large aquifer Good water quality High recharge	None	Red River Basin	Expansion	Fargo Metro Area
Pineland Sands Area	Large aquifer High recharge	Agricultural chemicals Geographically distant compared to other aquifers	None	None	
Two Rivers Surficial	Large aquifer High amount of water	Geographically distant compared to other aquifers	None	None	
Wadena Surficial	High recharge	Existing high use Geographically distant compared to other aAquifers	None	None	

Historical trends and use data show irrigation will continue to be the largest user of groundwater in the foreseeable future. Because of the dominance of irrigation, the potential groundwater resources available for MR&I use in the Red River Valley are limited. This limitation on capacity means that groundwater is only available as a supplemental source of water to a well managed surface water supply.

Table 3.6.3 shows the water systems that analysis predicts would have shortages and could use groundwater as a means to meet a portion of that shortage during a drought.

Table 3.6.3 – Water Systems with Potential Groundwater Sources.

Water Systems	Groundwater Source Description
Cass Rural Water Users District	Cass Rural Water Users District currently has wells in the West Fargo North Aquifer, but this study assumes that they would purchase water from Fargo as their primary source of water in the future. There is adequate capacity in the aquifer to meet short-term peaking needs.
Fargo	The West Fargo South Aquifer is located approximately 6 miles south of Fargo. The aquifer is not a good water source candidate for continuous withdrawals; however, it could serve Fargo's periodic peak day water demands in the future with ASR development.
Grand Forks	The Elk Valley Aquifer is located approximately 17 miles west of Grand Forks. The aquifer is heavily permitted, but there is potential to purchase or contract for irrigation water rights to meet peak day water shortages.
Grand Forks-Traill Water District	Grand Forks-Traill Water District currently uses the Elk Valley Aquifer as a water source. The aquifer is heavily permitted, but there is a potential to purchase and convert irrigation water rights to meet annual and peak day water demands and shortage.
Moorhead	Moorhead currently uses the Buffalo Aquifer as a water source. There is a potential to expand their well capacity in the aquifer to meet peak day demands. The Moorhead aquifer could also be stabilized with an ASR program.
Valley City	Valley City currently uses surface water from the Sheyenne River to recharge groundwater via a pond adjacent to the WTP. Their actual water supply comes from wells adjacent to the recharge pond.
West Fargo	An ASR system is planned in the West Fargo North Aquifer as a supplemental source of water for West Fargo in a drought.

3.6.2 Surface Water

Water shortages were estimated using a hydrologic model called StateMod. StateMod evaluated timing of river flows, water withdrawals, return flows, precipitation, and evaporation at many locations throughout the Red River Basin in the U.S.

Specific objectives were to:

- Examine surface water supply conditions to estimate 2005 and 2050 water supply shortages.
- Develop water supply options to meet future water needs.

A water shortage is defined as the difference between the water demand and how much water is available on a daily, monthly, or annual basis. Unavailability or timing of supply can cause shortages. Under normal climatic conditions, there are adequate surface water sources to meet current water demands. During a drought, however, there would be water shortages.

Some 2005 MR&I users in the service area would experience significant water shortages during a drought like the one that occurred from 1931 -1941. The hydrologic model forecasts that the maximum annual water shortage could be 16% in the sixth year of an extended drought. The maximum single monthly water shortage could be a 46% deficit in February of the seventh year.

Total service area shortages in 2050 would be almost 37,000 acre-feet for Scenario One, or 53,000 acre-feet for Scenario Two, during the worst year of a 1930s-style drought (table 3.5.2). The worst year for the Red River Valley in the U.S. corresponds to the 1934 flow year. This means the shortage could be encountered by the fourth year of a 1930s drought.

Hydrologic modeling identified which MR&I water systems would have water shortages in the year 2050. MR&I water systems and potential water shortages are listed in table 3.6.4. These shortages do not include those for irrigation or other permits that are not served by this Project. The options in chapter four are designed to supply water to meet the water demands quantified in chapter two and the water shortages estimated in this chapter.

Table 3.6.4 - Summary of MR&I Water Shortages in 2050 during a 1930s Drought.

	Scenario One			Scenario Two		
Water User	**Monthly Shortage**	**Daily Peaking Shortage**	**Estimated Annual Shortage (ac-ft)**	**Monthly Shortage**	**Daily Peaking Shortage**	**Estimated Annual Shortage (ac ft)**
Municipality						
Drayton	X	X	90	X	X	90
East Grand Forks						
Fargo	X	X	24,152	X	X	37,456
Grafton						
Grand Forks		X	0		X	1,927
Langdon	X	X	340	X	X	392
Moorhead	X	X	4,543	X	X	5,007
Valley City						
West Fargo	X	X	3,544	X	X	3,797
Rural Water Systems						
Agassiz Water Users District						
Cass Rural Water Users District	X	X	Included in Fargo Shortage	X	X	Included in Fargo Shortage
Dakota Rural Water District						
Grand Forks-Traill Water District	X	X	Included in Grand Forks Shortage	X	X	Included in Grand Forks Shortage
Langdon Rural Water District	X	X	101	X	X	190
Ransom-Sargent Water Users District						
Southeast Water District						
Traill County Water District						
Tri-County Water District						
Walsh Rural Water Distict						
Industry						
ADM Corn Processing	X		225	X		225
American Crystal, Permit 251						
American Crystal, Permit 1076						
American Crystal, MN Permit 450008	X	X	495	X	X	464
American Crystal, Permit 1917	X	X	447	X	X	447
Cargill	X	X	1,926	X	X	2,105
New Industry at Wahpeton	X	X	3,404	X	X	6,451

Chapter Four
Options

The Dakota Water Resources Act directs the Secretary of the Interior to conduct a comprehensive study of the water quality and quantity needs of the Red River Valley and options to meet those needs. This chapter describes seven options, also referred to as alternatives, that would meet the comprehensive water needs of the Red River Valley service area.

There are two types of options – supplemental and replacement. Six of the options propose to supplement existing water sources within the valley to meet future water supply shortages, and one option would replace all current service area water sources with imported Missouri River water. Three of the options propose to use in-basin water sources to meet water shortages and the remainder propose to import water from the Missouri River Basin. Options that propose importing water from the Missouri River have biota WTPs (water treatment plants) as features.

Section 4.1 summarizes basic guidelines for designing each option. These guidelines are referred to as design criteria and were developed to insure consistency among options. Options are made up of a series of water supply features which collectively meet future water demands. The design criteria are organized based on design requirements of features.

Section 4.2 describes each of the water supply features including operational assumptions associated with use of each feature. Some features are used in more than one option, such as ASR (aquifer storage and recovery), while other features are unique to just one option, like the Bismarck to Fargo and Grand Forks Pipeline.

Section 4.3 describes the options to meet water supply shortages. The shortages were identified in the previous hydrology chapter. The six supplemental options and one replacement option are comprised of features, which are described in section 4.2.

Section 4.4 identifies additional option analyses conducted as part of the studies. The purpose of this section is to provide additional information about the options beyond the costs presented in section 4.3. This section includes an evaluation of the construction phasing capability of each option, analysis of potential costs savings of drought contingency measures, and evaluation of the costs of meeting an minimum instream flows recommended by the NDGFD (North Dakota Game and Fish Department). Chapter four concludes with a summary of options (alternatives), including a financial analysis with per household and unit water cost estimates.

4.1 Design Criteria

Design criteria assure that features are designed using the same standards. This allows direct comparison between options that are a compilation of features. The design criteria used in this study may be revised during the final design phase if the Project (Red River Valley Water

Supply Project) ultimately is constructed. Refinements in specific design criteria can be made at the final design stage that are not practical at this design level due to the sheer number of options under consideration.

The design criteria for this Project are described in *Design Criteria, Red River Valley Water Supply Project, Needs and Options Study Element* (Houston Engineering Inc. 2005a). All water conveyance, storage, treatment, and supply features proposed in this chapter are described in the design criteria report and are summarized below. Design criteria for out-of-basin biota WTPs are described in the Reclamation Denver Technical Service Center report *Water Treatment Plant For Biota Removal and Inactivation, Preliminary Design & Cost Estimates, Red River Valley Water Supply Project* (Reclamation 2005b). Regional WTPs at Grand Forks and Fargo are under consideration by those municipalities, and it is assumed that both will be constructed as part of infrastructure improvements. Neither WTP is within the scope of the Project, but the Project proposes to deliver water to both plants for distribution by municipalities to their water users.

Pipelines

All of the options discussed in this chapter include pipelines, so a common set of guidelines for materials and design has been developed for this feature. Design criteria for pipelines incorporate excavation, bedding, backfill, depth of cover, thrust restraints, pipe materials based on size or pressure class required, pipe joints, corrosion protection, valves, blowoffs, manholes, turnouts, vaults, roadway crossings, utility crossings, wetland/creek crossings, metering, monumentation, and hydraulic design.

Booster Pump Stations

Booster pump stations are needed in most of the options that move water from source to delivery point. The options include pumping plants with a wide range of capacity requirements. Design criteria for booster pump stations incorporate siting (location), pump station structural type, pump selection, electrical service, instrumentation and control, supervisory control and data acquisition systems, emergency power, and design parameters (flow rate, total dynamic head, number of pumping units, and horsepower).

Water Storage

Water storage reservoirs or tanks are included in most options to regulate pipeline conveyance and to store water. Design criteria for water storage features include siting (location), operations, storage structure types (depending on volume requirements), control valves, and appurtenances.

Groundwater Wells, Wellfields, and Aquifer Storage and Recovery

Design criteria for groundwater wells and wellfields are needed because a number of features interconnect new wells in wellfields. Some new and expanded wellfields will also be developed into ASR systems to maintain groundwater levels. The specifics of how each well is designed are not included in the criteria, but are referenced in each ASR or wellfield design report (see Appendix C). The design criteria include standard elements of well construction, such as materials and construction techniques. Design criteria for ASR wells also incorporate valves for flow control as well as other special appurtenances.

Biota WTPs

Options that propose importing water from the Missouri River have WTPs designed to reduce the risk of interbasin transfer of biota that are not native to the Hudson Bay Basin. Design criteria for biota WTPs are not included in the design criteria document but are described in the Reclamation Denver Technical Service Center report (Reclamation 2005b). The design criteria for biota WTPs include treatment technologies and options, electrical service, instrumentation and control, SCADA (supervisory control and data acquisition) systems, emergency power, and design parameters.

Water Intakes and Outlets

Water intakes and outlets are structures located in bodies of water to facilitate withdrawal or release of water. Water intakes are required for biota WTPs, pumping plants, or storage reservoirs (capture and storage). Outlets return water to a body of water, such as releases of Project water to Lake Ashtabula. Design criteria for water intakes and outlets discuss structure type (depending on intake location), control structures, instrumentation and control, and SCADA systems.

System Instrumentation and Control

Some level of system instrumentation and control integrates features in each option. These instruments and controls operate and monitor biota WTPs, pumping plants, conveyance appurtenances, storage reservoirs, and wellfields. While some individual features, such as biota WTPs and pumping stations, may have their own SCADA capability, design criteria for Project-wide SCADA are also required for each option. Included are data exchange requirements, computer control centers, and system communications.

4.2 Feature Descriptions and Operational Assumptions

This section describes proposed water supply features and operational assumptions. For more details on feature design, layout drawings, hydraulic data, and cost estimates for both water demand scenarios consult Appendix C.

Table 4.2.1 identifies 21 features which in combination form the seven options described in section 4.3. An “x” in the matrix denotes which features are used in which option. Feature operational assumptions used to design and estimate annual operation and maintenance costs of each option are also provided in each feature description.

Terms Used to Quantify Water

Cubic Feet Per Second - (cfs) - Represents the rate at which water flows in a river or pipeline. A cubic foot of water is equal to 7.48 gallons. If 1,000 cfs of water from Baldhill Dam were released over an entire day, that would equal a volume of 1,983 acre-feet/day.

Acre-Feet (ac-ft) - An acre-foot is the volume of water that would cover 1 acre to a depth of 1 foot and equals about 326,000 gallons. At its normal summer operating level, Lake Ashtabula holds about 70,000 ac-ft of water. Ac-ft is also used to quantify the volume of water that can be withdrawn from a well.

Million Gallons per Day (mgd) – generally describes the amount of water treated in a day by a water treatment plant.

Most of the features in table 4.2.1 operate in the same manner regardless of the option, because these usually are designed to achieve a specific water supply goal. Import features, such as pipelines and biota WTPs, can vary significantly in design, because these are sized to meet all additional shortages above the amount of water provided by other features.

Table 4.2.1 – Options and Features Matrix.

		Options						
Features	**Feature Number**	**North Dakota In-Basin**	**Red River Basin**	**Lake of the Woods**	**GDU Import to Sheyenne River**	**GDU Import Pipeline**	**Missouri River Import to Red River Valley**	**GDU Water Supply Replacement Pipeline**
Biota WTP	1				x	x	x	x
Bismarck to Fargo Pipeline	2						x	
CRWUD Interconnection with Fargo	3	x	x	x	x	x	x	
GDU (Garrison Diversion Unit) – Assigned Costs Related to Principal Supply Works	4				x	x		x
GFTWD Interconnection with Grand Forks	5				x	x		
Grand Forks to Lake Ashtabula Pipeline	6	x						
Lake of the Woods Pipeline	7			x				
McClusky Canal to Fargo and Grand Forks Pipeline	8					x		
McClusky Canal to Lake Ashtabula Pipeline	9				x			
Minnesota Groundwater and Pipeline	10		x					
Moorhead ASR	11	x	x	x			x	
Moorhead Peak Day - Expanded use of Buffalo Aquifer	12	x	x	x			x	
New Groundwater to Serve Industries	13	x	x				x	
Peak Day Water Demand using Storage	14	x	x	x			x	
Pipeline to serve Southeast North Dakota Industries	15			x	x	x		
Purchase Elk Valley Aquifer Water Rights	16	x	x	x			x	
Replacement Pipeline	17							x
Relocation of Grafton River Intake	18	x	x	x	x	x	x	
Water Conservation	19	x	x	x	x	x	x	x
West Fargo North ASR	20	x	x	x			x	
West Fargo South ASR	21	x	x	x			x	

GDU is Garrison Diversion Unit.

The capacity results from StateMod hydrologic modeling (chapter three) are shown in table 4.2.2. The results are shown in cfs, which represents the capacity of the main pipeline conveyance feature or biota WTP, if the option involves a Missouri River import. A 5% pipeline loss is assumed in conveyance feature sizing.

Operational assumptions for each feature are described in this section including the average annual volume of water the feature will produce or convey. These were used to estimate annual OM&R (operation, maintenance, and replacement) costs. Table 4.2.3 shows the average annual production volumes in ac-ft for each of the options main conveyance feature. Table C.6 in Appendix C shows the annual water production volumes for each of the 21 features discussed later in this section. Again, a 5% water conveyance loss is estimated for main conveyance features, as shown in the third and fifth columns.

Table 4.2.2 – Option Capacity Results from StateMod Modeling.

Option and Feature	Scenario One Sizing (cfs)	Scenario Two Sizing (cfs)	Scenario One Sizing (w/ 5% losses) (cfs)	Scenario Two Sizing (w/ 5% losses) (cfs)
North Dakota In-Basin – Grand Forks to Lake Ashtabula Pipeline	50	67	53	71
Red River Basin – Minnesota Groundwater and Pipeline	42	68	45	72
Lake of the Woods – Lake of the Woods Pipeline	66	93	70	96
GDU Import to Sheyenne River – McClusky Canal to Lake Ashtabula Pipeline	59	92	62	97
GDU Import Pipeline – McClusky Canal to Fargo and Grand Forks Pipeline	152	192	160	202
Missouri River Import to Red River Valley – Bismarck to Fargo Pipeline	42	60	44	63
GDU Water Supply Replacement Pipeline – Replacement Pipeline	324	391	341	411

Table 4.2.3 – Average Annual Water Supplied by each Option.

Option and Feature	Scenario One Average Annual Water Supplied (ac-ft)	Scenario One Average Annual Water Supplied with Losses (ac-ft)	Scenario Two Average Annual Water Supplied (ac-ft)	Scenario Two Average Annual Water Supplied with Losses (ac-ft)
North Dakota In-Basin – Grand Forks to Lake Ashtabula Pipeline	7,300	7,600	9,000	9,400
Red River Basin – Minnesota Groundwater and Pipeline	2,600	2,800	4,600	4,800
Lake of the Woods – Lake of the Woods Pipeline	17,800	18,700	20,200	21,200
GDU Import to Sheyenne River – McClusky Canal to Lake Ashtabula Pipeline	10,300	10,800	20,100	21,100
GDU Import Pipeline – McClusky Canal to Fargo and Grand Forks Pipeline	20,300	21,300	22,800	24,000
Missouri River Import to Red River Valley – Bismarck to Fargo Pipeline	19,700	20,600	22,800	23,900
GDU Water Supply Replacement Pipeline – Replacement Pipeline	86,300	90,600	110,900	116,400

The values in table 4.2.3 reflect surface water modeling results discussed in chapter three. The average water supplied or conveyance values are based on the 71-year flow database run produced by the model. Refer to Appendix C for more detailed information on how these values were determined. The North Dakota In-Basin and Red River Basin Alternatives have relatively small annual average supply or conveyance values, because these options primarily operate during drought conditions. These two options would operate regularly during 1930s-type drought years, but only minimally during the remaining 61 years of flow data analyzed by StateMod. On average, the volume of water is quite small as compared to the other options. To assure some level of reliable operation, some minimum amount of water would be conveyed through these options in wet years. These minimum operational flows are discussed under the specific feature description later in this section.

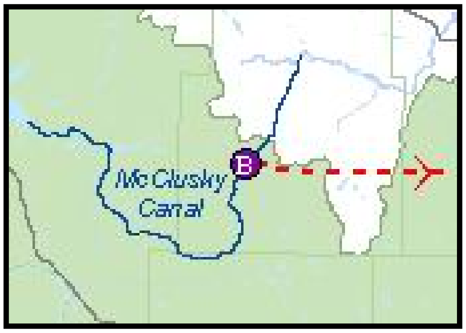
The next group of four options has similar annual average production flows ranging from 12,000 ac-ft to 24,000 ac-ft. These options include GDU Import to Sheyenne River, Lake of the Woods, GDU Import Pipeline, and Missouri River Import to Red River Valley alternatives. The GDU Import to Sheyenne River Alternative production flows are somewhat less than the other three options because it does not provide a piped water supply to Grand Forks like the others. However, higher water volumes are associated with this option, because it is designed to release peak day water demands from Lake Ashtabula into the Sheyenne River. This option is similar to the North Dakota In-Basin and Red River Basin alternatives in that it would operate minimally in wet or normal precipitation years. Here again, some minimum amount of water would be conveyed through this option to assure reliable operation.

The Lake of the Woods and Missouri River Import to Red River Valley Alternatives have higher production flows because these options provide a continuous flow of imported water (20 cfs) to Grand Forks. This provides 12,000 ac-ft to 14,000 ac-ft of additional production in an average water use year. The GDU Import Pipeline Alternative has higher annual water production, because it is designed to provide peak day water demands in the pipeline capacity. The GDU Water Supply Replacement Pipeline Alternative would use the largest annual water volume, because it would import water from the Missouri River to replace all Red River Basin water supplies under all climatic conditions.

Biota WTP Features

Biota WTPs are required in four of the seven options, because the options propose to transfer Missouri River water into the Red River Valley. Listed below are the options and the operational assumptions associated with the biota WTPs.

GDU Import to Sheyenne River Alternative Biota WTP

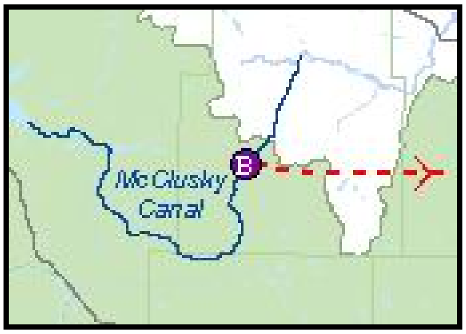


Feature Description A biota WTP adjacent to the McClusky Canal (Mile Marker 58 or three miles north of McClusky, North Dakota) is included in this option. The biota WTP has a capacity of 40 mgd (62 cfs) under Scenario One or 63 mgd (97 cfs) under Scenario Two. The biota WTP includes an intake structure to move water into the plant from the McClusky Canal. The treatment plant includes coagulation, flocculation, sedimentation, ultraviolet disinfection, and chlorine or chloramines for residual management as its primary treatment process. The treatment plant has a clearwell and pumps to convey treated water to the Sheyenne River via a pipeline, which is described as another feature. A more detailed description of the WTP is in Reclamation (2005b).

Operational Assumptions The biota WTP would be operated as needed to meet water demands during a drought. It would operate to maintain Lake Ashtabula's fish and wildlife conservation pool (28,000 ac-ft) all year, while releasing flows to serve water needs of downstream MR&I systems. During normal or wet climatic periods, the biota WTP would run a minimum amount of time to maintain facilities in reliable condition.

Based on hydrologic modeling, the average annual flow through a biota WTP would be 10,800 ac-ft under Scenario One or 21,100 ac-ft under Scenario Two. However, some minimum annual flows also would be maintained to assure reliable operation of the plant. To achieve this goal, the volume of water needed to operate the biota WTP for one month per year is added to the above totals. The volume of water for one month of biota WTP operation is equal to 3,700 ac-ft under Scenario One or 5,800 ac-ft under Scenario Two. Therefore, the average annual total used to estimate OM&R costs will be 14,500 ac-ft under Scenario One or 26,900 ac-ft under Scenario Two.

GDU Import Pipeline Alternative Biota WTP



Feature Description A biota WTP located adjacent to the McClusky Canal (Mile Marker 58 or three miles north of McClusky, North Dakota) is part of this option. The biota WTP would have a capacity of 104 mgd or 160 cfs for Scenario One or 131 mgd or 202 cfs for Scenario Two. This treatment capacity is designed to meet peak day water demand requirements, so the capacity of the system is approximately twice the size of other import options. The treatment plant includes coagulation, flocculation, sedimentation, ultraviolet disinfection, and chlorine or chloramines for residual management as its primary treatment process. The treatment process will not provide SDWA (Safe Drinking Water Act) compliant water quality so additional treatment at in-basin WTPs will be required to meet SDWA regulatory requirements. The biota WTP includes an intake structure that would move water into the plant from the McClusky Canal and clearwell pumps to convey treated water towards the Red River Valley. A more detailed description of the biota WTP is in Reclamation (2005b).

Operational Assumptions This biota WTP would be operated under all climactic conditions because a constant 20 cfs flow (or less than 20 cfs depending on overall water demands of Grand Forks) would be delivered to Grand Forks for blending with local surface water supplies. Because the biota WTP would operate continuously, no minimal operational flows are needed. It is possible that the option would be used in more than strictly a supplemental manner by water users in normal or wet climatic years, if it provided better quality water than current local water sources. However, OM&R cost estimates are based on modeling results. The model shows an average annual flow through biota WTP of 21,300 ac-ft under Scenario One or 24,000 ac-ft under Scenario Two.

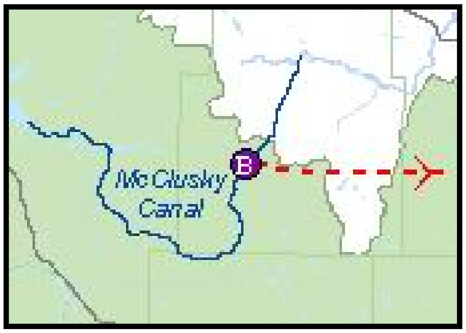
Missouri River Import to Red River Valley Alternative Biota WTP

Feature Description A biota WTP adjacent to the Missouri River south of Bismarck, North Dakota, would be required for this option. The biota WTP would have a capacity of 29 mgd (44 cfs) for Scenario One or 41 mgd (63 cfs) for Scenario Two. The treatment plant would have coagulation, flocculation, sedimentation, ultraviolet disinfection, and chlorine or chloramines for residual management as its primary treatment process. The treatment process would not provide SDWA compliant water quality, so additional treatment at in- basin WTPs would be required to meet SDWA regulatory requirements. A horizontal well collection system in the Missouri River assures reliable operation under varying river flow conditions. The WTP includes a clearwell and pumps to convey treated water east to the Red River Valley via pipeline. A more detailed description of the biota WTP is in Reclamation (2005b).

Operational Assumptions The Missouri River Import to Red River Valley Alternative conveyance system is designed to meet the supplemental water needs of the Red River Valley. This option not only includes a pipeline conveying water into the valley, but a spur pipeline to fill Lake Ashtabula. This 23 cfs (Scenario One) or a 42 cfs (Scenario Two) pipeline spur reduces the size of the import pipeline because water can be stored in Lake Ashtabula during moderate years and be released from Lake Ashtabula during drought years. The biota WTP would be operated as needed to meet MR&I water demands during a drought in addition to maintaining Lake Ashtabula within its operational target elevations.

This biota WTP would be operated under all climatic conditions at up to a 20 cfs flow for delivery to Grand Forks to blend with local surface water supplies. The biota WTP would be operated continuously, and no minimal operational flows would be set. OM&R cost estimates are based on modeling results for this biota WTP. Based on hydrologic modeling, the average annual flow through biota WTP would be 20,600 ac-ft under Scenario One or 23,900 ac-ft under Scenario Two.

GDU Water Supply Replacement Pipeline Alternative Biota WTP



Feature Description A biota WTP located adjacent to the McClusky Canal (Mile Marker 58 or three miles north of McClusky, North Dakota) is included in this option. The biota WTP is designed to meet a peak day demand of 221 mgd (341 cfs) under Scenario One demands or 266 mgd (411 cfs) under Scenario Two demands.

The plant for this option would include additional processes to deliver water treated to SDWA standards to the service area. Currently numerous water systems in the valley use groundwater and lack the capability to treat surface water. Therefore, treated water must be supplied to these systems or they would have to adapt their current groundwater WTP to treat surface water. To address this problem, the entire service area would receive bulk-treated water in this option. The treatment process would use lime softening, micro-filtration, ultraviolet disinfection, and chlorine or chloramines for residual management to generate water that fully complies with the SDWA. The combination of lime softening and microfiltration would be used to reduce the volume of residuals, because the McClusky Canal site lacks a watercourse for disposal. The biota WTP would include an intake structure to move water into the plant from the McClusky Canal and clearwell pumps to convey treated water via pipeline to the Red River Valley. A more detailed description of the biota WTP is in Reclamation (2005b).

Operational Assumptions The GDU Water Supply Replacement Pipeline Alternative conveyance system is designed to replace all existing water supplies in the Red River Valley. The water treatment and conveyance features would meet peak day water demand requirements. For OM&R cost estimating purposes, the annual average water volume produced by the biota WTP would be 90,600 ac-ft under Scenario One or 116,400 ac-ft under Scenario Two.

Other Features

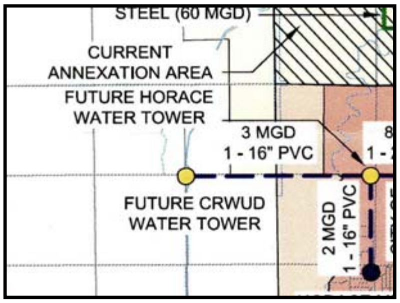
Described below are the other features listed in table 4.2.1 and included in the seven options described in section 4.3.

Bismarck to Fargo Pipeline

Feature Description This feature includes a 299 mile long pipeline conveyance system which would transport Missouri River water from a biota WTP south of Bismarck to the Fargo and Grand Forks areas. The pipeline from the biota WTP to Fargo has a capacity of 44 cfs under Scenario One or 63 cfs under Scenario Two. A spur off the main line near Casselton serves the Grand Forks area. The pipeline to Grand Forks delivers 20 cfs (21 cfs with pipe losses) to blend with existing surface water sources to improve water quality. A 23 cfs (Scenario One) or a 42 cfs (Scenario Two) pipeline spur from the main conveyance pipeline north to Lake Ashtabula is also included in order to use the lake as a regulating reservoir. Booster pump stations and storage tanks are also included based on hydraulic and operational considerations. The capacity estimates include 5% pipeline losses.

Operational Assumptions This Project feature would convey water from the biota WTP south of Bismarck to the Red River Valley. A spur pipeline connecting the main conveyance pipeline at Valley City with Lake Ashtabula is also included. This pipeline spur uses Lake Ashtabula as a regulating reservoir, which reduces the capacity of the main conveyance pipeline. The spur pipeline also allows regulation of the lake within its target elevations. The water needs of the valley are met by a combination of reservoir releases from Lake Ashtabula and by water conveyed via pipeline from Valley City to the Red River Valley. For operational assumptions see the biota WTP discussion under the Missouri River Import to Red River Valley Biota WTP previously discussed.

Cass Rural Water Users District Interconnection with Fargo



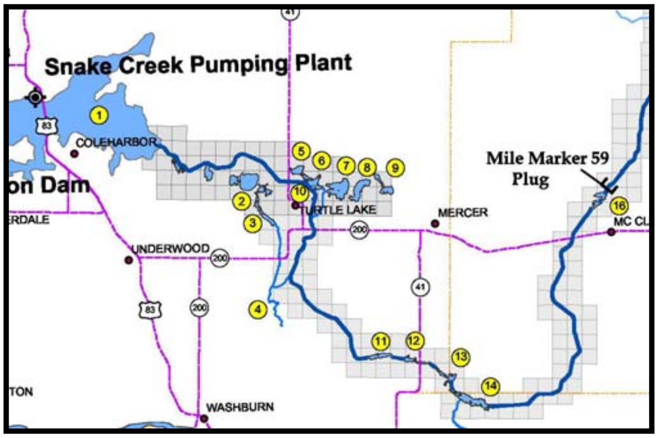
Feature Description This feature includes the cost of Cass Rural Water Users District interconnecting with Fargo and purchasing water to meet estimated shortages.

Reclamation's analysis of Cass Rural Water Users District existing groundwater sources in chapter three reveals that the water system would have adequate water supplies for its Phase II and III service areas but not for its Phase I area. The Phase I area is adjacent to Fargo, so Reclamation assumed that Cass Rural Water Users would interconnect with Fargo water system and would purchase water to meet their total Phase I service area needs. The feature includes 2.1 cfs (Scenario One) or a 3.2 cfs (Scenario Two) pipeline interconnection between Fargo and the Cass Rural Water Users District distribution system.

Operational Assumptions The annual OM&R costs for the Cass Rural Water Users Phase I service area are based on the average annual water demand, which is 340 ac-ft under Scenario One or 782 ac-ft under Scenario Two.

GDU– Assigned Costs Related to Principal Supply Works

Feature Description The GDU Principal Supply Works would be used to deliver Missouri River water for three of the seven options considered in this report. This feature covers the incremental costs of the GDU Principal Supply Works to be repaid based on the capacity used by option and water demand scenario. The estimated repayment capital and OM&R costs are in Appendix C, Attachment 7. These facilities were constructed in the late 1960s and 1970s and have been minimally maintained. Some major repairs or enhancements would be required if the facilities were used to supply water to the Red River Valley. This includes SCPP intake channel work, McClusky Canal slide repair, and modifying control structures for remote monitoring and winter operations. Detailed description of principal supply works repairs, rehabilitation and cost estimates are in *Update of Garrison Diversion Unit Principal Supply Works Costs* (Reclamation 2005a).



Operational Assumptions The OM&R costs are documented in Appendix C, Attachment 7.

Grand Forks to Lake Ashtabula Pipeline

Feature Description This 79 mile long pipeline feature would capture excess flows below the confluence of the Red and Red Lake Rivers and would convey it to Lake Ashtabula. This water would be stored in Lake Ashtabula until needed to meet downstream MR&I water demands. A river intake would withdraw the water from the river at Grand Forks. The intake would be located behind one of the existing low-head dams. A pumping station would be constructed

adjacent to the river. The pumping station and conveyance pipeline would have a capacity of 53 cfs under Scenario One or 71 cfs under Scenario Two. Booster pump stations and storage tanks are also included in this feature based on hydraulic and operational considerations. The above capacity estimates include 5% pipeline losses.

Operational Assumptions This feature would be operated continuously during a 1930s type drought when there would be more water in the lower Red River than in the upper portion of the river. It could be used intermittently during short-term drought events. Normally, OM&R cost estimates are based on an average annual volume of water conveyed, which is 7,600 ac-ft under Scenario One or 9,400 ac-ft under Scenario Two. However, the feature would be operated periodically, about one month a year during non-drought periods, to assure reliable operations. Based on flow capacities this would be 3,200 ac-ft under Scenario One or 4,200 ac-ft under Scenario Two. The total annual volume of water used for OM&R cost estimates is 10,800 ac-ft under Scenario One or 13,600 under Scenario Two.

Grand Forks-Traill Water District Interconnection with Grand Forks

Feature Description This feature includes Grand Forks-Traill Water Users interconnecting with the Grand Forks and purchasing water to meet estimated shortages.

Groundwater analysis in chapter three reveals that Grand Forks-Traill Water Users would experience a water shortage in the future. There are two ways to meet these future shortages – purchase additional groundwater rights in the Elk Valley Aquifer (described later in this section) or purchase water from Grand Forks. Grand Forks-Traill Water Users would need 26 miles of pipeline with 2.8 cfs of pipeline capacity under Scenario One or 4.0 cfs under Scenario Two to interconnect with the Grand Forks WTP to meet its estimated shortages.

Operational Assumptions Estimating the volume of water for annual OM&R costs is more difficult for Grand Forks-Traill Water District, because in average water use years, it has enough water under Scenario One demands or would need only 218 ac-ft under Scenario Two. The district maximum estimated shortage is 605 ac-ft under Scenario One or 1,142 ac-ft under Scenario Two. Assuming that the maximum annual withdrawal would be required approximately 15 out of 71 years above the average depletion, the overall average water volume would be 130 ac-ft under Scenario One or 460 ac-ft under Scenario Two. This assumes use only in drought years, so an additional 40 hours of operation annually (100 ac-ft per year) were added to assure reliable operation of the delivery system. OM&R cost estimates are based on withdrawals of 230 ac-ft under Scenario One or 560 ac-ft under Scenario Two.

Lake of the Woods Pipeline

Feature Description The 254 mile long pipeline feature would convey water from the Lake of the Woods east of Warroad, Minnesota, down the North Dakota side of the valley to Fargo, North Dakota. The pipeline from Fargo to Wahpeton is described as a separate feature. The Lake of the Woods pipeline is sized to meet the supplemental capacity or shortage requirements of the valley. The pipeline to Grand Forks has a capacity of 70 cfs under Scenario One or 96 cfs under Scenario Two. The pipeline from Grand Forks to Fargo conveys 49 cfs under Scenario One or 75 cfs under Scenario Two. This includes 21 cfs for Grand Forks (partial need) with the remainder serving other valley MR&I shortages. The feature also has a Lake of the Woods intake structure, pumping stations, and operational storage. The capacity estimates include 5% pipeline losses.

Operational Assumptions Similar to other features, the design capacity of the option is based on meeting shortages estimated for MR&I systems under 1930s climatic and hydrologic conditions. The pipeline has the potential to convey more water than hydrologic modeling results indicate. Based on hydrologic modeling, the average annual volume of water conveyed by the feature to meet supplemental needs is 18,700 ac-ft under Scenario One or 21,200 ac-ft under Scenario Two.

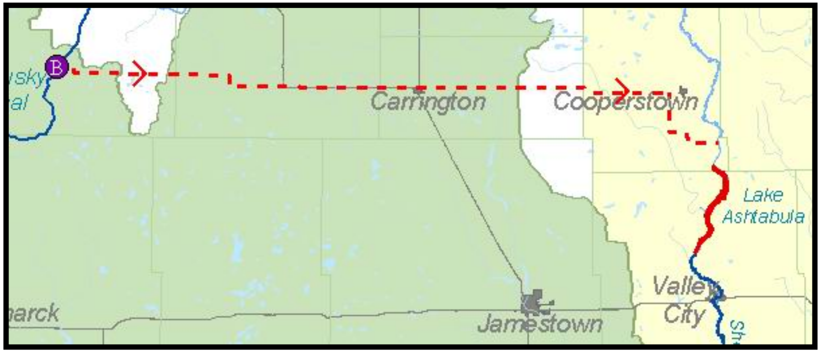
McClusky Canal to Fargo and Grand Forks Pipeline

Feature Description This 258 mile long pipeline feature conveys water from the biota WTP adjacent to the McClusky Canal via pipeline to the Fargo and Grand Forks areas. The conveyance feature is sized to meet the maximum monthly shortage identified in hydrologic modeling (chapter three). Approximately 250 miles of pipeline would run from the McClusky Canal to Fargo and Grand Forks. The main conveyance pipeline has a capacity of 160 cfs under Scenario One or 202 cfs under Scenario Two. The pipeline serving the Grand Forks area delivers 56 cfs under Scenario One or 61 cfs under Scenario Two. This includes 21 cfs for mixing flows, 35 cfs for Scenario One daily peaking, or 40 cfs for Scenario Two daily peaking. The pipeline serving the Fargo area has a capacity of 104 cfs under Scenario One or 141 cfs under Scenario Two. This includes 48 cfs for Scenario One daily peaking or 56 cfs for Scenario Two daily peaking. The feature also includes booster pump stations and storage reservoirs as needed for hydraulic considerations. The above capacity estimates include 5% pipeline losses.

Operational Assumptions Refer to the biota WTP discussion under the GDU Import Pipeline Biota WTP described previously for operational assumptions related to average annual conveyance volumes under water demand Scenarios One and Two.

McClusky Canal to Lake Ashtabula Pipeline

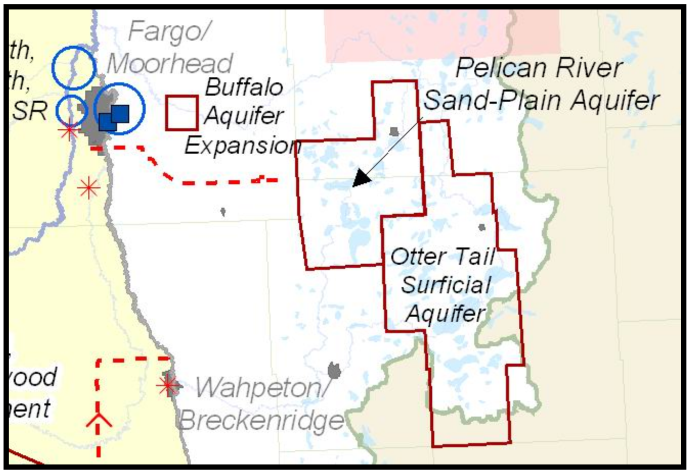
Feature Description This 129 mile long pipeline feature would convey water from the biota WTP adjacent to the McClusky Canal via pipeline to Lake Ashtabula. The conveyance feature is sized to keep Lake Ashtabula within target operation elevations while at the same time releasing treated water into the Sheyenne River to meet MR&I water demands in the Red River Valley. The pipeline would run from the McClusky Canal biota WTP to Lake Ashtabula. The pipeline has a capacity of 78 cfs for Scenario One or 120 cfs for Scenario Two. A structure with a capacity of 74 cfs under Scenario One or 114 cfs under Scenario Two would release Project water into Lake Ashtabula. The above capacity estimates include 5% pipeline losses.



Operational Assumptions Refer to the biota WTP discussion under the GDU Import to Sheyenne River Alternative Biota WTP described previously for operational assumptions related to average annual conveyance volumes under water demand Scenarios One and Two.

Minnesota Groundwater and Pipeline

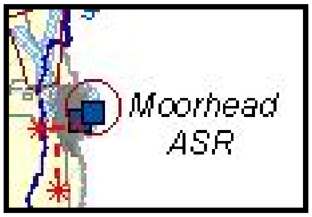
Feature Description This feature proposes developing wellfields and constructing a pipeline to deliver groundwater to the Fargo/Moorhead area. The wellfields would be located in the Otter Tail County area and would include portions of Pelican River Sand-Plain and Ottertail Outwash Surficial aquifers. The wellfields and conveyance pipeline are sized to meet the water shortage estimated by hydrologic modeling. The wellfields would yield 45 cfs for Scenario One or 72 cfs for Scenario Two. The feature has a 162 mile long (Scenario One) or a 229 mile long (Scenario Two) pipeline network within each wellfield to link wells to the main 35 mile long conveyance pipeline. The main conveyance pipeline would be sized to carry 45 cfs or 72 cfs, under Scenario One or Scenario Two, respectively. These capacity estimates include 5% pipeline losses.



Operational Assumptions Based on hydrologic modeling, the average annual yield from the wellfields would be 2,800 ac-ft under Scenario One or 4,800 ac-ft under Scenario Two. These volumes are small because they represent an average water demand over a 71-year hydrologic analysis (see chapter three). The conveyance feature capacities are much higher because of high demand during a 1930s-type drought. Other than during a drought, the wellfields would be used minimally to assure adequate water supply in the valley.

Some periodic operation of these facilities, at a volume of 2,700 ac-ft under Scenario One or 4,300 ac-ft under Scenario Two for approximately one month per year, would be required during non-drought periods to assure reliable operations. Therefore, the total annual volume of water used for OM&R cost estimates is 5,500 ac-ft under Scenario One or 9,100 ac-ft under Scenario Two.

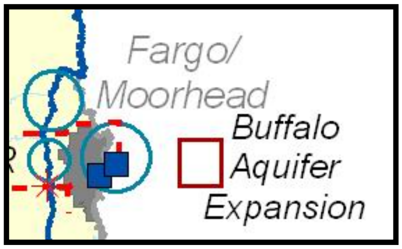
Moorhead Aquifer Storage and Recovery



Feature Description This ASR system would include two dual purpose ASR wells in the Moorhead Aquifer. The purpose of this feature would be to stabilize water levels in the aquifer so the water source can be used indefinitely. The ASR feature would inject treated water from the Moorhead WTP into the Moorhead Aquifer to recharge it during periods of adequate surface water supply. Groundwater would be withdrawn from the aquifer as needed. The Moorhead ASR feature has a capacity of 1.0 cfs under both water demand scenarios. Chapter three and Appendixes B and C describe this feature in detail, including cost estimates.

Operational Assumptions Annual OM&R costs are based on recharging during an average year at 120 ac-ft for Scenario One or 130 ac-ft per year for Scenario Two. The OM&R costs also include the cost of treating water to use in recharging the aquifer.

Moorhead Peak Day – Expanded Use of Buffalo Aquifer

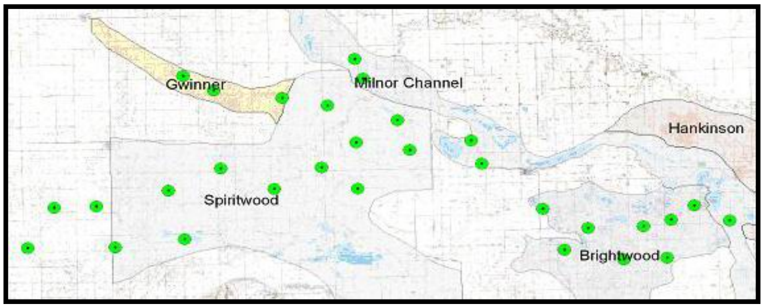


Feature Description This feature would increase the well capacity of the Buffalo Aquifer to meet Moorhead’s future peak day water demands. Moorhead currently pumps an average flow of 1.9 cfs annually from the Buffalo Aquifer. This feature proposes to expand the wellfield capacity from its present 6.0 cfs capacity to 7.0 cfs under Scenario One or to 8.3 cfs under Scenario Two. This would be a net expansion of 1.0 cfs under Scenario One or 2.3 cfs under Scenario Two. The existing wellfield pipeline is in poor condition and would be replaced. The new pipeline would run from the two Buffalo wellfields to the Moorhead WTP.

Operational Assumptions Annual OM&R costs are based on increased well capacity to meet peak day water needs. The maximum annual withdrawal for peaking is 519 ac-ft (Scenario One) or 642 ac-ft (Scenario Two). The increase in groundwater capacity would be 14.3% under Scenario One or 27.7% under Scenario Two. Using these percentages and the maximum annual withdrawals, Moorhead’s average annual withdrawal from the expanded Buffalo Aquifer wellfield would be 74 ac-ft under Scenario One or 178 ac-ft under Scenario Two.

New Groundwater to Serve Industries

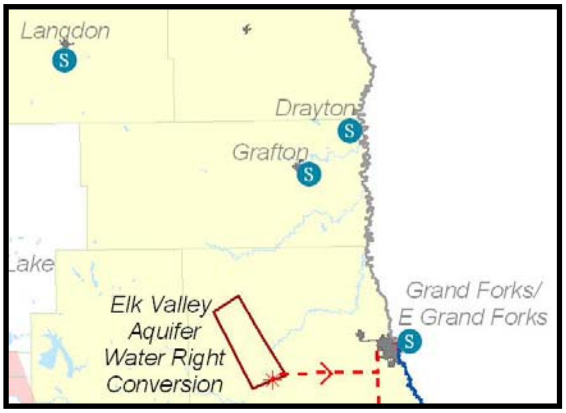
Feature Description This feature develops new groundwater capacity to supply existing and future industrial water demands in southeastern North Dakota near Wahpeton. The feature proposes wellfields in the Brightwood, Gwinner, Milnor Channel, and Spiritwood aquifers; 65 mile long (Scenario One) or a 90 mile long (Scenario Two) pipeline interconnecting wells; and a 35 mile long main conveyance pipeline running east into the Wahpeton area. The maximum annual wellfield production would be 5,330 ac-ft under Scenario One or 8,516 ac-ft under Scenario Two. The 71-year average water demand is 760 ac-ft under Scenario One or 1,350 ac-ft under Scenario Two. Chapter three has a more detailed description of the aquifers.



The main conveyance pipeline would have capacity of 9 cfs under Scenario One or 13 cfs under Scenario Two. Industries to be served by this feature are the existing Cargill Corn Processing Plant near Wahpeton and a proposed new industrial water demand near Wahpeton. Booster pump stations and storage tanks for this feature are based on hydraulic and operational considerations. The above capacity estimates include 5% pipeline losses.

Operational Assumptions Annual OM&R costs are based on an average annual water demand of 760 ac-ft under Scenario One or 1,350 ac-ft under Scenario Two. Some periodic operation of these facilities, at a volume of 540 ac-ft under Scenario One or 780 ac-ft under Scenario Two for approximately one month per year, would be required during non-drought periods to assure reliable operations. Therefore, the total annual volume of water used for OM&R cost estimates is 1,300 ac-ft under Scenario One or 2,130 ac-ft under Scenario Two. Water treatment is not part of this feature; industries would treat the water to their own specifications prior to use.

Peak Day Water Demand using Storage



Feature Description This feature would store water to meet peak day water demands for some selected cities that lack other methods, such as groundwater or an imported supply.

The cities of Drayton, East Grand Forks, Grafton, Langdon, and Langdon Rural Water District need sufficient storage to meet peak day water demands for the North Dakota In-Basin, Red River Basin, Lake of the Woods, and Missouri River Import to Red River Valley alternatives. In the other options, water system peak day water needs are met by increased capacity in pipelines or by releases to the Sheyenne River. The total storage capacity would be 15 Mgal (million gallons) under Scenario One or 19 Mgal under Scenario Two. Table 4.2.4 lists storage capacity for each city or water system.

Table 4.2.4 – Water Systems Requiring Storage to Meet Peak Day Water Demands.

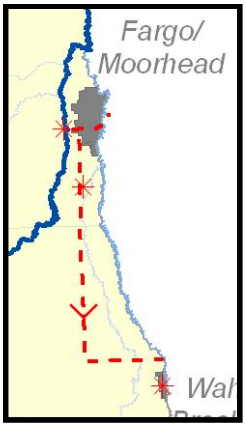
Water Systems	Scenario One Storage Capacity Requirement (Mgal)	Scenario Two Storage Capacity Requirement (Mgal)
Drayton	1.9	1.9
East Grand Forks	7.9	10.4
Grafton	2.7	3.8
Langdon (city and RWS)	2.5	2.9
Total	**15**	**19**

The supplemental options are designed to meet the monthly surface water shortage estimated by hydrologic modeling. Modeling on a daily time-step was not performed; therefore, these communities could experience inadequate water supply for brief periods of time without the storage capacity listed in table 4.2.4.

Operational Assumptions The storage feature would work by capturing water from the system's existing surface water source, storing it, and using it as needed when existing sources are insufficient. Cost estimates for OM&R are based on maintaining raw water storage reservoirs, as sized in table 4.2.4, plus pumping costs equal to 6% of average annual water demands for the five water systems. This is 180 ac-ft under Scenario One or 250 ac-ft under Scenario Two.

Pipeline to Serve Southeastern North Dakota Industries

Feature Description This 46 mile long pipeline feature would deliver water to existing and new industries in southeastern North Dakota from the Fargo area. A 9 cfs pipeline (Scenario One) or a 13 cfs pipeline (Scenario Two) to the Wahpeton area, pumping plants(s), and operation storage are part of this feature. Industries to be served include the existing Cargill Corn Processing Plant near Wahpeton and proposed new industrial water demands near Wahpeton. This feature has the same capacity requirements as previously described in the New Groundwater to Serve Industries feature. Capacity estimates incorporate 5% pipeline losses.

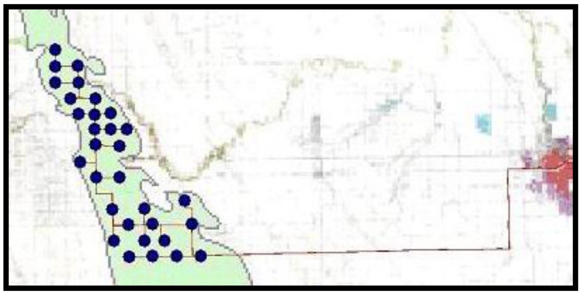


The maximum annual shortage conveyed to the southeast industries would be 5,330 ac-ft under Scenario One or 8,516 ac-ft under Scenario Two. The 71-year average water demand shortage is 760 ac-ft under Scenario One or 1,350 ac-ft under Scenario Two.

Operational Assumptions Annual OM&R costs are based on an average annual water demand for these industries of 760 ac-ft under Scenario One or 1,350 ac-ft under Scenario Two. Some periodic operation of these facilities, at a volume of 540 ac-ft under Scenario One or 780 ac-ft under Scenario Two for approximately one month per year, would be required during non-drought periods to assure reliable operations. Therefore, the total annual volume of water used for OM&R cost estimates is 1,300 ac-ft under Scenario One or 2,130 ac-ft under Scenario Two. Water treatment is not part of this feature; industries would treat the water to their own specifications prior to use.

Purchase Elk Valley Aquifer Water Rights

Feature Description Existing groundwater rights in the Elk Valley Aquifer would be purchased to meet peak day water demands for Grand Forks and shortages for the Grand Forks-Traill Water District. The feature includes the cost of purchasing water rights, installation of new wells, 37 miles of pipeline to interconnect wells, and a 26 mile long main conveyance pipeline to Grand Forks. Currently Grand Forks-Traill Water District receives its water supply from the Elk Valley Aquifer (see chapter three), so this feature would increase capacity to meet an estimated future shortage. Booster pump stations and storage tanks are also included in this feature based on hydraulic and operational considerations.



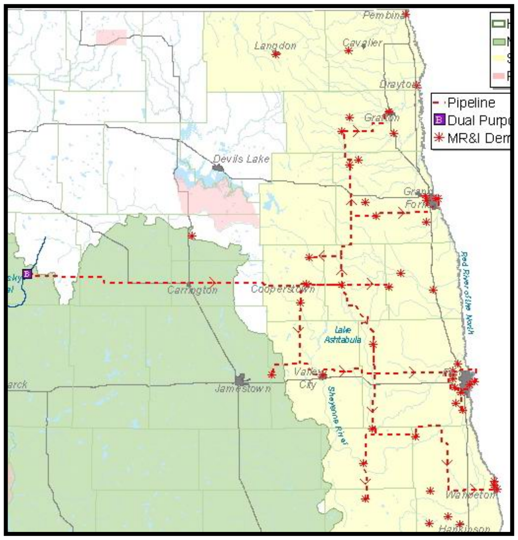
The Grand Forks and Grand Forks-Traill Water District would share the well capacity developed in this feature. The wellfield is sized to meet Grand Forks' short-term peak day water needs, while also providing Grand Forks-Traill Water District day-to-day additional well capacity to meet their annual estimated shortages of 605 ac-ft under Scenario One or 1,142 ac-ft under Scenario Two.

Grand Forks-Traill Water District would need 2.8 cfs of well capacity under Scenario One or 4.0 cfs of well capacity under Scenario Two to meet their estimated shortages. This would be accomplished by purchasing groundwater rights and constructing additional wells adjacent to their existing wells. The process of converting existing water rights from irrigation to domestic use is described in chapter three. The cost of conversion is estimated in Appendix C, Attachment 6. Grand Forks would purchase Elk Valley groundwater permits providing 27.1 cfs of capacity under Scenario One (28.5 cfs with 5% pipeline losses) or 28.7 cfs of capacity under Scenario Two (30.1 cfs with 5% pipeline losses) to meet estimated peak day water needs.

Operational Assumptions The maximum annual withdrawal for peak day demand would be 1,152 ac-ft under Scenario One or 1,221 ac-ft under Scenario Two for Grand Forks. The maximum annual withdrawal to meet shortages for Grand Forks-Traill Water District would be 605 ac-ft under Scenario One or 1,142 ac-ft under Scenario Two. The total maximum annual withdrawal would be 1,757 ac-ft under Scenario One or 2,363 ac-ft under Scenario Two. Assuming that the maximum withdrawals would occur approximately 15 out of 71 years based on StateMod modeling, the average annual withdrawal would be 371 ac-ft under Scenario One or 499 ac-ft under Scenario Two. This assumes use only in drought years, so an additional 40 hours of operation annually (100 ac-ft per year) are included to assure reliable operation of the wells. Therefore, OM&R cost estimates are based on withdrawals of 470 ac-ft under Scenario One or 600 ac-ft under Scenario Two.

Replacement Pipeline

Feature Description This 594 mile long pipeline feature would supply all service area water demands with Missouri River water conveyed through the GDU Principal Supply Works. The feature's pipeline would carry treated water from the McClusky Canal biota WTP to cities, rural water systems, and industries in the Red River Valley. The pipeline at the biota WTP would have a capacity of 341 cfs under Scenario One or 411 cfs under Scenario Two. The pipeline distribution system would interconnect all major water systems, except for a few isolated rural water systems, but it is sized to meet the peak day water demands of the entire service area. The cost of connecting isolated rural water systems is not included in this report. Booster pump stations and storage reservoirs are based on hydraulic and operational considerations. Capacity estimates have 5% pipeline losses.



Operational Assumptions Since the premise of the replacement option is to supply all service area water demands, the pipeline conveyance system would operate continuously. For a detailed description of operational assumptions and flows of the GDU Water Supply Replacement Pipeline Alternative Biota WTP refer to the previous discussion.

Relocation of Grafton River Intake

Feature Description This feature would relocate Grafton's intake from its present location east of Grafton on the Red River to approximately five miles north (downstream) on the Red River. This would increase water depth under low flow conditions to ensure reliable intake operation. The intake structure is currently sized at 5 cfs, which is higher than estimated Scenarios One or Two demands, but for continuity was estimated at 5 cfs.

Operational Assumptions The OM&R costs of the intake relocation are based on the additional annual energy costs of conveying an average of 930 ac-ft under Scenario One or 1,070 ac-ft under Scenario Two in an additional five miles of pipeline.

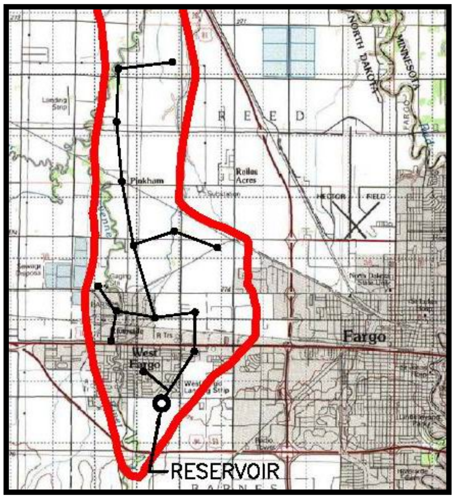
Water Conservation

Feature Description Water savings from water-system-based water conservation programs are accounted for in the per capita water demand estimates in chapter two (needs assessment). These water conservation water savings are estimated in the *Report on the Red River Valley Water Supply Project Needs and Options, Water Conservation Potential Assessment Final Report* (Reclamation 2004b). Project-wide, approximately 1.4 billion gallons (4,300 ac-ft) per year would be saved at an approximate annual cost of $780,000.

Operational Assumptions Water conservation programs would be operated in the same manner for all options at an annual cost of $780,000 per year.

West Fargo North Aquifer Storage and Recovery

Feature Description This feature proposes to construct an ASR system in the West Fargo North Aquifer to meet future water demands of West Fargo during a drought. During normal or wet periods West Fargo would be served by the Fargo regional WTP, which would withdraw water from the Red and Sheyenne Rivers. The ASR feature includes 45 groundwater wells and 15 miles of pipelines interconnecting wells and a main conveyance pipeline running from the wellfield to a regional WTP in the Fargo area.

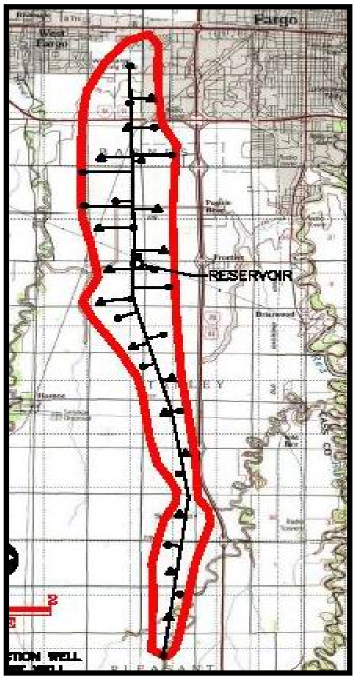


Treated water from a regional WTP would recharge the aquifer periodically to restore previously lost capacity. This stored groundwater would be used by West Fargo during droughts when diminished flows in the Sheyenne River would be used by Fargo and Moorhead. Hydrologic modeling reveals that West Fargo would be completely dependent on ASR water during a 1930s-type drought. The West Fargo South Aquifer ASR Project is designed to handle West Fargo's peak day water needs, which are 14.5 cfs (9.4 mgd) for Scenario One or 14.8 cfs (9.6 mgd) under Scenario Two. The West Fargo North Aquifer and the ASR feature are described in detail in chapter three and in Appendix C.

Operational Assumptions The ASR system would be used full time during a 1930s-type drought, intermittently during minor droughts, and not at all during normal or wet climate conditions. Conservatively, the ASR system would be relied upon during about 10 of the 71 modeled flow years, plus one month each year to ensure reliable operations. The maximum annual water demand is 4,261 ac-ft under Scenario One or 4,362 ac-ft under Scenario Two. Cost estimates for OM&R are based on 10 years of maximum annual usage over 71 years or an average annual use of 600 ac-ft plus one month of average use at 290 ac-ft for a total of 890 ac-ft under Scenario One. The maximum annual usage over 71 years is an average of 615 ac-ft plus one month of average use at 300 ac-ft for a total of 915 ac-ft under Scenario Two.

West Fargo South Aquifer Storage and Recovery

Feature Description This feature would use groundwater from the West Fargo South Aquifer to meet peak day water demands of Fargo. The feature includes 36 (Scenario One) or 42 (Scenario Two) groundwater wells plus 24 miles of pipelines interconnecting wells and a main conveyance pipeline running from the wellfield to Fargo. To assure that there would be no long-term depletion of the aquifer; this feature also has ASR capability. Groundwater wells would be developed for a capacity of 39.3 cfs under Scenario One or 46.7 cfs of capacity under Scenario Two. The West Fargo South Aquifer and ASR feature are described in detail in chapter three and in Appendix C.



The maximum annual demand for Fargo is 37,682 ac-ft under Scenario One or 44,833 ac-ft under Scenario Two. Approximately 6% of annual demands would be served from the ASR system, which is 2,270 ac-ft under Scenario One or 2,690 ac-ft under Scenario Two in a maximum water use year.

Operational Assumptions The aquifer would be recharged with treated water. The estimated maximum annual water withdrawal would be 2,270 ac-ft under Scenario One or 2,690 ac-ft under Scenario Two to meet peak day demands. Annual OM&R cost estimates are based on average annual peak day demand. Conservatively, the ASR system would be relied upon during about 10 of the 71 modeled flow years plus one month each year to ensure reliable operations. Cost estimates for OM&R are based on 10 years of maximum annual usage over 71 years, or an average annual use of 320 ac-ft plus one month of average use at 190 ac-ft, for a total of 510 ac-ft under Scenario One. The maximum annual usage over 71 years, or an average annual use of 380 ac-ft plus one month of average use at 230 ac-ft, for a total of 610 ac-ft under Scenario Two.

4.3 Options (Alternatives)

Seven options (alternatives) were developed for further consideration in the Needs and Options Report. Table 4.3.1 shows that six of the seven options propose to supplement existing water supplies with in-basin or imported water, and one option would replace all existing water supplies with water from the Missouri River. Each option is composed of features, that in combination, would meet all future MR&I water needs with water conservation. Some features are used in more than one option, because these are applicable to a variety of water supply solutions. Table 4.3.1 identifies the estimated volume of water each option would provide through its main supply feature using Scenario One or Two water demands. For example, the Red River Basin Alternative's main supply feature is Minnesota groundwater, while the main supply feature of the GDU Import Pipeline Alternative is the pipeline from the McClusky Canal.

Table 4.3.1 – Maximum Annual Water Volume Provided through Main Supply Feature for each Option.

Option	Option Type	Scenario One Main Feature Maximum Annual Delivery (ac-ft)	Scenario Two Main Feature Maximum Annual Delivery (ac-ft)
North Dakota In-Basin	Supplemental	29,566	42,669
Red River Basin	Supplemental	23,277	38,128
Lake of the Woods	Supplemental	41,421	57,658
GDU Import to Sheyenne River	Supplemental	41,525	65,752
GDU Import Pipeline	Supplemental	45,337	61,580
Missouri River Import to Red River Valley	Supplemental	30,410	43,435
GDU Water Supply Replacement Pipeline [1]	Replacement	113,702	142,380

[1] The GDU Water Supply Replacement Pipeline Alternative values are not actually shortages but a complete replacement of Red River Valley water supplies.

There is a wide range in the delivery values shown in table 4.3.1 for each option. The water provided to meet shortages for the North Dakota In-Basin, Red River Basin, Lake of the Woods and Missouri River Import to Red River Valley alternatives are similar and somewhat smaller, because these incorporate new in-basin groundwater sources into the alternatives. The GDU Import Pipeline Alternative uses no new in-basin groundwater sources, so its delivery volume is similar to the No Action shortage results determined by StateMod, as discussed in chapter three. The GDU Import to Sheyenne River Alternative has an even higher delivery volume because it is designed to release peak day water demands to the Sheyenne River. The greatest amount of water would be imported by the GDU Water Supply Replacement Pipeline Alternative, because it replaces all water supplies in the Red River Valley with Missouri River water. Water shortage values are discussed in more detail in chapter three.

All of the options are designed to meet peak day water demands estimated in chapter two. Three different methods were developed to meet peak day demands – groundwater, storage, and/or additional pipe conveyance capacity. The applicability of these three methods varies from option to option depending on available water sources.

Some of the options involve blending surface water and groundwater in the same distribution system. Chemical differences between different water sources can cause some operational water quality problems. However, Moorhead has historically used both sources of water successfully, so this is not considered a potential problem.

Cost estimates included in the discussion of each option are calculated based on January 2005 pricing levels. Total construction cost estimates developed for each option have contingencies for contractor overhead and profit (30%), contractor costs (15%), unlisted items (5%), contingencies (25%), non-contract engineering and administration (25%), and estimated right-of-way acquisition costs. These cost estimate mark-up costs are generally based on Reclamation's cost estimating practices. Contractor overhead and profit include office labor, regulatory costs, safety program, company overhead, and profit. Contractor costs cover bonding, insurance, vehicles, temporary buildings, utilities, communications, and staffing. Unlisted items comprise small value contract work not specifically estimated. Contingencies consist of changed field conditions or other unexpected circumstances that increase construction costs. Non-contract engineering and administration costs include permits, environmental compliance, design, field engineering, and testing for quality assurance. Right-of-way acquisition cost estimate methods and results are shown in Appendix C, Attachment 6. Estimates do not include interest during construction.

The cost estimates in this report should only be used to compare options. All of the options used the same assumptions and unit prices so they are directly comparable from a cost standpoint. However, more refined cost estimates would be required for Project funding estimates or other circumstances that require more accurate estimating. ***These estimates are not suitable for requesting authorization or construction fund appropriations from Congress.***

The cost estimates in this report should only be used for comparative purposes when evaluating the differences between options.

Annual OM&R costs are also estimated for each feature because these can vary greatly between options. Operation and maintenance costs include power, materials, and labor. Replacement costs are additional payments collected annually for use later in the Project to rehabilitate major features. Annualized costs were estimated, so options could be directly compared based on annualizing initial construction costs estimates and adding them to OM&R costs. Annualized construction costs are based on an assumed municipal bonding rate of 5% and a term of 45 years. A term of 45 years is used because the option cost estimates are based on 2005 prices, and the planning horizon is through 2050, for a total term of 45 years.

North Dakota In-Basin Alternative

This supplemental option in figure 4.3.1 uses mostly North Dakota in-basin water sources to meet future water needs. The exceptions are the use of groundwater from Minnesota sources for Moorhead and the use of natural flows in the Red Lake River for Grand Forks and East Grand Forks. The major feature is a pipeline that runs from the Red River (downstream of the confluence of the Red and Red Lake Rivers) to Lake Ashtabula. The pipeline captures Red River flows downstream of Grand Forks and recirculates flows back to Lake Ashtabula to meet Project water demands. Approximately 281 to 306 miles of pipeline, depending on the demand scenario, are included.

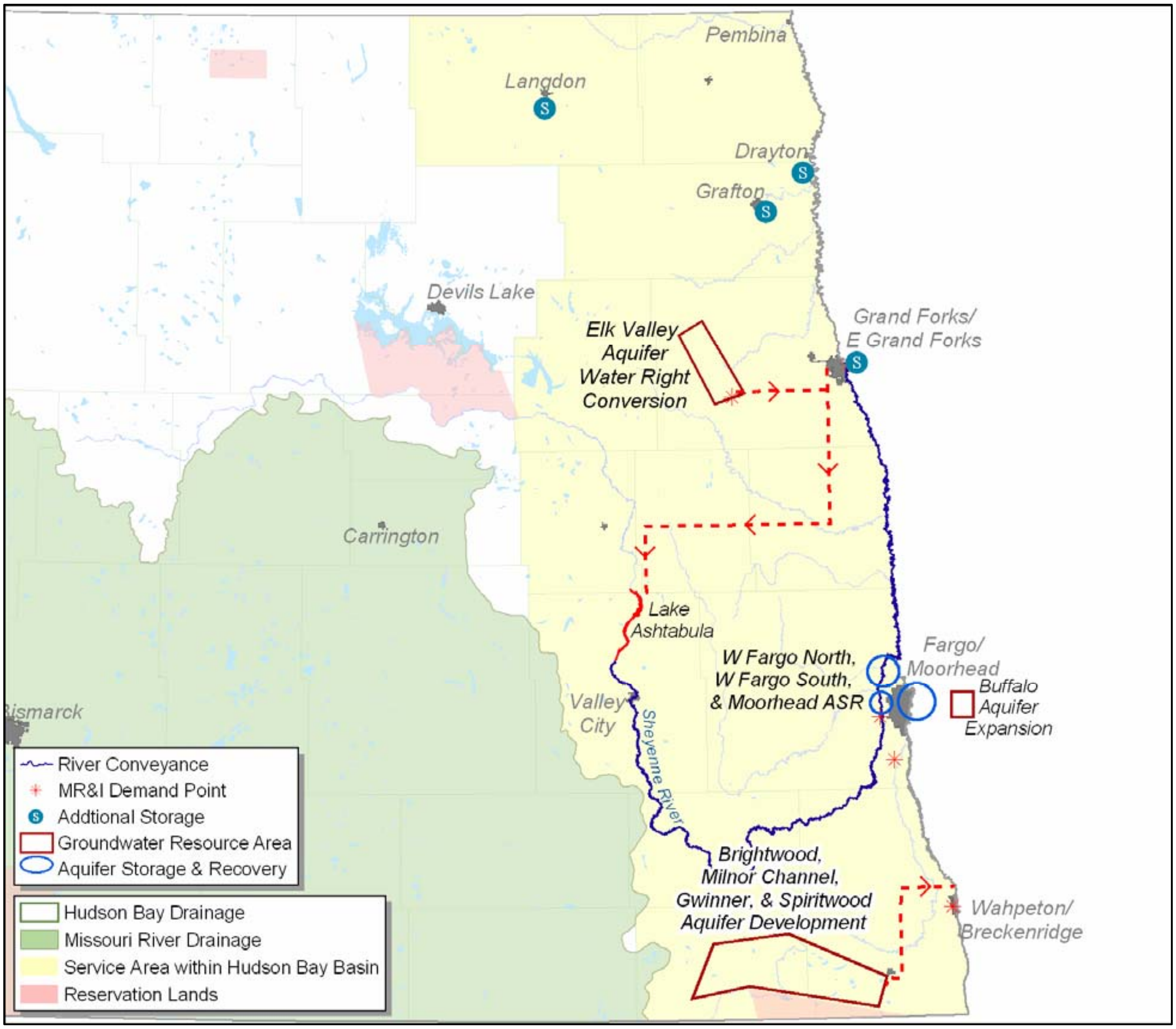


Figure 4.3.1 – North Dakota In-Basin Alternative.

The option also includes ASR systems in the West Fargo North, West Fargo South, and Moorhead aquifers, as well as development of new groundwater sources in southeastern North Dakota and expansion of the Buffalo Aquifer in Minnesota. The purchase or conversion of existing water rights in the Elk Valley Aquifer is also included for use by Grand Forks and

Grand Forks-Traill Water District. Cass Rural Water Users District would construct an interconnection to Fargo and purchase water to meet their future shortages. Grafton's intake structure in the Red River would be moved downstream (north) to have access to deeper water during periods of drought.

Peak day water demand would be met by developing 78 – 90 cfs of groundwater well capacity, plus constructing 15 -19 million gallons of reservoir storage for surface-water-dependent communities and rural water systems in the valley. To meet peak day water demand, West Fargo would use the West Fargo North ASR system, Fargo would use the West Fargo South ASR system, Moorhead would tap the Buffalo Aquifer, Valley City would continue to use their wellfield, and Grand Forks and Grand Forks-Traill Water District would purchase water existing water rights from irrigators on the Elk Valley Aquifer. Remaining water systems with peak day requirements would be served using additional storage reservoirs. These water systems include Drayton, East Grand Forks, Grafton, Langdon, and Langdon Rural Water District.

Table 4.3.2 lists the features included in this option and associated cost estimates for Scenario One or Scenario Two water demands. Water conservation is included in all options as an annual cost. Refer to section 4.2 for more information on specific features.

Table 4.3.2 – North Dakota In-Basin Alternative Cost Estimate.

Feature	Scenario One		Scenario Two	
	Construction Cost (2005 dollars)	Annual OM&R	Construction Cost (2005 dollars)	Annual OM&R
Cass Rural Water Users District Interconnection with Fargo	$6,437,000	$170,000	$6,437,000	$390,000
Grand Forks to Lake Ashtabula Pipeline	$261,892,000	$1,615,000	$291,815,000	$1,858,000
Moorhead ASR	$1,639,000	$128,000	$1,639,000	$132,000
Moorhead Peak Day - Expanded Use of Buffalo Aquifer	$2,727,000	$65,000	$4,064,000	$81,000
New Groundwater to Serve Industries	$57,560,000	$856,000	$94,170,000	$942,000
Peak Day Water Demand using Storage	$28,573,000	$58,000	$36,185,000	$59,000
Purchase Elk Valley Aquifer Water Rights	$93,215,000	$875,000	$93,279,000	$878,000
Relocation of Grafton River Intake	$3,689,000	$30,000	$3,689,000	$38,000
Water Conservation	$0	$780,000	$0	$780,000
West Fargo North ASR	$53,145,000	$1,101,000	$53,145,000	$1,261,000
West Fargo South ASR	$48,982,000	$1,009,000	$53,468,000	$1,096,000
Total	**$557,859,000**	**$6,686,000**	**$637,891,000**	**$7,515,000**

Costs in table are rounded to the nearest $1,000.

Red River Basin Alternative

This supplemental option would use a combination of North Dakota and Minnesota water sources to meet the future water needs of the Red River Valley. It includes existing Lake Ashtabula storage, ASR projects in both states, and new groundwater sources from both states, particularly Minnesota. Figure 4.3.2 shows water sources, pipelines, and demand points. Existing Red River Valley surface water reservoirs are used as currently configured. Approximately 399 to 491 miles of pipe, depending on the demand scenario, are included in this option.

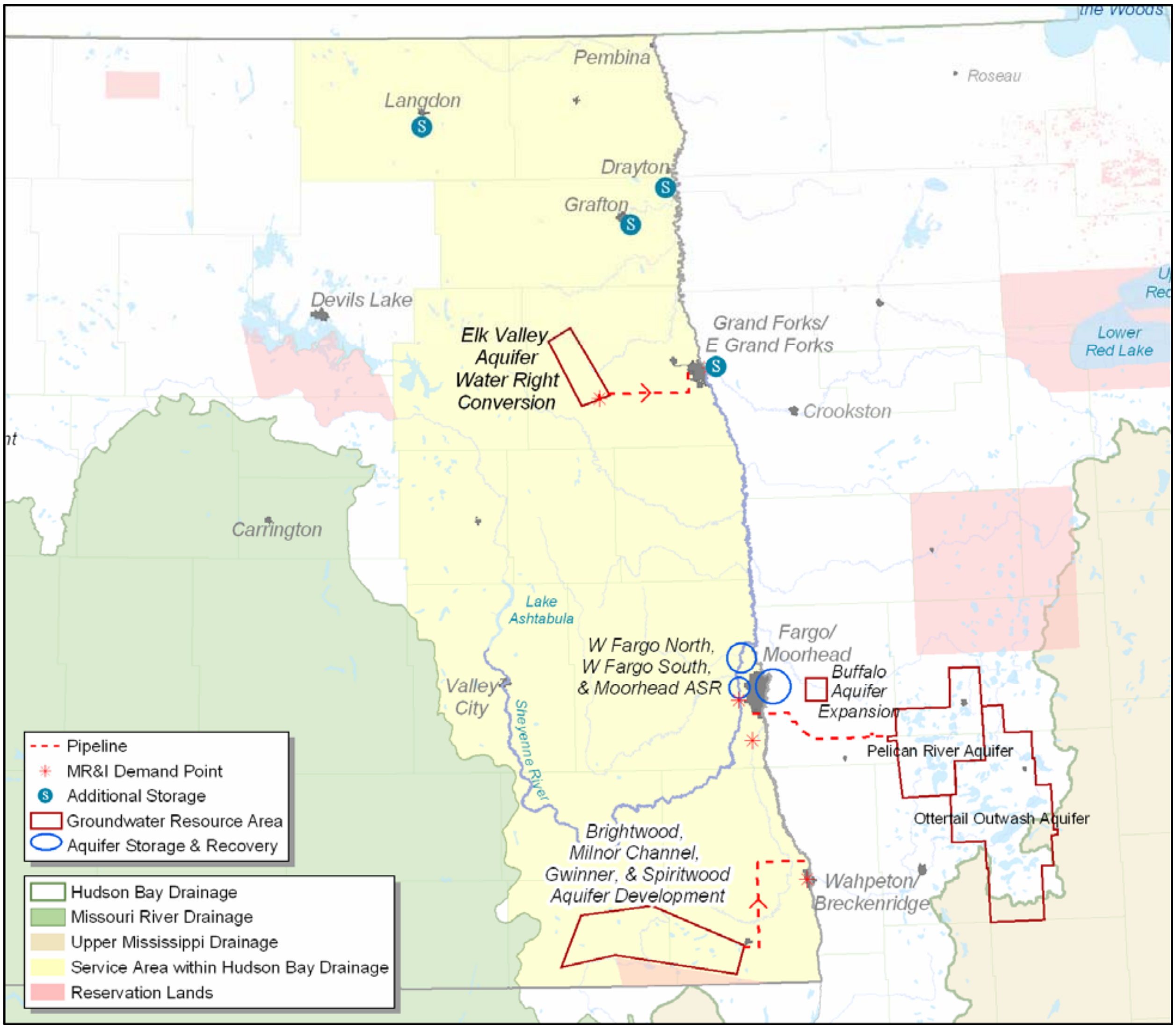


Figure 4.3.2 – Red River Basin Alternative.

The option also includes ASR systems in the West Fargo North, West Fargo South, and Moorhead aquifers, as well as developing new groundwater sources in southeastern North Dakota and expansion of the Buffalo Aquifer in Minnesota. Purchase or conversion of existing water rights in the Elk Valley Aquifer is included for use by Grand Forks and Grand Forks-Traill Water District. Cass Rural Water Users District would construct an interconnection to Fargo, and Grafton's intake structure in the Red River would be moved downstream (north) to access deeper water during periods of drought.

Peak day water demand is met by developing 78 – 90 cfs of groundwater well capacity, plus constructing 15 -19 million gallons of reservoir storage for surface-water-dependent communities and rural water systems in the valley. To meet peak day water demand, West Fargo would use the West Fargo North ASR system, Fargo would use the West Fargo South ASR system, Moorhead would tap the Buffalo Aquifer, Valley City would continue to use their wellfield, and Grand Forks and Grand Forks-Traill Water District would purchase existing water rights from users in the Elk Valley Aquifer. The remaining water systems with peak day requirements would be served using additional storage reservoirs. These water systems include Drayton, East Grand Forks, Grafton, Langdon, and Langdon Rural Water District.

Table 4.3.3 lists features included in this option and their associated cost estimates for Scenarios One and Two water demands including water conservation. Refer to section 4.2 for more information on specific features.

Table 4.3.3 - Red River Basin Alternative Cost Estimate.

Feature	Scenario One		Scenario Two	
	Construction Cost (2005 dollars)	Annual OM&R	Construction Cost (2005 dollars)	Annual OM&R
Cass Rural Water Users District Interconnection with Fargo	$6,437,000	$170,000	$6,437,000	$390,000
Minnesota Groundwater and Pipeline	$253,199,000	$2,410,000	$404,074,000	$3,212,000
Moorhead ASR	$1,639,000	$128,000	$1,639,000	$132,000
Moorhead Peak Day - Expanded Use of Buffalo Aquifer	$2,727,000	$65,000	$4,064,000	$81,000
New Groundwater to Serve Industries	$57,560,000	$856,000	$94,170,000	$942,000
Peak Day Water Demand using Storage	$28,573,000	$58,000	$36,185,000	$59,000
Purchase Elk Valley Aquifer Water Rights	$93,215,000	$875,000	$93,279,000	$878,000
Relocation of Grafton River Intake	$3,689,000	$30,000	$3,689,000	$38,000
Water Conservation	$0	$780,000	$0	$780,000
West Fargo North ASR	$53,145,000	$1,101,000	$53,145,000	$1,261,000
West Fargo South ASR	$48,982,000	$1,009,000	$53,468,000	$1,096,000
Total	**$549,166,000**	**$7,481,000**	**$750,150,000**	**$8,869,000**

Costs in table are rounded to the nearest $1,000.

Lake of the Woods Alternative

This supplemental option would use a combination of North Dakota and Minnesota water sources to meet the future water needs of the Red River Valley. Sources include Lake of the Woods, ASR projects in both states, and available storage in Lake Ashtabula. Figure 4.3.3 shows water sources, pipelines, and demand points. Existing Red River Valley surface water reservoirs are used as currently configured. Approximately 401 miles of conveyance pipe from Lake of the Woods to Wahpeton, North Dakota are included in this option. Table 4.3.4 lists the features included in this option and their associated cost estimates for Scenarios One and Two water demands including water conservation. Refer to section 4.2 for more information on the specific features.

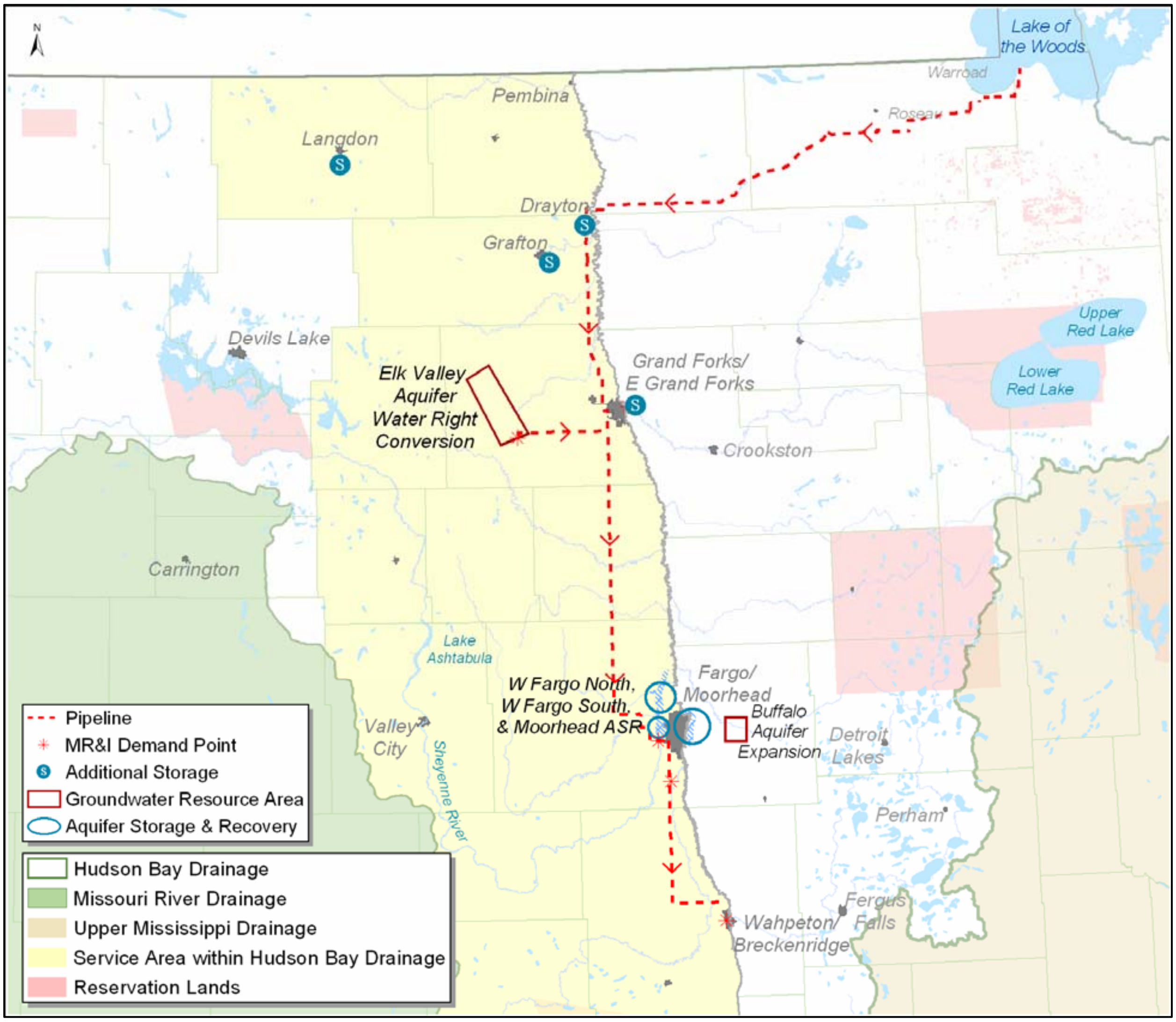


Figure 4.3.3 – Lake of the Woods Alternative.

The option also proposes ASR systems in the West Fargo North, West Fargo South, and Moorhead aquifers as well as development of new groundwater sources in the Buffalo Aquifer in Minnesota. Purchase or conversion of existing water rights in the Elk Valley Aquifer is included for use by Grand Forks and Grand Forks-Traill Water District. Cass Rural Water Users District would construct an interconnection to Fargo, and Grafton's intake structure in the Red River would be moved downstream (north) to access deeper water during drought events.

Peak day water demand would be met by developing 78 – 90 cfs of groundwater well capacity plus constructing 15 -19 million gallons of reservoir storage for surface-water-dependent communities and rural water systems in the valley. To meet peak day water demand, West Fargo would use the West Fargo North ASR system, Fargo would use the West Fargo South ASR system, Moorhead would tap the Buffalo Aquifer, Valley City would continue to use their wellfield, and Grand Forks and Grand Forks-Traill Water District would purchase existing water rights from users in the Elk Valley Aquifer. The remaining water systems with peak day requirements would be served using additional storage reservoirs. These water systems include Drayton, East Grand Forks, Grafton, Langdon, and Langdon Rural Water District.

Table 4.3.4 – Lake of the Woods Alternative Cost Estimate.

Feature	Scenario One		Scenario Two	
	Construction Cost (2005 dollars)	Annual OM&R	Construction Cost (2005 dollars)	Annual OM&R
Cass Rural Water Users District Interconnection with Fargo	$6,437,000	$170,000	$6,437,000	$390,000
Lake of the Woods Pipeline	$655,893,000	$3,512,000	$808,658,000	$3,979,000
Moorhead ASR	$1,639,000	$128,000	$1,639,000	$132,000
Moorhead Peak Day - Expanded Use of Buffalo Aquifer	$2,727,000	$65,000	$4,064,000	$81,000
Peak Day Water Demand using Storage	$28,573,000	$58,000	$36,185,000	$59,000
Pipeline to Serve Industries in Southeastern North Dakota	$42,928,000	$47,000	$52,015,000	$71,000
Purchase Elk Valley Aquifer Water Rights	$93,215,000	$875,000	$93,279,000	$878,000
Relocation of Grafton River Intake	$3,689,000	$30,000	$3,689,000	$38,000
Water Conservation	$0	$780,000	$0	$780,000
West Fargo North ASR	$53,145,000	$1,101,000	$53,145,000	$1,261,000
West Fargo South ASR	$48,982,000	$1,009,000	$53,468,000	$1,096,000
Total	**$937,228,000**	**$7,774,000**	**$1,112,579,000**	**$8,765,000**

Costs in table are rounded to the nearest $1,000.

GDU Import to Sheyenne River Alternative

This supplemental option would carry Missouri River water from the McClusky Canal via a pipeline to the upper portion of Lake Ashtabula and would use the lake as a regulating reservoir. The Sheyenne River below Baldhill Dam and the Red River would convey Project flows within the Red River Valley. Figure 4.3.4 shows the biota WTP, pipelines, and demand points.

The option includes a biota WTP located adjacent to the McClusky Canal at approximately mile marker 58 (south of Hoffer Lake). The treated water is pumped via pipeline to a release structure at the north end of Lake Ashtabula. The conservation pool of Lake Ashtabula (from elevation 1,257 or 28,000 ac-ft to elevation 1,266 or 68,600 ac-ft) would operate as a regulating reservoir to meet downstream demands for MR&I water supply.

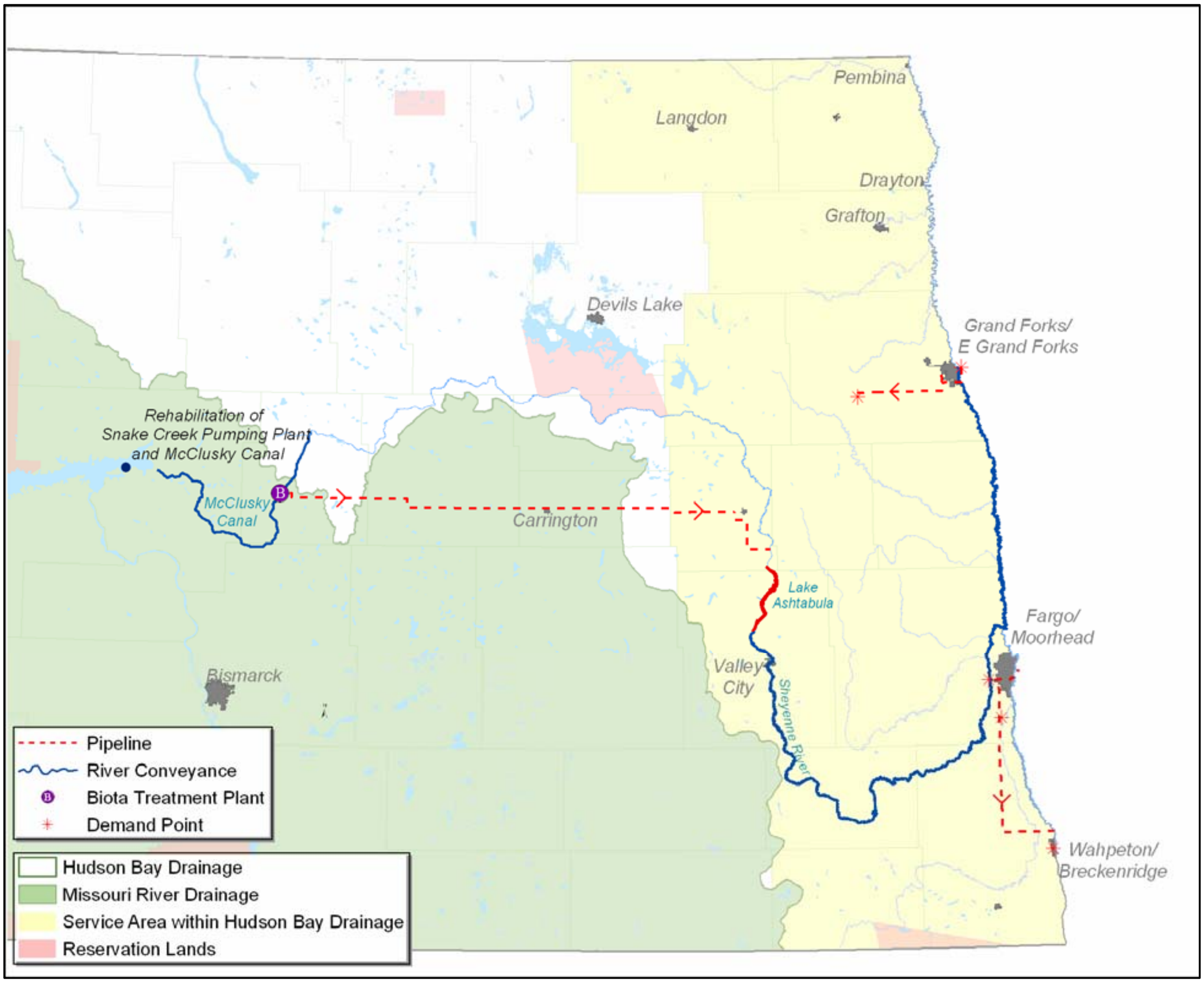


Figure 4.3.4 –GDU Import to Sheyenne River Alternative.

Approximately 200 miles of pipeline are included in this option. The option also serves the Wahpeton area industrial demands via a pipeline spur south of Fargo. The main conveyance pipeline is sized to facilitate the release of peak day water demands from Lake Ashtabula. Cass Rural Water Users District and Grand Forks-Traill Water District would construct interconnections to Fargo and Grand Forks, respectively, to meet their shortages. Grafton's intake structure in the Red River would be moved downstream (north) to access deeper water during periods of drought. Drayton, East Grand Forks, Grafton, Langdon, and Langdon Rural Water District peak day shortages are met with additional released surface water flows.

Since the GDU Import to Sheyenne River Alternative uses the GDU Principal Supply Works, the assigned costs to pay for these facilities are included.

Table 4.3.5 lists the features included in this option and associated cost estimates for Scenarios One and Two water demands, including water conservation. Refer to section 4.2 for more information on specific features**.**

Table 4.3.5 - GDU Import to Sheyenne River Alternative Cost Estimate.

Feature	Scenario One		Scenario Two	
	Construction Cost (2005 dollars)	Annual OM&R	Construction Cost (2005 dollars)	Annual OM&R
Biota WTP	$33,489,000	$1,588,000	$48,309,000	$2,263,000
Cass Rural Water Users District Interconnection with Fargo	$6,437,000	$170,000	$6,437,000	$390,000
GDU - Assigned Costs Related to Principal Supply Works	$5,649,000	$70,000	$8,838,000	$110,000
Grand Forks-Traill Water District Interconnection with Grand Forks	$7,474,000	$139,000	$9,028,000	$315,000
McClusky Canal to Lake Ashtabula Pipeline	$334,560,000	$1,000,000	$456,686,000	$1,016,000
Pipeline to serve Industries in Southeastern North Dakota	$42,754,000	$43,000	$52,015,000	$66,000
Relocation of Grafton River Intake	$3,689,000	$30,000	$3,689,000	$38,000
Water Conservation		$780,000		$780,000
Total	**$434,052,000**	**$3,819,000**	**$585,002,000**	**$4,978,000**

Costs in table are rounded to the nearest $1,000.

GDU Import Pipeline Alternative

This supplemental option would convey water from the Missouri River via the McClusky Canal and a pipeline to the Red River Valley. Figure 4.3.5 shows the biota WTP, pipelines, and demand points. A biota WTP adjacent to McClusky Canal south of Hoffer Lake (Mile Marker 58) is included in this option. The treated water is pumped east in an enclosed pipe which tees on the eastern side of North Dakota going south towards Fargo and north towards Grand Forks. It also serves the Wahpeton area industrial demands via a pipeline spur south of Fargo.

Approximately 329 miles of conveyance pipe is needed. Overall pipeline sizes are larger than the other supplemental options, because peak day demands would be met by increased pipe size rather than by storage or in-basin groundwater supplies. This in turn increases the size of the biota WTP.

Cass Rural Water Users District and Grand Forks-Traill Water District would construct interconnections to the cities of Fargo and Grand Forks, respectively, to meet their shortages. Grafton’s intake structure in the Red River would be moved downstream (north) to have access to deeper water during periods of drought. Drayton, East Grand Forks, Grafton, Langdon, and Langdon Rural Water District peak day shortages would be met with additional released surface water flows.

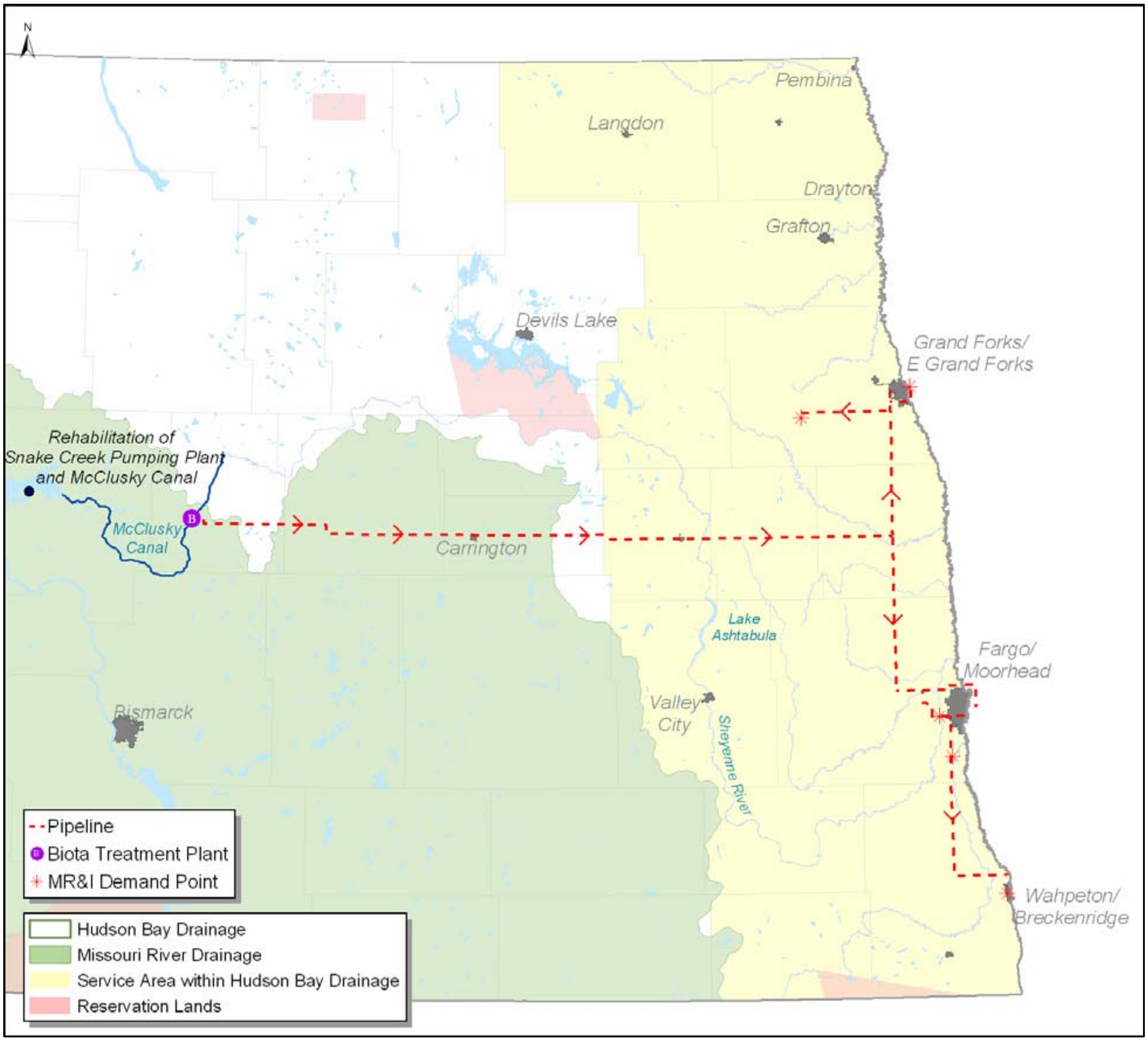


Figure 4.3.5 –GDU Import Pipeline Alternative.

Since the GDU Import Pipeline Alternative uses the GDU Principal Supply Works, the assigned costs to pay for these facilities are included in this option. Table 4.3.6 lists the features included in this option and associated cost estimates for Scenarios One and Two water demands, including water conservation. Refer to section 4.2 for more information on specific features**.**

Table 4.3.6 - GDU Import Pipeline Alternative Cost Estimate.

Feature	Scenario One		Scenario Two	
	Construction Cost (2005 dollars)	Annual OM&R	Construction Cost (2005 dollars)	Annual OM&R
Biota WTP	$76,521,000	$2,465,000	$93,820,000	$2,731,000
Cass Rural Water Users District Interconnection with Fargo	$6,437,000	$170,000	$6,437,000	$390,000
GDU - Assigned Costs Related to Principal Supply Works	$14,578,000	$181,000	$18,405,000	$228,000
Grand Forks-Traill Water District Interconnection with Grand Forks	$7,474,000	$139,000	$9,028,000	$315,000
McClusky Canal to Fargo and Grand Forks Pipeline	$1,050,784,000	$1,522,000	$1,224,327,000	$1,762,000
Pipeline to serve Industries in Southeastern North Dakota	$42,765,000	$43,000	$52,015,000	$66,000
Relocation of Grafton River Intake	$3,689,000	$30,000	$3,689,000	$38,000
Water Conservation		$780,000		$780,000
Total	**$1,202,248,000**	**$5,330,000**	**$1,407,721,000**	**$6,310,000**

Costs in table are rounded to the nearest $1,000.

Missouri River Import to Red River Valley Alternative

This supplemental option would convey treated water in an enclosed pipeline from the Missouri River near Bismarck directly to Fargo and Grand Forks. The pipeline also has a spur running to Lake Ashtabula, which would be used as a regulating reservoir. Figure 4.3.6 shows option features such as a biota WTP, pipelines, and demand points.

A biota WTP would be located south of Bismarck on the Missouri River. Approximately 500 to 525 miles of pipeline, depending on the demand scenario, are included in the option. Peak day water demands are met using available groundwater sources and storage.

The option also includes ASR systems in the West Fargo North, West Fargo South, and Moorhead aquifers as well as development of new groundwater sources in southeastern North Dakota and expansion of the Buffalo Aquifer in Minnesota. The purchase or conversion of existing water rights in the Elk Valley Aquifer is included in this option for use by Grand Forks and by Grand Forks-Traill Water District. Cass Rural Water Users District would construct an interconnection to Fargo and purchase water to meet their future shortages. Grafton’s intake structure in the Red River would be moved downstream (north) to have access to deeper water during periods of drought.

Peak day water demand would be met by developing 78 – 90 cfs of groundwater well capacity, plus constructing 15 -19 million gallons of reservoir storage for surface-water-dependent communities and rural water systems in the valley. To meet peak-day water demand, West Fargo would use the West Fargo North ASR system, Fargo would use the West Fargo South ASR system, Moorhead would tap the Buffalo Aquifer, Valley City would continue to use their wellfield, and Grand Forks and Grand Forks-Traill Water District would purchase existing water rights from users in the Elk Valley Aquifer. The remaining water systems with peak day requirements would be served using additional storage reservoirs. These water systems include Drayton, East Grand Forks, Grafton, Langdon, and Langdon Rural Water District.

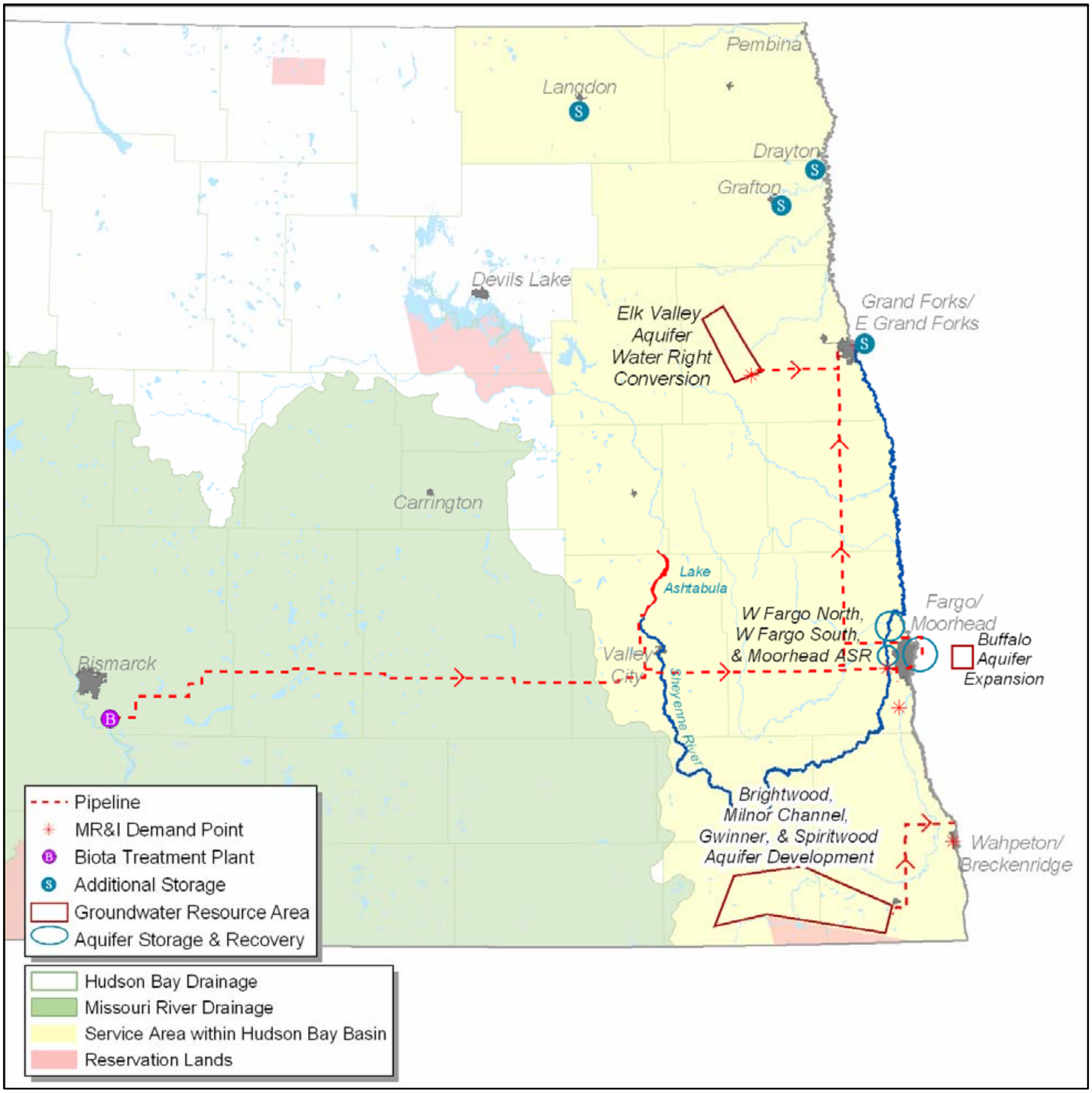


Figure 4.3.6 – Missouri River Import to Red River Valley Alternative.

Table 4.3.7 lists the features included in this option and their associated cost estimates for Scenarios One and Two water demands, including water conservation. Refer to section 4.2 for more information on specific features.

Table 4.3.7– Missouri River Import to Red River Valley Alternative Cost Estimate.

Feature	Scenario One		Scenario Two	
	Construction Cost (2005 dollars)	Annual OM&R	Construction Cost (2005 dollars)	Annual OM&R
Biota WTP	$35,111,000	$2,500,000	$50,315,000	$2,842,000
Bismarck to Fargo Pipeline	$544,300,000	$2,326,000	$617,560,000	$2,492,000
Cass Rural Water Users District Interconnection with Fargo	$6,437,000	$170,000	$6,437,000	$390,000
Moorhead ASR	$1,639,000	$128,000	$1,639,000	$132,000
Moorhead Peak Day - Expanded Use of Buffalo Aquifer	$2,727,000	$65,000	$4,064,000	$81,000
New Groundwater to Serve Industries	$57,560,000	$856,000	$94,170,000	$942,000
Peak Day Water Demand using Storage	$28,573,000	$58,000	$36,185,000	$59,000
Purchase Elk Valley Aquifer Water Rights	$93,215,000	$875,000	$93,279,000	$878,000
Relocation of Grafton River Intake	$3,689,000	$30,000	$3,689,000	$38,000
Water Conservation	$0	$780,000	$0	$780,000
West Fargo North ASR	$53,145,000	$1,101,000	$53,145,000	$1,261,000
West Fargo South ASR	$48,982,000	$1,009,000	$53,468,000	$1,096,000
Total	**$875,378,000**	**$9,897,000**	**$1,013,951,000**	**$10,991,000**

Costs in table are rounded to the nearest $1,000.

GDU Water Supply Replacement Pipeline Alternative

The GDU Water Supply Replacement Pipeline Alternative would meet all future water needs within the valley through 2050 by replacing all existing in-basin water sources with water imported from the Missouri River. This contrasts with the other options, which supplement existing water sources to meet future water supply shortages. Figure 4.3.7 shows option features, such as a biota WTP, pipelines, and demand points.

The option includes approximately 594 miles of pipeline. The other major feature is a biota WTP along the McClusky Canal. The biota WTP and conveyance system are designed to deliver peak day water demands. Not all of the water systems in the Red River Valley are connected to the pipeline system, such as Langdon or Drayton. The pipeline conveyance system has been designed with capacity to serve these water systems, but does not include cost of interconnection.

Table 4.3.8 lists features included in this option and their associated cost estimates for Scenarios One and Two water demands including water conservation. Refer to section 4.2 for more information on specific features.

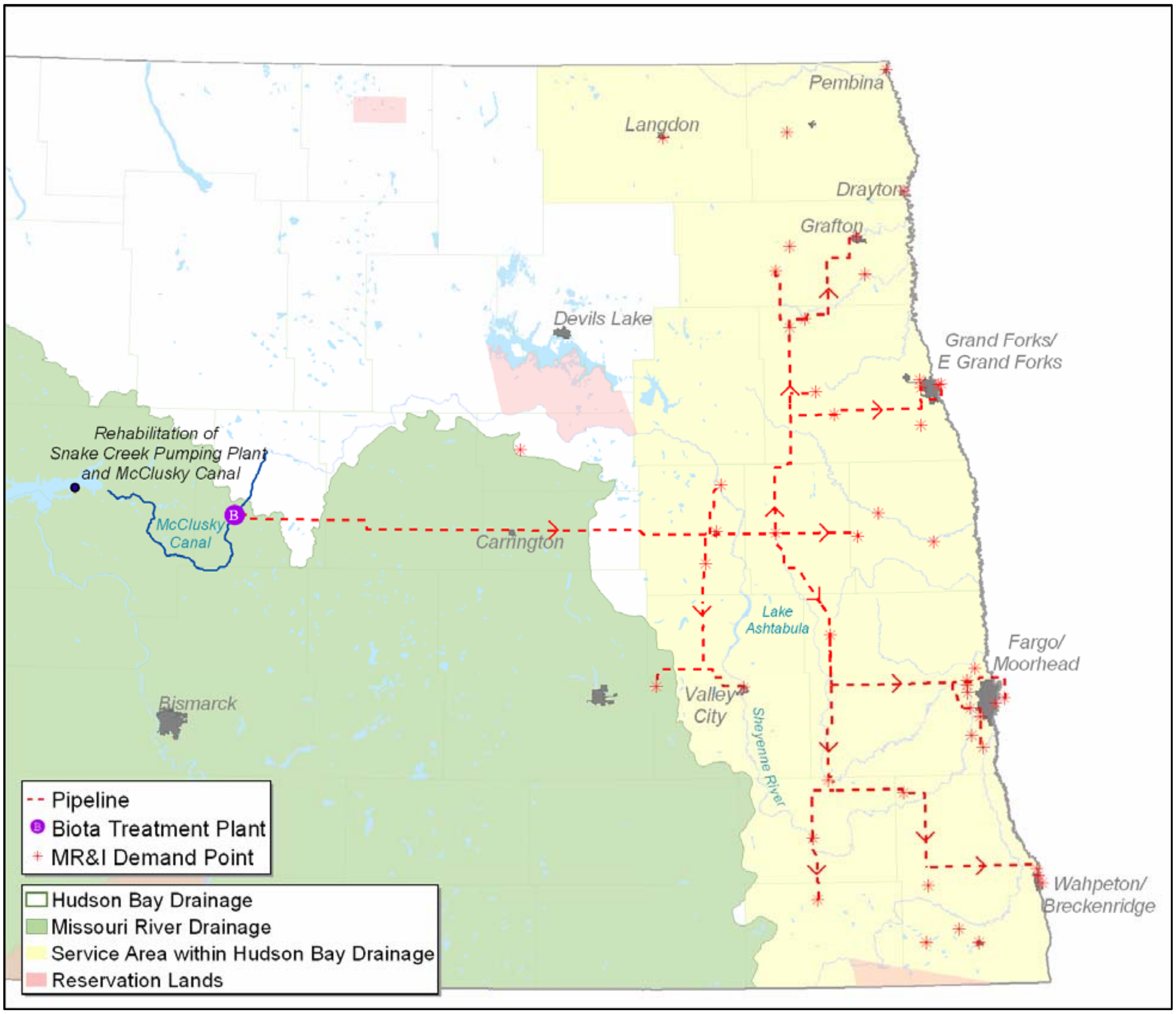


Figure 4.3.7 – GDU Water Supply Replacement Pipeline Alternative.

Table 4.3.8 – GDU Water Supply Replacement Pipeline Alternative Cost Estimate.

Feature	Scenario One		Scenario Two	
	Construction Cost (2005 dollars)	Annual OM&R	Construction Cost (2005 dollars)	Annual OM&R
Biota WTP	$314,289,000	$22,395,000	$370,624,000	$28,445,000
GDU - Assigned Costs Related to Principal Supply Works	$31,069,000	$386,000	$37,447,000	$465,000
Replacement Pipeline	$1,881,309,000	$1,874,000	$2,109,952,000	$1,984,000
Water Conservation		$780,000		$780,000
Total	**$2,226,667,000**	**$25,435,000**	**$2,518,023,000**	**$31,674,000**

Costs in table are rounded to the nearest $1,000.

4.4 Additional Option Analyses

Reviewers of the Draft Needs and Options Report suggested some additional technical analyses of the proposed options. This section summarizes the results of those analyses including phased construction of options, cost savings from drought contingency water demand reduction measures, and minimum instream flows recommended by the NDGFD (North Dakota Game and Fish Department). The construction phasing analysis evaluates the construction flexibility within each option and recognizes the advantages of phasing construction. The drought contingency analysis quantifies potential cost savings of various levels of drought contingency measures and the economic costs of imposing such measures. The minimum instream flow analysis estimates the costs of incorporating the NDGFD recommended flows into the options.

Phasing Construction of Options

The seven options proposed have varying degrees of construction phasing potential. The phasing potential of an option depends on the number and type of features included. An option in which construction can be phased or delayed has potential advantages over alternatives with limited phasing potential. The primary advantage is that Project features that are not immediately needed can be designed later when the size of the feature is better understood.

Table 4.4.1 lists each of the options, the number of features included in each option, and the percentage of the highest cost feature. The more diverse the water source features are in an option, the more flexibility water users have in constructing that option. Therefore, from the standpoint of the number of features, the Missouri River Import to the Red River Valley Alternative and the three in-basin options have the most construction flexibility.

A more accurate indication of construction flexibility is the percentage of the total cost of the highest cost feature in an option. This is shown in the last two columns in table 4.4.1. The highest cost feature is generally the main conveyance pipeline. The cost of the biota WTPs are included in the feature pipeline costs for the import options, because the pipeline feature cannot be used without treatment.

The North Dakota In-Basin Alternative has the lowest high cost feature, which ranges from 46% to 47%, closely followed by the Red River Basin Alternative, with a range of 46% to 54%. These options would have the most construction flexibility. The GDU Water Supply Replacement Pipeline Alternative, in which the main option feature represents 99% of the overall option cost, has the least construction flexibility. Generally, the Missouri River import options have less flexibility, except for the Missouri River Import to Red River Valley Alternative, which is slightly more flexible. The Lake of the Woods Alternative has a major potion of its cost in its conveyance pipeline, so it has limited construction flexibility with a range of 70% to 73%.

Table 4.4.1 – Options and Number of Water Supply Features.

Option	Number of Features	Scenario One Percent of Highest Cost Feature	Scenario Two Percent of Highest Cost Feature
North Dakota In-Basin	11	47%	46%
Red River Basin	11	46%	54%
Lake of the Woods	11	70%	73%
GDU Import to Sheyenne River [1]	8	87%	88%
GDU Import Pipeline [1]	8	94%	94%
Missouri River Import to Red River Valley [1]	12	66%	66%
GDU Water Supply Replacement Pipeline [1]	4	99%	99%

[1] Percentage includes the cost of biota WTP.

Drought Contingency Analysis

Drought Contingency Water Demand Reduction and Option Cost Savings

Appendix C, Attachment 9 documents a sensitivity analysis that calculates drought contingency water demand reductions and associated cost savings for each option. The analysis uses the five drought levels defined in the *City of Fargo Drought Management Plan* (Houston Engineering, Inc. 2003) to develop levels of water demand reduction for the Project. Revised construction costs were estimated based on these levels of water demand reduction.

Table 4.4.2 shows the drought levels included in the *City of Fargo Drought Management Plan* (Houston Engineering, Inc. 2003). Five phases or levels would be implemented depending on the severity of drought conditions. The Phase 1 drought is for normal climatic conditions with a 0% water demand reduction goal. Phases 2 through 5 address increasing levels of drought with water demand reduction goals of 5% - 10% (Phase 2), 10% - 20% (Phase 3), 20% - 30% (Phase 4), and 30% or more (Phase 5). Since the Fargo drought management plan showed demand reduction goals in ranges, the third column of the table was added to show specific water demand reduction goals used in this analysis. While a drought management plan could be monitored or implemented at different timescales, a monthly timescale was used in this analysis.

Table 4.4.3 (Scenario One) and table 4.4.4 (Scenario Two) show the cost savings of each of the four drought reduction phases. For example, if an occasional 7.5% water demand reduction would be acceptable, a range of $15.9 to $57.9 million could be saved in construction costs for an option to meet the Scenario One water demands. The construction cost savings would range from $20.5 to $74.7 million for an option sized to meet Scenario Two water demands.

Table 4.4.2 – City of Fargo Drought Management Plan.

Drought Levels	Demand Reduction Goal (%)	Demand Reduction used in Analysis (%)
Phase I – Normal Conditions	0	0
Phase 2 – Drought Advisory	5 - 10	7.5
Phase 3 – Drought Watch	10 – 20	15
Phase 4 – Drought Warning	20 - 30	25
Phase 5 – Drought Emergency	30+	35

Table 4.4.3 - Construction Cost Savings with Drought Contingency - Scenario One.

Option	Phase 2 7.5% Demand Reduction Goal	Phase 3 15% Demand Reduction Goal	Phase 4 25% Demand Reduction Goal	Phase 5 35% Demand Reduction Goal
North Dakota In-Basin	$15,907,000	$37,257,000	$69,612,000	$102,642,000
Red River Basin	$39,941,000	$93,551,000	$174,790,000	$257,727,000
Lake of the Woods	$34,845,000	$81,617,000	$152,492,000	$224,849,000
GDU Import to Sheyenne River	$30,001,000	$70,270,000	$131,292,000	$193,590,000
GDU Import Pipeline	$40,835,000	$95,647,000	$178,706,000	$263,501,000
Missouri River Import to Red River Valley	$27,539,000	$64,503,000	$120,517,000	$177,702,000
GDU Water Supply Replacement Pipeline	$57,905,000	$135,627,000	$253,405,000	$373,646,000

Table 4.4.4 - Construction Cost Savings with Drought Contingency - Scenario Two.

Option	Phase 2 7.5% Demand Reduction Goal	Phase 3 15% Demand Reduction Goal	Phase 4 25% Demand Reduction Goal	Phase 5 35% Demand Reduction Goal
North Dakota In-Basin	$20,512,000	$48,068,000	$88,772,000	$129,921,000
Red River Basin	$51,504,000	$120,695,000	$222,901,000	$326,222,000
Lake of the Woods	$44,934,000	$105,298,000	$194,466,000	$284,607,000
GDU Import to Sheyenne River	$38,687,000	$90,659,000	$167,430,000	$245,039,000
GDU Import Pipeline	$52,658,000	$123,398,000	$227,895,000	$333,531,000
Missouri River Import to Red River Valley	$35,512,000	$83,219,000	$153,690,000	$224,930,000
GDU Water Supply Replacement Pipeline	$74,669,000	$174,979,000	$323,156,000	$472,948,000

Table 4.4.5 (Scenario One) and table 4.4.6 (Scenario Two) show the overall reduced construction cost of each option under the four drought reduction phases. The second column shows the cost of the options with 0% water demand reduction, and columns 3 through 6 show corresponding reductions in costs of the five phases of demand reduction.

Table 4.4.5 - Construction Costs of Options with Drought Contingency - Scenario One.

Option	Phase 1 0% Demand Reduction Goal	Phase 2 7.5% Demand Reduction Goal	Phase 3 15% Demand Reduction Goal	Phase 4 25% Demand Reduction Goal	Phase 5 35% Demand Reduction Goal
North Dakota In-Basin	$557,859,000	$541,952,000	$520,602,000	$488,247,000	$455,217,000
Red River Basin	$549,166,000	$509,225,000	$455,615,000	$374,376,000	$291,439,000
Lake of the Woods	$937,228,000	$902,383,000	$855,611,000	$784,736,000	$712,379,000
GDU Import to Sheyenne River	$434,052,000	$404,051,000	$363,782,000	$302,760,000	$240,462,000
GDU Import Pipeline	$1,202,248,000	$1,161,413,000	$1,106,601,000	$1,023,542,000	$938,747,000
Missouri River Import to Red River Valley	$875,378,000	$847,839,000	$810,875,000	$754,861,000	$697,676,000
GDU Water Supply Replacement Pipeline	$2,226,667,000	$2,168,762,000	$2,091,040,000	$1,973,262,000	$1,853,021,000

Table 4.4.6 - Construction Costs of Options with Drought Contingency - Scenario Two.

Option	Phase 1 0% Demand Reduction Goal	Phase 2 7.5% Demand Reduction Goal	Phase 3 15% Demand Reduction Goal	Phase 4 25% Demand Reduction Goal	Phase 5 35% Demand Reduction Goal
North Dakota In-Basin	$637,891,000	$617,379,000	$589,823,000	$549,119,000	$507,970,000
Red River Basin	$750,150,000	$698,646,000	$629,455,000	$527,249,000	$423,928,000
Lake of the Woods	$1,112,579,000	$1,067,645,000	$1,007,281,000	$918,113,000	$827,972,000
GDU Import to Sheyenne River	$585,002,000	$546,315,000	$494,343,000	$417,572,000	$339,963,000
GDU Import Pipeline	$1,407,721,000	$1,355,063,000	$1,284,323,000	$1,179,826,000	$1,074,190,000
Missouri River Import to Red River Valley	$1,013,951,000	$978,439,000	$930,732,000	$860,261,000	$789,021,000
GDU Water Supply Replacement Pipeline	$2,518,023,000	$2,443,354,000	$2,343,044,000	$2,194,867,000	$2,045,075,000

Potential Economic Effects From the Implementation of Drought Contingency Measures

Implementation of drought contingency measures could have a similar effect as a drought on economic activity, commercial output, employment, and income, with some important differences. As water supply restrictions are imposed to reduce demand in response to water shortages, commercial activities would be expected to be adversely affected. However, drought contingency measures could conceptually be implemented to minimize economic impacts of water shortages.

These measures may allow flexibility in delivering water to sectors that rely heavily on water as a production input and could warn of coming shortages, which would allow businesses, industry, and residents to better prepare for shortages. Therefore, the economic impacts from water supply reductions associated with drought contingencies may be substantially less than the impacts associated with an unprepared water supply system. It should also be noted that the impacts would vary considerably depending on the length of time drought contingency plans are implemented. The geographic scope of this analysis is the Project service area.

The general economic related effects of water supply shortages include:

- Loss to industries directly dependent on agricultural production (e.g., machinery and fertilizer manufacturers, food processors, dairies, etc.).
- Unemployment from drought-related declines in production.
- Strain on financial institutions (foreclosures, credit risk, capital shortfalls).
- Reduced tax base for federal, state, and local governments.
- Loss to manufacturers and sellers of various types of equipment.
- Losses related to recreation activities - hunting and fishing, bird watching, etc.
- Revenue shortfalls to water suppliers.

Specific costs and losses to agricultural producers and other resources include:

- Annual and perennial crop losses and associated lost income.
- Reduced productivity/revenues from range/pasture land.
- Impaired productivity of forest land.
- Damage to fish habitat.

A study completed for the California Urban Water Agencies (Spectrum Economics, Inc. 1991) discussed the decisions that business managers need to make to minimize production costs during periods of drought. Examples of these decisions include minimizing costs of obtaining water from alternate water sources, reducing water use per unit of good or service produced, or reducing the level of production. The preferred method of dealing with a water shortage would be to implement relatively inexpensive conservation methods while maintaining output. This is what is typically observed when a drought is not severe and of short duration. However, when a drought becomes severe, and the most painless conservation methods have already been implemented, then a reduction in output most likely will occur. The study provides estimates of the reduction in output that could occur as a result of water supply shortages of various magnitudes.

In another study, Goddard and Fiske (2005) evaluated the impacts and degree of hardship that water shortages impose on municipal water systems. The study was conducted for Santa Cruz, California, and evaluated the potential impacts from water shortages ranging from 10% to 60% of a full supply. The survey included about 1,900 commercial business accounts and 45 industrial accounts. The study indicated a wide variation in production impacts associated with various water supply shortages.

Based on the results of the Spectrum Economics study and the Goddard and Fiske study, it is likely that a drought contingency goal of 7.5% will have a very small economic impact on the regional economy. A drought contingency goal of 7.5% is estimated to translate into a 5.0% to 5.1% water demand reduction. The average output impact of a 5% water supply reduction indicated by the California studies is essentially zero.

Based on the current level of economic activity in the counties included in the Red River Valley region and the estimated impacts discussed above, the impacts of imposing drought contingency goals and water supply reductions can be estimated. It should be stressed that there could be a great deal of variation in potential impacts depending on how the reductions are imposed on different sectors. Rough annual impact estimates from drought contingency goals are shown in table 4.4.7. These represent negative impacts.

Table 4.4.7 - Approximate Annual Impacts from Imposing Drought Contingency Goals.

Drought Contingency Goal	Impact Economic Decline	Approximate Annual Regional Impacts
7.5%	0%	$0
15%	5%	$492 million
25%	22%	$2.16 billion
35%	35%	$3.45 billion

The economic impact values shown in table 4.4.7 only represent implementation of drought contingency measures for a single year. The Needs and Options Report identified the 1930s drought as the critical hydrologic event for which all Project options are designed. The 1930s drought was a 10-year event that would require significant water use reduction measures if no Project were constructed.

Tables 4.4.8 (Scenario One) and 4.4.9 (Scenario Two) show the estimated water demand shortages for each year during the 1930s style drought. Based on the results from table 4.4.7, the last column in each table shows the estimated economic impact from implementation of the drought contingency measures in that year. The total estimated impact over the 10-year 1930s style drought would be $13.4 billion under Scenario One and $20.7 billion under Scenario Two.

Table 4.4.8 – Cumulative Economic Impact during 1930s Style Drought – Scenario One.

Year	Water Demand Shortage (ac-ft)	Water Demand Shortage[1] (%)	Approximate Annual Regional Impacts (millions $)
1931	9,060	8.0%	$30.7
1932	11,110	9.8%	$149.0
1933	14,628	12.9%	$352.0
1934	36,424	32.0%	$3,067.5
1935	14,717	12.9%	$357.1
1936	33,216	29.2%	$2,703.5
1937	26,961	23.7%	$1,945.2
1938	24,307	21.4%	$1,555.8
1939	18,603	16.4%	$719.0
1940	31,561	27.8%	$2,515.7
Total			$13,395.5

[1] Percentage based on 113,702 ac-ft annual water demand.

There could be a great deal of variability in these impact cost estimates. The cumulative affect from consecutive years of drought are not accounted for in this analysis. For example, an industry may have moderate reduction in output (lost revenue) during one-year due to reduced water availability; however, if that situation persisted for multiple years, the industry may eventually go bankrupt, so the economic impact is a 100% loss for that industry. Other industries may have some water use flexibility and be able to adapt to less water availability, which would reduce economic impact on their business.

Table 4.4.9 – Cumulative Economic Impact during 1930s Style Drought – Scenario Two.

Year	Water Demand Shortage (ac-ft)	Water Demand Shortage[1] (%)	Approximate Annual Regional Impacts (millions $)
1931	13,812	9.7%	$144.4
1932	23,828	16.7%	$781.5
1933	29,352	20.6%	$1,428.6
1934	53,015	37.2%	$3,738.3
1935	27,398	19.2%	$1,199.7
1936	52,343	36.8%	$3,677.4
1937	44,397	31.2%	$2,957.5
1938	37,125	26.1%	$2,298.6
1939	29,972	21.1%	$1,501.3
1940	44,902	31.5%	$3,003.2
Total			$20,730.5

[1] Percentage based on 142,380 ac-ft annual water demand.

Based on this analysis it is estimated that little economic impact would result from implementing drought contingency goals at a level of 7.5% or less. Water demand reductions above 7.5% start to create negative economic impacts. Balancing the desire to reduce construction costs while limiting potential economic impacts associated with the implementation of drought contingency measures is a difficult challenge for water managers. This analysis shows that from an economic impact standpoint, implementation of drought contingency goals greater than 7.5% could have severe economic costs far outweighing any short-term construction cost savings.

Cost Estimates for Meeting North Dakota Game and Fish Department Recommended Flows

The options considered in this report include meeting basic aquatic needs by maintaining the fish and wildlife conservation pool (28,000 ac-ft) for Lake Ashtabula and a minimum release of 13 cfs from Baldhill Dam. The NDGFD, in a letter dated September 28, 2005, recommended additional minimum instream flow requirements for the Sheyenne River and the Red River. These recommendations are listed in chapter two, section 2.10 and a side-analysis was conducted to estimate the cost of meeting the recommended flows. Only options using Scenario Two water demands were investigated in this analysis. Scenario One water demands should also be investigated if a decision is made to implement any instream flow regime beyond what is currently included in the options.

Table 4.4.10 shows a comparison of the original modeling results and results including NDGFD instream flow recommendations using Scenario Two water demands. The No Action Alternative results are shown as a maximum annual MR&I shortage in ac-ft since no conveyance system would be constructed with this alternative. The other alternative results are displayed as a maximum flow rate in the cfs required by the alternative's features to meet the demand. As is evident in the table, not all options can be modified to meet the minimum instream flows, as defined by NDGFD, without additional water supply features.

Table 4.4.10 shows that some options can be modified to meet the NDGFD flow recommendations, while others do not have that capability. The No Action, North Dakota In-Basin, and Red River Basin alternatives cannot be resized to meet both MR&I demands and

NDGFD flow recommendations. Both the North Dakota In-Basin and the Red River Basin alternatives would need additional water sources to meet the recommended flows.

Table 4.4.10 – Hydrologic Modeling Results with and without NDGFD Recommended Flows - Scenario Two.

Option	Major Water Supply Feature	Capacity of Major Water Supply Feature without the NDGFD Flows (cfs)[1]	Capacity of Major Water Supply Feature with the NDGFD Flows (cfs)[1]	Capacity Change (%)
No Action	none	53,000 ac-ft	61,000 ac-ft	NA
North Dakota In-Basin	Grand Forks to Lake Ashtabula Pipeline	71 cfs	Capacity cannot be increased to meet NDGFD flows without additional water supply features	NA
Red River Basin	Minnesota Groundwater and Pipeline	72 cfs	Capacity cannot be increased to meet NDGFD flows without additional water supply features	NA
Lake of the Woods	Lake of the Woods Pipeline	96 cfs	189 cfs	96.9%
GDU Import to Sheyenne River	McClusky Canal to Lake Ashtabula Pipeline	97 cfs	122 cfs	25.8%
GDU Import Pipeline	McClusky Canal to Fargo and Grand Forks Pipeline	202 cfs	295 cfs	46.0%
Missouri River Import to Red River Valley	Bismarck to Fargo Pipeline	63 cfs	93 cfs	44.4%
GDU Water Supply Replacement Pipeline	Replacement Pipeline	411 cfs	411 cfs	0%

[1] Results in cfs include 5% for water losses. NA means not applicable.

The GDU Water Supply Replacement Pipeline Alternative does not have to be resized to meet the NDGFD recommended flows, if Lake Ashtabula is dropped below the 28,000 ac-ft fish and wildlife conservation pool. The remaining four options shown in table 4.4.11 can be resized to increase the volume of water imported into the valley.

The GDU Import to Sheyenne River and Missouri River Import to Red River Valley Alternatives can meet the NDGFD recommended flows and maintain the 28,000 ac-ft fish and wildlife conservation pool in Lake Ashtabula through a severe drought. The Lake of the Woods and GDU Import Pipeline Alternatives can meet the NDGFD recommended flows, but Lake Ashtabula must be drawn down below the conservation pool frequently during a 1930s type drought.

Table 4.4.11 shows the original Scenario Two construction cost estimates for each option, the additional construction costs to meet the NDGFD recommended flows, and the cost difference. Meeting NDGFD flow recommendations would also increase OM&R costs, but that analysis was not conducted in this evaluation.

The least costly alternative, which meets both the MR&I need and the NDGFD recommended flows, is the GDU Import to Sheyenne River Alternative at $692.9 million. The GDU Water Supply Replacement Pipeline Alternative meets the NDGFD recommended flows without a cost increase, but it would be much more expensive to construct ($2.5 billion). The first three options in table 4.4.11 lack a cost estimate because these alternatives cannot be modified to meet the NDGFD flows without additional water supply features. The other three options that can meet the NDGFD flows are considerably more expensive than the GDU Import to Sheyenne River Alternative. These options also have much higher additional costs to meet the recommended flows, ranging from $192.7 to $500 million.

Table 4.4.11 – Option Construction Costs with and without NDGFD Recommended Flows – Scenario Two.

Option	Option Construction Cost without NDGFD Flows	Additional Construction Cost to Meet NDGFD Flows	Option Construction Cost with NDGFD Flows
No Action	NA	NA	NA
North Dakota In-Basin	$637,891,000	NA	Additional water supply features required
Red River Basin	$750,150,000	NA	Additional water supply features required
Lake of the Woods	$1,112,579,000	$500,046,000	$1,612,625,000
GDU Import to Sheyenne River	$585,002,000	$107,929,000	$692,931,000
GDU Import Pipeline	$1,407,721,000	$442,902,000	$ 1,850,623,000
Missouri River Import to Red River Valley	$1,013,951,000	$192,674,000	$1,206,625,000
GDU Water Supply Replacement Pipeline	$2,518,023,000	$0	$2,518,023,000

NA = Not applicable

The only two options that could meet both Reclamation’s basic aquatic need and NDGFD recommended flows at an additional cost are the GDU Import to Sheyenne River Alternative and the Missouri River Import to Red River Valley alternative. Both of these options retain a minimum level in Lake Ashtabula of 28,000 ac-ft in a 1930s drought. The GDU Water Supply Replacement Pipeline Alternative would not have an additional cost to meet the recommended flows, but storage in Lake Ashtabula would drop below the conservation pool to meet the NDGFD flows. The Lake of the Woods and GDU Import Pipeline Alternatives can also meet the NDGFD recommended flows at a significantly higher cost, but the options have to use Lake Ashtabula’s conservation pool to meet the NDGFD flows. The No Action, North Dakota In-Basin and Red River Basin alternatives as designed do not meet the NDGFD recommended flows.

4.5 Summary of Options (Alternatives)

Table 4.5.1 (Scenario One) and table 4.5.2 (Scenario Two) summarize estimated construction, OM&R, and annualized costs for each of the options considered in this report. Construction costs include supplying bulk water service to the Red River Valley service area. Annual OM&R costs cover all annual costs required to operate, maintain, and replace the water supply features. The annualized costs are a method of combining construction costs and annual OM&R costs into one composite value for comparison purposes. The total annualized costs are the annual equivalent of a capital cost added to the annual OM&R cost.

This analysis assumed a repayment period of 45 years (2005 – 2050) with an interest rate of 5%. For example, annual payments of $31,386,000 would have to be made to pay off the construction costs of the North Dakota In-Basin Alternative (Scenario One) at a cost of $557,859,000 (values in table 4.5.2 based on 45 years at 5%). The $31,386,000 plus the annual OM&R at $6,686,000 equals the total annualized costs of $38,072,000. Annualized costs are another method of evaluating option costs.

Table 4.5.1 - Summary of Option Cost Estimates – Scenario One.

Option	Construction Cost (2005 Dollars)*	Annual OM&R Costs*	Annualized Construction Cost*	Total Annualized Cost*
North Dakota In-Basin	$557,859,000	$6,686,000	$31,386,000	$38,072,000
Red River Basin	$549,166,000	$7,481,000	$30,897,000	$38,378,000
Lake of the Woods	$937,228,000	$7,774,000	$52,730,000	$60,504,000
GDU Import to Sheyenne River	$434,052,000	$3,819,000	$24,421,000	$28,240,000
GDU Import Pipeline	$1,202,248,000	$5,330,000	$67,641,000	$72,971,000
Missouri River Import to Red River Valley	$875,378,000	$9,897,000	$49,250,000	$59,147,000
GDU Water Supply Replacement Pipeline	$2,226,667,000	$25,435,000	$125,276,000	$150,711,000

* Values are rounded to the nearest $1,000.

Table 4.5.2 - Summary of Option Cost Estimates – Scenario Two.

Option	Construction Cost (2005 Dollars) *	Annual OM&R Costs*	Annualized Construction Cost*	Total Annualized Cost*
North Dakota In-Basin	$637,891,000	$7,515,000	$35,889,000	$43,404,000
Red River Basin	$750,150,000	$8,869,000	$42,205,000	$51,074,000
Lake of the Woods	$1,112,579,000	$8,765,000	$62,596,000	$71,361,000
GDU Import to Sheyenne River	$585,002,000	$4,978,000	$32,913,000	$37,891,000
GDU Import Pipeline	$1,407,721,000	$6,310,000	$79,201,000	$85,511,000
Missouri River Import to Red River Valley	$1,013,951,000	$10,991,000	$57,047,000	$68,038,000
GDU Water Supply Replacement Pipeline	$2,518,023,000	$31,674,000	$141,668,000	$173,342,000

* Values are rounded to the nearest $1,000.

The options range in construction costs from $434.05 million to $2.23 billion under Scenario One or $585.00 million to $2.52 billion under Scenario Two. OM&R costs vary from $3.82 million to $25.44 million under Scenario One or $4.98 million to $31.67 million under Scenario Two. The options total annualized costs range from $28.24 million to $150.71 million under Scenario One or $37.89 million to $ 173.34 million under Scenario Two. In general, the option with the lowest annualized cost is the least costly from a long term standpoint (through 2050), considering both initial construction costs and long-term annual OM&R costs.

Table 4.5.3 shows the individual feature costs estimates for Scenarios One and Two water demands. These are total construction costs including contract and non-contract costs. Costs are estimated based on January 2005 pricing levels. Documentation for feature cost estimates is provided in Appendix C.

Table 4.5.3 – Feature Construction Cost Estimates – Scenarios One and Two.

Features	Scenario One Cost Estimate*	Scenario Two Cost Estimate*
Biota WTP:		
GDU Import to Sheyenne River	$33,489,000	$48,309,000
GDU Import Pipeline	$76,521,000	$93,820,000
Missouri River Import to Red River Valley	$35,111,000	$50,315,000
GDU Water Supply Replacement Pipeline	$314,289,000	$370,624,000
Bismarck to Fargo Pipeline	$544,300,000	$617,560,000
Cass Rural Water Users District Interconnection with Fargo	$6,437,000	$6,437,000
GDU - Assigned Costs Related to Principal Supply Works:		
GDU Import to Sheyenne River	$5,649,000	$8,838,000
GDU Import Pipeline	$14,578,000	$18,405,000
GDU Water Supply Replacement Pipeline	$31,069,000	$37,447,000
Grand Forks-Traill Water District Interconnection with Grand Forks	$7,474,000	$9,028,000
Grand Forks to Lake Ashtabula Pipeline	$261,892,000	$291,815,000
Lake of the Woods Pipeline	$655,893,000	$808,658,000
McClusky Canal to Fargo and Grand Forks Pipeline	$1,050,784,000	$1,224,327,000
McClusky Canal to Lake Ashtabula Pipeline	$334,560,000	$456,686,000
Minnesota Groundwater and Pipeline	$253,199,000	$404,074,000
Moorhead ASR	$1,639,000	$1,639,000
Moorhead Peak Day - Expanded use of Buffalo Aquifer	$2,727,000	$4,064,000
New Groundwater to Serve Industries	$57,560,000	$94,170,000
Peak Day Water Demand using Storage	$28,573,000	$36,185,000
Pipeline to serve Southeast North Dakota Industries	$42,754,000	$52,015,000
Purchase Elk Valley Aquifer Water Rights	$93,215,000	$93,279,000
Replacement Pipeline	$1,881,309,000	$2,109,952,000
Relocation of Grafton River Intake	$3,689,000	$3,689,000
Water Conservation	na	na
West Fargo North ASR	$53,145,000	$53,145,000
West Fargo South ASR	$48,982,000	$53,468,000

*Values in table rounded to the nearest $1,000.

Financial Analysis of Options

Appendix C, Attachment 11 describes the financial analysis of the seven options proposed. The analysis estimates per household and per 1,000 gallon monthly costs to Project recipients, as well as federal costs, if an option would be constructed.

To conduct this analysis, a number of key assumptions were made. A term of 40 years to finance the Project was used in the analysis, which was based on the assumption that repayment of financial obligations would begin in 2010 and end by 2050. Although financing alternatives could be accomplished in a number of ways, this analysis assumed the Project would be funded in accordance with DWRA, as summarized below:

- The cost of construction of biota WTPs is a federal expense (federal grant), which would be non-reimbursable. This is based on the premise that compliance with the Boundary Waters Treaty of 1909 is a federal responsibility.

- DWRA authorized up to $200 million in federal loans for Project construction. The interest rate applied for use of GDU facilities for MR&I water supplies is 3.225%, which was the rate in 1965 when the Project was authorized. Since the 2000 enactment of DWRA, the indexed cost of the original $200 million is estimated to be $250 million.

- Any Project costs above the biota WTP and $250 million of federal loans would be financed by water users using municipal bonds. The interest rate used for non-federal cost share is 5%, which approximates the bonding rate for Fargo, North Dakota.

- Biota WTP OM&R costs would be funded by the federal government and considered non-reimbursable. All other OM&R costs are reimbursable by Project recipients.

- DWRA requires that the repayment of costs for existing GDU Principal Supply Works features (Snake Creek Pumping Plant, Audubon Lake, McClusky Canal, and Chain of Lakes) is to be based only on the proportion of capacity of each feature used by the Project. DWRA also requires that assigned costs of GDU supply facilities (construction and OM&R) be repaid at 3.225%. Although some alternatives provide a basic aquatic need and improved flow rates for recreation and/or water quality, no construction costs were allocated to these incidental benefits.

During construction of any option, interest costs will be incurred and accounted for in a financial analysis. These costs factor in the value of money between the start of construction when funds are borrowed and the completion of various construction contracts. This analysis assumed that interest during construction would equal 7% of construction costs for federal financing and 10.85% for non-federal financing.

Table 4.5.4 shows the estimated per household and per 1,000 gallon repayment costs for each alternative under Scenario One and Scenario Two water demands. The household repayment rate under Scenario One ranges from $7.03 to $33.02 per month. Under Scenario Two the rate is $7.01 to $26.88 per month. These are the amounts a typical household would pay in addition to their present monthly water bill. The table also provides estimated repayment rates based on 1,000 gallon increments. The 1,000 gallon incremental cost was calculated using the per household costs and dividing by 6, assuming a typical household uses about 6,000 gallons per month.

Results shown in table 4.5.4 would change if some of the assumptions used in the analysis were modified. These modified assumptions include increasing the level of federal or state grant funding, using a tiered rate structure, or using other repayment terms or interest rates.

Table 4.5.4 – Per Month Household and per 1,000 Gallon Repayment Rates – Scenarios One and Two.

Alternatives	Scenario One		Scenario Two	
	Dollars/Month	$ per 1,000 Gallons	Dollars/Month	$ per 1,000 Gallons
North Dakota In-Basin	$11.37	$1.89	$9.45	$1.57
Red River Basin	$11.44	$1.91	$11.27	$1.88
Lake of the Woods	$18.91	$3.15	$16.21	$2.70
GDU Import to Sheyenne River	$7.03	$1.17	$7.01	$1.17
GDU Import Pipeline	$20.99	$3.50	$17.81	$2.97
Missouri River Import to Red River Valley	$16.96	$2.83	$14.04	$2.34
GDU Water Supply Replacement Pipeline	$33.02	$5.50	$26.88	$4.48

Chapter Five
Conclusions

5.1 Introduction

1936 photo of the Red River near Fargo, North Dakota

The photo to the right shows the Red River at Fargo in 1936 during the 1930s drought. Fargo relies totally on surface water for their water supply. The vulnerability of surface water sources during a severe drought would result in water shortages for Fargo and other water systems in the Red River Valley. Analysis of the current (2005) water demands in the Red River Valley shows that the Fargo-Moorhead area would have a serious water shortage in the midst of a reoccurrence of a 1930s drought. In fact, hydrologic modeling of 2005 water demands forecasts that the worst single monthly service area MR&I (municipal, rural, and industrial) water shortage would be a 46% deficit in February, seven years into the drought.

Looking into the future, if a 1930s drought occurred in the valley in 2050, hydrologic modeling predicts that valley-wide MR&I monthly shortages would be as high as 89% in March of the seventh year. Both 2005 and 2050 modeling simulations reveal a very serious shortage problem would occur during the winter when typical drought measures, such as eliminating lawn watering, are not applicable. In such an event, water users in the valley would have to dramatically cut their commercial and indoor water use.

The impacts of a 1930s drought would be even worse in the Red River Valley if it were not for construction of Baldhill Dam and Lake Ashtabula by the Corps of Engineers in the 1950s. Water stored in Lake Ashtabula serves the water needs of a portion of the Red River Valley in the early years of a 1930s drought. Unfortunately, Lake Ashtabula’s ability to store water is limited because runoff above the lake is reduced significantly in a severe drought. About five years into a drought, water in Lake Ashtabula is depleted. Surface water hydrologic modeling shows that it takes another four years of normal precipitation for the reservoir to recover. So while better management of water use during the early years of a 1930s drought would be advisable, it would just delay major shortages a year or two at best.

Based on hydrologic modeling, increased 2050 water demands would exacerbate a water shortage that would occur even today during a drought.

A drought frequency investigation of the Red River Valley was conducted by Meridian Environmental Technology, Inc. (2004) for the Project (Red River Valley Water Supply Project). The fundamental conclusion of the study was that the 1930s drought was not an anomaly occurring every 1,000 years; it was a climatic event likely to be repeated before 2050. Based on this conclusion, Reclamation selected the period of 1931–2001 for modeling hydrologic flow conditions. Hydrologic modeling revealed that the key period of low-flow events of particular interest is 1931-1940.

Table 5.1.1 shows the 15 lowest, historic naturalized flow years in the Red River Valley for the period of 1931–2001 at Emerson, Manitoba. The naturalized flow, also known as unregulated flow, is the amount of water flowing by stream gages without human influence. These flow data can be used to estimate the amount of water available in any one year; however, not all of this water can be used. For example, most of the water demand within the service area is in the upper portion of the drainage near Fargo, while a significant amount of basin runoff is downstream from Fargo. The flat topography of the Red River Valley limits opportunities to capture and store river flows.

Table 5.1.1 shows that all ten years of the drought, starting in 1931, are ranked within the 15 lowest flow years. This demonstrates that not only were individual years during the 1930s very dry, but the period of 1931 through 1940 was significantly drier than any other recorded period in the last century. Surface water modeling of 2050 water demands (figures 3.5.4 and 3.5.5) illustrates that while there would be some moderate shortages in 1941 (the 11th year of a 1930s drought), no significant shortages would occur during the rest of the flow record through 2001. Flows in 1941 were just under 2 million ac-ft (acre-feet), which while still below the average of 3.1 million ac-ft per year, were sufficient to break the drought.

Table 5.1.1 – Ranked Lowest Historic Naturalized Annual Flows at Emerson, Manitoba (1931-2001).

Rank	Year	Naturalized Flow (ac-ft)
1	1934	240,236
2	1931	442,037
3	1935	474,059
4	1939	498,179
5	1933	596,448
6	1937	603,458
7	1936	627,380
8	1940	638,087
9	1961	683,014
10	1977	712,585
11	1938	739,694
12	1932	757,457
13	1990	800,285
14	1988	976,287
15	1959	1,097,747
71 year statistics		
Minimum		240,236
Maximum		9,677,655
Average		3,115,424

These flow data demonstrate one of the important aspects of Red River Valley hydrology. In 60 of the 71 years of analysis (figures 3.5.4 and 3.5.5), there is adequate water to meet most of the current and future MR&I water demands; however, during a 1930s drought there would be severe water shortages even with current water demands. Options developed in this study are more about addressing water shortages associated with drought than they are about projected increases in water demand, although future demands would be met. Based on hydrologic modeling, increased 2050 water demands would exacerbate a water shortage that would occur even today during a drought.

5.2 Future Water Demands

Comprehensive water supply needs identified in DWRA:
- **MR&I,**
- **water quality,**
- **aquatic environment,**
- **recreation, and**
- **water conservation measures**

Red River Valley water demands are projected to increase through the 2050 planning horizon. The Dakota Water Resources Act of 2000 (DWRA) specified the water needs to be evaluated as MR&I, water quality, aquatic environment, recreation, and water conservation measures [DWRA Section 8(b)(2)]. The objective of the Project is to meet MR&I water needs, including water conservation, through the year 2050 and to optimize water resources in an attempt to meet identified water quality, aquatic environment, and recreation needs. The service area for this Project includes the 13 eastern counties in North Dakota and the Minnesota cities of Breckenridge, East Grand Forks, and Moorhead.

Table 5.2.1 summarizes the 2050 Red River Valley water demand estimates for Scenarios One or Two. The average year water demand, maximum year water demand and peak day water demand are in units of ac-ft and cfs (cubic feet per second). Water use is divided into four demand categories: municipal, rural, industrial, and recreation. There are no consumptive water demands identified for the aquatic environment or for water quality. Water conservation is included in municipal and rural water system demand estimates.

Table 5.2.1 – Summary of Water Demand Estimates - Scenarios One or Two.

Water Use	Scenario One				Scenario Two			
	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Peak Day Water Demand (ac-ft)	Peak Day Water Demand (cfs)	Average Annual Water Demand (ac-ft)	Maximum Annual Water Demand (ac-ft)	Peak Day Water Demand (ac-ft)	Peak Day Water Demand (cfs)
Municipal	57,053	79,442	503.0	253.6	65,944	91,806	584.0	294.0
Rural Water System	6,388	8,804	39.2	19.7	8,131	11,174	49.0	24.9
Industrial	22,566	25,039	95.8	48.3	36,510	38,983	134.0	67.5
Recreation	290	417	5.1	2.5	290	417	5.0	2.5
Totals	**86,297**	**113,702**	**643.0**	**324.2**	**110,875**	**142,380**	**772.0**	**389.0**

Scenario One water demand includes the 2050 population numbers from Reclamation (2003b/Revised 2005) and the intermediate future industrial water demand projection from Bangsund and Leistritz (2004). Scenario Two includes 2050 population projections from water users and the high scenario future industrial water demand projection from Bangsund and Leistritz (2004). Water demands presented in table 5.2.1 do not include irrigation, because irrigation was not identified as a need in Section 8 of DWRA. The Red River Valley also has substantial irrigation depletions, which were incorporated into surface water modeling but were not included as a Project water demand. The primary difference between Scenario One and Scenario Two water demands relates to municipal and industrial demand estimates. The increase in municipal water demand links to the difference in population projections. For industrial water demands, the difference relates to the use of the intermediate water demand projection in Scenario One, as compared to the high water demand projection in Scenario Two (Bangsund and Leistritz 2004). The industrial study concludes that value-added food processing, and the water required for this activity, would continue to increase through the 2050 planning horizon based on past trends. There are minor differences between rural water demands for each scenario, and the same recreation demands are used in both scenarios.

Scenario One: Reclamation's 2050 population projections x (per capita water demand – water conservation) + Bangsund and Leistritz (2004) intermediate future industrial water demands + recreation consumptive use.

Scenario Two: Water users' 2050 population projections x (per capita water demand – water conservation) + Bangsund and Leistritz (2004) high future industrial water demands + recreation consumptive use.

Maximum annual water demands were used to evaluate whether water systems in the Red River Valley would have adequate water supplies through 2050. Maximum annual water demands were used to model future demands, because these more closely represent water demands in drought situations. Most of the water demands were developed from historic water use data documented during the last valley drought in 1988–1989.

Water systems were also evaluated to determine whether water supplies were adequate to meet their peak day water demands. Peak day water demands shown in table 5.2.1 were used in this analysis. The ratio, often referred to as the peaking factor, between peak day water demand and average day water demand is 2.72 for Scenario One or 2.54 under Scenario Two.

Table 5.2.2 compares the 2005 water demands with the 2050 Scenario One or Scenario Two water demand projections. Scenario One or Scenario Two water demands represent a substantial increase above the 2005 water demands. Most of this increase is associated with municipal and industrial water demands. Changes in rural water system and recreation water demands are minor in comparison. The predicted increase in municipal water demand is directly related to increasing population, particularly in the major metropolitan areas. The increase in industrial water demands is based on Bangsund and Leistritz (2004).

Table 5.2.2 - Comparison between Current (2005) and Future (2050) Water Demands.

Water Use	2005 Maximum Annual Water Demand (ac-ft)	Scenario One Maximum Annual Water Demand (ac-ft)	Scenario Two Maximum Annual Water Demand (ac-ft)
Municipal	48,359	79,442	91,806
Rural Water Systems	11,174	8,804	11,174
Industries	6,131	25,039	38,983
Recreation	0	417	417
Totals	**65,664**	**113,702**	**142,380**

Figure 5.2.1 illustrates the difference between current water demands and future water demands under the two water demand scenarios. Municipal and industrial water demands are projected to increase significantly in the future, while rural water use is predicted to remain relatively stable. Future recreation water demands are barely discernable on the graph due to the minor values estimated.

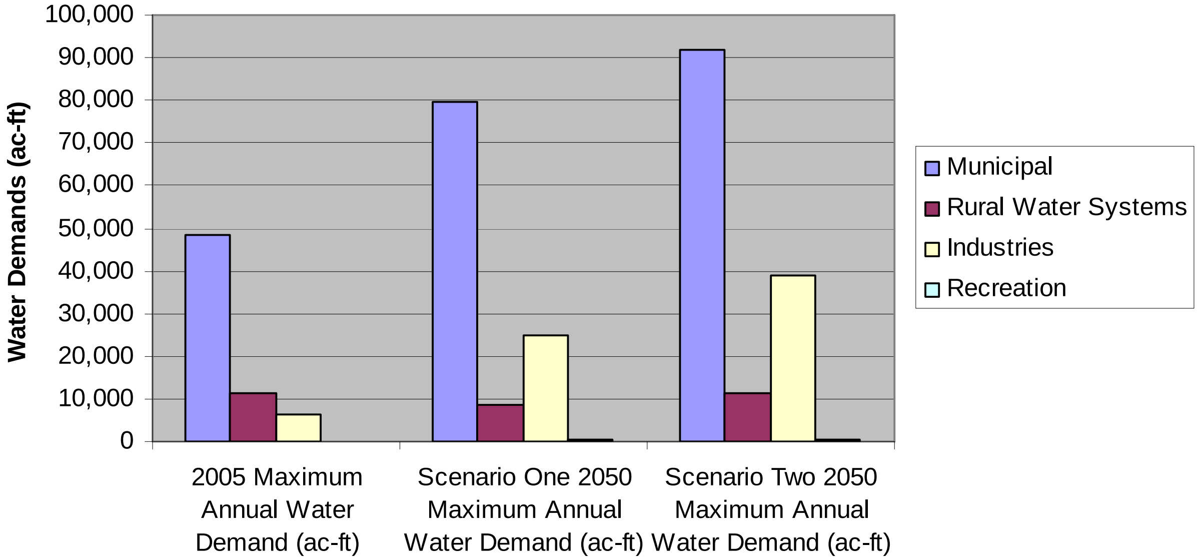


Figure 5.2.1 – Comparison of Current (2005) and Future (2050) Water Demand Estimates.

Reclamation evaluated the current and future water quality of selected MR&I water systems. These systems were analyzed to determine the quality of their existing water sources in regard to compliance with EPA's (Environmental Protection Agency) primary, secondary and potential future regulations under the SDWA (Safe Drinking Water Act).

All water systems currently meet National Primary Drinking Water Regulations; however, a few will not be able to meet a future lower arsenic standard. Some water systems report exceedances of some NSDWR (National Secondary Drinking Water Regulations) such as total dissolved solids, pH, and sulfate.

Water systems with concerns of meeting future arsenic standards will have to resolve this issue by 2006 according to EPA regulations. The options presented in this report did not resolve arsenic compliance problems, because the deadline for compliance is prior to the earliest possible date the Project could address any water quality issues. There are also some systems which exceed one or more NSDWR. These exceedances generally relate to aesthetic complaints (taste, odor, or staining of laundry or plumbing fixtures) or health concerns related to sulfate or other constituents. Reclamation conducted a regulatory overview of the SDWA (Reclamation 2003d) and came to the conclusion that no current NSDWR would be moved to an enforceable primary standard in the foreseeable future. While aesthetic or other water quality concerns are important, no water system was assumed to have their present water source changed based on constituents under NSDWR.

5.3 Hydrologic Modeling Results

Surface water hydrologic modeling reveals that the Red River Valley would have a water shortage problem under present (2005) water demand conditions in a 1930s drought. Water demand projections show that water use in the Red River Valley would increase in the future. Evaluation of future water demands and available water supplies in a drought reveals that water shortages would be larger in the future.

The hydrologic analysis is divided into three major parts: evaluation of groundwater, surface water, and peak day water demands. Groundwater supplies were evaluated first to determine whether water systems currently using groundwater would have adequate supplies to meet their future demands. This evaluation first determined if the water system's existing groundwater permit(s) was sufficient through 2050. For those systems that lack adequate permit capacity, additional water sources were investigated. An investigation to identify aquifers that are not fully developed and could potentially serve as a water supply feature was also conducted.

Once the limitations of groundwater were established, surface water sources were quantified and compared with future water demands. The underlying concept is that groundwater is a finite resource with replenishable and nonreplenishable sources while surface water is more variable in availability. Defining the amount and type of available groundwater and the water demand it can meet was completed in conjunction with identifying the water demands that can be imposed on surface water sources. Analysis of peak day water demand was calculated last, because it is based on the groundwater and surface water results, which used maximum annual demands.

Water systems in the Red River Valley service area that depend on groundwater as their primary source of water were evaluated. Three water systems were identified as having inadequate future groundwater supplies from a quantity standpoint. These are the West Fargo, Cass Rural Water Users District, and Grand Forks-Traill Water District. All of these systems would need to use some surface water to meet future water demands.

West Fargo and Cass Rural Water Users District Phase I Service Area are currently using the West Fargo Aquifer, which is not a sustainable water source capable of indefinitely meeting their needs. Harwood and Horace also use the West Fargo Aquifer, so the analysis assumed they would be served by Cass Rural Water Users District in the future. Grand Forks-Traill Water District currently uses the Elk Valley Aquifer, which is fully allocated, so they would need to purchase water from another source or convert irrigation water to MR&I use. Other water systems were identified as having minor shortage problems, but further investigation revealed they are in the process of procuring additional water supplies to address their needs.

ASR (Aquifer Storage and Recovery)
ASR is storage of water in a porous underground formation during times when excess surface water is available and recovery of water during times when it is needed.

Evaluation of groundwater sources revealed there are limited sources of undeveloped groundwater capacity in eastern North Dakota. An area with moderate potential is southeastern North Dakota, but those sources have limited capacity and could only meet water demands in the southeastern corner of the state. Other mechanisms to use existing groundwater sources more effectively, such as ASR, are identified as features in some of the proposed options. Some groundwater sources are available in west central Minnesota and are included as a feature in the Red River Basin Alternative.

Table 5.3.1 and figure 5.3.1 show the current level of use for groundwater and surface water sources in the Red River Valley and how Reclamation anticipates they would be used in the future, if no new groundwater sources are developed (groundwater in southeastern North Dakota and Minnesota groundwater). Reclamation estimates that groundwater, due to its limited availability, would be used at about the same rate during the next 45 years. In the future, a majority of the groundwater use would be by rural water systems and a few medium-sized cities. Eleven of 12 rural water systems in the Red River Valley in North Dakota currently use groundwater sources, and this is expected to continue. However, Cass Rural Water Users District is projected to use some surface water in the future. Grand Forks-Traill Water District would either use some surface water or would convert Elk Valley Aquifer irrigation permits to MR&I use. Currently, Langdon Rural Water District is the only rural water system using surface water in the valley.

Table 5.3.1 - Comparison between Current (2005) and Future (2050) Groundwater and Surface Water Use.

Water Source	2005 Maximum Annual Water Demand (ac-ft)	Scenario One 2050 Maximum Annual Water Demand (ac-ft)	Scenario Two 2050 Maximum Annual Water Demand (ac-ft)
Groundwater	14,427	12,678	14,104
Surface Water	51,237	101,024	128,276
Totals	**65,664**	**113,702**	**142,380**

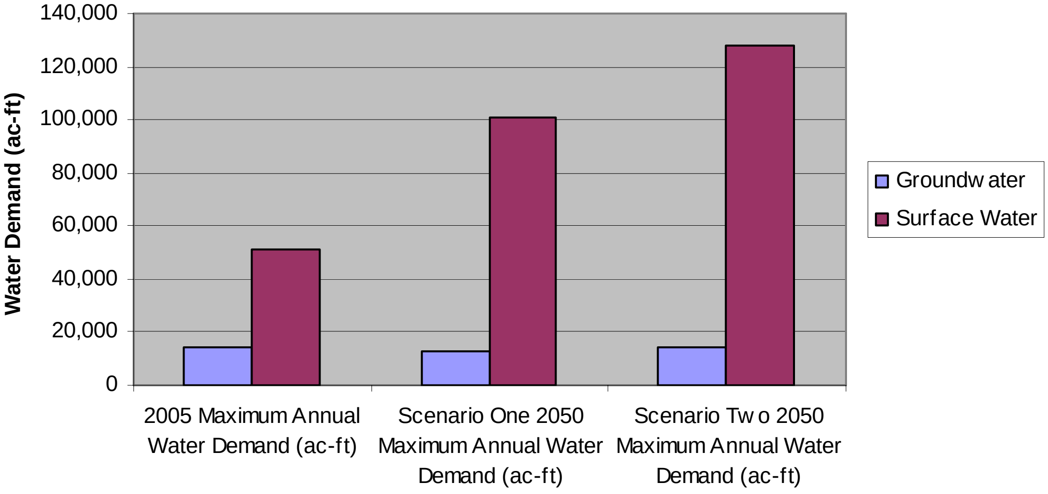


Figure 5.3.1 – Current (2005) and Future (2050) Water Source Use.

Projected groundwater use under Scenario One is slightly less than current use and less than Scenario Two. This difference can be attributed to the rural population projections as well as West Fargo no longer relying upon the West Fargo North Aquifer, except for yields provided by ASR. Scenario One includes Reclamation's rural water system population projections, which are slightly less than the current population level (2005) and those projected by the water users for 2050. Water user projections are used in the calculation of Scenario Two demands. Moorhead also uses a combination of groundwater and surface water, so the values in table 5.3.1 could fluctuate from year to year.

Based on groundwater assessments in chapter three and the above analysis, almost all future increased water demands would be met by using surface water sources in the Red River Valley. Two exceptions to this include proposed groundwater use in southeastern North Dakota to meet projected industrial demands included in several options and a Minnesota groundwater feature in the Red River Basin Alternative. If these groundwater features were included in table 5.3.1, the groundwater values would increase.

Table 5.3.2 summarizes the maximum annual water demands for Scenarios One and Two that were evaluated during surface water modeling. These water demand values are smaller than the values presented in table 5.3.1, because these do not include water demands served by groundwater.

Table 5.3.2 – Maximum Annual Water Demands Served from Surface Water in Scenarios One and Two.

Water Uses	Scenario One Maximum Year Water Demand (ac-ft)	Scenario Two Maximum Year Water Demand (ac-ft)
Municipal	75,181	87,283
Rural Water System	1,450	2,656
Industrial	23,976	37,920
Recreation	417	417
Totals	**101,024**	**128,276**

The StateMod model compared available surface water sources and estimated future water demands. If water demand for a water system exceeded the available supply of surface water, the model identified that as a shortage. The first modeling effort conducted by Reclamation was the No Action Alternative run (see section 3.5.4 for description of the No Action hydrologic modeling). No Action is the future without the Project, an alternative that is evaluated in the Project’s draft environmental impact statement (Reclamation and Garrison Diversion 2005). This modeling run estimates the total potential shortage in the Red River Valley in the year 2050 with current surface water sources, 2050 water demands, and no supplemental water supplies or change in reservoir operation plans.

In the No Action Alternative modeling run, Scenario One has an estimated water demand of 104,007 ac-ft with a projected shortage of 36,424 ac-ft or 35.0%. Scenario Two has an estimated water demand of 131,259 ac-ft with a projected shortage of 52,015 ac-ft or 39.6%. The 104,007 ac-ft and 131,259 ac-ft are demand totals from table 5.3.2 plus 2,983 ac-ft of other Project demands, which are defined later in this section. It is interesting to note that while the water demands increased 27,252 ac-ft or 26.2% from Scenario One to Scenario Two, the shortage increased 15,591 ac-ft or 57.2%. This shows that not all increased water demand results in a shortage; however, the surface water system is approaching a critical point where all additional water demand increases will incur an equal amount of shortage.

Table 5.3.3 shows the results of the No Action Alternative model run for Scenario One and Scenario Two water demands. A water demand category titled “Other Project Demands” is included in this table. These demands represent small commercial water users for which historic water demands were modeled at an annual demand of 2,983 ac-ft, resulting in a shortage of 1,472 or 1,547 ac-ft. The same water demand was modeled for both scenarios. Water demands or shortages for irrigation, are not included in the table, but hydrologic analysis reveals that irrigators would experience shortages of 6,774 ac-ft under Scenario One or 6,853 ac-ft under Scenario Two. Irrigation shortages are not addressed by the proposed Project options, but it is recognized that irrigators will be impacted by droughts and by increased future MR&I water demands. Water systems downstream of Fargo and Moorhead such as Grand Forks, Drayton and Grafton do not have any shortages because of Fargo/Moorhead wastewater return flows. The hydrologic modeling assumed that return flows would be available during low flows periods in the Red River.

Table 5.3.3 – No Action Alternative Surface Water Modeling Results - Scenarios One and Two.

Water System	Scenario One		Scenario Two	
	Maximum Annual Demand (ac-ft)	Maximum Annual Shortage (ac-ft)	Maximum Annual Demand (ac-ft)	Maximum Annual Shortage (ac-ft)
Fargo-Moorhead Area Water Demands [1]	60,397	28,388	76,405	42,190
Grand Forks	25,976	0	32,162	0
Drayton	607	0	607	0
Valley City	894	0	1,148	0
Grafton	927	0	1,401	0
East Grand Forks	2,384	0	3,312	0
Langdon & Langdon Rural Water District	720	202	842	260
Grand Forks-Traill Water District	605	0	1,142	0
Cargill at Wahpeton	2,104	1,926	2,104	1,926
American Crystal Sugar at Moorhead	104	53	104	53
American Crystal Sugar at Drayton	1,153	0	1,153	0
American Crystal Sugar at Hillsboro	733	447	733	447
ADM Corn Processing in Walhalla	298	150	298	150
New Industry in Richland County	3,705	3,404	6,448	6,060
New Recreation Demands	417	382	417	382
Other Project Demands	2,983	1,472	2,983	1,547
Totals	**104,007**	**36,424**	**131,259**	**53,015**

[1] The Fargo-Moorhead area demands include Fargo, West Fargo, Cass Rural Water Users District Phase I, Horace, Harwood, Cargill–West Fargo, Cass-Clay Creameries, Central Livestock, New Industry Cass County, Moorhead, Dilworth, and New Industry Clay County.

Table 5.3.4 summarizes the Scenario One and Scenario Two water demands and shortages for each water use category. In both scenarios, municipal water systems have the highest shortage. Industrial water use has a higher percent of water shortage because a significant amount of the demand is forecast for future growth and was modeled with junior water rights. Rural water systems have no surface water shortages in table 5.3.4, because their shortages are included in the municipality serving them. Figures 5.3.2 and 5.3.3 depict water demand and shortage estimates presented in table 5.3.4. The graphs show that the majority of future water demands and shortages are associated with municipal and industrial water use. Rural water systems, recreation and other Project demands account for less than 5% of future surface water demand and shortage.

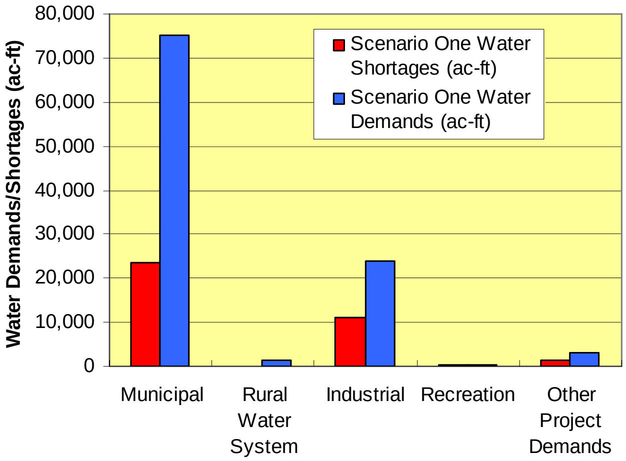


Figure 5.3.2 - Water Demands and Shortages for Scenario One.

Figures 5.3.4 and 5.3.5 depict shortage results from table 5.3.4. The pie charts reveal that the majority of future surface water shortages are municipal uses, ranging from 61% to 65%, and industrial uses, ranging from 30% to 35%. As water demands increase from Scenario One to Scenario Two, municipal shortages as a percentage decrease and industrial shortages increase. Future industrial water demands would have junior water permits, and as their demands increase, their share of shortages as a percentage would increase.

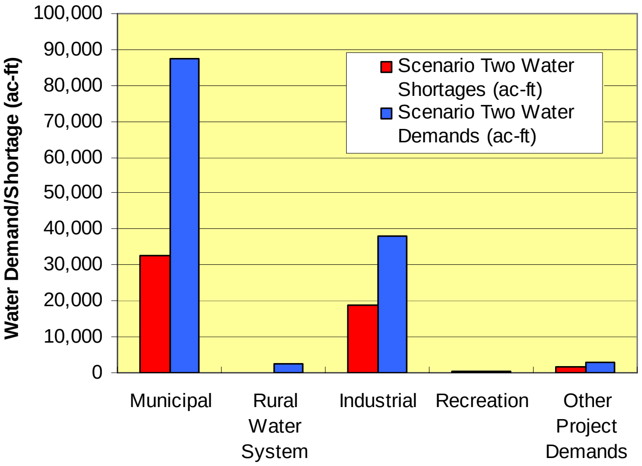


Figure 5.3.3 - Water Demands and Shortages for Scenario Two.

Table 5.3.4 - Summary of Water Demands and Shortages for Scenarios One and Two.

Water Use	Scenario One			Scenario Two		
	Water Demands (ac-ft)	Water Shortages (ac-ft)	% Short	Water Demands (ac-ft)	Water Shortages (ac-ft)	% Short
Municipal	75,181	23,511	31.3%	87,283	32,448	37.2%
Rural Water System	1,450	0	0.0%	2,656	0	0.0%
Industrial	23,976	11,059	46.1%	37,920	18,638	49.1%
Recreation	417	382	91.6%	417	382	91.6%
Other Project Demands	2,983	1,472	49.3%	2,983	1,547	51.9%
Totals	**104,007**	**36,424**	**35.0%**	**131,259**	**53,015**	**40.4%**

Water demands in the Fargo area were modeled individually for Fargo, Moorhead, and West Fargo. Industrial and rural demands to be served by these cities were added to the appropriate municipal water demand for modeling purposes. Although the model quantified a shortage for each city, the results must be viewed as a combined shortage for the metropolitan area. Differences in water law between Minnesota and North Dakota make it extremely difficult to account for shortages based on water permit seniority or on operational variability during modeling. Variations of the model runs showed that although the shortages could be shifted from city to city within the metro area by modifying operational rights, the resulting total shortage remained the same.

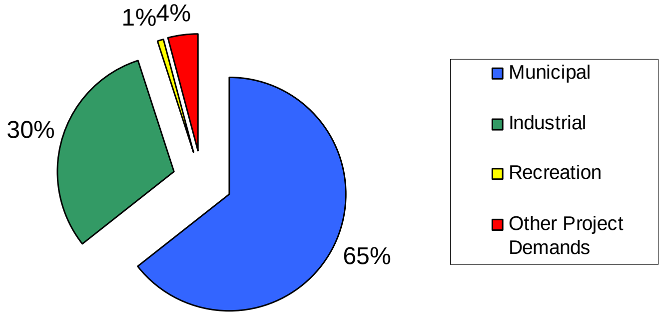


Figure 5.3.4 - Water Shortages for Scenario One.

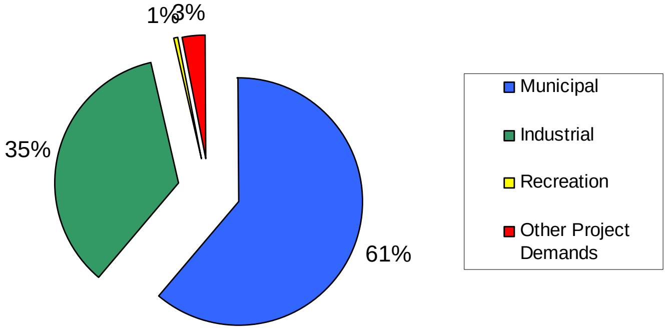


Figure 5.3.5 - Water Shortages for Scenario Two.

Table 5.3.5 shows the Fargo-Moorhead metro area water systems, their water demands, and estimated individual shortages. The shortages were estimated outside of the model based on a proportional split of water demands. Other methods related to water permit seniority could also be used to redistribute shortages.

West Fargo would need to rely on surface water in the future, but their existing surface water permit is less than their estimated future demands, so they may have higher shortages than shown in table 5.3.5. Modeling assumed that the West Fargo North Aquifer would not serve as a future water source, although it currently provides water for West Fargo, Cass Rural Water Users District, and small businesses. Moorhead modeling results include their historic use of groundwater.

New industries in Cass and Clay counties would have water rights junior to all other users if they procure their own water permits. This would create a situation where most of their water demands would not be met during drought conditions under No Action.

Table 5.3.5 – No Action Alternative Model Run with Fargo-Moorhead Water Demand and Shortage Distribution.

Water System	Scenario One			Scenario Two		
	Maximum Annual Demand (ac-ft)	% of Total Water Demand	Maximum Annual Shortage (ac-ft)	Maximum Annual Demand (ac-ft)	% of Total Water Demand	Maximum Annual Shortage (ac-ft)
Fargo	37,682	62.4%	17,711	44,833	58.7%	24,756
Cass Rural Water Users District	702	1.2%	330	1,250	1.6%	690
West Fargo	4,261	7.1%	2,003	4,362	5.7%	2,409
Moorhead	8,646	14.3%	4,064	10,696	14.0%	5,906
New Cass County Industry	7,282	12.1%	3,423	12,850	16.8%	7,096
New Clay County Industry	1,150	1.9%	541	1,740	2.3%	961
Small Fargo Industries	674	1.1%	317	674	0.9%	372
Totals	**60,397**	**100%**	**28,388**	**76,405**	**100%**	**42,190**

Seven options were developed to overcome shortages identified within the service area. A separate hydrologic model run was configured for each option and demand scenario. The primary configuration difference between this modeling effort and that which was done to determine shortages was the addition of water supply features from the seven options. Additionally, the Thompson-Acker Plan (NDSWC 2005a) that is used to appropriate stored water in Lake Ashtabula was turned off in the model. That means that storage in the reservoir was available for all water systems, not just those with storage allocations. This was done to overcome system inefficiencies and to optimize the water supply system as a whole. The Lake Ashtabula conservation pool was still held in reserve at 28,000 ac-ft if possible in all option model runs as well as a 13 cfs “minimum downstream flow requirement” (Corps 2005).

Table 5.3.6 shows the capacity requirement in cfs for each option’s main water supply feature, such as an import pipeline. For options that include an import, each model run was configured with a hypothetical reservoir. Through an optimization process, the volume of water released from the hypothetical reservoir to meet water demands was determined. The North Dakota In-Basin Alternative was modeled exactly as it would function, by withdrawing water from the Red River north of Grand Forks and by piping it back to Lake Ashtabula.

The GDU (Garrison Diversion Unit) Import Pipeline Alternative capacity of 160 cfs (Scenario One) or 202 cfs (Scenario Two) is a combination of modeling results using 73 cfs or 100 cfs plus additional flow to meet peak day water demands (79 cfs or 92 cfs, respectively). The GDU Water Supply Replacement Pipeline Alternative did not require modeling to determine the required conveyance capacity, because it was sized based on the total peak day water demand for the Red River Valley service area.

Columns two and three of table 5.3.6 show the conveyance capacity of each proposed option, with an additional 5% included for pipeline losses. The American Water Works Association recommends limiting water losses to 10% or less; a loss estimate of 5% was assumed for this analysis.

Table 5.3.6 – Option Capacity Results from StateMod Modeling.

Option and Feature	**Scenario One Sizing (w/ 5% losses) (cfs)**	**Scenario Two Sizing (w/ 5% loss) (cfs)**
North Dakota In-Basin - Grand Forks to Lake Ashtabula Pipeline	53	71
Red River Basin - Minnesota Groundwater and Pipeline	45	72
Lake of the Woods - Lake of the Woods Pipeline	70	96
GDU Import to Sheyenne River - McClusky Canal to Lake Ashtabula Pipeline	62	97
GDU Import Pipeline - McClusky Canal to Fargo and Grand Forks Pipeline	160	202
Missouri River Import to Red River Valley - Bismarck to Fargo Pipeline	44	63
GDU Water Supply Replacement Pipeline - Replacement Pipeline	341	411

5.4 Options

Seven options were developed to meet water demands through 2050 (see figures 5.4.1 through 5.4.7). They include three in-basin options and four import options. The options would use different methods to meet future water needs in the service area. Some would deliver enough water to meet the maximum month demand with peak day demands met locally, while other options would deliver enough water to meet both maximum month and peak day demands.

The options include a wide diversity of features designed to meet future water demands. Table 5.4.1 identifies the estimated maximum annual volume of water each option would provide through its main supply feature using Scenario One or Scenario Two water demands. For example, the Red River Basin Alternative's main supply feature would be Minnesota groundwater, while the GDU Import Pipeline Alternative's main supply feature would be a pipeline from McClusky Canal.

Six options would supplement current water supplies to meet the predicted water shortage. The seventh option, the GDU Water Supply Replacement Pipeline Alternative, would replace all existing MR&I water supplies in the service area with SDWA treated water imported from the Missouri River. Options that propose importing water from the Missouri River would have biota WTPs (water treatment plants) designed to reduce the risk of interbasin transfer of biota that are not native to the Hudson Bay Basin.

Table 5.4.1 – Maximum Annual Water Volume Provided through Main Supply Feature for each Option.

Option and Feature	Scenario One Maximum Annual Amount Provided to Meet Shortages (ac-ft)	Scenario Two Maximum Annual Amount Provided to Meet Shortages (ac-ft)
North Dakota In-Basin - Grand Forks to Lake Ashtabula Pipeline	29,566	42,669
Red River Basin - Minnesota Groundwater and Pipeline	23,277	38,128
Lake of the Woods - Lake of the Woods Pipeline	41,421	57,658
GDU Import to Sheyenne River - McClusky Canal to Lake Ashtabula Pipeline	41,525	65,752
GDU Import Pipeline - McClusky Canal to Fargo and Grand Forks Pipeline	45,337	61,580
Missouri River Import to Red River Valley - Bismarck to Fargo Pipeline	30,410	43,435
GDU Water Supply Replacement Pipeline - Replacement Pipeline [1]	113,702	142,380

[1] The GDU Water Supply Replacement Pipeline values are not shortages but are a complete replacement of Red River Valley water sources and would meet all peak day water demands.

North Dakota In-Basin Alternative

This alternative would primarily use the Red River and other North Dakota in-basin water sources to meet future water demands. The pipeline would capture Red River flows downstream of Grand Forks and recirculate flows back to Lake Ashtabula to meet MR&I water demands. The option also would include developing new groundwater sources in southeastern North Dakota and purchasing existing irrigation water rights in the Elk Valley Aquifer. Aquifer storage and recovery systems are proposed for Fargo, Moorhead, and West Fargo. Moorhead would continue to draw on Minnesota groundwater sources for some of their water demand. Additional storage reservoirs would be needed by communities in the northern end of the valley.

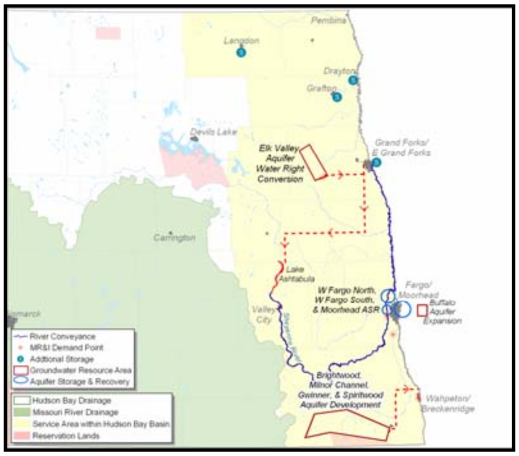


Figure 5.4.1 - North Dakota In-Basin Alternative.

Red River Basin Alternative

This alternative would draw on a combination of the Red River, other North Dakota in-basin water sources, and Minnesota groundwater to meet future water demands. A series of well fields would be developed in Minnesota with an interconnecting conveyance pipeline serving the Fargo-Moorhead metropolitan area. This alternative would rely on the existing storage and regulation capability of Lake Ashtabula to manage flows in the Sheyenne River. It would include the same North Dakota and Moorhead groundwater features as the North Dakota In-Basin Alternative. Communities in the northern end of the valley would need additional storage reservoirs.

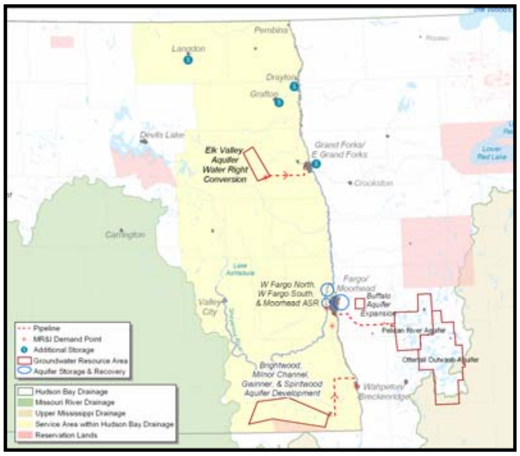


Figure 5.4.2 - Red River Basin Alternative.

Lake of the Woods Alternative

This alternative would use a combination of the Red River, other North Dakota in-basin water sources, and water from Lake of the Woods to meet future water demands. The primary feature would be a pipeline from Lake of the Woods to the major population centers of the Red River Valley. Like the previous alternative, it would rely on the existing storage and regulation capability of Lake Ashtabula. It would include the same North Dakota and Moorhead groundwater features as the North Dakota In-Basin Alternative. Additional storage reservoirs would be needed by communities in the northern end of the valley.

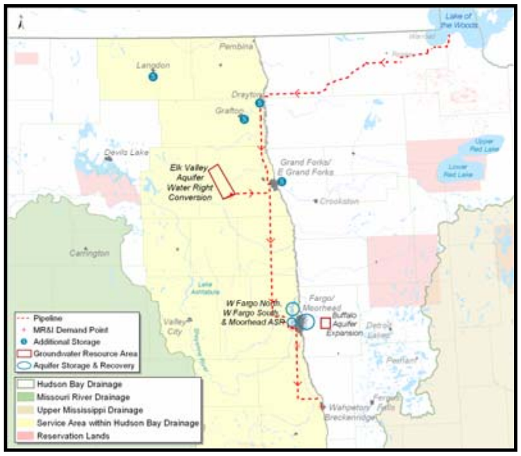


Figure 5.4.3 - Lake of the Woods Alternative.

GDU Import to Sheyenne River Alternative

This alternative would use a combination of the Red River, other North Dakota in-basin water sources, and Missouri River water to meet future water demands. The principal feature of this alternative would be a pipeline from the McClusky Canal to Lake Ashtabula that would release treated Missouri River water into the Sheyenne River. The pipe would be sized so peak day demands could be met by Lake Ashtabula releases. The alternative would include a biota WTP at the McClusky Canal and a pipeline to serve industrial water demands in southeastern

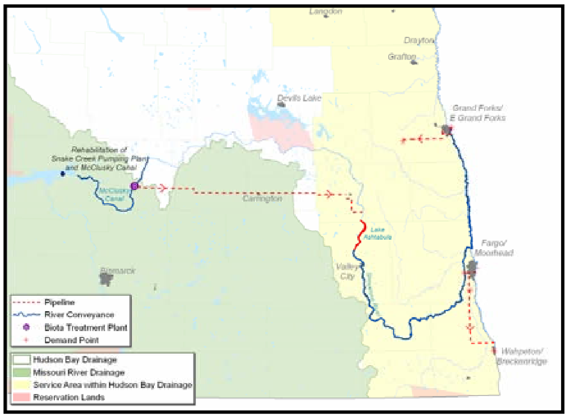


Figure 5.4.4 - GDU Import to Sheyenne River Alternative.

North Dakota. The biota treatment process would use coagulation, flocculation, sedimentation, and ultraviolet disinfection.

GDU Import Pipeline Alternative

This alternative proposes a combination of the Red River, other North Dakota in-basin water, and imported Missouri River water to meet future water demands. The principal feature would be a pipeline from the McClusky Canal to the Fargo and Grand Forks metropolitan areas sized to meet peak day shortages. It would include a biota WTP at the McClusky Canal and a pipeline to serve industrial water demands in southeastern North Dakota. The alternative would rely on the existing storage and regulation capability of Lake Ashtabula to meet some of the downstream MR&I water demands. The biota treatment process would use coagulation, flocculation, sedimentation, and ultraviolet disinfection.

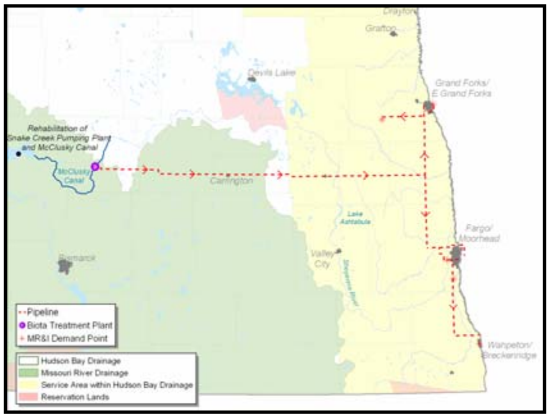


Figure 5.4.5 - GDU Import Pipeline Alternative.

Missouri River Import to Red River Valley Alternative

This alternative would use a combination of the Red River, other North Dakota in-basin water sources, and imported Missouri River water to meet future water demands. It would include a biota WTP at the Missouri River. The biota treatment process would use coagulation, flocculation, sedimentation, and ultraviolet disinfection.

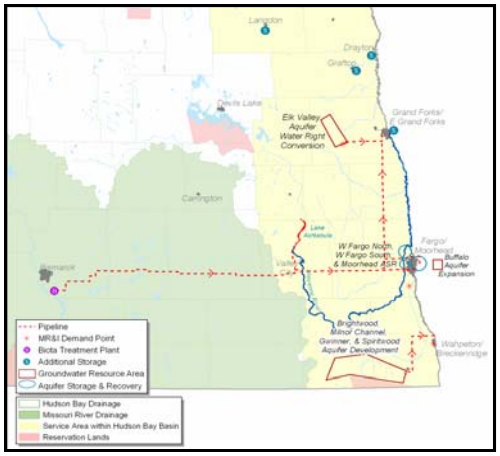


Figure 5.4.6 - Missouri River Import to Red River Valley Alternative.

The principal feature would be a pipeline from the Missouri River at Bismarck to the Fargo and Grand Forks metropolitan areas. The size of the pipeline would be optimized by including a spur pipeline to release treated Missouri River water into Lake Ashtabula. The lake would be a regulating reservoir. The alternative would also include the same North Dakota and Moorhead groundwater features as in the North Dakota In-Basin Alternative. Communities in the northern end of the valley would need additional storage reservoirs.

GDU Water Supply Replacement Pipeline Alternative

This alternative would only use water imported from the Missouri River to replace other water supplies in the service area to meet future water demands. The principal feature would be a pipeline from the McClusky Canal into the Red River Valley interconnecting most of the cities, rural water systems, and industries. A few extreme northern and southern water systems would not be connected to the system, but capacity to serve them in the future is provided for in the design. The conveyance pipeline would have a capacity to meet the peak day water demand of the entire service area.

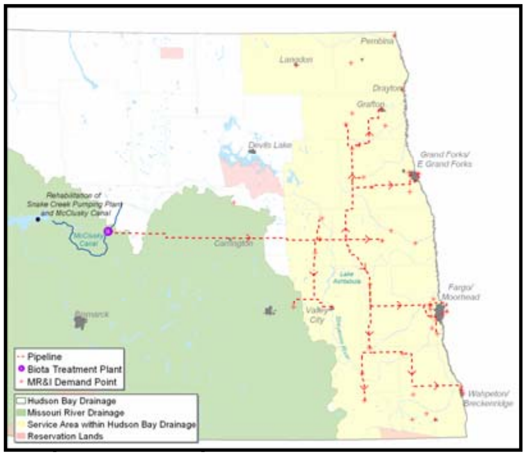


Figure 5.4.7 – GDU Water Supply Replacement Pipeline Alternative.

It also would include a biota WTP at the McClusky Canal. A biota WTP for this option includes additional processes to deliver water treated to SDWA regulations to the Red River Valley. Numerous water systems in the valley use groundwater and lack the capability to treat surface water. Therefore, treated water must be supplied to these systems, or they would have to adapt their current groundwater WTP to treat surface water. To address this problem, the entire service area would receive bulk-treated water in this alternative. The treatment process would use lime softening, micro-filtration, and ultraviolet disinfection to generate a source of water that fully complies with the SDWA.

Summary of Option Costs

Tables 5.4.2 and 5.4.3 summarize estimated construction, OM&R (operation, maintenance, and replacement), and annualized costs for each of the options considered using 2005 pricing levels. Table 5.4.2 summarizes Scenario One costs and table 5.4.3 summarizes Scenario Two costs. The cost estimates in this report should only be used to compare options. All of the options used the same assumptions and unit prices so they are directly comparable from a cost standpoint. ***These estimates are not suitable for requesting authorization or construction fund appropriations from Congress.***

Construction costs include supplying bulk water service to the Red River Valley service area. Annual OM&R costs include all annual costs required to operate, maintain and replace the water supply features. The annualized costs are a method of combining construction costs and annual OM&R costs into one composite value for comparison purposes. The total annualized costs are the annual equivalent of a capital cost added to the annual OM&R cost. This analysis assumed a repayment period of 45 years (2005 – 2050) with an interest rate of 5%. For example, annual payments of $31,386,000 would have to be made to pay off the construction costs of the North Dakota In-Basin Alternative (Scenario One) at a cost of $557,859,000 (values in table 5.4.2 based on 45 years at 5%). The $31,386,000 plus the annual OM&R at $6,686,000 equals the total annualized costs of $38,072,000. Annualized costs are another method of evaluating option costs.

Table 5.4.2 - Summary of Option Cost Estimates – Scenario One.

Option	Construction Cost (2005 Dollars)*	Annual OM&R Costs*	Annualized Construction Cost*	Total Annualized Cost*
North Dakota In-Basin	$557,859,000	$6,686,000	$31,386,000	$38,072,000
Red River Basin	$549,166,000	$7,481,000	$30,897,000	$38,378,000
Lake of the Woods	$937,228,000	$7,774,000	$52,730,000	$60,504,000
GDU Import to Sheyenne River	$434,052,000	$3,819,000	$24,421,000	$28,240,000
GDU Import Pipeline	$1,202,248,000	$5,330,000	$67,641,000	$72,971,000
Missouri River Import to Red River Valley	$875,378,000	$9,897,000	$49,250,000	$59,147,000
GDU Water Supply Replacement Pipeline	$2,226,667,000	$25,435,000	$125,276,000	$150,711,000

* Values are rounded to the nearest $1,000.

Table 5.4.3 - Summary of Option Cost Estimates – Scenario Two.

Option	Construction Cost (2005 Dollars) *	Annual OM&R Costs*	Annualized Construction Cost*	Total Annualized Cost*
North Dakota In-Basin	$637,891,000	$7,515,000	$35,889,000	$43,404,000
Red River Basin	$750,150,000	$8,869,000	$42,205,000	$51,074,000
Lake of the Woods	$1,112,579,000	$8,765,000	$62,596,000	$71,361,000
GDU Import to Sheyenne River	$585,002,000	$4,978,000	$32,913,000	$37,891,000
GDU Import Pipeline	$1,407,721,000	$6,310,000	$79,201,000	$85,511,000
Missouri River Import to Red River Valley	$1,013,951,000	$10,991,000	$57,047,000	$68,038,000
GDU Water Supply Replacement Pipeline	$2,518,023,000	$31,674,000	$141,668,000	$173,342,000

* Values are rounded to the nearest $1,000.

The options range in construction costs from $434.05 million to $2.23 billion under Scenario One or $585.00 million to $2.52 billion under Scenario Two. OM&R costs vary from $3.82 million to $25.44 million under Scenario One or $4.98 million to $31.67 million under Scenario Two. The options total annualized costs range from $28.24 million to $150.71 million under Scenario One or $37.89 million to $ 173.34 million under Scenario Two. In general, the option with the lowest annualized cost is the least costly from a long term standpoint (through 2050), considering both initial construction costs and long-term annual OM&R costs. Figures 5.4.8 and 5.4.9 graphically compare the construction and OM&R costs for each option under each water demand scenario.

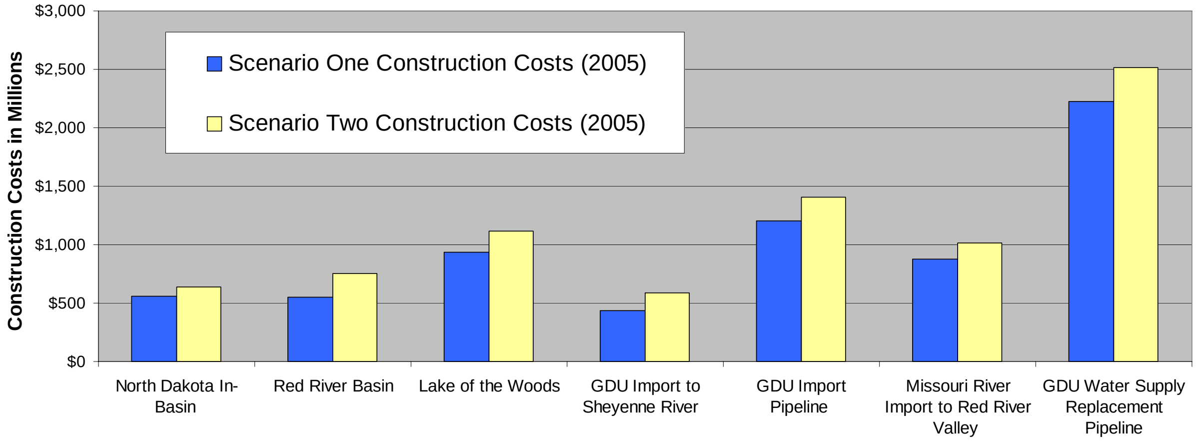


Figure 5.4.8 – Option Construction Cost Estimates for Scenarios One and Two.

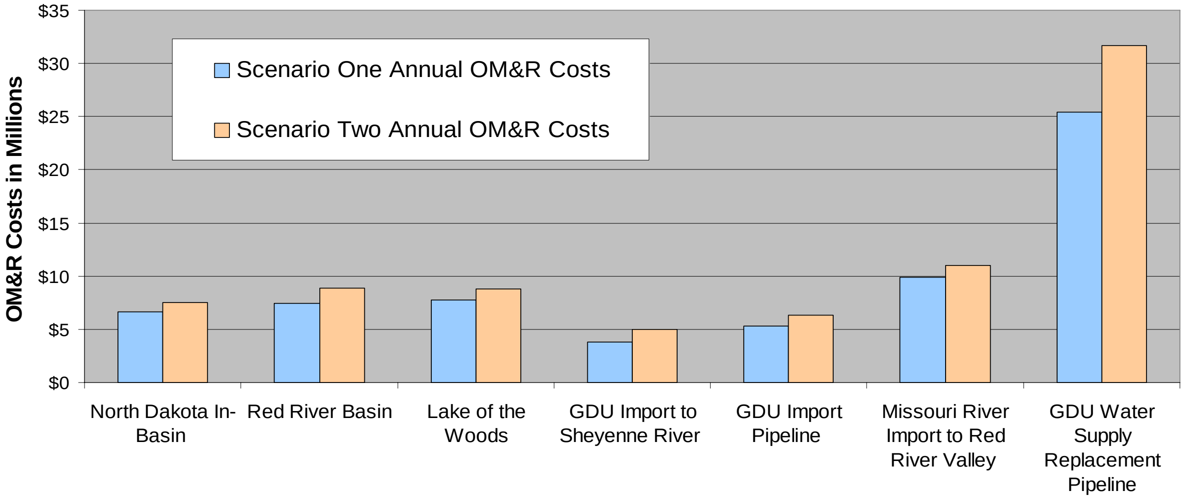


Figure 5.4.9 – Option OM&R Cost Estimates for Scenarios One and Two.

5.5 Use of Report Results

The *Final Report on the Red River Valley Water Needs and Options* has been distributed to interested agencies, organizations and individuals. Reclamation will transmit the *Final Report on the Red River Valley Water Needs and Options* to Congress, as required by the Dakota Water Resources Act of 2000[Section 8(b)(3)].

The Act also directs the Secretary to jointly prepare an EIS (environmental impact statement) for the Project with the State of North Dakota. In preparing the EIS, Reclamation is representing the Secretary, and Garrison Diversion Conservancy District is representing the State of North Dakota. The environmental effects of the options in the *Final Report on the Red River Valley Water Needs and Options*, along with No Action, are analyzed in the EIS. The draft EIS is scheduled for distribution to the public for comment in December 2005.

DWRA also specifies the process for selecting a preferred alternative for the Project. After the Final Needs and Options Report and Final EIS are completed, “the Secretary shall transmit to Congress a comprehensive report which provides:

(i) a detailed description of the proposed project feature;
(ii) a summary of major issues addressed in the environmental impact statement;
(iii) likely effects, if any, on other States bordering the Missouri River and on the State of Minnesota; and
(iv) a description of how the project feature complies with the requirements of section 1(h)(1) of this Act (relating to the Boundary Waters Treaty of 1909)” [Section 8(a)(3)].

After transmitting the comprehensive report to Congress, “the Secretary, in consultation and coordination with the State of North Dakota in coordination with affected local communities, shall select 1 or more project features described in subsection (a) that will meet the comprehensive water quality and quantity needs of the Red River Valley. The Secretary's selection of an alternative shall be subject to judicial review” [DWRA Section 8(d)(1)].

Literature Cited

Armstrong, Clarence Allen. 1982. *Ground-Water Resources of Ransom and Sargent Counties, North Dakota.* North Dakota State Water Conservation Commission County Ground-Water Studies 31 – Part III. North Dakota Geological Survey Bulletin 69, pt. 3. Prepared by the U.S. Geological Survey in cooperation with the North Dakota State Water Commission, North Dakota Geological Survey, Ransom County Water Management District, and Sargent County Water Management District. North Dakota Geological Survey, Bismarck.

Baker, Claud H, Jr., and Q. F. Paulson. 1967. *Geology and Ground Water Resources, Richland County, North Dakota.* North Dakota Geological Survey Bulletin 46. North Dakota State Water Commission County Ground Water Studies 7. Prepared by the U.S. Geological Survey in cooperation with the North Dakota Geological Survey, North Dakota State Water Commission, and Richland County Board of Commissioners. North Dakota Geological Survey and North Dakota State Water Commission, Bismarck.

Bangsund, D.A., and F. L. Leistritz. 2004. *Industrial Water Needs Assessment for the Red River Valley Water Supply Project.* Final Contract Report. Prepared for Garrison Diversion Conservancy District, Carrington, North Dakota. Department of Agribusiness and Applied Economics, North Dakota State University, Fargo.

Bartlett and West. 2003. *Report on Phase I Water Supply, Bartlett and West Engineers Inc. 2003*. Prepared for Cass Rural Water Users District. Bartlett and West, Inc., Fargo.

Bloetscher, F., A. Muniz, and G. Witt. 2005. *Groundwater Injection, Modeling, Risks, and Regulations*. McGraw-Hill.

Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. *Instream Flow Information Paper No. 12*. U.S. Fish and Wildlife Service.

Bovee, K.D. 1997. Data collection procedures for the Physical Habitat Simulation System. U.S. Geological Survey, Biological Resources Division. Fort Collins, Colorado

Boyle, Jayson. [North Dakota State Water Commission]. 2004. *Personal communication, email correspondence with Wade Klingsporn [Bureau of Reclamation, Dakotas Area Office, Bismarck]*. November 5, 2004.

Bureau of Reclamation. 1989. *James River Comprehensive Report, Garrison Diversion Unit.* Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation. 1998. *Red River Valley Water Needs Assessment, Phase I Part A; MR&I Appraisal Report.* United States Department of the Interior.

Bureau of Reclamation. 1999a. *Red River Valley Water Needs Assessment, Final Appraisal Report, Phase I Part B, Instream Flow Needs Assessment.* United States Department of the Interior.

Bureau of Reclamation. 1999b. *High Plains States Groundwater Demonstration Program: Huron Recharge Demonstration Project Summary*. U. S. Department of the Interior, Bureau of Reclamation in Cooperation with South Dakota State University.

Bureau of Reclamation. 2000. *Red River Valley Water Needs Assessment Phase II; Appraisal of Alternatives to Meet Projected Shortages*. Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation. 2003a. *Report on Red River Valley Water Supply Project Needs and Options, Aquatic Needs Assessment, Instream Flows for Aquatic Life and Riparian Maintenance, Final Report.* Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation. 2003b. *Report on Red River Valley Water Supply Project Needs and Options, Current and Future Population of the Red River Valley Region 2000 through 2050, Final Report*. Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota (Revised 2005).

Bureau of Reclamation. 2003c. *Report on Red River Valley Water Supply Project Needs and Options, Recreation Needs Assessment, Final Report.* Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation. 2003d. *Report on Red River Valley Water Supply Project Needs and Options, Water Quality Needs, Regulatory Overview of the Safe Drinking Water Act, Final Report*. Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation. 2004a. *Report on Red River Valley Water Needs and Options, Assessment of Commercial Needs, Future Business and Industrial Activity in the Red River Valley, Final Report.* Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation. 2004b. *Report on Red River Valley Water Needs and Options, Water Conservation Potential Assessment, Final Report.* Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation. 2004c. *Report on Red River Valley Water Needs and Options, Water System Assessment Executive Summary, Final Report.* Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation. 2004d. *Report on Red River Valley Water Needs and Options, Industrial Needs Assessment: Future Red River Valley Commercial Water Demands, Final Report.* Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation. 2005a. *Update of Garrison Diversion Unit Principal Supply Works Costs*. Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation. 2005b. *Water Treatment Plant for Biota Removal and Inactivation Preliminary Design & Cost Estimates, Red River Valley Water Supply Project.* Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota.

Bureau of Reclamation and Garrison Diversion Conservancy District. 2005. *Red River Valley Water Supply Project Draft Environmental Impact Statement.* Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota, in progress.

Corps (Corps of Engineers) see U.S. Army Corps of Engineers.

Downey, J.S. 1973. *Ground-Water Resources Nelson and Walsh Counties, North Dakota.* North Dakota State Water Commission Water Studies no. 17, Part III; and North Dakota Geological Survey Bulletin 57, Part III. North Dakota State Water Commission and North Dakota Geological Survey, Bismarck.

EPA (Environmental Protection Agency) see U.S. Environmental Protection Agency.

Emerson, D.G. 2005. *Historic and Naturalized Monthly Streamflow for Selected Sites in the Red River of the North basin in North Dakota, Minnesota, and South Dakota, 1931-2001.* U.S. Geological Survey Scientific Investigations Report, 2005-5092.

Emerson, D.G., and V.M. Dressler. 2002. *Historic and Unregulated Monthly Streamflow for Selected Sites in the Red River of the North Basin in North Dakota, Minnesota, and South Dakota, 1931-1999.* U.S. Geological Survey Water-Resources Investigations Report 02-4095.

Emerson, D.G.; A. V. Vecchia; and A. L. Dahl. 2005. *Evaluation of Drainage-Area Ratio Method Used to Estimate Streamflow for the Red River of the North Basin, North Dakota and Minnesota.* U.S. Geological Survey Scientific Investigations Report 2005-5017.

Environment Canada. 2002. Canadian environmental quality guidelines. Available at: http://www.ec.gc.ca/CEQG-RCQE/English/default.cfm, last accessed March 1, 2005.

Froelich, Larry L. 1974 *Geohydrology of the Wahpeton Area, Richland County, North Dakota*. North Dakota Ground-Water Studies no. 76. State Water Commission Project no. 1518. North Dakota State Water Commission, Bismarck.

Goddard, Toby and Fiske, Gary. Impacts of Municipal Water Shortages. Posted on United Lot Owners of Cambria website, http://www.unloc.org/archives.html. Accessed August 2005.

HDR Engineering. 1998. *Maple River Dam and Reservoir, Cass County Joint Water Resource District, Cass County, North Dakota, Draft Environmental Impact Statement, October 1998.* HDR Engineering, Inc., Bismarck, North Dakota.

Helgesen, J.O. 1977. *Ground-Water Appraisal of the Pineland Sands Area, Central Minnesota.* USGS Water Resources Investigations 77-102.

Houston Engineering, Inc. 2003. *City of Fargo Drought Management Plan*. Fargo, North Dakota.

Houston Engineering, Inc. 2005a. *Design Criteria, Red River Valley Water Supply Project, Needs and Options Study Element.* Fargo, North Dakota.

Houston Engineering, Inc. 2005b. Revised Final Technical Memorandum: Red River Valley Water Supply Project – Existing Water Quality Conditions, Impact Assessment Methods, and Environmental Consequences.

Hutchinson, R. D. 1977. *Ground-Water Resources of Cavalier and Pembina Counties, North Dakota.* Prepared by the U.S. Geological Survey in cooperation with the North Dakota Geological Survey, North Dakota State Water Commission, Cavalier County Water Management District, and Pembina County Board of Commissioners. North Dakota State Water Commission County Groundwater Studies no. 20 Part 3; and North Dakota Geological Survey Bulletin no. 62 pt. 3. North Dakota State Water Commission and North Dakota Geological Survey, Bismarck.

International Lake of the Woods Control Board 2005 see Walden 2004.

Jensen, Ray E. No Date. Climate of North Dakota. National Weather Service, North Dakota State University, Fargo, North Dakota. Northern Prairie Wildlife Research Center, Jamestown, North Dakota. Document in electronic format is available at: http://www.npwrc.usgs.gov/resource/othrdata/climate/climate.htm (Version 02APR98).

Krenz, G., and J. Leitch. 1993. *A River Runs North, Managing an International River.* Red River Water Resources Council [no place of publication given].

Kopechanski, Roma. [Ontario Power Generation]. 2005. *Personal communication, email correspondence with Wade Klingsporn [Bureau of Reclamation, Dakotas Area Office, Bismarck]*, January 21.

Macek-Rowland, K.M.; A. D. Arntson; K. R. Ryberg; A. L. Dahl; A. Leib. 2004. *Water-Use Data for the Red River of the North Basin, North Dakota, Minnesota, and South Dakota, 1979-2001*. U.S. Geological Survey Open-File Report 2004-1308.

Meridian Environmental Technology, Inc. 2004. *Red River Valley Climate Study on Drought Frequency Investigations of the Red River of the North Basin.* Presented to the Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota. Meridian Environmental Technology, Inc., Grand Forks, North Dakota.

Miller, J.E., and D. L. Frink. 1984. *Changes in Flood Response of the Red River of the North Basin, North Dakota-Minnesota.* U.S. Geological Survey Water-Supply Paper 2243.

Minnesota Pollution Control Agency. 2001. *Rainy River Basin Information Document*. Minnesota Pollution Control Agency, St. Paul.

Minnesota Pollution Control Agency. 2004. 2004 Final List of Impaired Waters. Available Online at Http://Www.Pca.State.Mn.Us/Publications/Reports/Tmdl-List-2004.Pdf . Last Accessed October 31, 2005.

North Dakota Department of Health. 2004. North Dakota 2004 Integrated Section 305(b) Water Quality Assessment Report and Section 303(d) List of Waters Needing Total Maximum Daily Loads. Bismarck, North Dakota.

North Dakota Parks and Recreation Department. 1987. *North Dakota Rivers Study*, North Dakota Parks and Recreation Department, Bismarck.

North Dakota Parks and Recreation Department. 1995. *State Comprehensive Outdoor Recreation Plan, 1996-2000, North Dakota*. North Dakota Parks and Recreation Department. Bismarck.

North Dakota Parks and Recreation Department. 2003. *State Comprehensive Outdoor Recreation Plan, 2003-2008, North Dakota*. North Dakota Parks and Recreation Department, Bismarck. Document in electronic format is available at: http://www.ndparks.com/Acrobat/SCORP.pdf

North Dakota State Water Commission. 1992. North Dakota State Water Commission Office Memo, November 27, from Craig Odenbach, Water Resource Engineer; to Milton Lindvig, Director Hydrology Division; subject: Lake Ashtabula Allocations.

North Dakota State Water Commission. 1995. North Dakota State Water Commission Office Letter, May 10, from Milton O. Lindvig, Water Appropriation Division Director; to Roger Burnett, Bureau of Reclamation; subject: Appraisals of Major Aquifers in the Red River Valley.

NDSWC 2000 see Ripley 2000.

North Dakota State Water Commission. 2004. The Data Resources pages http://www.swc.state.nd.us/dataresources.html on the NDSWC website provide a search interface to provisional data on the following data types: construction permits, retention structure, drains, precipitation, water permits, private contractor logs, ground/surface water, digital maps, government surveys, and software utilities. This link is for ground/surface water data: http://www.swc.state.nd.us/4DLink2/4dcgi/WellSearchForm

North Dakota State Water Commission. 2005a. Office of the North Dakota State Engineer, memo, March 17, from Robert B. White, Water Resource Engineer; to Dave Ripley, Director, Water Appropriation Division; subject: Baldhill Dam Review.

North Dakota State Water Commission. 2005b. Memo, January 27, from Dave Ripley, Director, Water Appropriation Division; to Allen Schlag, Bureau of Reclamation; Subject: Appraisals of Selected Aquifers in the Red River Valley of North Dakota.

Northwest Economic Associates. 2003*. Population Projections for Red River Valley Counties and Municipalities, 2000 through 2050.* Presented to the Bureau of Reclamation, Dakotas Area Office, Bismarck, North Dakota. Northwest Economic Associates, Vancouver, Washington.

Ontario Power Generation 2005 see Kopechanski 2005.

Reclamation see Bureau of Reclamation.

Reppe, Thomas H. C. 2005. *Ground-Water Availability from Surficial Aquifers in the Red River of the North Basin, Minnesota*. *USGS Scientific Investigations Report* 2005-5204 (available online at http://pubs.water.usgs.gov/sir2005-5204/)

Ripley, David P. 2000. *Water Resource Characteristics of the West Fargo Aquifer System, Cass and Richland Counties, North Dakota*. Prepared in cooperation with the Southeast Cass Water Resource District. North Dakota Ground-Water Studies no. 106 Part II. North Dakota State Water Commission, Bismarck.

Ripley 2005 see NDSWC 2005b.

Schoenberg, Michael E. 1998. *Hydrogeology and Sources of Recharge to the Buffalo and Wahpteon Aquifers in the Southern Part of the Red River of the North Drainage Basin, West-Central Minnesota and Southeastern North Dakota.* Prepared in cooperation with the Minnesota Department of Natural Resources and Moorhead [Minnesota] Public Service. Water-Resources Investigations Report 97-4084. U.S. Geological Survey, Mounds View, Minnesota.

Shaver, Robert B. 1998. [Hydrologist, North Dakota State Water Commission, Bismarck]. Memorandum on Conditional Water Permit Application #5188 [Ransom-Sargent Water Users], June 9, to David Sprnczynatyk, State Engineer, through Milton O. Lindvig, Director, State Water Appropriation Division, NDSWC.

Sloan, Charles, E. 1972. *Ground-Water Hydrology of Prairie Potholes in North Dakota*. U.S. Geological Survey Professional Paper 585-C.

Spectrum Economics, Inc. 1991. Cost of Industrial Water Shortages. Prepared California Urban Water Agencies. San Francisco, California.

Stalnaker, C., B. L. Lamb, J. Hendricksen, K. Bovee, and J. Bartholow. 1995. The Instream Flow Incremental Methodology. A Primer for IFIM. *Biological Report 29*. National Biological Service.

Strobel, M.L., and N.D. Haffield. 1995. *Salinity in surface water in the Red River of the North Basin, northeastern North Dakota.* U.S. Geological Survey Water-Resources Investigations Report 95-4082.

Tennant, D.L. 1976. Instream Flow Regimens for Fish, Wildlife, Recreation, and Related Environmental Resources. In: *Proceedings of Symposium and Specialty Conference on Instream Flow Needs*. J.F. Orsborn and C.H. Allman ed. American Fisheries Society, pp. 359-373.

Thielman, Gregg. 2003. Memorandum to Garrison Diversion Conservancy District from Houston Engineering, Inc., Regarding Needs 3.2 – Unserved Rural Residents, August 14.

Thorleifson, L. H., K. Harris, J. Berg, R. Tipping, Z. Malolepszy, B. Lusardi, D. Setterholm, and F. Anderson; 2005; *Geological Mapping and 3D Model of Deposits That Host Ground-Water Systems in The Fargo-Moorhead Region, Minnesota and North Dakota*. Minnesota Geological Survey Report, submitted to the U.S. Department of the Interior, Bureau of Reclamation in Fulfillment of Cooperative Agreement No 04FG601925, in Support of the Red River Valley Water Supply Project; Accompanied by 1:200,000 Surficial Geology Map, 1: 400,000 Bedrock Geology map, Drillhole Database, and Digital Files Depicting Extent, Thickness, and Elevation of Mapped Strata

Tornes, Lan H. 2005. *Water Quality of Streams in the Red River of the North Basin, Minnesota, North Dakota, and South Dakota.* Scientific Investigations Report 2005-5095. Prepared in cooperation with the Bureau of Reclamation. U.S. Department of the Interior, U.S. Geological Survey.

Tornes, L.H., M.E. Brigham, and D.L. Lorenz. 1997. *Nutrients, suspended sediment, and pesticides in streams in the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1993-1995.* U.S. Geological Survey Water Resources Investigations Report 97-4053.

U. S. Army Corps of Engineers, St. Paul District. 1983. *Red River of the North Drainage Basin Water Supply and Flood Control: Baldhill Dam & Lake Ashtabula, Sheyenne River Reservoir Regulation Manual, Revised.* U.S. Army Corps of Engineers. St. Paul, Minnesota.

U.S. Army Corps of Engineers. 2001. See WEST Consultants 2001.

U.S. Army Corps of Engineers, St. Paul District. 2003. *Final Integrated Planning Report/Environmental Impact Statement. Devils Lake, North Dakota Study.* U.S. Army Corps of Engineers. St. Paul, Minnesota.

U.S. Army Corps of Engineers, Omaha District. 2004. Missouri River Basin Mainstem Reservoir System Master Water Control Manual. U.S. Army Corps of Engineers, Reservoir Control Center, Northwest Division-Missouri River Basin. Omaha, Nebraska.

U.S. Army Corps of Engineers, St. Paul District. 2005. Draft Revised Water Control Manual, Baldhill Dam and Lake Ashtabula, Sheyenne River - Water Supply and Flood Control. St. Paul, Minnesota.

U.S. Bureau of Reclamation see Bureau of Reclamation.

U.S. Environmental Protection Agency. 1986. *Quality Criteria for Water 1986.* U.S. Environmental Protection Agency Report Number 440/5-001.

U.S. Environmental Protection Agency. 2005. Water Quality Standards. Available at http://www.epa.gov/OST/standards, last accessed March 2, 2005.

Vining, K.C. 2003. *Estimation of Monthly Evaporation from Lake Ashtabula in North Dakota, Orwell Lake in Minnesota, and Lake Traverse in Minnesota and South Dakota, 1931-2001.* U.S. Geological Survey Water-Resources Investigations Report 03-4282.

Vecchia, A.V. 2005. Water Quality Trend Analysis and Sampling Design for Streams in the Red River of the North Basin, Minnesota, North Dakota, and South Dakota, 1970-2001. U.S. Geological Survey Scientific Investigations Report 2005-5224.

Walden, Rick. [International Lake of the Woods Control Board]. 2004. *Personal Communication, Phone conversation with Wade Klingsporn*. December 22.

WEST Consultants. 2001. Sheyenne River Geomorphology Study. Prepared for U.S. Army Corps of Engineers St. Paul District, Contract DACW37-00-D-0001, Task Order No. 0005. WEST Consultants, Inc., San Diego, California.

Williams-Sether, Tara. 2004. *River Gain and Loss Studies for the Red River of the North Basin, North Dakota and Minnesota.* U.S. Geological Survey Open-File Report 2004-1076.

Windom, H.B., J.T. Byrd, R.G. Smith, And F. Huan. 1991. Inadequacy of NASQAN Data for Assessing Metal Trends in the Nation’s Rivers. *Environmental Science and Technology* 25:1137-1142.