Estimated Ground-Water Use in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, for 2030 and 2050

By Thomas A. Winterstein

Prepared in cooperation with the U.S. Department of the Interior, Bureau of Reclamation

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch per year (in/yr)	2.54	centimeter per year (cm/yr)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meters per day (m/d)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
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)
billion gallons (Ggal)	3.785	millions of cubic meters (Mm^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)
million gallons per year (Mgal/yr)	3,785	cubic meter per year (m^3/yr)

Inch/Pound to Inch/Pound

Multiply	By	To obtain
	Volume	
cubic foot (ft^3)	7.481	gallon (gal)
gallon (gal)	0.133672	cubic foot (ft^3)
million gallons (Mgal)	3.0689	acre-foot (acre-ft)
billion gallons (Ggal)	3,068.9	acre-foot (acre-ft)
	Flow Rate	
gallon per minute (gal/min)	0.00223	cubic foot per second (ft^3/s)
gallon per day (gal/d)	0.1337	cubic foot per day (ft^3/d)

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Abstract

The U.S. Department of the Interior, Bureau of Reclamation, is studying six alternatives for delivering water to the Red River of the North Valley in North Dakota and to the cities of Breckenridge, Moorhead, and East Grand Forks, Minnesota. In order to evaluate these alternatives the Bureau of Reclamation needs estimates of ground-water use for 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 ground-water use in these counties for 2030 and 2050.

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

Between 74 and 82 percent of the reported ground-water use in the 6 years from 2000 to 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 6-year period.

The total estimated 2030 ground-water use for the six counties ranges from 27,826–37,161 million gallons per year (Mgal/yr), and the total estimated 2050 ground-water use ranges from 31,313–41,746 Mgal/yr.

The estimated recharge to the Buffalo aquifer, Otter Tail surficial aquifer, and Pelican River sand-plain aquifer is 3,707, 51,000, and 4,900–8,900 Mgal/yr, respectively. The range of the estimated 2050 ground-water withdrawals from the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers is 1,234–1,776 Mgal/yr from the Buffalo aquifer, 11,728–14,820 Mgal/yr from the Otter Tail surficial aquifer, and 3,385–4,298 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, written commun., 2006). 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 water-use in Fargo, N. Dak., and Moorhead, Minn. The peak capacity of the well field(s) would be 19,300 gallons per minute (gal/min). The maximum annual depletion volume is estimated to be 8,139 million gallons (Mgal) (Allen Schlag, Bureau of Reclamation, written commun., 2006). Withdrawals from the Buffalo aquifer for peak-day water use in the City of Moorhead would be expanded by 450–1,050 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 to serve Moorhead’s total needs during drought after its existing water supply in the Red River is depleted (Allen Schlag, Bureau of Reclamation, written commun., 2006). Peak-day use would be increased from 2,700 gal/min to 3,150 gal/min. Annual withdrawals from the aquifer would be as much as 14,451 million gallons per year (Mgal/yr) during a severe drought and as little as 326 Mgal/yr during nondrought years for maintenance flows (Allen Schlag, Bureau of Reclamation, written commun., 2006). In two other alternatives, the North Dakota In-Basin and the Missouri River Import to Red River Valley Alternatives, additional water would be withdrawn only from the Buffalo aquifer (Bureau of Reclamation, 2005c). In these alternatives, peak-day withdrawals from the aquifer would be expanded by 450–1,050 gal/min. To evaluate these alternatives, Reclamation needed estimates of ground-water use for 2030 and 2050 for six

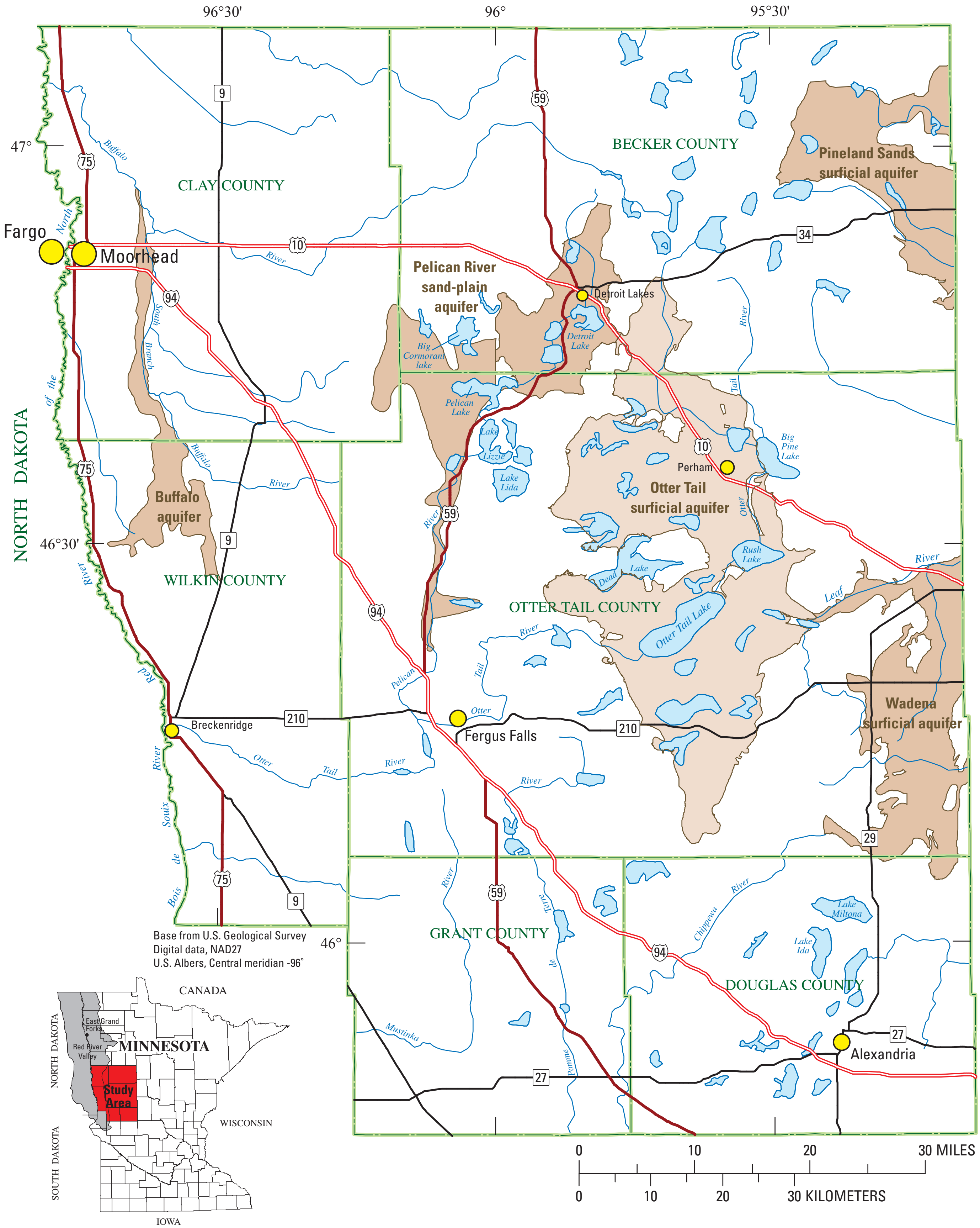

Figure 1. Study area showing major surficial aquifers.

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 ground-water use in these counties for 2030 and 2050.

Purpose and Scope

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

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 use for 2030 and 2050 with estimates of aquifer recharge is for illustrative purposes only. The comparison does not include a discussion on whether the estimated ground-water use can be withdrawn from the aquifers without affecting other uses of water from the aquifers nor does it include a discussion of possible changes in recharge to the aquifers because of changes in climate. Estimates of inflow to the three aquifers are from Reppe (2004) and are based on previously published reports.

Previous Studies

Several studies of 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 for 2050 for municipal water-supply systems, rural water supply systems, and industrial water supply in the 13 eastern counties of North Dakota and for water systems in the Minnesota communities of Breckenridge, Moorhead, and East Grand Forks (Bureau of Reclamation, 2005a, 2005c). Water use 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 use for 2050 for counties.

Properties of Surficial Aquifers

Reppe (2004) summarized existing information about three surficial aquifers, the Buffalo, Otter Tail surficial, and Pelican River sand-plain, within the study area, (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 altitude of 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 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 * * *. 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 * * *. (Reppe, 2004, p. 18).

The following descriptions of the aquifers are from Reppe (2004, 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 miles (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 square miles (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 feet (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.

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

[From table 1, Reppe (2004); 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; >, 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 (gal/min)			Maximum volume of water capable of being stored (Ggal)
			Maximum	Mean	Maximum	Minimum	Mean	Maximum	Minimum				Maximum	Minimum	Mean	
Buffalo aquifer (Wolf, 1981; Schoenberg, 1998)	66	220	200	90	70,000	2,500	--	500	20	0.00003–0.032	0.30	0.20	10,000	200	--	[1] 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, U.S. Geological Survey, unpublished data, 1980; Miller, 1982)	195	140	>100	60	12,500	100	5,000	210	130	--	0.20	0.17–0.29	1,200	40	600	300

[1] Estimated by Wolf, 1981.

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

[From Table 2, Reppe (2004). Mgal, millions of gallons; mi^2, square miles; in/yr, inches per year; Mgal/yr, million gallons per year; --, data not available; ft^3/s, cubic feet per second; ×, multiplied by]

Sources										
							Sources of water to aquifer (Mgal/yr)			
Aquifer	Method of determination	Maximum aquifer storage[2] (Mgal)	Area of aquifer (mi^2)	Year of areal recharge data[3]	Mean areal recharge rate[3] [range] (in/yr)	Percentage of mean areal recharge to mean annual precipitation	Mean areal recharge (area × rate)	Flow from surface water	Flow across boundaries	Total sources (inflows) to the aquifer
Buffalo aquifer[1] (Schoenberg, 1998)	Hydrograph analysis	270,000	25[4]	1993	4.8 [3.6–5.5]	23	407	3,300	--	3,707
Otter Tail surficial aquifer (Reeder, 1972)	Hydrograph analysis	500,000	510	1969	5.5 [3–6]	27	49,000	--	2,000	51,000
Pelican River sand-plain aquifer (Miller, 1982)	Steady-state "Detroit Lakes" simulation	300,000	195	1979–80	4.7 [4.5–4.9]	--	5,500	1,900	1,500	8,900
	Steady-state "Scrambler" simulation	300,000					3,800	1,100	--	4,900

Losses								
		Losses of water from aquifer (Mgal/yr)						
Aquifer	Method of determination	Evapotranspiration[5]	Flow to surface water[5]	Flow across boundaries[5]	Withdrawals by pumped wells[5]	Total losses (outflows) of water from aquifer	Differences 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 "Detroit Lakes" simulation	5,000	3,900	--	--	8,900	0	Steady-state simulation.
	Steady-state "Scrambler" simulation	1,900	2,900	100	--	4,900	0	Steady-state simulation.

[1] The water budget does not reflect steady-state conditions. [2] Aquifer storage from published information or estimated from saturated thickness data and aquifer extent. [3] Values reported directly from cited reference. [4] Area of unconfined part of the Buffalo aquifer. [5] Values calculated (converted to similar units) from data reported in cited reference.

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 annual volume of water recharging 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. Ground-water 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 inches per year (in/yr)] is the primary source of recharge to the Otter Tail surficial aquifer, accounting for 96 percent (49,000 Mgal/yr) of the total inflow to the aquifer (table 2). The remaining 4 percent (2,000 Mgal/yr) is estimated to be ground-water flow across boundaries 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 gray, 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 (Miller, 1982) indicate that areal recharge to the aquifer is between 62 to 78 percent (3,800–5,500 Mgal/yr) of the total inflow to the aquifer, ground-water flow across the boundaries of the aquifer is as much as 17 percent (1,500 Mgal/yr) of the total inflow, and ground-water flow from surface water is 21 to 22 percent (1,100–1,900 Mgal/yr) of the total inflow (table 2).

Two computer simulations of the aquifers (Miller, 1982) indicate that evapotranspiration was 39 to 56 percent of the total losses from the aquifer (1,900–5,000 Mgal/yr), ground-water flow to surface water was 44 to 59 percent of the total losses (2,900–3,900 Mgal/yr), and ground-water flow across boundaries to adjacent geologic units was 0 to 2 percent of the total losses (100 Mgal/yr) table 2).

Estimating Ground-Water Use for 2030 and 2050

The estimates of ground-water use for 2030 and 2050 for the six counties are in four water-use categories: domestic, commercial, industrial, and irrigation. Future ground-water use is the sum of the estimates of ground-water use in the four categories. Water-use estimates were made only for the entire county for each of the six counties.

Water-Use Data

The data for these estimates 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 also often respond. The survey of public-water suppliers includes the following information:

1. population served,
2. water used by year for five categories of water use: domestic, commercial, industrial, agricultural, and other (For each category, the data base has the gallons of water used, the number of connections, and the number of metered connections.),
3. gallons of water sold by year, and
4. gallons of water appropriated by year.

The responses to the survey of public-water suppliers in the six counties for 2000–2005 are summarized in tables 1–1 and 1–2 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 in any year or more than 1,000,000 gal/yr (Minnesota Department of Natural Resources, 2006). The permit holders are required to report the total water withdrawn each year. Table 1–3 (in the appendix) summarizes the water withdrawn from ground and surface waters in the six counties by water-use category during 2000–2005. Wells in the data base that were pumped during 2000–2005 are shown in figure 2.

The public domestic category includes water used by municipal and private waterworks. Private waterworks are water suppliers for trailer courts and other small housing developments. The public commercial category includes water suppliers for business, industry, or hospitals. The industrial category includes water used for sand and gravel washing, and metal processing. The agricultural processing category includes water used for agricultural processing (food and livestock). The power generation category includes cooling water used for once-through and wet cooling by steam power plants and for uses other than cooling. The non-major crop irrigation category includes water used for irrigating golf courses, athletic fields, landscaping, sod farms, and nurseries. The other category includes water used for once through heating or air conditioning, construction site dewatering, temporary agricultural irrigation, water-level maintenance, pollution containment, aquaculture, snowmaking, and livestock watering. The major crop irrigation category is composed of water used for irrigating major crops except wild rice.

Between 74 and 82 percent of the reported ground-water use in the 6 years from 2000 to 2005 was used for irrigation of major crops. The next major use of ground water was from 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 during 2000–2005.

Methods for Estimating Domestic Water Use

Domestic water use for 2030 and 2050 is estimated by multiplying the estimated population in the six counties for 2030 and 2050 by an estimated rate of domestic water use in gallons per person per day (gal/p/d). 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.

Estimated Population for 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, 2002, p. 6; Northwest Economic Associates, 2003; Smith and others, 2001). A cohort represents a group of individuals who have specific factors, such as age and sex, in common. The cohorts used by the three sources for their population estimates are composed of the population (male or female) within a 5-year age span, such as, 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:

$$P_1 = P_0 + NM - D \qquad (1)$$

where

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

NM 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, *NM* 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:

$$P_{0–4} = B + NM - D \qquad (2)$$

where *B* is the births during the previous 5-years and *NM* 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 of age 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.

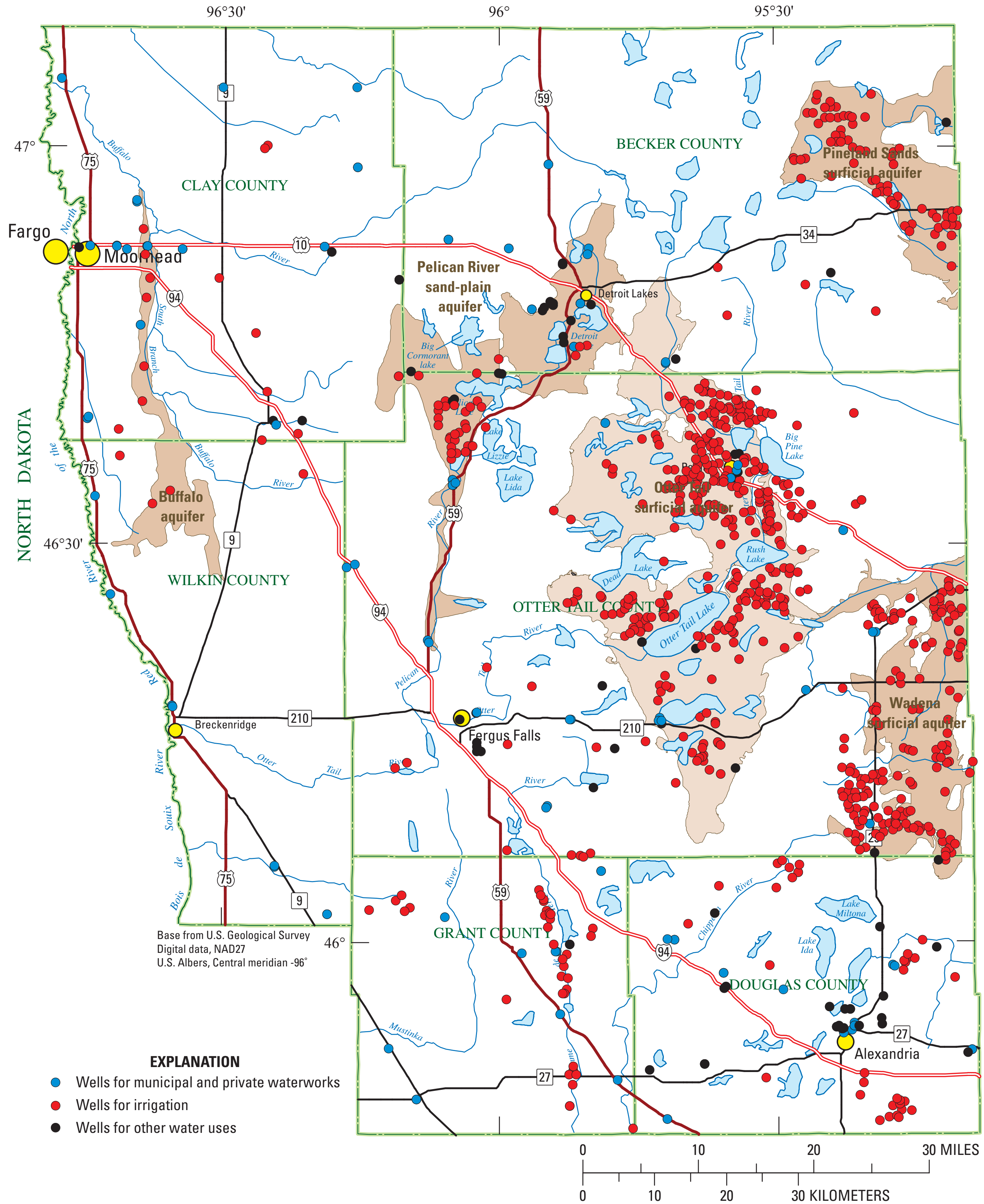

Figure 2. Wells in the water-appropriation permit data base from which water was withdrawn during 2000–2005. (Data from Sean Hunt, Minnesota Department of Natural Resources, written commun., 2006.)

Population Estimates Made by the Bureau of Reclamation

Estimated populations for 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 estimates 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 estimates of population for 2030 and 2050; one estimation assumes that net migration will be zero and one assumes that net migration will follow the past trends in migration and population growth (table 3) (Northwest Economic Associates, 2003, p. 7–8).

Reclamation made three estimates of the population of Clay, Wilkin, and Otter Tail Counties (table 3) (Bureau of Reclamation, 2005b). They made two estimates using the cohort-component method. One estimate assumes that the net migration would be zero for each county. The second estimate assumes the migration patterns for Minnesota from 1990 to 2000 presented in McMurray (2002) (Bureau of Reclamation, 2005b) will continue through 2050. In the third estimate Reclamation used an estimation method that was based upon a combination of the migration assumptions (optimistic growth). 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 for estimating the population for the entire region of 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). Reclamation calls this an estimate based on optimistic growth and current distribution of population. The estimates made by the three methods are in table 3. Reclamation used the results of the third estimation (optimistic growth) to determine water use for 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 estimates from 2005 to 2030, at 5-year intervals, for the six counties (Minnesota State Demographic Center, 2004). Their population estimates were prepared using the cohort-component method (McMurray, 2002). Their 2030 population estimates for the six counties are in table 3.

Population Estimates Made in This Study

The 2030 population estimates 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 estimates were made for each of the six counties (table 3, fig. 3). In the first estimate, it was assumed that the migration rates and the survival rates would be constant during the period 2030–2050. The rates used were the same as those used by the Minnesota State Demographic Center for the period 2025–2030 (Martha McMurray, Minnesota state Demographic Center, written commun., 2006). This produced the lowest estimated population for 2050. In the second estimate, it was assumed that migration rates would be constant during 2030–2050 and that the survival rates would change. The migration rates used were those used by the Minnesota State Demographic Center for the period 2025–2030. 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 for the period 2000–2030 and projecting forward. This produced an intermediate estimated population for 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 produced the largest estimated populations for 2050.

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 1–1). The average domestic water use in the six counties is 65.7 gal/p/d or 24,000 gallons per person per year (gal/p/yr). 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, oral commun., 2006). The average of the average year per-capita water use for 12 rural water systems in North Dakota (Bureau of Reclamation, 2005c, p. 2–38), is 90.4 gal/p/d. For this analysis, the water use in these 12 rural water systems is assumed to be primarily domestic water use. Two domestic water-use rates were used in this analysis. The low rate is 70 gal/p/d and the high rate is 90 gal/p/d.

Table 3. Estimated populations and estimated annual domestic water use in 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 based upon per capita water use of 70 gallons per person per day (gal/p/d); high estimate water use based on per capita water use of 90 gal/p/d. Shaded data are the estimates of domestic water use used in this study. Mgal/yr, million gallons per year; --, not estimated or not calculated. Data from Bureau of Reclamation (2005c), McMurry (2002), and Northwest Economic Associates (2003)]

Source	Becker County			Clay County			Douglas County		
		Water use per year (Mgal)			Water use per year (Mgal)			Water use per year (Mgal)	
	Population	Low estimate	High estimate	Population	Low estimate	High estimate	Population	Low estimate	High estimate
2030									
Minnesota State Demographer	37,190	950	1,222	53,570	1,369	1,760	46,180	1,180	1,517
Northwest Economic Associates									
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 [1]	1,935 [1]	--	--	--
					740 [2]	951 [2]			
Maximum	--	--	--	70,600	1,804	2,319	--	--	--
Range	--	--	--	17,030	435	559	--	--	--
2050									
This study									
2025–2030 migration an 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 Associates									
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 [1]	1,975 [1]	53,700	1,372	1,764
					597 [2]	767 [2]			
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

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

Source	Grant County			Otter Tail County			Wilkin County		
		Water use per year (Mgal)			Water use per year (Mgal)			Water use per year (Mgal)	
	Population	Low estimate	High estimate	Population	Low estimate	High estimate	Population	Low estimate	High estimate
2030									
Minnesota State Demographer	6,920	177	227	78,250	1,999	2,571	7,070	181	232
Northwest Economic Associates									
Net migration is zero	--	--	--	54,381	1,389	1,786	7,449	190	245
Current net migration trends projected forward	--	--	--	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									
This study									
2025–2030 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 projected forward	--	--	--	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

[1] Assumed that all of the city of Moorhead's domestic water use came from ground water.

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

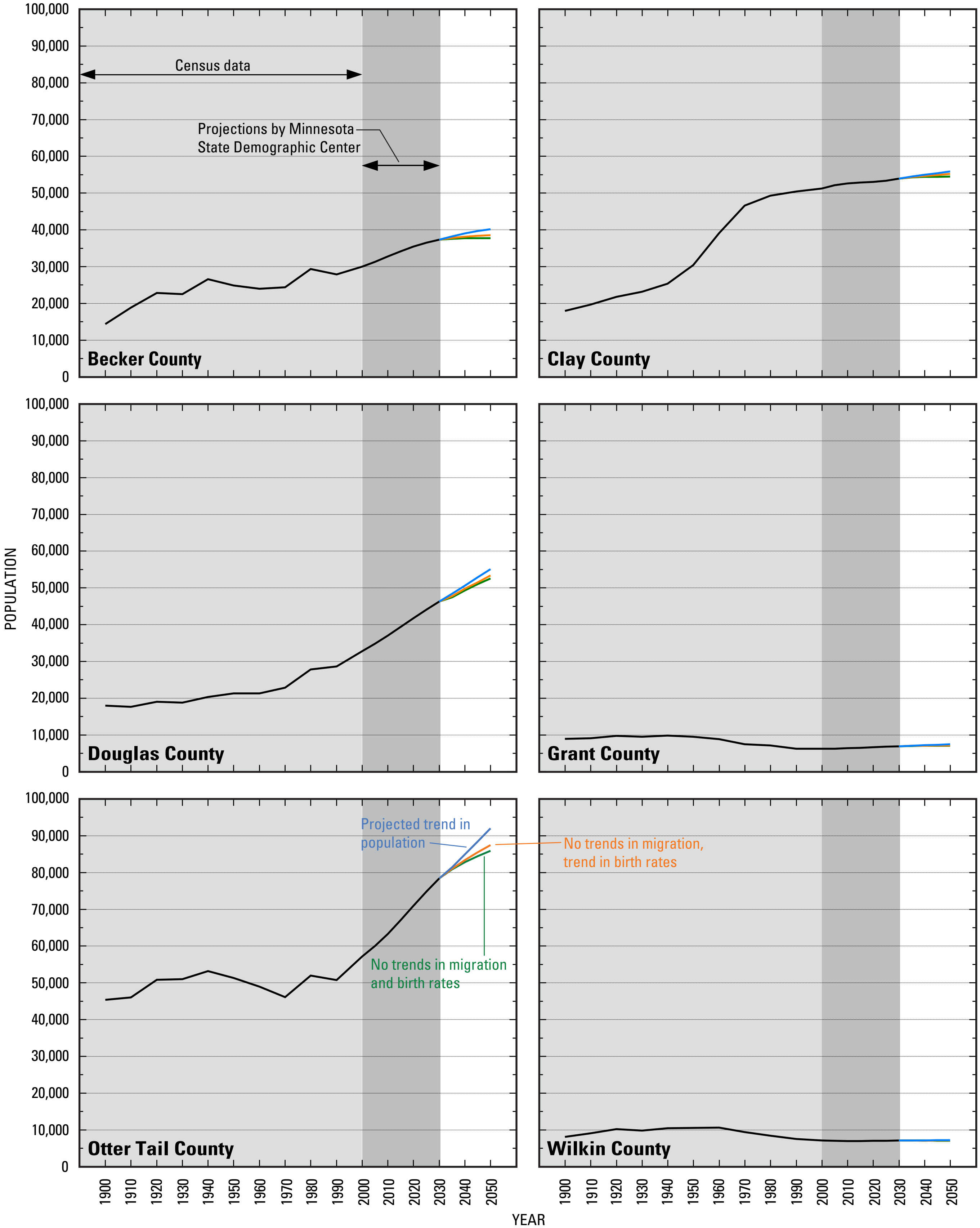

Figure 3. Census and estimated populations for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1900–2050.

Estimated Ground Water Used for Domestic Water Use for 2030 and 2050

The estimates of annual domestic water use in the six counties for 2030 and 2050 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 estimates can be great, for example, there is a difference of 47,100 persons between the low and high estimates for Otter Tail County for 2050. The range in population estimates demonstrates how difficult it is to estimate county populations almost 50 years in the future. Because of the uncertainty in estimating population, the averages of the population estimates for Clay, Otter Tail, and Wilkin Counties were used for estimating domestic water use in these counties for 2030 and 2050. The population estimates from the Minnesota State Demographic Center (McMurray, 2002) were used to estimate 2030 domestic water use in Becker, Douglas, and Grant Counties, and the the estimated population trend projected forward to 2050 was used to estimate 2050 domestic water use in these three counties.

Domestic water use is most likely from ground water in the six counties. Water from private wells most likely is used by homes not connected to municipal water-supply systems. In the water-appropriation permit data base, municipalities in the six counties reported 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.

Two scenarios, therefore, 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 for 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 for 2030 (Minnesota State Demographic Center, 2004) and 44,200 for 2050 (Bureau of Reclamation, 2005c). The projected population of Clay County used for this analysis is 58,889 for 2030 (table 3) and 60,130 for 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 for 2030 is 740 at 70 gal/p/d and 951 Mgal at 90 gal/p/d. The estimated amount of ground water used for domestic supply for 2050 is 597 and 767 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 for 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 for 2050 is 1,536 and 1,975 Mgal, at 70 and 90 gal/p/d, respectively.

The estimates of ground water used for domestic supply in this study for 2030 and 2050 are shaded in table 3. The high and low estimates of domestic water use can range by almost a factor of two. The range for 2050 domestic water use from ground water is estimated to be 1,027–1,321 Mgal/yr for Becker County; 597–767 Mgal/yr, scenario 1, or 1,536–1,975 Mgal/yr, scenario 2, for Clay County; 1,408–1,810 Mgal/yr for Douglas County; 192–246 Mgal/yr for Grant County; 1,972–2,536 Mgal/yr for Otter Tail County; and 172–221 Mgal/yr for Wilkin County.

Estimated Ground Water Used for Commercial Water Use for 2030 and 2050

The Bureau of Reclamation determined that the water used in some commercial and industrial water use categories increases proportionately with population growth in the Red River Valley (Bureau of Reclamation, 2004a, p. 25) while the water used in the other categories would not. As a result, this study divided water use into commercial and industrial categories. This study assumed that water use in the commercial category would increase proportionately with population while water use in the industrial category would not. Estimated water use in the commercial category for 2030 and 2050 is described in this section; estimated water use in the industrial category for 2030 and 2050 is described in the next section.

For this study, two sources of information on commercial water and industrial ground-water use were used: the survey of public-water suppliers and the water-appropriation permit data base. The nondomestic water use reported in the survey of public-water suppliers was assumed to come from ground water and was used in this analysis. Reported data in the water-appropriation permit data base that was coded as coming from ground water (wells, pits/holding ponds, quarries, mines, or gravel pits) was used in this analysis.

Commercial water use was composed from these data: (1) the commercial water use category in the survey of public-water suppliers, and (2) private water works category or commercial or institutional waterworks category (business, industry, or hospitals) in the water-appropriation permit data base.

The estimates of commercial water use for 2030 and 2050 for the six counties are shown in table 4. The estimated 2050 commercial water use from ground water is 308, 313, 593, 83, 561, and 30 Mgal/yr for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, respectively.

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

[Mgal/yr, millions of gallons per year; 2000 census data from McMurry (2002); 2030 and 2050 estimated population from table 3; ×, multiplied by; ÷, divided by; --, not calculated]

	1	2	3	4	5	6	7	8		Estimated industrial ground-water use (Mgal/yr)			
	Population			Estimated population growth rate		Commercial ground-water use (Mgal/yr)				2030		2050	
County	2000 census	2030 estimated	2050 estimated	2000–2030 [col. 2 ÷ col. 1]	2000–2050 [col. 3 ÷ col. 1]	[1]Average 2000–2005	2030 estimated [col. 4 × col. 6]	2050 estimated [col. 5 × col. 6]	[2]Average industrial water use 2000–2005 (Mgal/yr)	Low estimate	High estimate	Low estimate	High estimate
Becker	30,000	37,190	40,200	1.24	1.34	185	230	308	411	411 [3]	711 [4]	411 [3]	711 [4]
Clay	51,229	58,889	60,130	1.15	1.17	267	307	313	666	891 [5]	1,006 [5]	1,041 [6]	1,233 [7]
Douglas	32,821	46,180	55,100	1.41	1.68	353	498	593	388	388 [3]	388 [3]	388 [3]	388 [3]
Grant	6,289	6,920	7,500	1.10	1.19	70	77	83	44	44 [3]	44 [3]	44 [3]	44 [3]
Otter Tail	57,159	68,775	77,184	1.20	1.35	415	498	561	738	738 [3]	1,038 [4]	738 [3]	1,038 [4]
Wilkin	7,138	7,177	6,713	1.01	0.94	32	32	30	9	9 [3]	9 [3]	9 [3]	9 [3]
Totals	**184,636**	**225,132**	**246,827**	--	--	--	**1,642**	**1,888**	**2,256**	**2,481**	**3,196**	**2,631**	**3,423**

[1] The average commercial water use for the period 2000–2005 is the average reported water use in the commercial water use category, 2000–2005, from the survey of public-water suppliers plus the average of reported ground-water use, 2000–2005, from the water-appropriation data base that was coded as private waterworks and as commercial and institutional (business, industry, hospital).

[2] The average industrial water use during 2000–2005 is the average reported water use, 2000-2005, in the industrial, agricultural, and other water use categories from the survey of public-water suppliers plus the average reported ground-water use, 2000–2005, that was coded as power generation, air conditioning, industrial, temporary, water-level maintenance, special categories, or non-crop irrigation in the water-appropriation permit data base.

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

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

[5] Linear interpolation between average industrial water use, 2000–2005, and estimated water use in 2050.

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

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

Estimated Ground Water Used for Industrial Water Use for 2030 and 2050

Industrial water use was not assumed to increase proportionately with population. Industrial water use was composed from these data: (1) industrial, agricultural, and other water-use categories in the survey of public-water suppliers, and (2) power generation, air conditioning, industrial, temporary, water-level maintenance, special, or non-crop irrigation categories in the water-appropriation permit data base.

Estimates 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 do not currently exist. An example of an industry with rapid growth is ethanol-fuel production, which has grown from 11 Mgal/yr, statewide, in 1990 to 420 Mgal/yr in 2005 (Minnesota Department of Agriculture, 2006).

It was assumed that industrial water use will not increase by 2050 in Douglas, Grant, and Wilkin Counties from the 2000–2005 average of 388, 44, and 9 Mgal/yr, respectively. This follows the assumptions of the Bureau of Reclamation (2005c, p. 2–65) that there would be no significant industrial developments in Wilkin County. Therefore, the average industrial water use supplied by ground-water in the period 2000–2005 was used as the estimated industrial water use supplied by ground-water for 2030 and 2050 in these counties (table 4).

Two estimates of industrial water use supplied by ground water were made for Becker and Otter Tail Counties for 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 was used as the projected low water-use estimate for 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 by 2030. New ethanol plants in Minnesota can produce 50 Mgal/yr of ethanol (Minnesota Department of Agriculture, 2006), although a plant was proposed that would 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 315 Mgal/yr of water. This additional water use, which was rounded to 300 Mgal/yr, was added to the average industrial use for Becker and Otter Tail Counties during 2000–2005 (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 estimates for the two counties.

Reclamation estimated that industrial water use would increase between 375 and 567 Mgal/yr in Clay County (Bureau of Reclamation, 2004c, tables 2.8.9 and 2.8.10). The low estimate of 2050 industrial water use of 1,041 Mgal/yr in Clay County is the average industrial water use of 666 Mgal/yr in the period 2000–2005 from the water-appropriation data base for Clay County plus 375 Mgal/yr (table 4). For the high estimate for 2050 of 1,233 Mgal/yr, 567 Mgal/yr was added to the average of the 2000–2005 industrial water use, 666 Mgal/yr (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 for 2050 (table 4).

The estimated industrial water use from ground water for 2050 is 388, 44, and 9 Mgal/yr for Douglas, Grant, and Wilkin Counties, respectively. The range of estimated industrial water use from ground water for 2050 is 411–711 Mgal/yr for Becker County, 1,041–1,233 Mgal/yr for Clay County, and 738–1,038 Mgal/yr for Otter Tail County.

Estimated Ground Water Used for Irrigation for 2030 and 2050

Irrigation water use in the six counties during 1980–2005 is shown in figure 4. Between 73 to 79 percent of the ground water used for irrigation in the six counties was used by Otter Tail County. Becker County was the next largest user of ground water for irrigation; Becker County used 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 are from the Agricultural Census (National Agricultural Statistics Service, 1992 and 2002). The number of acres irrigated steadily increased 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. No discernable trend is observed in Becker County. The amount of water used for irrigation shows no trends for the six counties during 2000–2005. Fluctuations in water use and acreage are shown in figure 4 and table 5, and the average annual usage of ground water for irrigation in each county is shown in table 6 for 2000–2005.

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

[Data from National Agricultural Statistics Service (1992, table 8; 2002, table 10)]

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

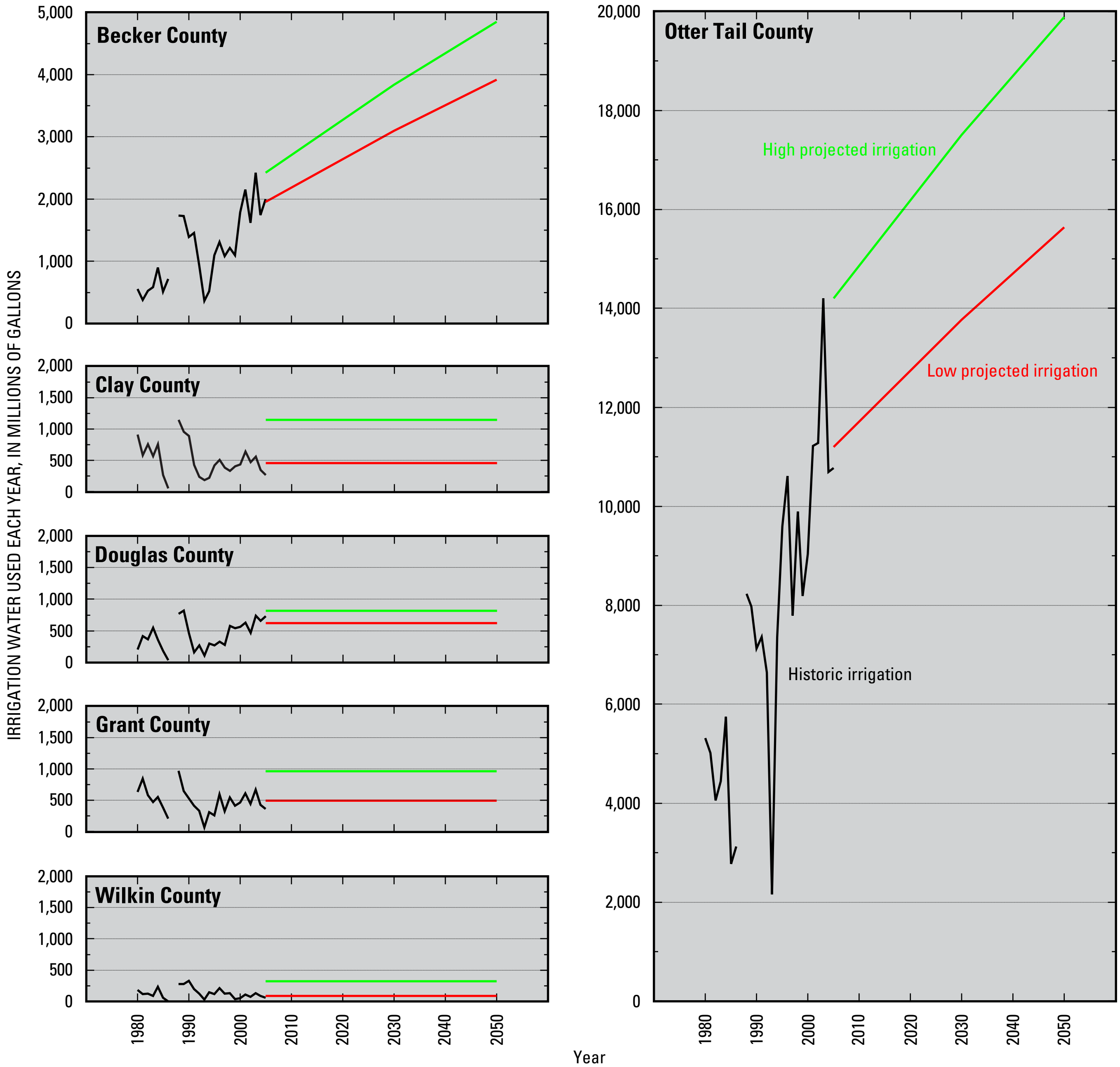

Figure 4. Historic and estimated irrigation water use for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 1980–2050.

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

[Mgal, millions of gallons; Mgal/yr, millions of gallons per year; --, not applicable; acres irrigated in 2002 from National Agricultural Statistics Service (2002); irrigation water used, 2000–2005, from Minnesota Department of Natural Resources water-appropriation data base (Sean Hunt, Minnesota Department of Natural Resources, written commun., 2006); estimated increase in irrigated acreage for Becker and Otter Tail Counties from Bruce Becker, Jeff Norby, and Dean Hendrickson, Natural Resources Conservation Service (personal commun., 2006); ×, multiplied by; ÷, divided by]

	1	2	3	4	5	6	7	8	9	Estimated irrigation water use from ground for 2030 (Mgal)		Estimated irrgation water use from ground water for 2050 (Mgal)	
County	Acres irrigated in 2002	Average ground water used for irrigation 2000–2005 (Mgal/yr)	Maximum ground water used for irrigation 2000–2005, (Mgal/yr)	Maximum ground water used for irrigation 1980–2005, (Mgal/yr)	Average irrigation rate 2000–05, gallons per acre [col. 2 ÷ col. 1]	Maximum irrigation rate 2000–05, gallons per acre [col. 3 ÷ col. 1]	Estimated increase in irrigated acreage, ratio	Estimated irrigated acreage for 2030, acres	Estimated irrigated acreage for 2050, acres [col. 1 × col. 7]	Low estimate	High estimate	Low estimate	High estimate
Becker	4,792	1,964	2,424	2,424	410,000	506,000	2	7,600 [7]	9,600	3,116 [1]	3,846 [3]	3,936 [2]	4,858 [4]
Clay	4,295	454	644	1,146	106,000	150,000	1	4,300	4,300	454 [5]	1,146 [6]	454 [5]	1,146 [6]
Douglas	2,143	644	753	895	301,000	351,000	1	2,100	2,100	644 [5]	895 [6]	644 [5]	895 [6]
Grant	3,716	500	673	1,093	135,000	181,000	1	3,700	3,700	500 [5]	1,093 [6]	500 [5]	1,093 [6]
Otter Tail	56,158	11,278	14,292	14,292	201,000	254,000	1.4	69,200 [7]	78,600	13,909 [1]	17,577 [3]	15,799 [2]	19,964 [4]
Wikin	1,440	93	140	370	65,000	97,000	1	1,400	1,400	93 [5]	370 [6]	93 [5]	370 [6]
Totals	**72,544**	**14,933**	**--**	**--**	**--**	**--**		**88,300**	**99,700**	**18,716**	**24,927**	**21,426**	**28,326**

[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 4.

[7] Linear interpolation of acres irrigated in 2002 and estimated irrigation acreage for 2050.

The average annual usage of ground water for irrigation by well, 2000–2005, is shown in figure 5. As seen in figure 5, the largest withdrawals of ground water are on land overlying the surficial aquifers, both in the number of wells per square mile and the average amount of water withdrawn.

It was 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 or not a field is large enough to be efficiently irrigated, and the preferences of the land owner. Much of this information is not readily available in electronic data bases, and, therefore, it is not feasible to determine the additional irrigated acreage. Finally, regulatory 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 (Jerry Wright, University of Minnesota Agricultural Extension Service; Bruce Becker, Jeff Norby, and Dean Hendrickson, Natural Resources Conservation Service) were asked to estimate how much more land could be irrigated in the six counties by 2050. 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, oral commun., 2006; Bruce Becker, Jeff Norby, and Dean Hendrickson, Natural Resources Conservation Service, oral commun., 2006). As a result, the irrigated acreage in 2002 (National Agricultural Statistics Service, 2002) was used as the irrigated acreage for 2030 and 2050 in these four counties (table 6). Bruce Becker (Natural Resources Conservation Service, oral 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, oral commun., 2006) estimated that irrigated acreage could be expected to double in Becker County by 2050. Therefore, 1.4 times the irrigated acreage in 2002 for Otter Tail County was used as the irrigated acreage for 2050 in Otter Tail County, and twice the irrigated acreage in 2002 for Becker County was used as the irrigated acreage for 2050 in Becker County (table 6). The estimated irrigated acreage for 2030 in Becker and Otter Tail Counties is the proportional increase in irrigated acreage from 2002 to 2050 (table 6).

The average irrigation water used, 2000–2005, for the six counties ranged from 93 Mgal/yr in Wilkin County to 11,278 Mgal/yr in Otter Tail County (table 6). Irrigation water use fluctuates but does not increase between 1980 and 2005 in Clay, Douglas, Grant, and Wilkin Counties (fig. 4). As a result, because there are no better estimates and no apparent trends, the low estimate of water use for 2030 and 2050 for these counties was set equal to the average irrigation water used during 2000–2005 and the high estimate of irrigation water use for 2030 and 2050 was set equal to the maximum annual irrigation water use during 1980–2005 (fig. 4; table 6). The range in estimated 2050 irrigation-water usage from ground water for these counties is 454–1,146 Mgal/yr for Clay County, 644–895 Mgal/yr for Douglas County, 500–1,093 Mgal/yr for Grant County, and 93–370 Mgal/yr for Wilkin County. Irrigation water use increases between 1980 and 2005 in Becker and Otter Tail Counties (fig. 4). A low and a high estimate of irrigation water use was made for each county for 2030 and 2050. The low estimates of irrigation water use in these two counties were calculated by multiplying the estimated acreage for 2030 and 2050 by the average rate of irrigation water use during 2000–2005 (fig. 4; table 6). The high estimates of irrigated water use were calculated by multiplying the estimated acreage by the maximum rate of irrigation water use during 2000–2005 (fig. 4; table 6). The range in estimated 2050 irrigation-water usage from ground water for these two counties is 3,936–4,858 Mgal/yr for Becker County and 15,799–19,964 Mgal/yr for Otter Tail County.

Comparison of Estimated Ground-Water Use With Estimated Recharge to Buffalo, Otter Tail Surficial, and Pelican River Sand-Plain Aquifers

The estimated ground-water use for 2030 and 2050 for the six counties is summarized in table 7. The total estimated 2030 ground-water use for the six counties ranges from 27,826–37,161 Mgal/yr, and the total estimated 2050 ground-water use ranges from 31,313–41,746 Mgal/yr. The estimated ground-water use for 2050 ranges from 5,622–7,198 Mgal/yr for Becker County, 2,405–3,459 Mgal/yr, scenario 1, and 3,344–4,667 Mgal/yr, scenario 2, for Clay County, 3,033–3,686 Mgal/yr for Douglas County, 819–1,466 Mgal/yr for Grant County, 19,070–24,099 Mgal/yr for Otter Tail County, and 304–630 Mgal/yr for Wilkin County.

In addition to the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers, the ground water used in the counties is drawn from two other large aquifers, the Pineland Sands aquifer and Wadena surficial aquifer (fig. 1). 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 water-appropriation permit data base (table 8). It was assumed that these percentages would be the same in 2030 and 2050 (table 9).

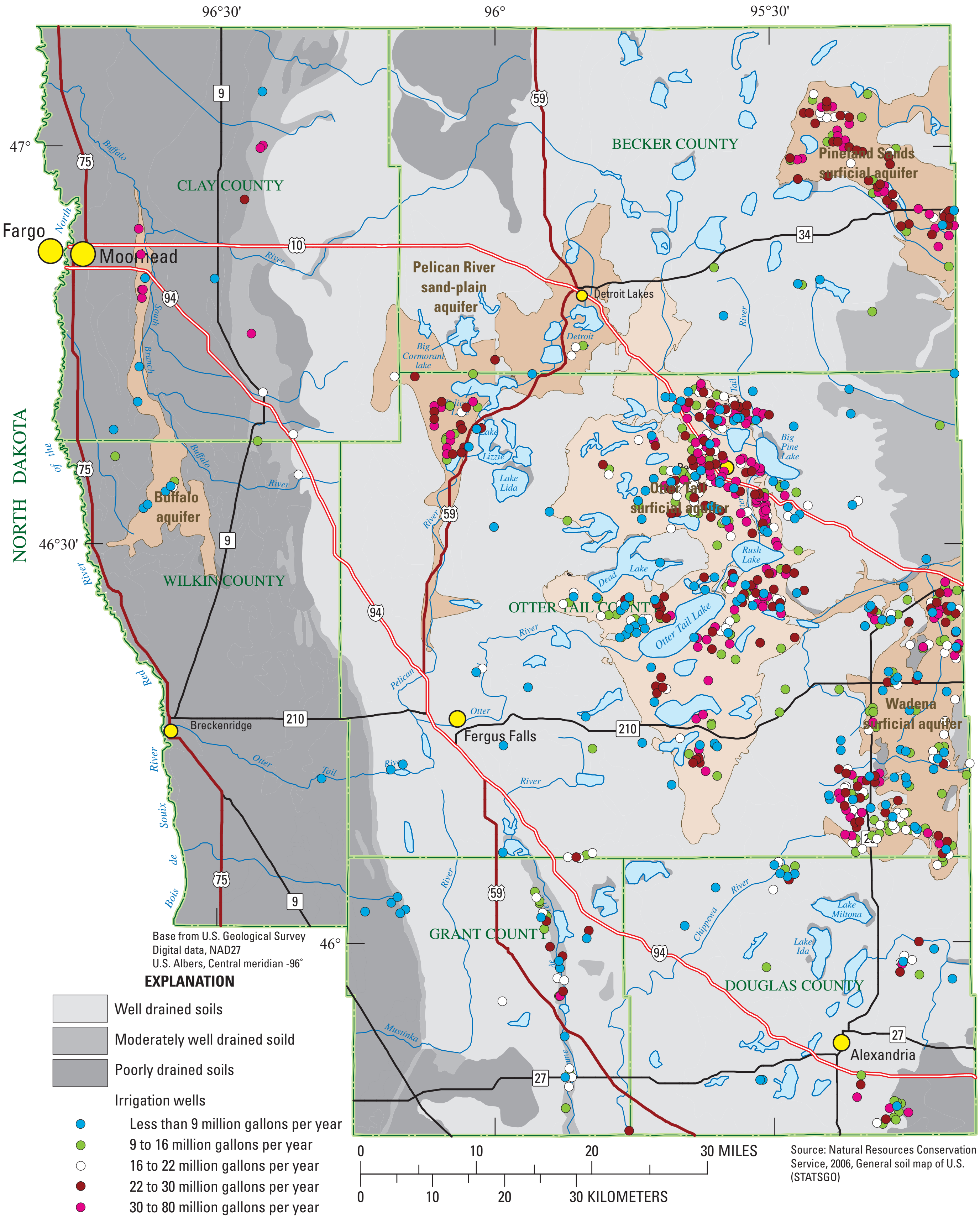

Figure 5. Average rate of ground-water usage per year for irrigation by well, 2000–2005, in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota.

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

[Mgal/yr, millions of gallons per year; gw, ground water; sw, surface water; data from tables 3, 4, and 6]

County	Domestic ground-water use (Mgal/yr)		Commercial ground-water use (Mgal/yr)	Industrial ground-water use (Mgal/yr)		Irrigation ground-water use (Mgal/yr)		Total ground-water use by county (Mgal/yr)	
	Low estimate	High estimate		Low estimate	High estimate	Low estimate	High estimate	Low estimate	High estimate
2030									
Becker	950	1,222	230	411	711	3,116	3,846	4,707	6,009
[1]Clay (current gw/sw ratio)	740	951	307	891	1,006	454	1,146	2,392	3,410
[2]Clay (all gw)	1,505	1,935						3,157	4,394
Douglas	1,180	1,517	498	388	388	644	895	2,710	3,298
Grant	177	227	77	44	44	500	1,093	798	1,441
Otter Tail	1,757	2,259	498	738	1,038	13,909	17,577	16,902	21,372
Wilkin	183	236	32	9	9	93	370	317	647
Total (current gw/sw ratio)	4,987	6,412	1,642	2,481	3,196	18,716	24,927	27,826	36,177
Total (all gw)	5,752	7,396						28,591	37,161
2050									
Becker	1,027	1,321	308	411	711	3,936	4,858	5,682	7,198
[1]Clay (current gw/sw ratio)	597	767	313	1,041	1,233	454	1,146	2,405	3,459
[2]Clay (all gw)	1,536	1,975						3,344	4,667
Douglas	1,408	1,810	593	388	388	644	895	3,033	3,686
Grant	192	246	83	44	44	500	1,093	819	1,466
Otter Tail	1,972	2,536	561	738	1,038	15,799	19,964	19,070	24,099
Wilkin	172	221	30	9	9	93	370	304	630
Total (current gw/sw ratio)	5,368	6,901	1,888	2,631	3,423	21,426	28,326	31,313	40,538
Total (all gw)	6,307	8,109						32,252	41,746

[1] The 2000–2005 ratio between ground water and surface water for domestic water use in Moorhead is assumed to continue through 2050.

[2] All domestic water use in Clay County is assumed to be from ground water.

The recharge to the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers (tables 2 and 9) is 3,707 Mgal/yr, 51,000 Mgal/yr , and 4,900–8,900 Mgal/yr, respectively (Reppe, 2004). The range of the estimated 2050 ground-water withdrawals from the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers is 1,234–1,776 Mgal/yr from the Buffalo aquifer, 11,728–14,820 Mgal/yr from the Otter Tail surficial aquifer, and 3,385–4,298 Mgal/yr from the Pelican River sand-plain aquifer.

The high estimated water withdrawals for 2050 from the Buffalo aquifer (1,776 Mgal) and from the Pelican River sand-plain aquifer (4,298 Mgal) are about one-half of the estimated inflow to the aquifers reported by Reppe (2004) (tables 2 and 9). The high estimated water withdrawal for 2050 from the Otter Tail surficial aquifer, 14,820 Mgal, is about a one-third of estimated inflow to the aquifer reported by Reppe.

This comparison between estimated ground-water withdrawals and recharge to the aquifers does not indicate, for instance, that an additional 30,000 Mgal/yr can be withdrawn from the Otter Tail surficial aquifer in 2050. First, the estimated inflows to the aquifers reported by Reppe (2004) may have large errors. The water budgets for the three aquifers, Buffalo, Otter Tail surficial, and Pelican River sand-plain, were based on decades old and often incomplete data (Reppe, 2004). The steady-state conditions shown in table 2 may not represent drought conditions, which could reduce the ground-water available for use. Second, much of the inflow to the aquifers shown in table 2 is not available for use by municipalities or industry. For example, as shown in table 2, between 39 (1,900/4,900 Mgal/yr) to 56 percent (5,000/8,900 Mgal/yr) of the estimated steady-state inflow to the Pelican River sand-plain aquifer is lost to evapotranspiration and would not be available for use.

Many potential errors are in the estimate of water use for 2030 and 2050 for the six counties. These potential errors are discussed below.

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

[Mgal, millions of gallons. Data from Minnesota Department of Natural Resources appropriation-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)	Percentage of ground water used in county
Becker	17,875	Otter Tail surficial	366	2.0
		Pelican sand-plain	5,687	31.8
		Pineland sands surficial	10,724	60.0
		All three aquifers	**16,777**	**93.8**
Clay	7,185	Buffalo	2,477	34.5
		Pelican sand-plain	235	3.3
		Both aquifers	**2,712**	**37.8**
Douglas	10,173	Wadena surficial	165	1.6
Grant	4,056	None	--	--
Otter Tail	75,367	Otter Tail surficial	45,927	60.9
		Pelican sand-plain	5,780	7.7
		Wadena surficial	14,390	19.1
		All three aquifers	**66,097**	**87.7**
Wilkin	1,298	Buffalo	343	26.4

The estimated ground-water use for 2050 is not a forecast. Estimates show what would be true if the assumptions used to make the estimate were to hold true. By definition estimates are always correct barring a mathematical error in calculating them. A forecast, on the other hand, is the estimate that the analyst believes is most likely to provide an accurate prediction of future water use (Smith and others, 2001, p. 2). Forecasts 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 estimates made in this study cannot be determined.

The average water-use data for the period 2000–2005 from the public survey and water-appropriation permit data bases (tables 1–1 through 1–3), which were used as the basis for the estimates of water use, have several probable errors. First, the data in the data bases do not include self-supplied water (water from privately owned wells). As a result, the estimated water use for 2030 and 2050 may be too low. Second, in the public survey data base the reported water appropriated was often greater than the sum of the water categories in the data base. This is water that is not accounted for or lost in the water-supply system. The difference between water appropriated by the municipal water-supply system and the total reported water use ranged from 0 to 26.2 percent; the average was 10.4 percent. As a result, the estimated water use derived from this data base is probably too low. Finally, there may be errors in both data bases.

The differences in population estimates for 2030 and 2050 were large (table 3), primarily because future migration into and out of the counties could not be accurately forecasted. 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 for these categories. Little information is available to estimate future commercial and industrial water use and, as a result, many assumptions had to be made in the estimations. Irrigation water usage has been historically variable, as shown in figure 4.

Table 9. Estimated withdrawals from the Buffalo aquifer, Otter Tail surficial aquifer, and Pelican sand-plain aquifer, 2030 and 2050.

[Mgal, millions of gallons; Mgal/yr, millions of gallons per year; total inflow to aquifers from Reppe (2004); percent of ground water withdrawn in county from table 8; estimated ground water used in county from table 7]

County	Aquifer	Percentage of ground water withdrawn in county	Water use by aquifer (Mgal)			
			2030		2050	
			Low estimate	High estimate	Low estimate	High estimate
			Estimated ground water used in county			
Becker		--	4,707	6,009	5,682	7,198
			Estimated ground water withdrawn from aquifer			
	Buffalo	0.0	0	0	0	0
	Otter Tail surficial	2.0	94	120	114	144
	Pelican River sand-plain	31.8	1,497	1,911	1,807	2,288
	Total	34.4	1,591	2,031	1,921	2,432
			Estimated ground water used in county			
Clay			3,157	4,394	3,344	4,667
			Estimated ground water withdrawn from aquifer			
	Buffalo	34.5	1,089	1,516	1,154	1,610
	Otter Tail surficial	0.0	0	0	0	0
	Pelican River sand-plain	3.3	104	145	110	154
	Total	37.5	1,193	1,661	1,264	1,764
			Estimated ground water used in county			
Douglas			2,710	3,298	3,033	3,686
			Estimated ground water withdrawn from aquifer			
	Buffalo	0.0	0	0	0	0
	Otter Tail surficial	0.0	0	0	0	0
	Pelican River sand-plain	0.0	0	0	0	0
	Total	0	0	0	0	0
			Estimated ground water used in county			
Grant			798	1,441	819	1,466
			Estimated ground water withdrawn from aquifer			
	Buffalo	0.0	0	0	0	0
	Otter Tail surficial	0.0	0	0	0	0
	Pelican River sand-plain	0.0	0	0	0	0
	Total	0	0	0	0	0

Table 9. Estimated withdrawals from the Buffalo aquifer, Otter Tail surficial aquifer, and Pelican sand-plain aquifer, 2030 and 2050.—Continued

County	Aquifer	Percentage of ground water withdrawn in county	Water use by aquifer (Mgal): 2030 Low estimate	2030 High estimate	2050 Low estimate	2050 High estimate
			Estimated ground water used in county			
			16,902	21,372	19,070	24,099
			Estimated ground water withdrawn from aquifer			
Otter Tail	Buffalo	0.0	0	0	0	0
	Otter Tail surficial	60.9	10,293	13,016	11,614	14,676
	Pelican River sand-plain	7.7	1,301	1,646	1,468	1,856
	Total	70.0	11,594	14,662	13,082	16,532
			Estimated ground water used in county			
			317	647	304	630
			Estimated ground water withdrawn from aquifer			
Wilkin	Buffalo	26.4	84	171	80	166
	Otter Tail surficial	0.0	0	0	0	0
	Pelican River sand-plain	0.0	0	0	0	0
	Total	26.4	84	171	80	166

	Aquifer	Estimated ground-water use by aquifer (Mgal): 2030 Low estimate	2030 High estimate	2050 Low estimate	2050 High estimate	Total sources (inflows) of water to the aquifer (Mgal/yr)
All counties	Buffalo	1,173	1,687	1,234	1,776	3,707
	Otter Tail surficial	10,387	13,136	11,728	14,820	51,000
	Pelican River sand-plain	2,902	3,702	3,385	4,298	4,900–8,900

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 ratio 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. Most of the ground water used in the six counties is used for irrigation. Changing patterns in climate, changes in the crops grown, changes in the economics of irrigation, or new, competing use, for the ground water could reduce the demand for irrigation and, thereby, reduce the water used for irrigation. This analysis also assumed that the percentage of ground water withdrawn in 2000–2005 within a county from each aquifer would remain the same in 2050. It is probable that that these percentages will change. Finally, it was outside of the scope of this study to project probable climate changes and to estimate the effects of possible climate change on future water use.

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, Minn. In order to evaluate these alternatives the Reclamation needs estimates of ground-water use for 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 ground-water use in these counties for 2030 and 2050.

The results of this study were based on published reports and other publicly available information. Water-use trend estimates were based on existing water-use information and trends in population, industry, and agriculture. The estimates of ground-water use for 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. 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 82 percent of the reported ground water used in the 6 years from 2000 to 2005 was used for irrigation of major crops. The next significant use of ground water was public water supply for domestic use, between 13 and 19 percent of the reported ground-water use. Together they accounted for 90 to 95 percent of the appropriated ground water in the 6 years.

Domestic water use for 2030 and 2050 was estimated by multiplying the estimated population in the six counties for 2030 and 2050 by an estimated rate of domestic water use in gallons per person per day (gal/p/d). Population of the six counties for 2030 and 2050 was estimated by the Minnesota State Demographic Center, the Bureau of Reclamation, and this study. Two per capita water use rates were used in this study, 70 and 90 gal/p/d. The range for 2050 domestic water use from ground water is estimated to be 1,027–1,321 million gallons per year (Mgal/yr) for Becker County; 597–767 Mgal/yr, scenario 1, or 1,536–1,975 Mgal/yr, scenario 2, for Clay County; 1,408–1,810 Mgal/yr for Douglas County; 192–246 Mgal/yr for Grant County; 1,972–2,536 Mgal/yr for Otter Tail County; and 172–221 Mgal/yr for Wilkin County.

Commercial water use data for 2000–2005 were obtained from the survey of public-water suppliers and the water-appropriation permit data base. Commercial water use was assumed to increase proportionately with population increases. The estimated 2050 commercial water use from ground water is 308, 313, 593, 83, 561, and 30 Mgal/yr for Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, respectively.

Industrial water use data for 2000–2005 was obtained from the survey of public-water suppliers and the water-appropriation permit data base. It was assumed in this study that industrial water use would not increase for 2050 above the average industrial water use from ground water for 2000–2005 in Douglas, Grant, and Wilkin Counties of 388, 44, and 9 Mgal/yr, respectively. For Becker and Otter Tail Counties, it was assumed that industrial water use would either be the average of 2000–2005 industrial water use for the low estimate or the average plus 300 Mgal/yr for the high estimate. The range of estimated industrial water use from ground water for 2050 is 411–711 Mgal/yr for Becker County and 738–1,038 Mgal/yr for Otter Tail County. Reclamation's low estimate for additional industrial water use for 2050 in Clay County was 375 Mgal/yr and its high estimate was 567 Mgal/yr. The estimated industrial water use for Clay County for 2050 from ground water, 1,041 to 1,233 Mgal/yr, was assumed to be the average industrial water use for 2000–2005 plus Reclamation estimates of increased water usage.

Irrigated acreage is not expected to increase in Clay, Douglas, Grant, and Wilkin Counties by 2050. The lower estimation of irrigation for 2050 for these counties is the average of irrigated water use during 2000–2005. The higher estimation of irrigation for these counties is the maximum irrigation water used between 1980 and 2005. The range in estimated 2050 irrigation-water usage from ground water for these counties is 454–1,146 Mgal/yr for Clay County, 644–895 Mgal/yr for Douglas County, 500–1,093 Mgal/yr for Grant County, and 93–370 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 from ground water for these two counties is 3,936–4,858 Mgal/yr for Becker County and 15,799–19,964 Mgal/yr for Otter Tail County.

The total estimated 2030 ground-water use for the six counties ranges from 27,826–37,161 Mgal/yr, and the total estimated 2050 ground-water use ranges from 31,313–41,746 Mgal/yr. The range in total estimated 2050 ground water use for Becker County is 5,622–7,198 Mgal/yr, for Clay County is 2,405–3,459 Mgal/yr, scenario 1, and 3,344–4,667 Mgal/yr, scenario 2, for Douglas County is 3,033–3,686 Mgal/yr, for Grant County is 819–1,466 Mgal/yr, for Otter Tail County is 19,070–24,099 Mgal/yr, and for Wilkin County is 304–630 Mgal/yr.

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

The range of the estimated 2050 ground-water withdrawals from the Buffalo, Otter Tail surficial, and Pelican River sand-plain aquifers is 1,234–1,776 Mgal/yr from the Buffalo aquifer, 11,728–14,820 Mgal/yr from the Otter Tail surficial aquifer, and 3,385–4,298 Mgal/yr from the Pelican River sand-plain aquifer. The comparison between estimates of ground-water use for 2030 and 2050 with estimates of aquifer recharge was for illustrative purposes .

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Appendix 1. Supplemental Water-Use Data

Table 1–1. Average domestic water use for public suppliers in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2000–2005.

[Average water use rounded to nearest 1,000 gallons; data from Minnesota Department of Natural Resources survey of public-water suppliers (Sean Hunt, Minnesota Department of Natural Resources, written commun., 2006)]

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

Table 1–2. Average commercial, industrial, agricultural, and other water uses for public water suppliers in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2000–2005.

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

Name of public-water supplier	First year of period	Last year of period	Number of years with record of commercial 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 agricultural 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
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	--	--	--	--	--	--	--	--

Table 1–3. Water use by category for major water users in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2000–2005.

[All values in million gallons per year, --, not reported; data from the Minnesota Department of Natural Resources water-appropriation permit data base (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

Table 1–3. Water use by category for major water users in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 2000–2005.—Continued

		Becker	Clay	Douglas	Grant	Otter Tail	Wilkin	Total
2002								
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								
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	--	49.1	--	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

Table 1–3. Water use by category for major water users in Becker, Clay, Douglas, Grant, Otter Tail, and Wilkin Counties, Minnesota, 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