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Estimated ground-water use in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkins counties, Minnesota, to 2030 and 2050

By T.A. Winterstein

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Contents

Abstract 7

Introduction 8

Purpose and scope 9

Previous studies 10

Properties of surficial aquifers 11

Buffalo Aquifer 12

Otter Tail Surficial Aquifer 13

Pelican River Sand-Plain Aquifer 13

Estimating ground-water demands in 2030 and 2050 14

Water use data 14

Domestic Water Use 16

Domestic water use rate 16

Estimated population in 2030 and 2050 17

Population estimates made by the Bureau of Reclamation 18

Population estimates made by the Minnesota State Demographic Center 19

Population estimates made in this study 20

Estimated domestic water use 2030 and 2050 21

Estimated commercial water use in 2030 and 2050 22

Estimated ground water used for irrigation in 2030 and 2050 25

PRELIMINARY DRAFT – FOR REVIEW PURPOSES ONLY

Comparison of estimated water use with estimated recharge to Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers 28

Summary 31

References Cited 34

Appendix 37

Figures

1. Study area showing major surficial aquifers 9
2. Ground-water wells from which at least 10,0000 gallons per day or at least 1,000,000 gallons per year were pumped in the years 2000-2005 16
3. Census and estimated populations for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1900—2050 20
4. Historic and estimated irrigation for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1980--2050 25
5. Average water pumped per year for irrigation, 2000-05, in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota 26

Tables

1. Aquifer characteristics of Buffalo, Otter Tail surficial, and Pelican River sand-plan aquifers, northwestern Minnesota 11
2. Water budgets for Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers, northwestern Minnesota 11
3. Estimated and estimated populations and estimated annual domestic water use for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2030 and 2050 18
4. Estimated commercial and industrial water use in Becker, Clay, Douglas, Grant, Otter Tail, Wilkin Counties, Minnesota, 2030 and 2050 23
5. Acres of irrigated crop land in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1987 – 2002 25
6. Estimated irrigation water use in 2030 and 2050 for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota 27
7. Estimated total ground water use in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2030 and 2050 28

8. Total appropriated ground water by aquifer in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2000 - 2005 28
9. Estimated withdrawals from the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers in 2030 and 2050 29
A1. Average domestic water use for public suppliers in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005 37
A2. Average commercial, industrial, agricultural, and other water uses for public water suppliers in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005....37
A3. Water use by category for major water users in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005....37

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow Rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Inch/Pound to Inch/Pound

Multiply	By	To obtain
	Volume	
acre-foot (acre-ft)	325,851	gallon (gal)
acre-foot (acre-ft)	0.3258	million gallons (Mgal)
acre-foot (acre-ft)	43,560	cubic feet (ft^3)
cubic foot (ft^3)	7.481	gallon (gal)

gallon (gal)	0.133672	cubic foot (ft^3)
million gallons (Mgal)	3.0689	acre-feet (acre-ft)
	Flow Rate	
cubic feet per second (ft^3/s)	448.83	gallons per minute (gal/min)
cubic feet per second (ft^3/s)	646,317	gallons per day (gal/d)
cubic feet per second (ft^3/s)	235.91	million gallons per year (Mgal/yr)

Estimated ground-water use in the Becker, Clay, Douglas, Grant, Otter Tail, and Wilkins counties, Minnesota, to 2030 and 2050

By Thomas A. Winterstein

Abstract

The U.S. Department of the Interior, Bureau of Reclamation, (Reclamation) is studying six alternatives for delivering water to the Red River of the North Valley in North Dakota and the cities of Breckenridge, Moorhead, and East Grand Forks, Minnesota. In order to evaluate these alternatives the Reclamation needs estimations of water demands on ground-water supplies in 2030 and 2050 for six counties in Minnesota: Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties. The U.S. Geological Survey, in cooperation with the Bureau of Reclamation, conducted a study to estimate the water demands on ground water supplies in these counties in 2030 and 2050.

This report (1) describes the methods used to estimate the demands on ground-water supplies for the years 2030 and 2050 for six Minnesota counties: Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, (2) presents the estimated demands on ground-water supplies to the years 2030 and 2050 for these six counties, and (3) and compares the estimated demands on ground-water supplies with published estimates of recharge to three surficial aquifers: Buffalo, Otter Tail surficial, and Pelican River sand-plain.

Between 74 and 84 percent of the reported ground-water use in the six years from 2000 – 2005 was used for irrigation of major crops. The next major use of ground-water was public water supply for domestic use, between 13 and 19 percent of the reported ground-water use. Together they account for 90 to 95 percent of the appropriated ground water in the six-year period.

The total estimated 2030 ground-water use for the six counties ranges from 27,654 to 36,845 million gallons per year (Mgal/yr) and the total estimated 2050 ground-water use ranges from 31,075 to 41,376 Mgal/yr.

The estimated recharge to the Buffalo aquifer, Otter Tail surficial aquifer, and Pelican River sand-plain aquifer is 3,707 Mgal/yr, 51,000 Mgal/yr, and 4,900-8,900 Mgal/yr, respectively. The range of the estimated 2050 water withdrawals from the aquifers are 1,205 to 1,737 Mgal/yr from the Buffalo aquifer, 11,963 to 15,179 Mgal/yr from the Otter Tail surficial aquifer, and 3,362 to 4,287 Mgal/yr from the Pelican River sand-plain aquifer.

Introduction

Most of the population in the Red River of the North valley in North Dakota and Minnesota (fig. 1) rely on the Red River of the North and its tributaries as primary or sole sources of drinking water. The Red River of the North valley could face critical water shortages if a severe drought, similar to that of the 1930s, were to occur (Bureau of Reclamation, 2005a). The U.S. Department of the Interior, Bureau of Reclamation, (Reclamation) is studying six alternatives for delivering water to the Red River of the North Valley in North Dakota and the cities of Breckenridge, Moorhead, and East Grand Forks, Minnesota (Allen Schlag, Bureau of Reclamation, 2006, written commun.) . In one of the proposed alternatives, the Red River Basin Alternative, water would be withdrawn from the Otter Tail surficial aquifer or the Pelican River sand-plain aquifer or from both aquifers (fig. 1) to help meet future demands in Fargo, North Dakota, and Moorhead, Minnesota. The peak capacity of the well field(s)

would be 19,300 gal/min. The maximum annual depletion volume is estimated to be 8,139 Mgal (Allen Schlag, Bureau of Reclamation, 2006, written commun.). Withdrawals from the Buffalo Aquifer for peak-day water use in the City of Moorhead would be expanded by 450 to 1,050 gal/min (Bureau of Reclamation, 2005a). In a second alternative, the GDU Import Pipeline Alternative, the use of the Buffalo aquifer by the City of Moorhead would be expanded (Allen Schlag, Bureau of Reclamation, 2006, written commun.). Peak-day use would be increased from 2,700 gal/min to 3,150 gal/min. The use of the Buffalo aquifer would be expanded to serve Moorhead's total needs during drought after its existing water supply in the Red River is depleted. Annual production in the aquifer would be as high as 14,451 Mgal/yr during a severe drought with as little as 326 Mgal/yr during non-drought years for maintenance flows (Allen Schlag, Bureau of Reclamation, 2006, written commun.). In two other alternatives, the North Dakota In-Basin and Missouri River Import to Red River Valley Alternatives, additional water would be withdrawn only from the Buffalo aquifer (Bureau of Reclamation, 2005c). Peak-day withdrawals from the aquifer in these alternatives would be expanded by 450 to 1,050 gal/min. In order to evaluate these alternatives, Reclamation needed estimations of water demands on ground-water supplies in 2030 and 2050 for six counties in Minnesota: Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties. The U.S. Geological Survey, in cooperation with the Bureau of Reclamation, conducted a study to estimate the water demands on ground water supplies in these counties in 2030 and 2050.

FIGURE 1 NEAR HERE

1. Study area showing major surficial aquifers

Purpose and scope

The purpose of this report is to (1) describe the methods used to estimate the demands on ground-water supplies for the years 2030 and 2050 for six Minnesota counties: Becker, Clay, Douglas,

Grant, Otter Tail, and Wilkin Counties, (2) present the estimated demands on ground-water supplies for the years 2030 and 2050 for these six counties, and (3) and compare the estimated demands on ground-water supplies with published estimates of recharge to three surficial aquifers: Buffalo, Otter Tail surficial, and Pelican River sand-plain.

The results of this study are based on published reports and other publicly available information. Water-use trend estimates are based on existing water-use information and trends in population, industry, and agriculture. The comparison between estimates of ground-water demands in 2030 and 2050 with estimates of aquifer recharge is for illustrative purposes only and the comparison does not include a safe-yield discussion nor a discussion of possible changes in recharge to the aquifer because of changes in climate. Estimates of recharge to the three aquifers are from Reppe (2004) and are based on previously published reports.

Previous studies

Several studies on water use in the Red River of the North Valley have been conducted as part of the ongoing feasibility study for supplying water to the Red River of the North Valley (Bangsund and Leistritz 2004, Bureau of Reclamation, 2003, 2004a, 2004b, 2005a, 2005b, and 2005c). These studies estimated domestic, commercial, and industrial water use in 2050 for municipal water supply systems, rural water supply systems, and industrial water supply in the 13 eastern counties of North Dakota but also for water systems in the Minnesota communities of Breckenridge, Moorhead, and East Grand Forks (Bureau of Reclamation, 2005a, 2005c). Water demand was not estimated for households and commercial or industrial users who have their own wells (self-supply), for agricultural irrigation, or for other uses such as maintenance of water levels. Reclamation did not estimate water demand in 2050 for counties.

Properties of surficial aquifers

Reppe (2004) summarized existing information about three surficial aquifers within the study area, Buffalo, Otter Tail surficial, Pelican River sand-plain (tables 1 and 2, fig. 1). Except for the Buffalo aquifer, the water-budget estimates compiled by Reppe are for steady-state conditions, where variations in the ground-water table and storage volume are minimal over time and sources of water to the aquifers will be equal to losses of water from the aquifers.

TABLE 1 NEAR HERE

1. Aquifer characteristics of Buffalo, Otter Tail surficial, and Pelican River sand-plan aquifers, northwestern Minnesota

TABLE 2 NEAR HERE

2. Water budgets for Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers, northwestern Minnesota

"The general sources of water to the surficial aquifers (and inflow components in the water-budget estimations) include (1) infiltration of precipitation to the water-table (referred to as areal recharge in general and as net areal recharge when the loss of water by evapotranspiration is not included as a separate component of the water budget); (2) flow from surface water (rivers, streams, lakes, and wetlands); and (3) flow into the aquifers across their boundaries from adjacent geologic units, including confined aquifers and confining units (table 1). In general, net areal recharge is greatest in the unconfined parts of the aquifers. Losses of water from the surficial aquifers are the result of (1) evapotranspiration directly from the water table; (2) flow to surface water; (3) ground-water flow across the aquifers' boundaries to adjacent geologic units (including aquifers and confining units); and (4) withdrawals of ground water by pumping wells (table 2)." (Reppe, 2004, p. 18).

The following descriptions of the aquifers are from Reppe (p. 20-26).

Buffalo Aquifer

The Buffalo aquifer is a narrow, elongate sand-and-gravel deposit located in the Red River Valley Lake Plain area (fig. 1). The aquifer is 1 to 2 mi wide in the northern part of Clay County, extends southward about 36 mi, and is as wide as 9 mi in northern Wilkin county. The Buffalo aquifer is 66 mi^2 in area (table 1). It is a complex, heterogeneous channel-fill deposit of fine to coarse-grained sand, cobbly gravel, silt and clay, incised into the bed of Glacial Lake Agassiz and underlying glacial sediment. The water table of the Buffalo aquifer is 5 to 15 ft below land surface along its north-south trending axis and 30 to 40 ft below land surface in the southwestern part of the aquifer. Ground-water flow in the Buffalo aquifer is generally to the west .

The water budget for the aquifer (table 2) does not represent steady-state conditions. The total flow into the aquifer was estimated to be 3,707 Mgal/yr in 1993 (table 2). The net areal recharge to the unconfined part of the aquifer (25 mi^2) was 407 Mgal/yr, about 11 percent of the sources of water to the aquifer. Additional ground-water flow to the aquifer occurred as inflow from the Buffalo River and its tributaries. The total volume of water flowing to the aquifer from adjacent units across its entire extent may be substantial (Reppe, 2004, p. 20).

The Buffalo aquifer discharges primarily into the Buffalo River and its South Branch and as outflow across the boundaries of the aquifer, mainly to the west. Groundwater evapotranspiration from the aquifer itself is negligible, except from gravel pits that intersect the aquifer (Reppe, 2004, p.20). Pumpage from the aquifer accounted for 408 Mgal/yr of outflow from the aquifer in 2003, equivalent to 11 percent of the assumed total ground-water losses when losses equal inflows under steady-state conditions (table 2).

Otter Tail Surficial Aquifer

The Otter Tail surficial aquifer covers 510 mi^2 (table 1) in Becker and Otter Tail Counties (fig. 1). It consists of ice-contact and outwash deposits, primarily well-sorted sand with varying gradations of fine- to coarse-grained sand and gravel and lenses of clay. The depth to the aquifer's water table ranges from 0 to 70 ft below land surface depending on local topography. Ground-water flow in the aquifer is towards the Otter Tail River (and the lakes along the river) and south and west along the axis of the river (fig. 1). In the southern one-third of the aquifer, ground water flows north-northwest toward the Otter Tail and Leaf rivers.

Net areal recharge (mean 5.5. in/yr) is the primary source of recharge to the Otter Tail surficial aquifer, accounting for 96 percent of the total inflow to the aquifer (table 2). The remaining 4 percent is estimated to be ground-water flow from adjacent aquifers. Flow from surface water is not a substantial source of water to the aquifer.

Water losses from the Otter Tail surficial aquifer are the result of evapotranspiration, outflow across the aquifer's boundaries, flow to rivers and streams, and ground water withdrawn through pumped wells (table 2). Estimates of flow to surface water and ground water discharged to wells were not available. Ground-water flow to adjacent aquifers in the vicinity of the Otter Tail River at the southwest end of Otter Tail Lake was estimated to be 2,000 Mgal/yr, about 4 percent of the estimated water budget.

Pelican River Sand-Plain Aquifer

The Pelican River sand-plain aquifer is 195 mi^2 in area (table 1) and is located in parts of Becker, Clay, and Otter Tail Counties (fig. 1). The aquifer is bounded laterally by relatively heterogeneous glacial till with low permeability, and consists of clay, silt, sand, and gravel underlain by a grey, silty till. Ground-water flow in the northern part of the aquifer is to the south-southeast toward

the Pelican River, and Detroit and Pelican Lakes and to the west and southwest in the southern part of the aquifer and along the eastern boundary.

Flow of water to the Pelican River sand-plain aquifer is from areal recharge, flow across the boundaries of the aquifer, and flow from surface water. Two computer simulations of the aquifer indicate that areal recharge to the aquifer is between 62 to 78 percent of the total inflow to the aquifer, ground-water flow across the boundaries of the aquifer is 0 to 17 percent of the total inflow, and ground-water flow from surface water is 21 to 22 percent of the total inflow (table 2).

Two computer simulations of the aquifers indicate that evapotranspiration was 39 to 56 percent of the total losses from the aquifer, ground-water flow to surface water was 44 to 59 percent of the total losses, and ground-water flow to adjacent geologic units was 0 to 2 percent of the total losses (table 2).

Estimating ground-water demands in 2030 and 2050

The estimations of ground-water demand in 2030 and 2050 for the six counties are in four water use categories: (1) domestic water use, (2) commercial water use, (3) industrial water use, and (4) irrigation water use. Future ground-water demand is the sum of the estimates of ground-water use in the four categories. Water-use estimations were made only for the six counties; estimations were not made for cities or for municipal and rural water supplies within the counties.

Water use data

The data for these estimations come from two sources: (1) the annual survey of public-water suppliers in Minnesota (Sean Hunt, Minnesota Department of Natural Resources, written commun., 2006) and (2) the water-appropriation permit data base maintained by the Minnesota Department of Natural Resources (Sean Hunt, Minnesota Department of Natural Resources, written commun., 2006).

Public-water suppliers who supply water to more than 1,000 persons are required to respond to the annual survey of public-water suppliers, but water-suppliers who supply water to less than 1,000 persons often respond. The database of public-water suppliers has this information:

1. population served,
2. water used that year for five categories of water use: domestic, commercial, industrial, agricultural, and other,
3. gallons of water sold that year, and
4. gallons of water appropriated that year.

For each of the five categories of water use the database shows the gallons of water used, the number of connections, and the number of metered connections. The responses to the survey by public-water suppliers in the six counties, 2000-2005, are summarized in tables A1 and A2 in the appendix.

The Minnesota Department of Natural Resources issues permits for water withdrawn from ground and surface water in Minnesota when the withdrawal is more than 10,000 gal/d or 1,000,000 gal/yr (Minnesota Department of Natural Resources, 2006). The permit holders are required to report the water withdrawn each year. Table A3 (in the appendix) summarizes the water withdrawn from ground and surface waters in the six counties by water category during 2000-2005. Wells in the data base that were pumped from 2000 – 2005 are shown in figure 2. The municipal and private waterworks category includes water used by municipal and private waterworks. Private waterworks are waterworks for trailer courts and other small housing developments. The commercial and institutional waterworks category includes waterworks for business, industry, or hospitals. The power generation category includes cooling water used for once through and wet cooling by steam power plants and for uses other than cooling. More than 99.97 percent of the water in this category is used by the Otter Tail Power Company for once through cooling. The industrial category includes water used for agricultural

processing (food and livestock), sand and gravel washing, and metal processing. The non-crop irrigation category includes water used for irrigating golf courses, athletic fields, landscaping, sod farms, and nurseries. The major crop irrigation category is water used for irrigating crops except wild rice. The other category includes water used for once-through heating or air conditioning, construction dewatering, temporary agricultural irrigation, water-level maintenance, pollution containment, aquaculture, snowmaking, and livestock watering.

FIGURE 2 NEAR HERE

2. Ground-water wells from which at least 10,0000 gallons per day or at least 1,000,000 gallons per year were pumped in the years 2000-2005

Between 74 and 84 percent of the reported ground-water use in the six years from 2000 – 2006 is used for irrigation of major crops. The next major use of ground-water is public water supply for domestic use, between 13 and 19 percent of the reported ground-water use. Together they account for 90 to 95 percent of the appropriated ground water in the six counties, 2000-2005.

Domestic Water Use

Domestic water use in 2030 and 2050 is estimated by multiplying the estimated population in the six counties in 2030 and 2050 by an estimated rate of domestic water use in gal/p/d (gallons per person per day). This estimation includes the domestic water use for both rural residents, who have their own wells (self supply) and urban residents, who receive water from a municipal water supply.

Domestic water use rate

The range of domestic water usage in the public-water supply survey is from 35 gal/p/d reported by the City of Alexandria to 124 gal/p/d reported by the City of Dalton (table A2). The average domestic water use in the six counties is 65.7 gal/p/d or 24,000 gal/p/yr (gallons per person per year). In

the 1995 and 2000 water use compilations for Minnesota, the U.S. Geological Survey used 70 gal/p/d as the average domestic water use for the state (Allan Arntson, U.S. Geological Survey, personal commun., 2006). The average and median average-annual per capita water use for 12 rural water systems in North Dakota (p. 2-57, Bureau of Reclamation, 2005c), is 90.4 and 83.5 gal/p/d, respectively. The water use in these 12 rural water systems is assumed to be primarily domestic water use for this discussion. Two domestic-water use rates will be used in this analysis. The low rate is 70 gal/p/d and the high rate is 90 gal/p/d.

Estimated population in 2030 and 2050

Population estimates for the six counties are from three sources: the Bureau of Reclamation, Minnesota State Demographic Center, and the estimates made in this study. The primary method used to make these estimates is the cohort component method (Bureau of Reclamation, 2005b, p. 9; McMurray, 2002b, p. 6; Northwest Economic Associates, 2003; Smith and others, 2001). A cohort represents a group of individuals that have specific factors, such as age and sex, in common. The cohorts used by the these three sources for their population estimates are composed of the population (male or female) within a 5-year age span: 0–4 years, 5–9 years, and so on. The population of the cohort at the end of the 5 year period (P_1) is:

$$P_1 = P_o + M - D \qquad (1)$$

where:

P_0 is the population of the cohort at the beginning of the 5-year period,

M is the migration into the county of persons within the cohort's age range (it is negative if there is a net migration out of the county), and

D is the number of deaths within the cohort during the 5-year period.

The migration and death values for each cohort, M and D, are determined by applying migration rates and death rates to the cohort population in the previous 5-years.

The population of the first age cohorts, P_{0-4}, is:

$$P_{0-4} = B + M - D \qquad (2)$$

where B is the births that occurred in the previous 5-years and M and D are as previously defined. The number of births, B, is determined by applying birth rates to the cohorts of females between 15 and 44 years to obtain the number of births for each cohort and then multiplying the births by the proportion that are male to determine the number of males, and consequently females, that were born.

Population estimates made by the Bureau of Reclamation

Estimated populations in 2030 and 2050 in Clay, Otter Tail, and Wilkin Counties determined by the Bureau of Reclamation or its contractor are detailed in two reports, Northwest Economic Associates, 2003, and Bureau of Reclamation, 2005b.

Northwest Economic Associates made population estimations for Clay, Otter Tail, and Wilkin Counties using the cohort component method (Northwest Economic Associates, 2003). Because of the difficulties in estimating migration into and out of counties and cities, Northwest Economic Associates made two estimations of population in 2030 and 2050; one estimation assumes that net migration was zero and one assumes that net migration followed the past trends in migration and population growth (table 3) (Northwest Economic Associates, 2003, p. 7-8).

TABLE 3 BELONGS NEAR HERE

3. Estimated and estimated populations and estimated annual domestic water use for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2030 and 2050

Reclamation made three estimations of the population of Clay, Wilkin, and Otter Tail Counties (table 3) (Bureau of Reclamation, 2005b). They made two estimations using the cohort method. One

estimation assumes that the net migration was zero for each county. The second estimation uses the migration patterns for Minnesota from 1990 to 2000 presented in McMurray, 2002a (Bureau of Reclamation, 2005b) will continue through 2050. In the third estimation Reclamation used a estimation method that was based upon a combination of the cohort component modeling results. They assumed for this estimation that past net migration patterns for urban counties will continue and the decline in rural county populations will stabilize, as represented by the zero net migration scenario for rural counties. These assumptions were used in estimating the population for the entire region (13 counties in North Dakota and 8 counties in Minnesota). The estimated population was then redistributed within the region based on current population patterns to account for growth in the most urbanized and rapidly growing areas (Bureau of Reclamation, 2005b, p. 19; Bureau of Reclamation, 2005c, p. 2-23 – 2-24). They call this a estimation based on optimistic growth and current distribution of population. The estimations made by the three methods are in table 3. Reclamation used the results of the third estimation (optimistic growth) to determine water demands in 2030 and 2050 in the three counties (Bureau of Reclamation, 2005c). Reclamation states, however, that this estimation method " *** may inflate future population projections for the region because the combination of those assumptions [optimistic growth and current population patterns] would require the movement of people from rural to urban areas while the rural areas stabilize." (Bureau of Reclamation, 2005b, p. 19,).

Population estimates made by the Minnesota State Demographic Center

The Minnesota State Demographic Center made population estimations from 2005 to 2030, at 5-year intervals, for the six counties (Minnesota State Demographic Center, 2006). Their population estimations were prepared using the cohort-component method, (McMurray, 2002b). The following rates were used in the estimations by the Minnesota State Demographic Center (McMurray, 2002b). Each county had a different set of birth rates for the six female cohorts from ages 15 through 44. However, the birth rates used did not change over 2000 – 2030. The same set of survival rates was used

for the six counties. However, the survival rates changed each 5 years. The migration rates changed each 5 years and from county to county. Their 2030 population estimates for the six counties are in table 3.

Population estimates made in this study

The 2030 population estimations by the Minnesota State Demographic Center were used as the basis for the 2050 population estimates made by this study for the six counties (table 3). Three 2050 population estimations were made for each of the six counties (table 3, fig. 3). In the first estimation, it was assumed that the migration rates and the survival rates were constant during the period 2030-50. The rates used were the same as used by the Minnesota State Demographic Center in the period 2025-30 (Martha McMurray, Minnesota state Demographic Center, written commun., 2006). This gave the lowest estimated population in 2050. In the second estimation, it was assumed that migration rates would be constant during 2030-50 and that the survival rates would change. The migration rates used were those used by the Minnesota State Demographic Center in the period 2025-30. The survival rates between 2030 and 2050 were estimated by fitting a second order polynomial to the survival rates used by the Minnesota State Demographic Center, 2000-30, and projecting forward. This gave an intermediate estimated population in 2050. In the third estimation, a linear regression or a second order polynomial was fitted to the census (1980-2000) and estimated (2005 – 2030) populations and projected forward to 2050. This gave the largest estimated populations for 2050.

FIGURE 3 NEAR HERE

3. Census and estimated populations for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1900—2050

Estimated domestic water use 2030 and 2050

The estimations of annual domestic water use in the six counties for 2030 and 2050 are given in table 3. The estimations were computed by multiplying the estimated population for the county with 70 gal/p/d (the low estimate) or 90 gal/p/d (the high estimate) and multiplying by 365 days. As shown in table 3, the range in population estimations can be great, for example, a difference of 47,100 persons between the low and high estimations for Otter Tail County in 2050. The range in population estimations demonstrates how difficult it is to predict county populations almost 50 years in the future. The estimated water use in either the low estimation category or the high estimation category can range by almost a factor of two (for example, the estimations of water use in Otter Tail County in 2050, table 3). The high and low estimations of domestic water use used in this study are highlighted in table 3. Because of the uncertainty in estimating population, the average of the population estimations for Clay, Otter Tail, and Wilkin Counties were used for estimating domestic water use in these counties to 2030 and 2050. The estimated population trend to 2050 was used to estimate 2050 domestic water use in Becker, Douglas, and Grant Counties.

Domestic water use is most likely from ground water in the six counties. Water from private wells most likely is used by most homes not on municipal water supply systems. Municipalities in the six counties reported, in the water-appropriation permit data base, that they used ground-water except for Moorhead, Minnesota, which reported that ground water supplied 13.1–21.9 percent of its domestic water use (average 16.8 percent) between 2000–2005. The rest was supplied by water from the Red River of the North.

As a result, two scenarios were used to determine the amount of ground water used for domestic supply in Clay County. In the first scenario, 16.8 percent of the domestic water used by Moorhead in 2030 and 2050 came from ground-water. In the second scenario, all the domestic water used by Moorhead came from ground water, which is likely if drought greatly reduces the flow in the Red River

of the North. In both scenarios, the domestic water used by the rest of the county is assumed to be from ground water.

The projected population for Moorhead used for this analysis is 35,989 in 2030 (Minnesota State Demographic Center, 2004) and 44,200 in 2050 (Bureau of Reclamation, 2005c). The projected population of Clay County used for this analysis is 58,889 in 2030 (table 3) and 60,130 in 2050, the average of the population estimates in table 3.

Under the first scenario, the estimated amount of ground water used for domestic supply in Clay County in 2030 is 739.6 and 950.9 Mgal, at 70 and 90 gal/p/d, respectively. The estimated amount of ground water used for domestic supply in 2050 is 596.7 and 767.2 Mgal, at 70 and 90 gal/p/d, respectively. Ground water used in this scenario declines from 2030 to 2050 because the methods used to estimate the populations of the City of Moorhead and Clay County assumed a shift in population from the rural areas of Clay County to Moorhead, resulting in fewer persons using self-supplied ground water for domestic supply.

Under the second scenario, the estimated amount of ground water used for domestic supply in Clay County in 2030 is 1,505 and 1,935 Mgal, at 70 and 90 gal/p/d, respectively (table 3). The estimated amount of ground water used for domestic supply in 2050 is 1,536 and 1,975 Mgal, at 70 and 90 gal/p/d, respectively.

Estimated commercial water use in 2030 and 2050

The Bureau of Reclamation determined that the water used in some commercial categories increases proportionately with population growth in the Red River Valley (Bureau of Reclamation, 2004a, p. 25). This study had two sources of information on commercial water use: the survey of public water suppliers and the water-appropriation permit data base. The water-use reported in the two data bases was divided into water use that would increase proportionately with population and water use that would not.

The non-domestic water use reported in the survey of public water suppliers data base was assumed to all come ground water. Reported water use in the commercial water use category from this data base was assumed to increase proportionately with population. In the data from the water-appropriation permit data base only water that was coded as coming from ground water (wells, pits/holding ponds, quarries, mines, or gravel pits) was used. Water use coded as private waterworks, and commercial and institutional (business, industry, hospital) in the this data base was assumed to increase proportionately with population. The estimates of commercial water use in 2030 and 2050 for the six counties are shown in table 4.

Reported water use in the industrial, agricultural, and other water use categories from the survey of public water suppliers was assumed to not increase proportionately with population (table 4). Reported water use in the water-appropriation data base that was not coded as domestic supply, major-crop irrigation, private waterworks or commercial and institutional, was grouped as industrial water use and were assumed to not increase proportionately with population (table 4).

TABLE 4 NEAR HERE

4. Estimated commercial and industrial water use in Becker, Clay, Douglas, Grant, Otter Tail, Wilkin Counties, Minnesota, 2030 and 2050

Estimations of future industrial water use for the next 50 years potentially have a large error. Based upon the industrial history of the last 50 years, some current major industries will decline or disappear, some minor industries will grow to be major industries, and new industries will develop that don't currently exist. An example of a minor industry growing rapidly is ethanol-fuel production, which has grown from 11 Mgal/yr in 1990 to 420 Mgal/yr in 2005 (Minnesota Pollution Control Agency, 2006).

It was assumed that industrial water use will not increase by 2050 in Douglas, Grant, and Wilkin counties. This follows the assumptions of the Bureau of Reclamation (2005c) that there would be no significant industrial developments in these counties. Therefore, the average industrial water use in the period 2000–2005 from the water-appropriation data base was used as the projected water use in 2030 and 2050 in these counties (table 4).

Two estimates of water use were made for Becker and Ottertail Counties in 2030 and 2050. The low estimate assumes that there will be no significant increase in industry in the two counties. For this estimate the average industrial water use in the period 2000–2005 from the water-appropriation data base was used as the projected water use in 2030 and 2050 in these counties (table 4).

For the high estimate, it was assumed that an ethanol plant, or its equivalent in water use would be built in Becker County and in Otter Tail County. New ethanol plants in Minnesota can produce 50 Mgal/yr of ethanol (Minnesota Department of Agriculture, 2006), although a plant was proposed that could produce 100 Mgal/yr of ethanol (Keeney, 2006). In 2005 about 4.2 gallons of water were required to make 1 gallon of ethanol (Keeney, 2006). Assuming that the hypothetical ethanol plants could produce 75 Mgal/yr of ethanol, they would require 300 Mgal/yr of water. This additional water use, 300 Mgal/yr, was added to the average industrial use for Becker and Otter Tail Counties during 2000-05 (table 4). Although this additional water use is not justified by past record of industrial water use in the two counties, it encompasses what is believed to be a reasonable margin of error in the estimations for the two counties.

For Clay County, Reclamation estimated that industrial water use would increase between 375 and 567 Mgal/yr. The low estimate of 2050 industrial water use in Clay County is the average industrial water use average industrial water use in the period 2000–2005 from the water-appropriation data base for Clay County plus 375 Mgal/yr (table 4). For the high estimate in 2050 567 Mgal/yr was added to the average of the 2000–2005 industrial water use (table 4). The estimated 2030 industrial water use for

Clay County is a linear interpolation between the average of the 2000–2005 industrial water use and the estimated industrial water use in 2050 (table 4).

Estimated ground water used for irrigation in 2030 and 2050

Irrigation water use in the six counties 1980 – 2005 is shown in figure 4. Between 74 – 79 percent of the ground water used for irrigation in the six counties is used by Otter Tail County. Becker County is the next largest user of ground water for irrigation; between 11 to 15 percent of the ground water used for irrigation in the six counties. The number of acres irrigated in each county is shown in table 5; the data is taken from the Agricultural Census (National Agricultural Statistics Service, 1992 and 2002). There has been a steady increase in the number of acres irrigated, from 1987 through 2002, in Otter Tail County. The general increase in acreage irrigated in Clay and Grant Counties is less than in Otter Tail County. Irrigated acreage has generally decreased in Wilkin County. There is no observed trend in Becker County. The amount of water used for irrigation shows no trends for the six counties during 2000—05. Because of the fluctuations in discharge and acreage shown in figure 4 and table 5, the average annual usage of ground water for irrigation in each county is shown in table 6 for 2000–05.

TABLE 5 NEAR HERE

5. Acres of irrigated crop land in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1987 – 2002

FIGURE 4 NEAR HERE

4. Historic and estimated irrigation for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1980--2050

The average annual usage of ground water for irrigation, 2000 – 05, is shown in figure 5. As seen in figure 5, the largest withdrawals of ground water are on agricultural land overlying the surficial aquifers, both in the number of wells per square mile and the average amount of water withdrawn.

FIGURE 5 NEAR HERE

5. Average water pumped per year for irrigation, 2000-05, in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota

It is difficult to estimate future irrigation for several reasons. First, the number of acres irrigated and the amount of ground water used for irrigation varies from year to year (figure 4; table 5). Irrigation increases during droughts and decreases during periods of increased precipitation, and, as a result, trends in irrigation cannot be used to estimate future ground water needs for irrigation. Second, the decision to irrigate depends upon several factors: soil type, crop type, availability of water, cost of irrigation, whether a field is large enough to be efficiently irrigated, and the preferences of the farmer. Much of this information is not readily available in electronic data bases, and, therefore, it is not feasible to use geographic information systems analysis to determine the additional irrigated acreage. Finally, external constraints may limit irrigation on land that could be irrigated. For instance, withdrawing ground-water near rivers can affect the stream flow in the river and can affect uses of the river water, such as public water supply, recreation, or maintaining aquatic life.

Therefore, specialists in irrigation were asked to estimate how much more land they thought could be irrigated in the study area. The specialists believed that there would not be an expansion of irrigation in Clay, Douglas, Grant, and Wilkin Counties because of prior restrictions on the use of ground-water or because the soils in the county were not conducive to irrigation (Jerry Wright, University of Minnesota Agricultural Extension Service, personal commun., 2006; Bruce Becker, Jeff Norby, and Dean Hendrickson, Natural Resources Conservation Service, personal commun., 2006). As

a result, the irrigated acres in 2002 (National Agricultural Statistics Service, 1992) was used as the irrigated acreage in 2030 and 2050 in these four counties. Bruce Becker (Natural Resources Conservation Service, personal commun., 2006) estimated that the irrigated acreage in Otter Tail County would increase by 30 to 40 percent over the next two or three decades. Jeff Norby and Dean Hendrickson (Natural Resources Conservation Service, personal commun., 2006) estimated that irrigated acreage could be expected to double in Becker County. Therefore, twice the irrigated acreage in 1992 for Becker County was used as the irrigated acreage in 2050 in Becker County, and 1.4 times the irrigated acreage in 1999 for Otter Tail County was used as the irrigated acreage in 2050 in Otter Tail County (table 6). The estimated irrigated acreage in 2030 in Becker and Otter Tail Counties is the proportional increase in irrigated acreage from 2002 to 2050 (table 6).

TABLE 6 NEAR HERE

6. Estimated irrigation water use in 2030 and 2050 for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota

The average annual irrigation rate, 2000- 2005, for the six counties ranged from 87 Mgal/yr in Wilkin County to 11,201 Mgal/yr in Otter Tail County (table 6). Irrigation water use stays approximately the same between 1980 and 2005 in Clay, Douglas, Grant, and Wilkin Counties (fig. 4; table 6). As a result, because there are no better estimates and no apparent trends, the low estimation of water use in 2030 and 2050 for these counties was set equal to the average irrigation water used during 2000-05 and the high estimation of irrigation water use in 2030 and 2050 was set equal to the maximum annual irrigation water use during 1980-2005 (fig. 4; table 6). Irrigation water use increases between 1980 and 2005 in Becker and Otter Tail Counties (fig. 4). A low and a high estimation of irrigation water use was made for each county in 2030 and 2050. The low estimations of irrigation water use in these two counties were calculated by multiplying the estimated acreage by the average rate of irrigation

water use during 2000-05 (fig. 4; table 6). The high estimations of irrigated water use were calculated by multiplying the estimated acreage by the maximum rate of irrigation water use during 2000-05 (fig. 4; table 6).

Comparison of estimated water use with estimated recharge to Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers

The estimated ground water use in 2030 and 2050 for the six counties is summarized in table 7. The total estimated average ground water use, 2000 – 2005, for the six counties ranges from 22,309 to 24,342 Mgal/yr The total estimated 2030 water use for the six counties ranges from 27,651 to 36,845 Mgal/yr and the total estimated 2050 water use ranges from 31,075 Mgal/yr to 71,376 Mgal/yr.

TABLE 7 NEAR HERE

7. Estimated total ground water use in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2030 and 2050

The ground water used in the counties is drawn from two other aquifers, the Pineland Sands aquifer and Wadena surficial aquifer, in addition to the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers (fig. 1). In order to estimate the ground water withdrawn from these three aquifers in 2030 and 2050, the percentage of total ground water withdrawn from the five major aquifers in the six counties (fig. 1) and other sources was determined for 2000 – 2005 from the appropriated-water permit data base (table 8). It was assumed that these percentages would be the same in 2030 and 2050 and were applied to the estimations for ground-water use in 2030 and 2050 (table 9).

TABLE 8 NEAR HERE

8. Total appropriated ground water by aquifer in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2000 - 2005

TABLE 9 NEAR HERE

9. Estimated withdrawals from the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers in 2030 and 2050

The recharge to the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers (tables 2 and 9) are 3,707 Mgal/yr, 51,000 Mgal/yr , and 4,900-8,900 Mgal/yr, respectively.

The estimated water withdrawals in 2050 from the Buffalo aquifer is about half the estimated inflow to the aquifer reported by Reppe (2004) (tables 2 and 9). The estimated water withdrawals in 2050 from the Pelican River sand-plain aquifer are about the same as the estimated inflow to the aquifer reported by Reppe. The estimated water withdrawals in 2050 for the Otter Tail surficial aquifer is about a third of estimated inflow to the aquifer reported by Reppe.

This comparison between estimated ground-water withdrawals and recharge to the aquifer does not mean, for instance, that an additional 30,000 Mgal/yr can be withdrawn from the Otter Tail surficial aquifer in 2050. The reasons for this are described in the following paragraphs.

The estimated ground-water use in 2050 is not a forecast. Estimations show what would be true *if* the assumptions used to make the estimation were to hold true. By definition estimations are always right barring a mathematical error in calculating them. A forecast, on the other hand, is the estimation that the analyst believes is most likely to provide an accurate prediction of future water use (p.2. Smith and others, 2001). They are explicitly judgmental and can be proven wrong by future events. Because of the uncertainty of the data used, the accuracy of the water use estimations made in this study or by the Bureau of Reclamation cannot be determined.

The base water use used for the estimations, average water use 2000-05 from the public survey and permitted water use data bases (tables A1–A3), has several probable errors. First, the data in the data bases does not include self-supplied water (water from privately owned wells). As a result, the estimated water use in 2030 and 2050 may be too low. Second, the water use data derived from the public supply data base does not include water not accounted for (water appropriated – water used) from

the public water supply system. This difference ranged from 0 to 26.2 percent; the average percentage of water not accounted for was 10.4 percent. Finally, there may be errors in both data bases. As an example, for some of the reported water use in the public survey data base the water use by category does not total to reported water used.

The differences in population estimations for 2030 and 2050 were large (table 3), primarily because we cannot accurately forecast future migration into and out of the counties. This means that there is likely to be significant error in the estimated domestic water use for 2030 and 2050.

Many assumptions were made in estimating future commercial, industrial, and irrigation water use and therefore there may be large errors in the estimated water use. There is little information available to estimate future commercial and industrial water use and, as a result, many assumptions were made in the estimations. Irrigation water usage has been historically highly variable, as shown in figure 4.

The effects of water conservation, changing patterns of water usage, or changes in climate were not considered in this analysis. This analysis assumed that the current split between surface-water and ground-water usage will continue into the future. It is likely that in a future drought water usage may be shifted from surface water to ground water as surface water supplies dwindle.

The water budgets for the three aquifers, Buffalo, Otter Tail surficial, and Pelican River sand-plain, were based on old and often incomplete data (Reppe, 2004). The total inflows to the aquifers, as shown in table 2, are not available for withdrawal. For example, as shown in table 2, between 39 to 57 percent of the steady-state inflows to the Pelican River sand-plain aquifer are lost to evapotranspiration and would not be available for use. The steady-state conditions shown in table 2 may not represent drought conditions, which could reduce the ground-water available for use. New simulations and water budgets will have to be constructed under transient water-stress conditions to more accurately predict the water that will be available in a drought from the three aquifers. Such simulations and water budgets

will require more data about the aquifers, inflows, outflows, withdrawals, and aquifer characteristics, than we currently have.

Summary

The U.S. Department of the Interior, Bureau of Reclamation, (Reclamation) is studying six alternatives for delivering water to the Red River of the North Valley in North Dakota and the cities of Breckenridge, Moorhead, and East Grand Forks, Minnesota. In order to evaluate these alternatives the Reclamation needs estimations of water demands on ground-water supplies in 2030 and 2050 for six counties in Minnesota: Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties. The U.S. Geological Survey, in cooperation with the Bureau of Reclamation, conducted a study to estimate the water demands on ground water supplies in these counties in 2030 and 2050.

The purpose of this report is to (1) describe the methods used to estimate the demands on ground-water supplies for the years 2030 and 2050 for six Minnesota counties: Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, (2) estimate demands on ground-water supplies to the years 2030 and 2050 for these six counties, and (3) and compare the estimated demands on ground-water supplies with published estimates of recharge and to three surficial aquifers: Buffalo, Otter Tail surficial, and Pelican River sand-plain.

Several studies on water use in the Red River of the North Valley have been conducted as part of the ongoing feasibility study for supplying water to the Red River of the North Valley.

The estimated recharge to the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers are 3,707, 51,000, and 4,900 to 8,900 Mgal/yr, respectively. These recharges are for steady state conditions where variations in the ground-water table and storage volume are minimal over time and sources of water to the aquifers will be equal to losses of water from the aquifers.

The estimations of ground-water demand in 2030 and 2050 for the six counties are in four water use categories: (1) domestic water use, (2) commercial water use, (3) industrial water use, (4) irrigation water use. The data for these estimations come from two sources: (1) the annual survey of public-water suppliers in Minnesota and (2) water-appropriation permit data base maintained by the Minnesota Department of Natural Resources.

Between 74 and 84 percent of the reported ground-water use in the six years from 2000 – 2005 is used for irrigation of major crops. The next major use of ground-water is public water supply for domestic use, between 13 and 19 percent of the reported ground-water use. Together they account for 90 to 95 percent of the appropriated ground water in the six years.

Domestic water use in 2030 and 2050 is estimated by multiplying the estimated population in the six counties in 2030 and 2050 by an estimated rate of domestic water use in gal/p/d (gallons per person per day). County populations were estimated forward to 2050 by the Bureau of Reclamation, Northwest Economic Associates, and this study. Two per capita water use rates were used in this study, 70 and 90 gal/p/d. These rates were derived from an analysis of reported water use by public suppliers in the six counties and analysis by Reclamation of water use in rural water systems. The range in 2050 domestic water use is estimated to be 1,027 to 1,321 Mgal/yr for Becker County, 1,536 to 1,975 Mgal/yr for Clay County, 1,408 to 1,810 Mgal/yr for Douglas County, 192 to 246 Mgal/yr for Grant County, 1,972 to 2,536 Mgal/yr for Otter Tail County, and 172 to 221 Mgal/yr for Wilkin County.

The water use in the commercial water use category from the survey of public water suppliers was assumed to increase proportionately with population and it was assumed to all come from ground water. Ground water reported in private waterworks and commercial and industrial water use categories in the permitted data base were assumed to increase proportionately with population. The estimated 2050 water use in these categories are 233, 431, 592, 87, 655, and 30 Mgal/yr for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties respectively.

The water use in the industrial, agricultural processing, non-major crop irrigation, power generation, and other water use categories of the public supply data base were assumed to not to increase proportionately with an increase in population. It was assumed that industrial water use would not increase in 2050 above the average industrial water use for 2000-2005 in Douglas, Grant, and Wilkin Counties, 403, 40, and 16 Mgal/y, respectively. Reclamation's low estimation for additional industrial water use in Clay County is 375 Mgal/yr and its high estimation is 567 Mgal/yr. The estimated industrial water use for Clay County in 2050, 913 to 1,106 Mgal/yr, was assumed to be the average industrial water use for 2000-2005 plus Reclamation estimations for increased water usage. In Becker and Otter Tail Counties it was assumed that industrial water use would either be the average of 2000-2005 industrial water use or the average plus 300 Mgal/yr. The range of estimated 2050 industrial water use is 403 to 703 Mgal/yr for Becker County and 715 to 1,015 Mgal/yr for Otter Tail County.

Irrigated acreage is not expected to increase in Clay, Douglas, Grant, and Wilkin Counties. The low estimation of irrigation in 2050 for these counties is the average of irrigated water use 2000-2005. The high estimation of irrigation for these counties is the maximum irrigation water usage between 1980 and 2005. The range in estimated 2050 irrigation water usage for these counties is 454 to 1,144 Mgal/y for Clay County, 632 to 818 Mgal/yr for Douglas County, 497 to 971 Mgal/yr for Grant County, and 87 to 330 Mgal/yr for Wilkin County. Irrigated acreage is expected to increase between 30 to 40 percent by 2050 in Otter Tail County and by 100 percent in Becker County. The range in estimated 2050 irrigation water usage for these two counties is 3,917 to 4,848 Mgal/yr for Becker County and 15,641 to 19,886 Mgal/yr for Otter Tail County.

The total estimated average ground water use, 2000 – 2005, for the six counties ranges from 22,309 Mgal/yr to 24,432 Mgal/yr. The total estimated 2030 water use for the six counties ranges from 27,654 Mgal/yr to 36,845 Mgal/yr and the total estimated 2050 water use ranges from 31,705 Mgal/yr to 41,376 Mgal/yr.

The range of the estimated 2050 water withdrawals from the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers is 1,205 to 1,737 Mgal/yr from the Buffalo aquifer, 11,963 to 15,179 Mgal/yr from the Otter Tail surficial aquifer, and 3,362 to 4,287 Mgal/yr from the Pelican River sand-plain aquifer.

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Appendix

TABLE A1 NEAR HERE

A1. Average domestic water use for public suppliers in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005

TABLE A2 BELONGS NEAR HERE

A2. Average commercial, industrial, agricultural, and other water uses for public water suppliers in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005

TABLE A3 BELONGS NEAR HERE

A3. Water use by category for major water users in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005

Table 1. Aquifer characteristics of Buffalo, Otter Tail surficial, and Pelican River sand-plan aquifers, northwestern Minnesota

[mi^2, square miles; ft, feet; ft^2/d, square feet per day; ft/d, feet per day; gal/min, gallons per minute; Ggal, billions of gallons; max, maximum; min, minimum; >, greater than; -- data not available/not applicable]

Aquifer	Areal extent (mi^2)	Maximum aquifer thickness (ft)	Saturated thickness (ft)		Transmissivity (ft^2/d)			Hydraulic conductivity (ft/d)		Storativity (dimensionless)	Porosity (dimensionless)	Specific yield (dimensionless)	Theoretical well yield[1] (gal/min)			Maximum volume of water capable of being stored (Ggal)
			Maximum	Mean	Maximum	Maximum	Mean	Maximum	Maximum				Maximum	Maximum	Mean	
Buffalo aquifer (Wolf, 1981; Schoenberg, 1998)	66	220	200	90	70,000	2,500	--	500	20	3E-05-3.2E-02	0.30	0.20	10,000	200	--	[2] 270
Otter Tail surficial aquifer (Winter and others, 1969; Reeder, 1972)	510	100	>100	50	26,800	6,700	14,500	410	86	0.1-0.2	--	0.12	1,500	200	--	500
Pelican River sand-plain aquifer (Anderson, 1980; Miller, 1982)	195	140	>100	60	12,500	100	5,000	210	130	--	.20	0.17-0.29	1,200	40	600	300

[1] Theoretical well yields represent general conditions and relative difference in the water-yielding capabilities of the aquifers, and are limited by various assumptions inherent to the methods of estimation.

[2] Estimated by Wolf, 1981

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 2. Water budgets for Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers, northwestern Minnesota

[From Table 2, Reppe (2004). Mgal, millions of gallons; mi ^{2}, square miles; in/yr, inches per year; Mgal/yr, millions of gallons per year; --, data not available; ft3/s, cubic feet per second]

Sources

Aquifer	Method of determi-nation	Maximum aquifer storage (Mgal)	Area of aquifer (mi^2)	Mean area recharge rate [range] (in/yr)	Percentage of mean area recharge to mean annual precipi-tation	Sources of water to aquifer: Mean area recharge (area x rate) (Mgal/yr)	Sources of water to aquifer: Flow from surface water (Mgal/yr)	Sources of water to aquifer: Flow across boundaries (Mgal/yr)	Total sources (inflows) of water to the aquifer (Mgal/yr)
Buffalo aquifer[1] (Schoenberg, 1998)	hydrograph analysis	270,000	25	4.8 [3.6-5.5]	23	407	3,300	--	3,707
Otter Tail surficial aquifer (Reeder, 1972)	hydrograph analysis	500,00	510	5.5 [3-6]	27	49,000	--	2,000	51,000
Pelican River sand-plain aquifer (Miller, 1982)	steady-state simulation	300,000	195	4.7 [4.5-4.9]	--	5,500	1,900	1,500	8,900
	steady-state simulation	300,000			--	3,800	1,100	--	4,900

Losses

Aquifer	Method of determina-tion	Losses of water from aquifer: Evapotrans-piration (Mgal/yr)	Losses of water from aquifer: Flow to surface water (Mgal/yr)	Losses of water from aquifer: Flow across boundaries (Mgal/yr)	Losses of water from aquifer: With-drawals by pumped well (Mgal/yr)	Total losses (outflows) of water from aquifer (Mgal/yr)	Dif-ferences between sources and losses of water in aquifer (Mgal/yr)	Explanation of estimated water budget
Buffalo aquifer	hydrograph analysis	--	--	--	408	408	3,299	Losses include withdrawals through wells and exclude flow across boundaries to Glacial Lake Agassiz sediment and confined till
Otter Tail surficial aquifer	hydrograph analysis	--	--	2,000	--	2,000	49,000	Includes only sources of water and losses of water across boundaries to adjacent aquifers.
Pelican River sand-plain aquifer	steady-state	5,000	3,900	--	--	8,900	0	Steady-state simulation
	steady-state	1,900	2,900	100	--	4,900	0	Steady-state simulation

[1] The water budget does not reflect steady state conditions

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 3. Projected and estimated populations and estimated annual domestic water use for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2030 and 2050

[Water use calculated by multiplying population by water use by 365 days. Low estimate water use is 70 gal/p/d; high estimate water use is 90 gal/pd/d. Highlighted cells are the estimates of domestic water use used in this study. Mgal, million gallons; gal/p/d, gallons per person per day. --, not estimated or not calculated. Data from McMurry, 2002b, Northwest Economic Associates, 2003, and Bureau of Reclamation, 2005c.]

Source	Becker County			Clay County			Douglas County		
		Water use per year			Water use per year			Water use per year	
	Population	Low estimate, Mgal/y	High estimate, Mgal/y	Population	Low estimate, Mgal/y	High estimate, Mgal/y	Population	Low estimate, Mgal/y	High estimate, Mgal/y
	2000			2000			2000		
U.S. Bureau of the Census	30,000	767	986	51,229	521 [1]	670 [1]	32,821	839	1,078
	2030			2030			2030		
Minnesota State	37,190	950	1,222	53,570	1,369	1,760	46,180	1,180	1,517
Northwest Economic									
Net Migration is Zero	--	--	--	60,056	1,534	1,973	--	--	--
Current Net Migration Trends Projected Forward	--	--	--	57,208	1,462	1,879	--	--	--
Bureau of Reclamation									
Net Migration is Zero	--	--	--	56,000	1,431	1,840	--	--	--
Current Net Migration Trends Projected Forward	--	--	--	55,900	1,428	1,836	--	--	--
Optimistic Growth	--	--	--	70,600	1,804	2,319	--	--	--
Minimum	--	--	--	53,570	1,369	1,760	--	--	--
Average	--	--	--	58,889	1,505 740 [1]	1,935 951 [1]	--	--	--
Maximum	--	--	--	70,600	1,804	2,319	--	--	--
Range	--	--	--	17,030	435	559	--	--	--
	2050			2050			2050		
This Study									
2025--30 Migration and Survival Rates	37,700	963	1,238	54,500	1,392	1,790	52,600	1,344	1,728
2025--2030 Migration Rates and Projected Survival Rates	38,600	986	1,268	55,200	1,410	1,813	53,400	1,364	1,754
Population trend projected forward	40,200	1,027	1,321	55,900	1,428	1,836	55,100	1,408	1,810
Northwest Economic									
Net Migration is Zero	--	--		61,053	1,560	2,006	--	--	--
Current Net Migration Trends Projected Forward	--	--		58,286	1,489	1,915	--	--	--
Bureau of Reclamation									
Net Migration is Zero	--	--		56,300	1,438	1,849	--	--	--
Current Net Migration Trends Projected Forward	--	--		56,200	1,436	1,846	--	--	--
Optimistic Growth	--	--		83,600	2,136	2,746	--	--	--
Minimum	37,700	963	1,238	54,500	1,392	1,790	52,600	1,344	1,728
Average	38,833	992	1,276	60,130	1,536 597 [1]	1,975 767 [1]	53,700	1,372	1,764
Maximum	40,200	1,027	1,321	83,600	2,136	2,746	55,100	1,408	1,810
Range	2,500	64	82	29,100	744	956	2,500	64	82

[1] Assumed that only 16.8 percent of the City of Moorhead's domestic water use came from ground water.

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 3. Projected and estimated populations and estimated annual domestic water use for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2030 and 2050 -- Continued

Source	Grant County			Otter Tail County			Wilkin County		
	Population	Water use per year: Low estimate, Mgal/y	Water use per year: High estimate, Mgal/y	Population	Water use per year: Low estimate, Mgal/y	Water use per year: High estimate, Mgal/y	Population	Water use per year: Low estimate, Mgal/y	Water use per year: High estimate, Mgal/y
	2000			2000			2000		
U.S. Bureau of the Census	6,289	161	207	57,159	1,460	1,878	7,138	182	234
	2030			2030			2030		
Minnesota State	6,920	177	227	78,250	1,999	2,571	7,070	181	232
Northwest Economic									
Net Migration is Zero	--	--	--	54,381	1,389	1,786	7,449	190	245
Current Net Migration Trends	--	--	--	73,420	1,876	2,412	6,896	176	227
Bureau of Reclamation									
Net Migration is Zero	--	--	--	54,900	1,403	1,803	7,449	190	245
Current Net Migration Trends Projected Forward	--	--	--	81,300	2,077	2,671	7,800	199	256
Optimistic Growth	--	--	--	70,400	1,799	2,313	6,400	164	210
Minimum	--	--	--	54,381	1,389	1,786	6,400	164	210
Average	--	--	--	68,775	1,757	2,259	7,177	183	236
Maximum	--	--	--	81,300	2,077	2,671	7,800	199	256
Range	--	--	--	26,919	688	884	1,400	36	46
	2050			2050			2050		
This Study									
2025--30 Migration and Survival Rates	7,100	181	233	85,900	2,195	2,822	7,000	179	230
2025--2030 Migration Rates and Projected Survival Rates	7,200	184	237	87,500	2,236	2,874	7,100	181	233
Population trend projected forward	7,500	192	246	91,900	2,348	3,019	7,200	184	237
Northwest Economic Associates									
Net Migration is Zero	--	--	--	51,329	1,311	1,686	7,216	184	237
Current Net Migration Trends	--	--	--	69,845	1,785	2,294	6,587	168	216
Bureau of Reclamation									
Net Migration is Zero	--	--	--	51,100	1,306	1,679	8,000	204	263
Current Net Migration Trends Projected Forward	--	--	--	98,200	2,509	3,226	5,700	146	187
Optimistic Growth	--	--	--	81,700	2,087	2,684	4,900	125	161
Minimum	7,100	181	233	51,100	1,306	1,679	4,900	125	161
Average	7,267	186	239	77,184	1,972	2,536	6,713	172	221
Maximum	7,500	192	246	98,200	2,509	3,226	8,000	204	263
Range	400	10	13	47,100	1,203	1,547	3,100	79	102

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 4. Estimated commercial and industrial water use in Becker, Clay, Douglas, Grant, Otter Tail, Wilkin Counties, Minnesota, 2030 and 2050

[Mgal/yr, millions of gallons per year]

	1	2	3	4	5	6	7	8					
	Population			Population Growth		Commercial Water Use, (Mgal/yr)				Industrial Water Use, (Mgal/yr)		Industrial Water Use, (Mgal/yr)	
										2030		2050	
County	2000	2030	2050	2000 - 2030 [col. 2/col1.]	2000 - 2050 [col. 3/col.1]	2000	2030 [col. 4 * col. 6]	2050 [col. 5 * col. 6]	Average Industrial Water Use 2000–05 (Mgal/yr)	Low Projection	High Projection	Low Projection	High Projection
Becker	30,000	37,190	37,700	1.240	1.257	185	230	233	403	403 [1]	703 [2]	403 [1]	703 [2]
Clay	51,229	58,889	83,600	1.150	1.632	264	304	431	539	764 [3]	879 [3]	913 [4]	1,106 [5]
Douglas	32,821	46,180	55,100	1.407	1.679	353	496	592	371	371 [1]	371 [1]	371 [1]	371 [1]
Grant	6,289	6,920	7,500	1.100	1.193	73	80	87	40	40 [1]	40 [1]	40 [1]	40 [1]
Otter Tail	57,159	68,775	77,184	1.203	1.350	485	583	655	715	715 [1]	1,015 [2]	715 [1]	1,015 [2]
Wilkin	7,138	7,177	6,713	1.006	0.940	32	32	30	16	16 [1]	16 [1]	16 [1]	16 [1]

[1] Average of industrial water use for county, 2000–2005

[2] Average of industrial water use for county, 2000–2005, plus 300 Mgal/yr

[3] Linear interpolation between average industrial water use and estimated water use in 2050

[4] Average of industrial water use for county, 2000–2005, plus 375 Mgal/yr

[5] Average of industrial water use for county, 2000–2005, plus 567 Mgal/yr

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 5. Acres of irrigated crop land in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1987 -- 2002

Data from table 8, National Agricultural Statistics Service, 1992 and table 10, National Agricultural Statistics Service, 2002]

County	Irrigated crop land in acres			
	1987	1992	1997	2002
Becker	1,917	5,443	1,548	4,792
Clay	3,967	3,039	3,943	4,295
Douglas	1,269	2,804	2,184	2,143
Grant	2,492	3,067	4,200	3,716
Otter Tail	34,026	38,172	48,968	56,158
Wilkin	2,066	3,470	2,952	1,440

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 6. Projected irrigation water use in 2030 and 2050 for Becker, Clay, Douglas, Grant, Ottertail, and Wilkin Counties, Minnesota

[Mgal, millions of gallons; Mgal/yr, millions of gallons per year; --, not applicable]

	1	2	3	4	5	6	7	8	9				
										Low projection of irrigation water needs, Mgal		High projection of irrigation water needs, Mgal	
County	Acres irrigated in 2002	Average irrigation water used 2000- 2005, Mgal/yr	Maximum irrigation water used 2000 - 2005, Mgal/yr	Maximum irrigation water used 1980 - 2005, Mgal/yr	Average irrigation rate 2000 - 2005, gallons per acre [col. 2/col. 1]	Maximum irrigation rate 2000-2005, gallons per acre [col. 3/col 1]	Estimated increase in in irrigated farmland, ratio	Estimated irrigated farmland in 2030, acres[8]	Estimated irrigated farmland in 2050, acres [col. 1*col. 7]	2030	2050	2030	2050
Becker	4,792	1,955	2,422	2,422	408,000	505,000	2	7,600	9,600	3,101 [1]	3,917 [2]	3,838 [3]	4,848 [4]
Clay	4,295	454	644	1,144	106,000	150,000	1	4,300	4,300	454 [5]	454 [5]	1,144 [7]	1,144 [7]
Douglas	2,143	632	737	818	295,000	344,000	1	2,100	2,100	632 [5]	632 [5]	818 [7]	818 [7]
Grant	3,716	497	673	971	134,000	181,000	1	3,700	3,700	497 [5]	497 [5]	971 [7]	971 [7]
Otter Tail	56,158	11,201	14,199	14,199	199,000	253,000	1.4	69,200	78,600	13,771 [1]	15,641 [2]	17,508 [3]	19,886 [4]
Wikin	1,440	87	134	330	61,000	93,000	1	1,400	1,400	87 [5]	87 [5]	330 [7]	330 [7]
Totals	**72,544**	**14,827**	**--**	**--**	**--**	**--**		**88,300**	**99,700**	**18,542**	**21,229**	**24,608**	**27,997**

[1] Column 5 * column 8/1,000,000

[2] Column 5 * column 9/1,000,000

[3] Column 6 * column 8/1,000,000

[4] Column 6 * column 9/1,000,000

[5] Column 2

[6] Column 3

[7] Column 4

[7] Interpolated from values in column 1 and column 9

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 7. Projected total ground water use in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2030 and 2050

[Two domestic water-use estimates are made for Clay County. In one the 2000-2005 ratio between ground water and surface water for domestic water use in Moorhead is assumed to continue through 2050; in the other, all domestic water is from ground water. Water use in millions of gallons per year; gw, ground water; sw, surface water.]

Average water use, 2000–2005

County	Domestic Water Use		Commercial Water Use	Industrial Water Use	Irrigation Water Use	Total Water Use by County	
	Low Estimate	High Estimate				Low Estimate	High Estimate
Becker	767	986	189	403	1,955	3,313	3,532
Clay (current gw/sw ratio)	521	670	303	539	454	1,817	1,966
Douglas	839	1,078	364	371	632	2,206	2,445
Grant	161	207	79	40	497	776	822
Otter Tail	1,460	1,878	501	715	11,201	13,878	14,295
Wilkin	182	234	33	16	87	319	371
Total	3,930	5,052	1,469	2,083	14,827	22,309	23,432

2030

County	Domestic Water Use		Commercial Water Use	Industrial Water Use		Irrigation Water Use		Total Water Use by County	
	Low Estimate	High Estimate		Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Becker	950	1,222	234	403	1	3,101	3,838	4,688	5,295
Clay (current gw/sw ratio)	740	951	349	764	3	454	1,144	2,306	2,447
Clay (all gw)	1,505	1,935						3,071	3,431
Douglas	1,180	1,517	512	371	1	632	818	2,695	2,847
Grant	177	227	87	40	1	497	971	800	1,286
Otter Tail	1,757	2,259	603	715	1	13,771	17,508	16,846	20,371
Wilkin	183	236	33	16	1	87	330	319	600
Total (current gw/sw ratio)	4,987	6,412	1,818	2,308	8	18,542	24,608	27,654	32,846
Total (all gw)	5,752	7,396						28,419	33,830

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 7. Projected total ground water use in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2030 and 2050 -- Continued

2050									
County	Domestic Water Use		Commercial Water Use	Industrial Water Use		Irrigation Water Use		Total Water Use by County	
	Low Estimate	High Estimate		Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Becker	1,027	1,321	253	703	2	3,917	4,848	5,900	6,424
Clay (current gw/sw ratio)	597	767	356	879	3	454	1,144	2,286	2,271
Clay (all gw)	1,536	1,975						3,225	3,479
Douglas	1,408	1,810	610	371	1	632	818	3,022	3,239
Grant	192	246	94	1	1	497	971	783	1,312
Otter Tail	1,972	2,536	677	1,015	2	15,641	19,886	19,305	23,100
Wilkin	172	221	31	16	1	87	330	305	582
Total (current gw/sw ratio)	5,367	6,900	2,022	2,984	10	21,229	27,997	31,601	36,928
Total (all gw)	6,306	8,108						32,541	38,137

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 8. Total appropriated ground water by aquifer in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2000 - 2005

[Mgal, millions of gallons. Data from the Minnesota Department of Natural Resources appropriated-water permit data base (Sean Hunt, Minnesota Department of Natural Resources, written commun., 2006). '--, no ground water withdrawn from one of the five aquifers)

County	Total ground water used in county, 2000-2005 (Mgal)	Total ground-water use by aquifer in each county, 2000-2005		
		Aquifer	Ground water used (Mgal)	Percent of ground water used in county
Becker	17,874.6	Otter Tail surficial	398.4	2.2
		Pelican sand-plain	5,719.1	32.0
		Pineland sands surficial	11,178.3	62.5
		All three aquifers	**17,295.8**	**96.8**
Clay	7,185.3	Buffalo	2,477.3	34.5
		Pelican sand-plain	235.4	3.3
		Both aquifers	**2,712.7**	**37.8**
Douglas	10,173.2	Wadena surficial	165.1	1.6
Grant	4,056.1	None	--	--
Otter Tail	75,366.5	Otter Tail surficial	46,947.2	62.3
		Pelican sand-plain	5,805.1	7.7
		Wadena surficial	14,535.4	19.3
		All three aquifers	**67,287.7**	**89.3**
Wilkin	1,298.3	Buffalo	342.8	26.4

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 9. Projected withdrawals from the Buffalo, Otter Tail surficial, and Pelican sand-plain aquifers in 2030 and 2050

County	Aquifer	Percent of ground water withdrawn in county	Water Use By Aquifer					
			2000		2030		2050	
			Low Estimate, (Mgal)	High Estimate, (Mgal)	Low Estimate, (Mgal)	High Estimate, (Mgal)	Low Estimate, (Mgal)	High Estimate, (Mgal)
			Total ground water used in county					
		--	3,313	3,532	4,688	5,295	5,900	6,424
			Ground water withdrawn from aquifer					
Becker	Buffalo	0.0	0	0	0	0	0	0
	Otter Tail surficial	2.2	74	79	104	118	132	143
	Pelican sand-plain	32.0	1,060	1,130	1,500	1,694	1,888	2,055
	Total	34.4	1,134	1,209	1,604	1,812	2,019	2,199
			Total ground water used in county					
			1,817	1,966	3,071	3,431	3,225	3,479
			Ground water withdrawn from aquifer					
Clay	Buffalo	34.5	627	678	1,059	1,183	1,112	1,199
	Otter Tail surficial	0.0	0	0	0	0	0	0
	Pelican sand-plain	3.3	60	64	101	112	106	114
	Total	37.5	686	742	1,160	1,295	1,218	1,313
			Total ground water used in county					
			2,206	2,445	2,695	2,847	3,022	3,239
			Ground water withdrawn from aquifer					
Douglas	Buffalo	0.0	0	0	0	0	0	0
	Otter Tail surficial	0.0	0	0	0	0	0	0
	Pelican sand-plain	0.0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0
			Total ground water used in county					
			776	822	800	1,286	783	1,312
			Ground water withdrawn from aquifer					
Grant	Buffalo	0.0	0	0	0	0	0	0
	Otter Tail surficial	0.0	0	0	0	0	0	0
	Pelican sand-plain	0.0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0
			Total ground water used in county					
			13,878	14,295	16,846	20,371	19,305	23,100
			Ground water withdrawn from aquifer					
Otter Tail	Buffalo	0.0	0	0	0	0	0	0
	Otter Tail surficial	62.3	8,645	8,905	10,493	12,689	12,025	14,390
	Pelican sand-plain	7.7	1,069	1,101	1,298	1,569	1,487	1,779
	Total	70.0	9,714	10,006	11,791	14,258	13,512	16,169

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table 9. Projected withdrawals from the Buffalo, Otter Tail surficial, and Pelican sand-plain aquifers in 2030 and 2050

County	Aquifer	Percent of ground water withdrawn in county	Water Use By Aquifer					
			2000		2030		2050	
			Low Estimate, (Mgal)	High Estimate, (Mgal)	Low Estimate, (Mgal)	High Estimate, (Mgal)	Low Estimate, (Mgal)	High Estimate, (Mgal)
			Total ground water used in county					
			319	371	319	600	305	582
			Ground water withdrawn from aquifer					
Wilkin	Buffalo	26.4	84	98	84	158	81	154
	Otter Tail surficial	0.0	0	0	0	0	0	0
	Pelican sand-plain	0.0	0	0	0	0	0	0
	Total	26.4	84	98	84	158	81	154

	Aquifer	Total Water Use By Aquifer All Counties						
		2000		2030		2050		
		Low Estimate, (Mgal)	High Estimate, (Mgal)	Low Estimate, (Mgal)	High Estimate, (Mgal)	Low Estimate, (Mgal)	High Estimate, (Mgal)	Recharge to aquifer, (Mgal/yr)
All Counties	Buffalo	711	776	1,143	1,341	1,193	1,353	3,707
	Otter Tail surficial	8,719	8,983	10,598	12,807	12,157	14,533	51,000
	Pelican sand-plain	2,189	2,296	2,898	3,376	3,480	3,949	4,900-8,900

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table A1. Average residential water use for public suppliers in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005

[Data from Sean Hunt, Minnesota Department of Natural Resources, written commun., 2006; averge water use rounded to nearest 1,000 gallons]

Name of public water supplier	First year of period	Last year of period	Number of years with record	Average residential water use per year, gallons	Average population	Average per capita residential water use, gallons per person per day
Becker County						
City of Audubon	2000	2004	4	19,298,000	436	122
Detroit Lakes Public Utility	2000	2005	6	166,323,000	7,390	62
City of Frazee	2000	2005	6	39,999,000	1,372	80
Clay County						
City of Barnesville	2000	2005	6	57,843,000	2,212	72
City of Comstock	2002	2004	3	2,289,000	123	51
City of Dilworth	2000	2005	6	68,981,000	3,006	63
City of Georgetown	2000	2004	3	3,301,000	119	76
City of Glyndon	2000	2005	5	28,233,000	1,069	72
City of Hawley	2000	2005	6	37,371,000	1,883	54
Moorhead Public Service	2000	2005	6	722,675,000	36,336	55
Douglas County						
City of Alexandria	2000	2005	6	121,227,000	9,410	35
City of Osakis	2000	2005	6	25,207,000	1,543	45
Grant County						
City of Barrett	2000	2005	6	8,088,000	363	60
City of Elbow Lake	2000	2005	6	28,157,000	1,261	61
City of Hoffman	2004	2005	2	14,452,000	665	60
City of Wendell	2001	2005	3	7,170,000	176	112
Otter Tail County						
City of Battle Lake	2000	2004	5	19,688,000	760	71
City of Dalton	2003	2003	1	12,000,000	265	124
City of Deer Creek	2003	2004	2	6,560,000	316	57
City of Elizabeth	2001	2002	2	6,114,000	160	105
City of Fergus Falls	2000	2004	5	239,177,000	13,296	49
City of New York Mills	2000	2005	6	20,014,000	1,157	47
City of Pelican Rapids	2000	2005	6	62,362,000	2,318	73
City of Perham	2000	2005	6	77,612,000	2,597	82
Wilkin County						
City of Breckenridge	2000	2005	6	57,717,000	3,608	44
City of Nashua	2000	2003	3	1,026,000	37	78

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table A2. Average commercial, industrial, agricultural, and other water uses for public water suppliers in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005

[Data from Sean Hunt, Minnesota Department of Natural Resources, written commun., 2006; water use rounded to nearest 1,000 gallons; --, no data or water use not reported]

Name of public water supplier	First year of period	Last year of period	Number of years with record of commer-cial water use	Average commercial water use per year, gallons	Number of years with record of industrial water use	Average industrial water use per year, gallons	Number of years with record of agricul-tural water use	Average agricultural water use per year, gallons	Number of years with record of other water use	Average other water use per year, gallons
Becker County										
City of Audubon	2000	2004	--	--	--	--	--	--	--	--
Detroit Lakes Public Utility	2000	2005	6	178,691,000	--	--	--	--	--	--
City of Frazee	2000	2005	6	2,341,000	--	--	--	--	6	3,787,000
Clay County										
City of Barnesville	2000	2005	6	12,872,000	--	--	--	--	--	--
City of Comstock	2002	2004	3	74,000	--	--	3	10,000	6	2,796,000
City of Dilworth	2000	2005	6	8,582,000	--	--	--	--	6	150,000
City of Georgetown	2000	2004	--	--	--	--	--	--	--	--
City of Glyndon	2000	2005	5	3,060,000	--	--	--	--	5	1,000,000
City of Hawley	2000	2005	6	20,109,000	--	--	6	572,000	--	--
City of Hitterdale	2000	2005	--	--	--	--	3	28,000	--	--
Moorhead Public Service	2000	2005	6	219,672,000	6	417,586,000	--	--	6	30,054,000
City of Sabin	2004	2005	--	--	--	--	2	300,000	--	--
Douglas County										
City of Alexandria	2000	2005	6	313,899,000	--	--	--	--	--	--
City of Osakis	2000	2005	6	13,345,000	--	--	--	--	6	10,874,000
City of Kensington	2005	2005	--	--	1	269,000	--	--	--	--
Grant County										
City of Barrett	2000	2005	6	5,241,000	6	2,766,000	6	346,000	6	300,000
City of Elbow Lake	2000	2005	6	64,729,000	6	2,355,000	6	1,312,000	6	4,641,000
City of Hoffman	2004	2005	2	2,000,000	--	--	--	--	--	--
City of Wendell	2001	2005	3	639,000	--	--	3	153,000	3	1,250,000

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table A2. Average commercial, industrial, agricultural, and other water uses for public water suppliers in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005—Continued

Name of public water supplier	First year of period	Last year of period	Number of years with record of commer-cial water use	Average commercial water use per year, gallons	Number of years with record of industrial water use	Average industrial water use per year, gallons	Number of years with record of agricul-tural water use	Average agricultural water use per year, gallons	Number of years with record of other water use	Average other water use per year, gallons
Otter Tail County										
City of Battle Lake	2000	2004	5	4,016,000	--	--	5	173,000	5	205,000
City of Dalton	2003	2003	1	4,800,000	--	--	--	--	--	--
City of Deer Creek	2003	2004	2	1,760,000	--	--	--	--	2	195,000
City of Elizabeth	2001	2002	2	1,800,000	--	--	--	--	--	--
City of Fergus Falls	2000	2004	5	356,530,000	--	--	--	--	5	8,790,000
City of New York Mills	2000	2005	6	13,380,000	6	1,075,000	6	25,000	6	7,283,000
City of Pelican Rapids	2000	2005	6	38,151,000	6	147,490,000	--	--	--	--
City of Perham	2000	2005	6	58,779,000	6	134,955,000	--	--	--	--
Wilkin County										
City of Breckenridge	2000	2005	6	31,926,000	6	14,458,000	--	--	6	1,388,000
City of Nashua	2000	2003	--	--	--	--	--	--	--	--

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table A3. Water use by category for major water users in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005

[in million gallons per year, --, not reported; data from the Minnesota Department of Natural Resources (Sean Hunt, Minnesota Department of Natural Resources, written commun., 2006)]

2000								
		Becker	Clay	Douglas	Grant	Otter Tail	Wilkin	Total
Public Domestic	Ground Water	615.9	532.9	613.6	166.0	988.0	126.2	3,042.7
	Surface Water	--	1,296.5	--	--	634.5	--	1,931.0
Public Commercial	Ground Water	0.9	--	26.1	--	3.1	--	30.0
	Surface Water	--	--	--	--	--	--	0.0
Industrial	Ground Water	246.3	98.7	2.3	--	0.1	--	347.3
	Surface Water	15.6	83.9	--	--	--	--	99.5
Agricultural Processing	Ground Water	--	--	88.7	--	223.7	--	312.5
	Surface Water	--	--	--	--	279.8	--	279.8
Power Generation	Ground Water	--	--	0.4	--	0.5	--	0.9
	Surface Water	--	0.0	--	--	25,676.6	--	25,676.6
Non-major Crop Irrigation	Ground Water	95.5	1.9	140.5	32.4	110.5	--	380.9
	Surface Water	7.6	34.2	4.5	--	34.6	0.5	81.3
Other	Ground Water	2.4	9.6	50.4	--	67.6	--	130.0
	Surface Water	--	--	94.4	--	82.9	--	177.3
Major Crop Irrigation	Ground Water	1,788.1	357.1	565.0	461.7	8,978.0	46.3	12,196.3
	Surface Water	--	75.8	24.3	--	148.6	21.0	269.7
Total Ground Water		2,749.1	1,000.2	1,487.0	660.1	10,371.5	172.6	16,440.5
Total Surface Water		23.2	1,490.4	123.2	0.0	26,856.9	21.5	28,515.2
Total Water Reported for County		2,772.3	2,490.6	1,610.2	660.1	37,228.5	194.1	44,955.8

2001								
		Becker	Clay	Douglas	Grant	Otter Tail	Wilkin	Total
Public Domestic	Ground Water	633.8	606.1	658.0	152.8	908.1	120.4	3,079.3
	Surface Water	--	1,288.1	--	--	600.7	--	1,888.8
Public Commercial	Ground Water	0.9	--	22.5	--	3.4	--	26.8
	Surface Water	--	--	--	--	--	--	0.0
Industrial	Ground Water	235.2	85.2	14.2	--	29.8	--	364.4
	Surface Water	6.7	81.6	--	--	--	--	88.2
Agricultural Processing	Ground Water	--	--	114.1	--	188.4	--	302.5
	Surface Water	--	--	--	--	265.8	--	265.8
Power Generation	Ground Water	--	--	--	--	1.0	--	1.0
	Surface Water	--	0.0	--	--	26,192.5	--	26,192.6
Non-major Crop Irrigation	Ground Water	98.6	6.0	125.8	29.8	142.3	--	402.5
	Surface Water	9.3	39.1	8.6	--	45.1	5.6	107.8
Other	Ground Water	45.9	13.5	48.1	--	17.6	--	125.1
	Surface Water	0.0	--	97.8	--	130.9	--	228.7
Major Crop Irrigation	Ground Water	2,154.4	573.0	624.5	633.0	11,141.4	74.9	15,201.1
	Surface Water	--	71.4	29.1	--	155.7	50.7	306.8
Total Ground Water		3,168.7	1,283.8	1,607.2	815.5	12,432.2	195.3	19,502.8
Total Surface Water		16.0	1,480.2	135.6	0.0	27,390.7	56.3	29,078.8
Total Water Reported for County		3,184.8	2,764.1	1,742.8	815.5	39,822.8	251.6	48,581.5

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table A3. Water use by category for major water users in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005—Continued

2002								
		Becker	Clay	Douglas	Grant	Otter Tail	Wilkin	Total
Public Domestic	Ground Water	583.9	477.9	711.0	144.4	877.6	124.5	2,919.2
	Surface Water	--	1,336.5	--	--	531.4	--	1,867.9
Public Commercial	Ground Water	0.9	--	21.6	--	2.3	--	24.8
	Surface Water	--	--	--	--	--	--	0.0
Industrial	Ground Water	200.6	111.4	6.9	--	48.8	--	367.7
	Surface Water	--	80.9	--	--	--	--	80.9
Agricultural Processing	Ground Water	--	--	63.8	--	169.0	--	232.8
	Surface Water	--	--	--	--	156.8	--	156.8
Power Generation	Ground Water	--	--	--	--	0.2	--	0.2
	Surface Water	--	0.0	--	--	25,251.1	--	25,251.1
Non-major Crop Irrigation	Ground Water	86.3	6.1	111.9	38.7	126.4	--	369.5
	Surface Water	9.1	39.1	3.6	--	47.8	4.4	104.0
Other	Ground Water	22.4	8.8	71.3	--	37.6	--	140.3
	Surface Water	1.2	--	80.4	--	56.3	--	137.9
Major Crop Irrigation	Ground Water	1,622.3	354.4	466.6	444.9	11,196.0	51.6	14,135.9
	Surface Water	--	118.0	5.3	--	160.9	24.9	309.0
Total Ground Water		2,516.5	958.7	1,453.1	628.0	12,457.9	176.2	18,190.3
Total Surface Water		10.3	1,574.5	89.3	0.0	26,204.2	29.3	27,907.6
Total Water Reported for County		2,526.8	2,533.2	1,542.4	628.0	38,662.1	205.4	46,097.9

2003								
		Becker	Clay	Douglas	Grant	Otter Tail	Wilkin	Total
Public Domestic	Ground Water	619.3	563.1	691.4	141.1	827.0	138.3	2,980.3
	Surface Water	--	1,428.0	--	--	539.9	--	1,967.8
Public Commercial	Ground Water	0.9	--	19.2	--	2.1	--	22.2
	Surface Water	--	--	--	--	--	--	0.0
Industrial	Ground Water	212.2	152.1	1.8	--	49.2	--	415.3
	Surface Water	--	83.7	12.6	--	--	--	96.3
Agricultural Processing	Ground Water	--	--	96.6	--	15.3	--	111.9
	Surface Water	--	--	--	--	--	--	0.0
Power Generation	Ground Water	--	--	--	--	6.3	--	6.3
	Surface Water	--	0.0	--	--	23,627.6	--	23,627.7
Non-major Crop Irrigation	Ground Water	108.8	8.4	150.9	41.6	138.0	--	447.7
	Surface Water	10.3	52.6	1.1	--	53.1	8.8	126.0
Other	Ground Water	57.3	11.5	58.9	--	58.0	--	185.8
	Surface Water	1.0	--	85.2	--	20.2	--	106.5
Major Crop Irrigation	Ground Water	2,421.6	444.8	732.5	672.8	14,074.9	100.8	18,447.5
	Surface Water	2.4	117.6	20.2	--	216.6	38.8	395.7
Total Ground Water		3,420.2	1,180.0	1,751.4	855.5	15,170.7	239.2	22,617.0
Total Surface Water		13.8	1,681.9	119.2	0.0	24,457.5	47.7	26,320.0
Total Water Reported for County		3,434.0	2,861.9	1,870.6	855.5	39,628.2	286.8	48,937.0

PRELIMINARY DRAFT -- FOR REVIEW ONLY

Table A3. Water use by category for major water users in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, 2000-2005—Continued

2004								
		Becker	Clay	Douglas	Grant	Otter Tail	Wilkin	Total
Public Domestic	Ground Water	590.7	578.0	633.1	127.0	886.9	130.3	2,946.0
	Surface Water	--	1,337.9	--	--	497.4	--	1,835.3
Public Commercial	Ground Water	0.9	--	34.3	--	2.2	--	37.3
	Surface Water	--	--	--	--	--	--	0.0
Industrial	Ground Water	338.7	78.4	231.2	--	49.6	--	697.9
	Surface Water	--	73.3	16.0	--	--	--	89.3
Agricultural Processing	Ground Water	--	--	113.2	--	302.7	--	415.8
	Surface Water	--	--	--	--	--	--	0.0
Power Generation	Ground Water	--	--	--	--	0.9	--	0.9
	Surface Water	--	0.0	--	--	19,866.2	--	19,866.3
Non-major Crop Irrigation	Ground Water	92.4	8.9	134.1	33.8	124.3	6.4	400.0
	Surface Water	7.9	46.2	0.5	--	66.9	--	121.5
Other	Ground Water	68.4	10.4	57.7	--	51.8	--	188.3
	Surface Water	1.4	0.1	96.1	--	123.0	--	220.6
Major Crop Irrigation	Ground Water	1,795.7	272.1	661.0	431.3	10,640.7	35.7	13,836.5
	Surface Water	--	76.0	6.8	--	117.2	54.5	254.5
Total Ground Water		2,886.8	947.8	1,864.5	592.2	12,059.0	172.4	18,522.8
Total Surface Water		9.4	1,533.6	119.4	0.0	20,670.7	54.5	22,387.5
Total Water Reported for County		2,896.2	2,481.4	1,983.9	592.2	32,729.7	226.9	40,910.3

2005								
		Becker	Clay	Douglas	Grant	Otter Tail	Wilkin	Total
Public Domestic	Ground Water	601.3	538.6	644.4	123.1	946.5	134.3	2,988.1
	Surface Water	--	1,390.1	--	--	493.0	--	1,883.1
Public Commercial	Ground Water	0.9	--	29.2	--	2.0	--	32.1
	Surface Water	--	--	--	--	--	--	0.0
Industrial	Ground Water	267.7	79.0	248.1	--	42.3	--	637.1
	Surface Water	--	75.5	15.7	--	--	--	91.2
Agricultural Processing	Ground Water	--	--	92.9	--	434.9	--	527.9
	Surface Water	--	--	--	--	--	--	0.0
Power Generation	Ground Water	--	--	--	--	0.1	--	0.1
	Surface Water	--	0.1	--	--	29,434.0	--	29,434.1
Non-major Crop Irrigation	Ground Water	87.5	8.9	142.8	22.6	89.1	--	350.9
	Surface Water	13.1	47.1	1.7	--	64.7	3.1	129.7
Other	Ground Water	149.9	22.2	58.4	--	59.4	--	289.9
	Surface Water	1.7	0.7	61.0	--	58.7	--	122.1
Major Crop Irrigation	Ground Water	1,999.1	239.1	727.6	359.0	10,708.1	36.1	14,069.1
	Surface Water	0.1	25.9	1.4	--	129.1	24.3	180.8
Total Ground Water		3,106.4	887.9	1,943.3	504.7	12,282.4	170.4	18,895.1
Total Surface Water		14.9	1,539.4	79.8	0.0	30,179.5	27.4	31,841.0
Total Water Reported for County		3,121.4	2,427.2	2,023.1	504.7	42,461.9	197.8	50,736.1

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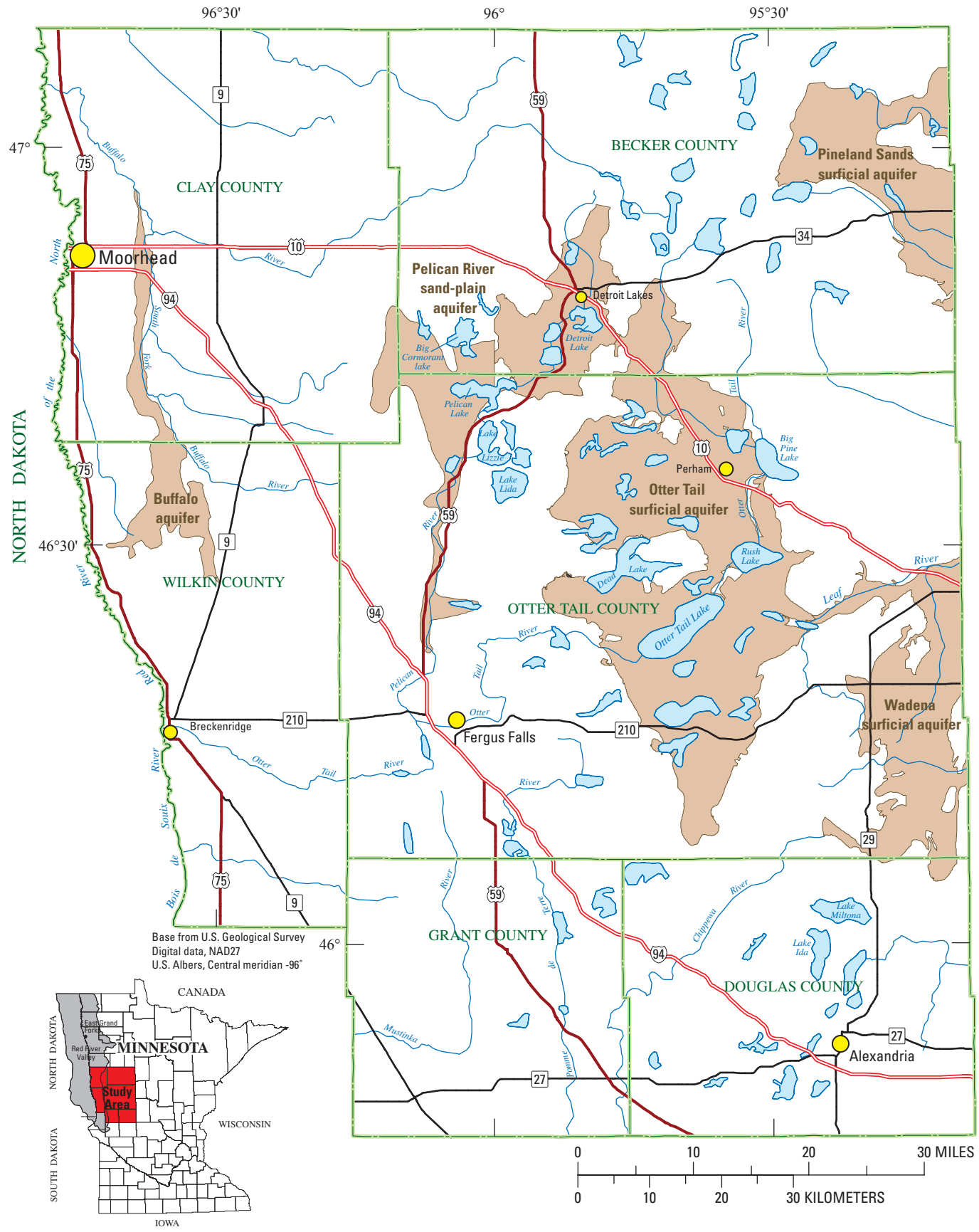

Figure 1. Study area showing major surficial aquifers.

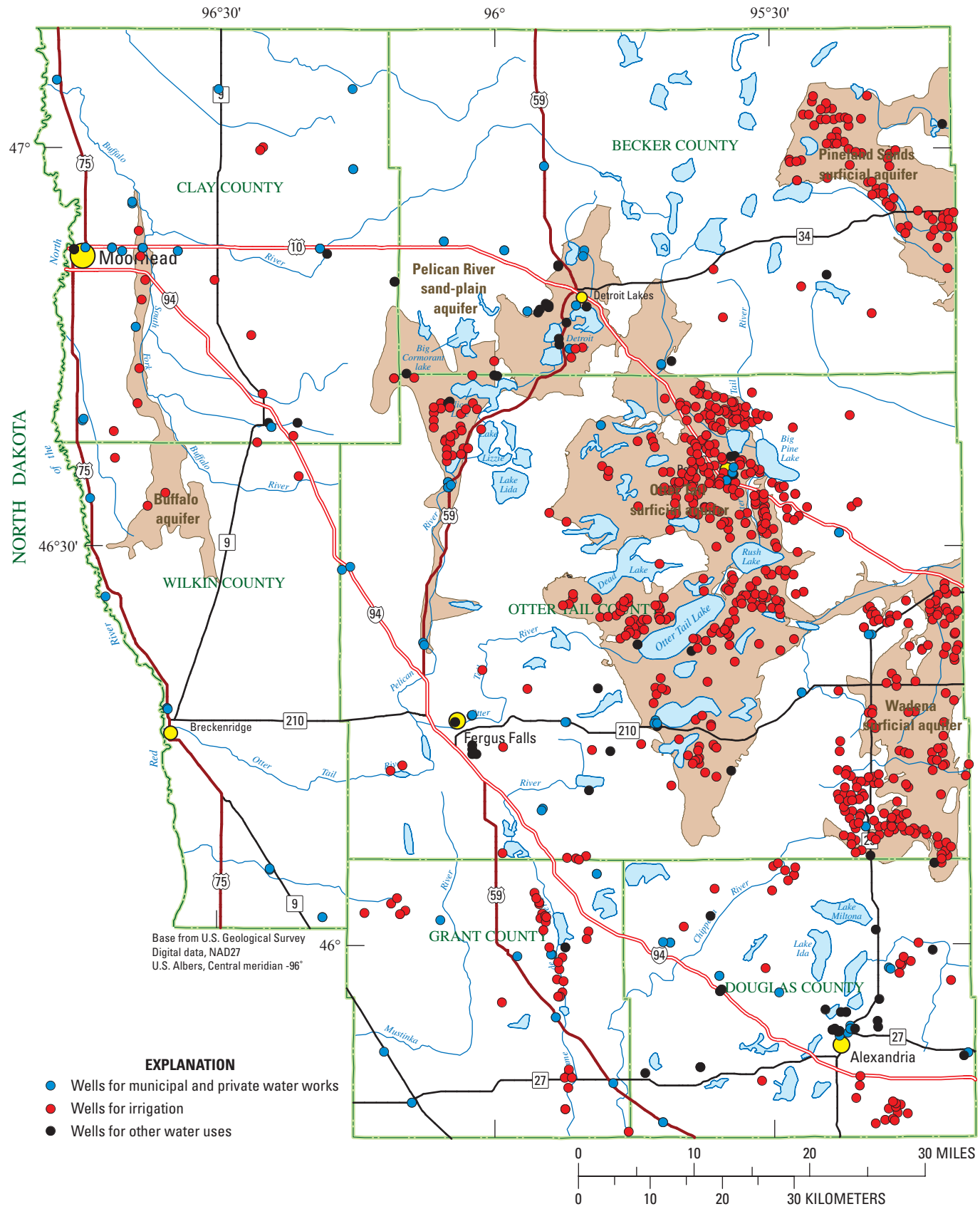

Figure 2. Ground-water wells from which at least 10,000 gallons per day or at least 1,000,000 gallons per year were pumped in the years 2000-2005.

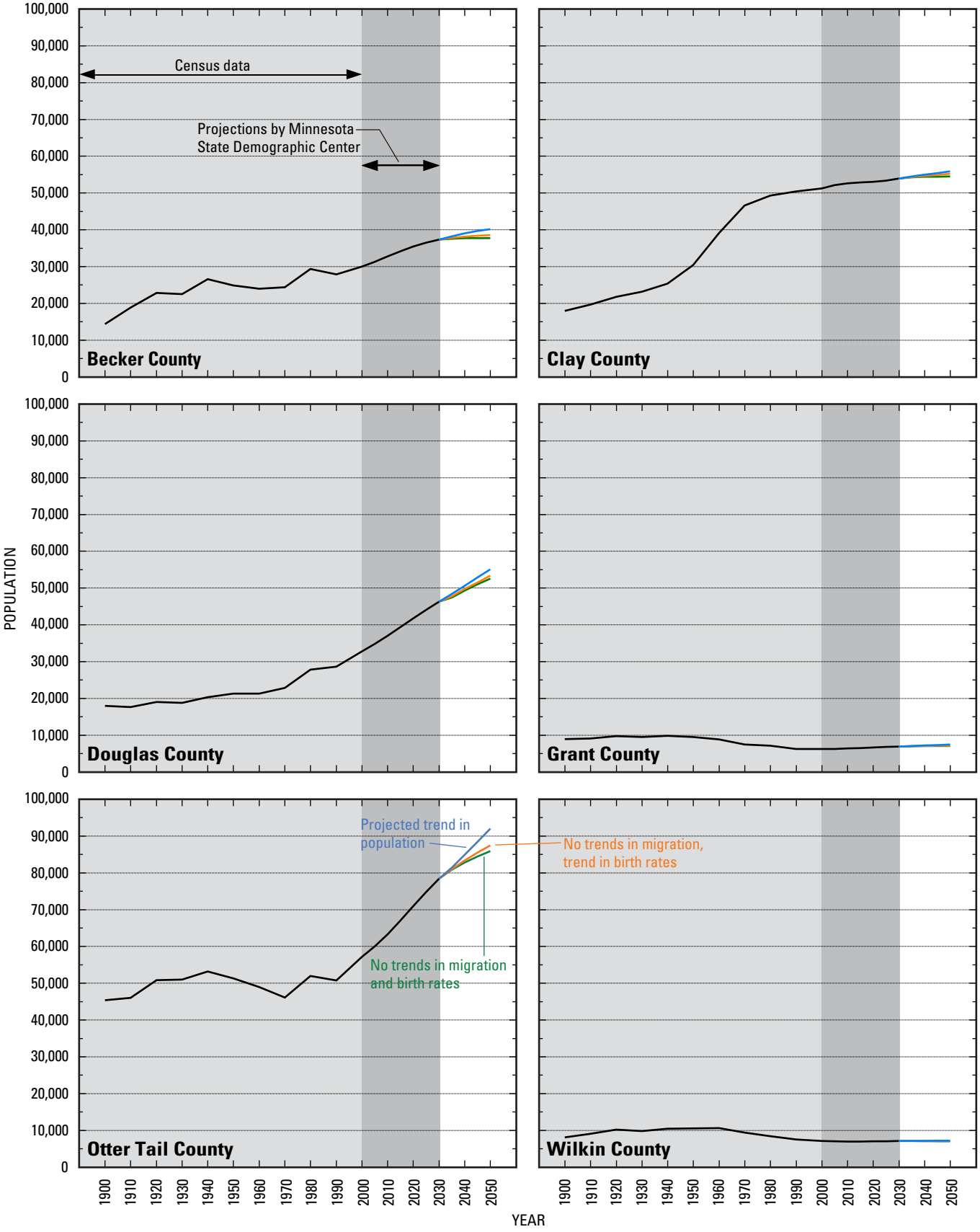

Figure 3. Census and projected populations for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1900-2050.

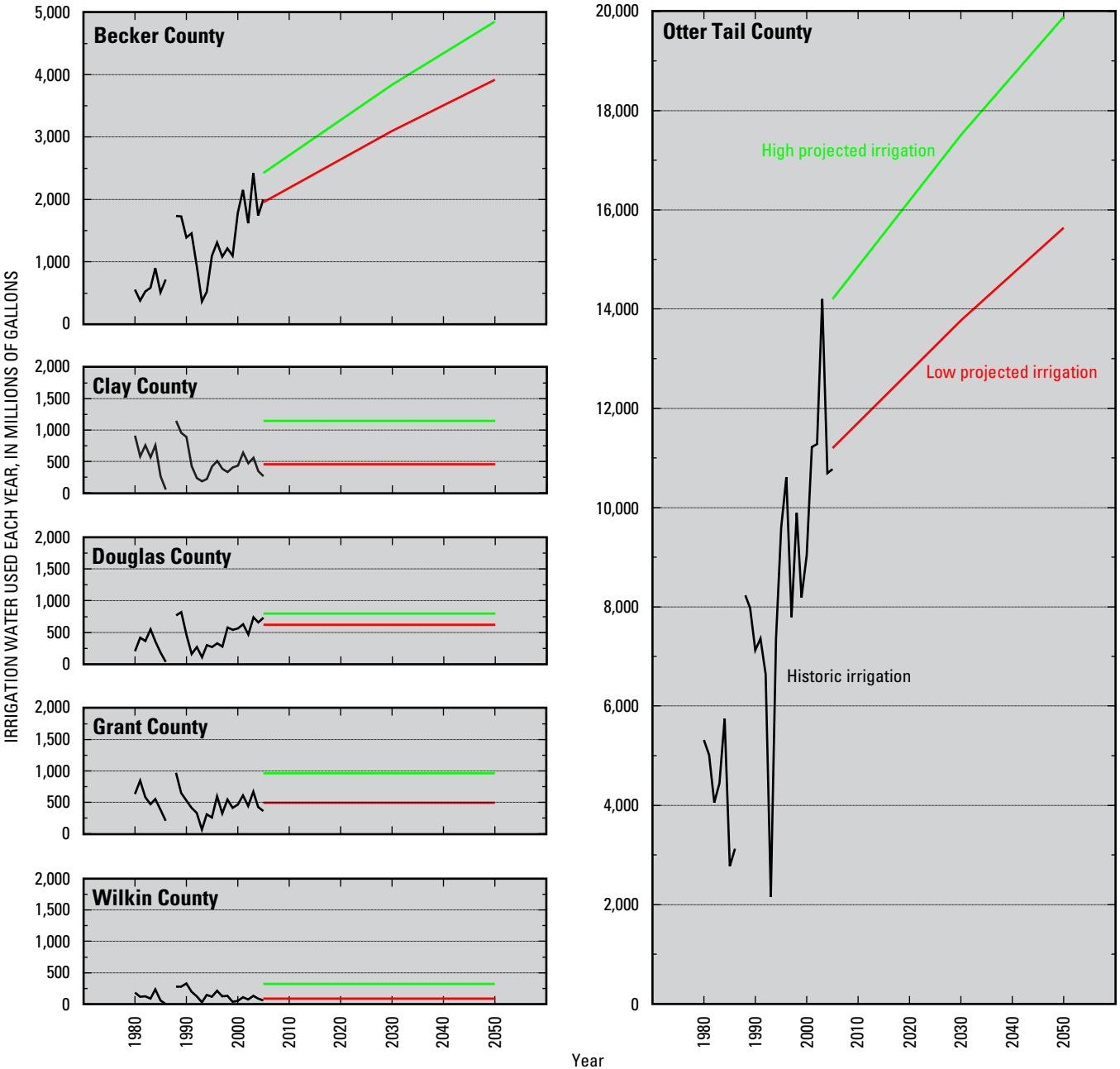

Figure 4. Historic and projected irrigation for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1980--2050.

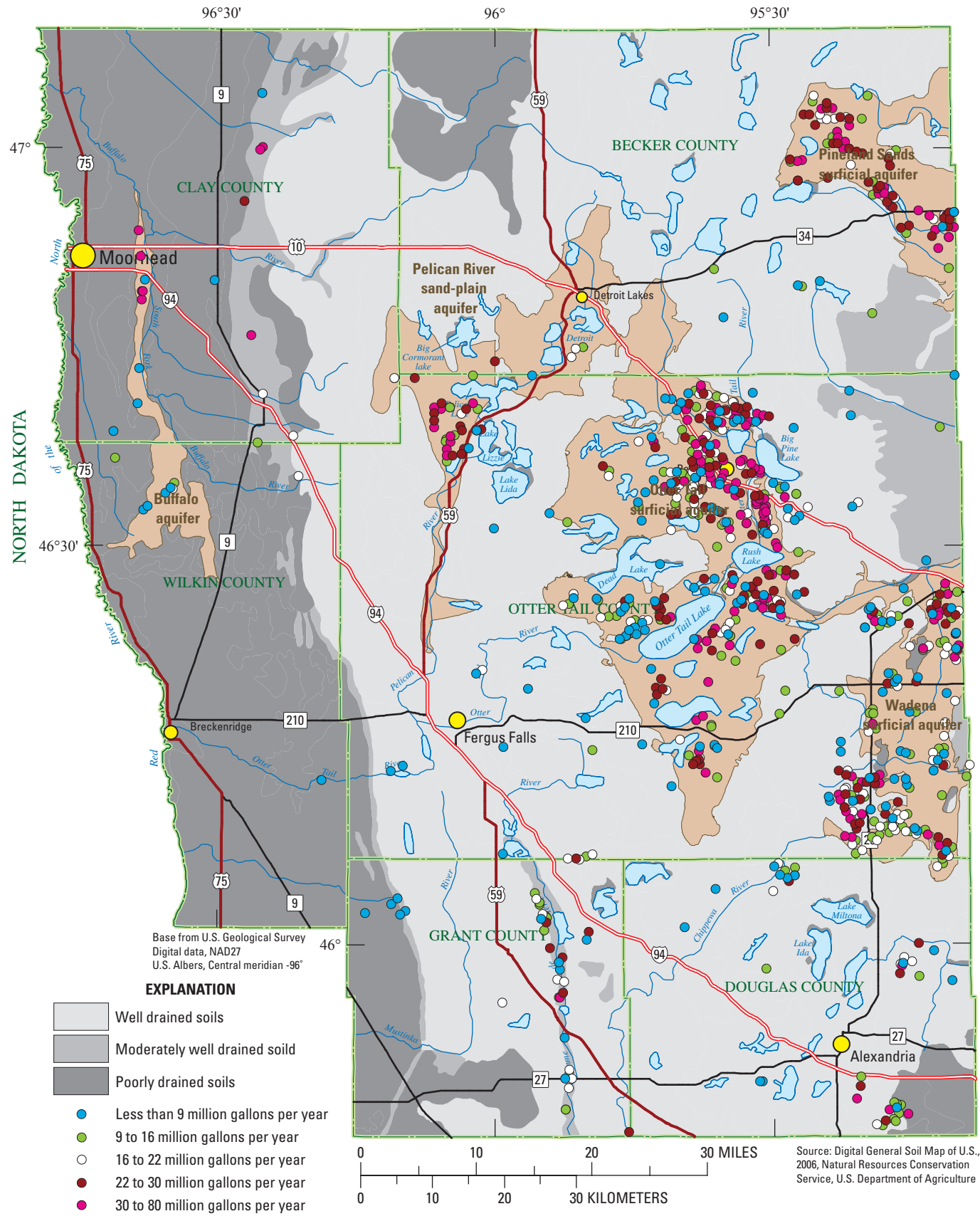

Figure 5. Average rate of water withdrawal per year for irrigation, 2000-2005, in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota.