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TRENDS IN WATER USE IN THE UPPER MIDWEST*

by

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ABSTRACT: This report traces the demand for water in various sectors of the economy of six Upper Midwest States of the United States. Expected trends in water demand are projected. The conclusions show that for the period from 1960 to 1985 the annual rate of increase for the demand for water withdrawals in each of the six Upper Midwest States increased between 1.3 percent to 2.4 percent for the mountain states and between 3.3 and 5.1 percent for the plains states.

* This report is the fourth in a series of four reports concerning water institutions, laws, and use trends in South Dakota and the Upper Midwest states. The four reports are entitled:

"Water Institutional Structure in South Dakota" Economics Research Report 91-5 Economics Department South Dakota State University August 1991;
"Water Use Trends in South Dakota" Economics Research Report 91-6 Economics Department South Dakota State University August 1991;
"Water Institutional Structure in the Upper Midwest" Economics Research Report 92-2 Economics Department South Dakota State University June 1992;
"Trends in Water Use in the Upper Midwest" Economics Research Report 92-3 Economics Department South Dakota State University May 1992.

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INTRODUCTION

The upper Great Plains and Mountain States of the United States withdraws a substantial quantity of water, exceeding 40 billion gallons of water per day (45 million acre feet of water per year). Primary uses are irrigation, domestic, and industrial. The amount of water used is increasing as population grows, as more users exercise water rights, as farmers implement the use of irrigation to reduce risk, and as the state's economies become more diverse. Within the upper midwest there is both geographic and temporal variability of water supply, resulting in various degrees of scarcity relative to the quantities demanded. The allocation method for the available water must be appropriate for these variations.

The Upper Midwest region, defined here as the states of Montana, Wyoming, Colorado, North Dakota, South Dakota, and Nebraska, is a semi-arid area comprising of cropland, large open prairie and majestic mountains. Each state differ in their basic approach to water use. Some states favor more mobile resources and thus more immediate economic benefit, while others favor more regulation in favor of conservation, at the expense of economic return. Also, states differ as to the degree of need of aggressive, new water laws, based on the supply and demand situation in the state. For these reasons, it becomes apparent that the legal situation of water allocation is largely a reflection of the conditions of the state and advance only upon need.

The laws of states such as California, Arizona, and New Mexico reflect greater water mobility as a result of water shortages and more aggressive water use plans. Northwestern and central states such as the Dakotas, Wyoming, and Montana are in less advanced water allocation environments probably because they have more rain, smaller populations and smaller, less diverse economies. Leaders of these states should recognize that, in the long run, the circumstances of water scarcity that the southwestern states are confronting now are somewhat inevitable in their own states as population and economic growth occurs. Therefore, implementation of water laws that are appropriate for these conditions and that are proven successful should occur.

TRENDS IN WATER DEMAND

An analysis of the growth rates of the various water user sectors of within a state illustrates the changing demand for water. A comparison between six regional states allows the development of regional water use patterns that will help in the assessment of future water demands in the region.

Description of the Sectors of Water Use

The focus of the growth rate analysis of water use data will be in the categories of population, total water use, water delivered for irrigation, rural water for domestic and livestock water use, public supplied water withdrawals, and total self supplied industrial water use. These categories represent the combination of the most reliable data and the breadth of water uses necessary to make conclusions regarding regional and statewide demand for water. The term "water use" is defined as withdrawals of water and consumptive use of water. Consumptive use of water is that part of withdrawn water that is evaporated, transpired, and/or "consumed" into products or humans so that the water is removed from water environment system.

The data are divided into four sectors of water use: irrigation, rural, public supplied and self supplied. These sectors represent the categories of all uses of water as defined by the U.S. Geological Survey (U.S. Department of the Interior, 1988). The sectors are defined as:

> Irrigation water - "artificial application of water on lands to assist in the growing of crops and pastures or to maintain vegetative growth in recreational lands, such as parks and golf courses".

> Rural water - "water used in suburban or farm areas for domestic and livestock needs. The water generally is self supplied and includes domestic use, drinking water for livestock, and other uses, such as dairy sanitation, evaporation from stock-watering ponds, and cleaning and waste disposal".

> Public supplied - "water withdrawn by public and private water suppliers and delivered to groups of users. Public suppliers provide water for a variety of uses, such as domestic, commercial, thermoelectric power, industrial, and public water use".

> Public water - "water supplied from a public water supply and used for such purposes as fire fighting, street washing, and municipal parks and swimming pools".

> Self supplied water - water withdrawn from a surface or ground water source by a user rather than being obtained from a public supply.

> Industrial water - "water used for industrial purposes such as fabrication, processing, washing, and cooling, and includes such industries as steel, chemical and allied products, mining, and petroleum refining. The water may be obtained from a public supply or may be self supplied".

The water use sector that has the greatest impact on the total use of water in the western states is irrigation. An understanding of the farm sector is important in comprehending the trend of irrigation water use. The Farm Data consist of an analysis of the growth in several farm related categories defined by the U.S. Department of Commerce in the Census years from 1940 to 1987: the number of farms, harvested acres, irrigated farms, acres irrigated and irrigated cropland harvested. The categories are defined as:

> "Farms" - the total number of farms in the state that year.

> "Harvested acres" - the total number of acres harvested on the farms.

> "Irrigated farms" - the number of farms where irrigation was used on some portion of the land during that year.

"Acres irrigated" - the total number of acres that were irrigated on the irrigated farms.

"Irrigated cropland harvested" - the total number of acres of irrigated cropland that was harvested.

These categories represent direct and indirect indicators of substantial change in water use. For instance, an increase in the number of irrigated farms while the total number of farms decreases, indicates an increase in the proportion of existing farms that use irrigation. All of these factors relate to indirect indicators of water use. When combined with the irrigation Water Use Data, a more accurate projection of water use can be made. Irrigation accounts for over two-thirds of the water use in the state. Therefore, its impact on the overall trend of water use is substantial.

Current Water Use

Recent water use rates by sector and state are given in Tables 1 and 2. The quantity of water differs dramatically from state to state and from region to region, as well as between sectors in the economy of each state. Note from the tables that one acre foot of water is approximately 326,000 gallons thus one million gallons per day translates roughly to three acre feet of water per day or 1,120 acre feet per year.

Trends

An exponential growth function is used to project the trends of water use. The dependent variables include, among others, the sectors described above, such as, water delivered for irrigation, self supplied water, and public supplied water. The independent variable is the progression of time, i.e., the census year. The data used in this analysis are obtained from the Census of Agriculture collected every several years by the U.S. Department of Commerce, thus, representing a sample of the total data. The estimated least

Table 1: Water Use Data for 1985
(millions gallons per day unless otherwise noted)

Sector of Water Use	South Dakota	North Dakota	Nebraska	Montana	Wyoming	Colorado
General						
population (thousand)	706	688	1,605	823	509	3,231
water use per capita (gal/day)	956	1,690	6,250	10,500	12,200	4,190
total water withdrawals	675	1,160	10,000	8,650	6,220	1,360
total water consumed	361	201	4,910	1,900	2,670	4,850
Irrigation Sector						
water delivered (1000 ac ft/yr)	516	173	8,140	9,310	6,340	13,900
water consumed (1000 ac ft/yr)	313	139	5,220	1,980	2,870	5,120
Rural Sector						
domestic & livestock use	124	76	293	156	90	534
domestic & livestock consumption	66	40	203	100	46	175
Public Supplied Sector						
total water withdrawals	80	69	248	158	98	737
water withdrawal per capita (gal/day)	147	135	187	257	298	245
water delivered for:						
industrial & commercial use	19.4	16.3	99	30.2	17.2	130
domestic & public use	61	53	149	128	79	594
Self Supplied Industrial Sector						
total water use	71.2	905	2,377	127	422	321
total water consumption	15.1	35	31.8	54	64	36
thermoelectric use	4.3	892	2,210	67	238	110
thermoelectric consumption	0.1	23	1.8	18	38	37
other industry use	66.9	13	167	60	184	211
other industry consumption	15	12	30	36	26	49

Source: U.S. Department of the Interior. Geological Survey. 1988.

Table 2: Farm Data for 1987

Category of Farm Data	South Dakota	North Dakota	Nebraska	Montana	Wyoming	Colorado
farms	36,376	35,289	60,502	24,568	9,205	27,284
harvested acres (thousands)	12,983	18,364	15,276	9,128	1,717	5,522
irrigated farms	1,869	809	22,596	9,520	5,221	14,916
acres irrigated (thousands)	362	168	5,682	1,997	1,518	3,014
irrigated cropland harvested (thousands)	351	162	5,562	1,542	1,132	2,442

Source: U.S. Department of Commerce. Bureau of the Census. 1989.

squares method is used to predict the coefficient value of the independent variable. The specific functional relationship of the model is of the form:

$Y = ae^{bX}$ where Y = dependent variable (i.e., water use by sector)
a = constant
e = exponential
b = X-coefficient (growth rate)
X = independent variable (the census year)

$$\ln Y = \ln a + bX$$
$$d(\ln Y) = d(\ln a) + d(bX)$$
$$d(\ln Y)/dX = b = (\text{percent change } Y)/(\text{change } X)$$

Using ordinary least squares, the results of each regression analysis include the X-coefficient, the R-square, and the level of significance. The X-coefficient is the most important result of the model. The independent variable, the census year, for each of the dependent variables, is regressed such that the X-coefficient, b, results. This coefficient, when multiplied by 100, results in an annual percent rate of growth of the dependent variable, or category. The growth rate of the dependent variable is proportional to the unit change in the independent variable. Predictions of future growth of the dependent variable are based on the X-coefficient and the degree of reliability of the data.

The R-square is a measure of the proportion of the variation in the dependent variable explained by the explanatory or independent variable. A high R^2 (roughly greater than 0.6) indicates a strong predictive capacity of the dependent variable by the independent variable. The level of significance (based on the probability of the t-statistic is different than zero) is a measure of the reliability of the X-coefficient.

The regression analysis results are reported in Tables 3 to 14. There are two tables for each state. The tables consist of the results of the state by state water use analysis and farm regression analysis. The tables are identical in structure for each state. For example, in Table 3, the X-coefficient value for population indicates a 0.14 percent increase in population in South Dakota per year. The R-square value, 0.4122 indicates the X-coefficient's goodness-of-fit. The level of significance (the t-test statistic) is 0.20.

Another example is the category public supplied water delivered for industrial and commercial uses in South Dakota. The X-coefficient indicates a 4.48 percent increase in this category's use of water per year. The R-square goodness-of-fit value is 0.5555. The level of significance is at the 0.10 level. The Farm Data Analysis tables display rates of change per year for farm size, harvest and irrigation data.

Plains States

South Dakota

The rate of use of water in South Dakota is increasing in all water use sectors (See Table 3). Per capita water use is increasing as a result of slow population growth and significant increases in the use of water, particularly in the following sectors: water delivered for irrigation, public supplied water delivered for industrial and commercial use, and self supplied industrial water for thermoelectric use. All sectors and subsectors show increases in the use of water. The only decrease is in self supplied industrial water consumption for thermoelectric use. This may suggest an increase in the efficiency of thermoelectric use of water.

The total number of farms and the total number of acres in farms are decreasing in South Dakota (See Table 4). The number of irrigated farms, acres irrigated and acres of irrigated cropland harvested are increasing. The

Table 3: Water Use Analysis for South Dakota

Sector of Water Use	X-coefficient	R-squared	level of significance
General			
population	0.00137	0.4122	0.20
water use per capita	0.02333	0.7855	0.02
total water withdrawals	0.03275	0.7950	0.02
total water consumed	0.03138	0.8084	0.02
Irrigation Sector			
water delivered	0.04386	0.8933	0.01
water consumed	0.04631	0.8484	0.01
Rural Sector			
domestic & livestock use	0.00303	0.0079	> 0.20
domestic & livestock consumption	0.02936	0.2680	0.20
Public Supplied Sector			
total water withdrawals	0.02080	0.7240	0.05
water withdrawal per capita	0.01039	0.3609	> 0.20
water delivered for:			
industrial & commercial use	0.04475	0.5555	0.10
domestic & public use	0.01651	0.2826	> 0.20
Self Supplied Industrial Sector			
total water use	0.04078	0.2099	> 0.20
total water consumption	0.01780	0.1105	> 0.20
thermoelectric use	0.07253	0.6895	0.05
thermoelectric consumption	-0.03611	0.0687	> 0.20
other industry use	0.03852	0.1778	> 0.20
other industry consumption	0.01325	0.0288	> 0.20

Table 4: Farm Data Analysis for South Dakota

Category of Farm Data	X-coefficient	R-squared	level of significance
farms	-0.01627	0.9869	0.01
harvested acres	-0.00277	0.1208	> 0.20
irrigated farms	0.01886	0.7624	0.01
acres irrigated	0.04337	0.9305	0.01
irrigated cropland harvested	0.04572	0.9449	0.01

individual rates at which this is occurring indicate that farms using irrigation are irrigating more acres of their land each year, resulting in a significant increase in the number of acres of irrigated harvested cropland. The annual growth rate in the number of acres of irrigated cropland harvested was 2.4 times the growth rate in the number of irrigated farms. Similarly, for each one percent growth in irrigated acres, there was a 1.05 percent growth in the irrigated cropland harvested. The growth rate of irrigation cropland harvested is greater than the growth rate of irrigated acres, suggesting an increase in the productivity of irrigated land. Irrigation is a significant influence in the determination of farm income and risk minimization and stability.

In summary, the demand for water in South Dakota is increasing at a significant rate. All water using sectors are increasing their demand for water. As the largest water use sector in South Dakota, irrigation water use is sensitive to shortages of water.

North Dakota

Water use in North Dakota is increasing at a rapid rate (See Table 5). The primary sources of growth are in the subsectors thermoelectric self supplied industrial water use and industrial and commercial public supplied water use. These uses are heavily influenced by urban growth and economic industrialization.

As the single largest user of water, the irrigation sector has a significant impact on total water demand in North Dakota. The farm sector trend indicates the total number of farms is decreasing but the number of farms using irrigation is increasing, thus, continued increases in the rate of irrigation water use is expected (See Table 6). Also, as irrigation is

Table 5: Water Use Analysis for North Dakota

Sector of Water Use	X-coefficient	R-squared	level of significance
General			
population	0.00247	0.2993	> 0.20
water use per capita	0.07324	0.8906	0.01
total water withdrawals	0.08063	0.8969	0.01
total water consumed	0.02964	0.5761	0.10
Irrigation Sector			
water delivered	0.02704	0.4189	0.20
water consumed	0.03760	0.5259	0.20
Rural Sector			
domestic & livestock use	-0.00549	0.2254	> 0.20
domestic & livestock consumption	-0.01100	0.5219	0.20
Public Supplied Sector			
total water withdrawals	0.03191	0.9291	0.20
water withdrawal per capita	0.01580	0.6720	0.05
water delivered for:			
industrial & commercial use	0.07435	0.7066	0.05
domestic & public use	0.02577	0.8056	0.02
Self Supplied Industrial Sector			
total water use	0.15231	0.8506	0.01
total water consumption	0.10005	0.9109	0.01
thermoelectric use	0.17276	0.8265	0.02
thermoelectric consumption	0.11500	0.7879	0.10
other industry use	-0.00165	0.0019	> 0.20
other industry consumption	0.08031	0.7673	> 0.20

Table 6: Farm Data Analysis for North Dakota

Category of Farm Data	X-coefficient	R-squared	level of significance
farms	-0.01661	0.9918	0.01
harvested acres	0.00042	0.0050	> 0.20
irrigated farms	0.02155	0.6618	0.01
acres irrigated	0.04668	0.9574	0.01
irrigated cropland harvested	0.04670	0.9422	0.01

applied more prevalently, the number of acres of irrigated cropland harvested increases. As the North Dakota economy expands and diversifies, continued increases in water use can be expected. The farm sector changes impacting the use of irrigation water suggest continued increases in agricultural demand. Urbanization and industrialization are important factors in the economic diversification of North Dakota.

Nebraska

The state of Nebraska is experiencing significant growth in the use of water (See Table 7). All four sectors of water use are increasing. Combined with a very low population growth rate, the increases in water demand result in an increase in per capita water use. The sectors with the greatest increases in the use of water are irrigation and self supplied industry. Both subsectors of self supplied industry are growing. The rural and public supplied sectors, particularly the domestic and public use subsector, are increasing water use.

Increases in the number of irrigated farms, acres irrigated and irrigated cropland harvested indicate that the use of irrigation is spreading, both to new farms and to new acres on farms already with some irrigation (See Table 8). As with North Dakota, the total number of farms is decreasing, the relative number of farms using irrigation is increasing. Irrigated cropland harvested is increasing at a 2.07 percent rate faster than irrigated farms (0.05697 divided by 0.02751).

Growth in water use in such diverse sectors, particularly in the largest sector, irrigation, can be expected to continue. The demand for water in Nebraska will increase.

Table 7: **Water Use Analysis for Nebraska**

Sector of Water Use	I-coefficient	R-squared	level of significance
General			
population	0.00510	0.9955	0.01
water use per capita	0.03751	0.8467	0.01
total water withdrawals	0.05112	0.9016	0.01
total water consumed	0.06076	0.7346	0.05
Irrigation Sector			
water delivered	0.05294	0.8456	0.01
water consumed	0.06200	0.7240	0.05
Rural Sector			
domestic & livestock use	0.02411	0.8313	0.02
domestic & livestock consumption	0.02908	0.9713	0.01
Public Supplied Sector			
total water withdrawals	0.01788	0.6339	0.10
water withdrawal per capita	0.00791	0.2250	> 0.20
water delivered for:			
industrial & commercial use	0.00734	0.0737	> 0.20
domestic & public use	0.02568	0.5197	0.20
Self Supplied Industrial Sector			
total water use	0.05485	0.8734	0.01
total water consumption	0.09285	0.7535	0.05
thermoelectric use	0.05529	0.8531	0.01
thermoelectric consumption	0.04998	0.1554	> 0.20
other industry use	0.04434	0.6187	0.10
other industry consumption	0.07701	0.4288	0.20

Table 8: Farm Data Analysis for **Nebraska**

Category of Farm Data	I-coefficient	R-squared	level of significance
farms	-0.01632	0.9816	0.01
harvested acres	-0.00463	0.4412	0.05
irrigated farms	0.02751	0.8440	0.01
acres irrigated	0.05776	0.9695	0.01
irrigated cropland harvested	0.05697	0.9655	0.01

Summary of the Plains States

The three Plains States have similar water use data and trends. Population growth is similar among the Plains states. All three exhibit slow, yet stable growth in population, ranging from 0.14 to 0.51 percent per year. Overall water withdrawal is increasing rapidly, from 3.28 to 8.06 percent per year. The sectors influencing this growth are primarily irrigation, public supplied and self supplied. The sector of greatest impact on the growth of water use in these states is irrigation. In all three states irrigation accounts for over half of the water used. The agricultural economy is the chief benefactor in all three states, emphasizing the importance of the irrigation sector. There is consistent growth in the number of irrigated farms (1.88 to 2.75 percent per year), irrigated acres (4.34 to 5.78 percent per year), and in irrigated cropland harvested (4.57 to 5.70 percent per year). This suggests that in the Plains States the use of irrigation and the production on irrigated land are increasing at similar rates. The impacts of the relative uniform regional increases in irrigation trends suggest a probability of similar trends of agricultural practice of irrigation water use in all three states. The combined effect of industrialization, urbanization, and increases in the use of irrigation suggest continued increases in future demand for water in this region.

Mountain States

Montana

The annual trend of water use in the state of Montana is increasing (see Table 9). The population is growing at a low rate. The combined result of these changes in water use and population is a slight increase in per capita water use. The sectors responsible for the increasing use of water are

Table 9: Water Use Analysis for Montana

Sector of Water Use	X-coefficient	R-squared	level of significance
General			
population	0.00758	0.7747	0.05
water use per capita	0.00731	0.1040	> 0.20
total water withdrawals	0.02375	0.5696	0.10
total water consumed	-0.02046	0.2338	> 0.20
Irrigation Sector			
water delivered	0.02558	0.6147	0.10
water consumed	-0.02184	0.2433	> 0.20
Rural Sector			
domestic & livestock use	0.02620	0.6890	0.05
domestic & livestock consumption	0.04250	0.8744	0.02
Public Supplied Sector			
total water withdrawals	0.01707	0.8479	0.01
water withdrawal per capita	0.00626	0.3096	> 0.20
water delivered for:			
industrial & commercial use	0.02779	0.4301	0.20
domestic & public use	0.01243	0.3464	> 0.20
Self Supplied Industrial Sector			
total water use	-0.00994	0.0863	> 0.20
total water consumption	0.02815	0.2600	> 0.20
thermoelectric use	0.03037	0.2703	> 0.20
thermoelectric consumption	0.40943	0.8235	> 0.20
other industry use	-0.03735	0.7618	0.05
other industry consumption	0.00682	0.0257	> 0.20

Table 10: Farm Data Analysis for Montana

Category of Farm Data	X-coefficient	R-squared	level of significance
farms	-0.01260	0.8943	0.01
harvested acres	0.00706	0.6920	0.01
irrigated farms	-0.01120	0.8468	0.01
acres irrigated	0.00503	0.6841	0.01
irrigated cropland harvested	0.00216	0.3922	0.10

irrigation, rural, and public supplied. The self supplied water use sector is decreasing, reflecting a decreasing rate in the other industry subsector.

The public supplied domestic and public subsector, and rural subsector are growing faster than the population. Domestic uses are accounting for a significant portion of the overall growth. The industrial and commercial subsector is growing at a significant rate, indicating diversification of the Montana economy.

Both, the number of irrigated farms is decreasing at approximately the same rate as the total number of farms (See Table 10). However, the number of acres irrigated is increasing slightly, as are the number of acres of irrigated cropland harvested. The rate of growth of the acres irrigated is about twice the rate of growth of the acres of irrigated cropland harvested, suggesting that some of the newly irrigated acres are not harvested or are used as irrigated pasture. Combined with the similar decreasing rates of total numbers of farms and increasing harvested acres so that farm size is getting larger, irrigation alone appears to have little affect on the survival of farms in Montana.

The demand for water in Montana is increasing slightly, due to small increases in use in the irrigation sector and the population affected sectors, rural and public supplied. A similar rate of growth can be expected in the future.

Wyoming

The use of water is increasing in Wyoming (See Table 11). All sectors of water use are growing. The population is growing at a faster rate than the overall water use such that a slight decrease in per capita water use exists.

Table 11: **Water Use Analysis for Wyoming**

Sector of Water Use	X-coefficient	R-squared	level of significance
General			
population	0.01974	0.8891	0.01
water use per capita	-0.00925	0.2396	> 0.20
total water withdrawals	0.02016	0.5375	0.10
total water consumed	0.01115	0.7240	0.05
Irrigation Sector			
water delivered	0.01960	0.4791	0.20
water consumed	0.01154	0.7207	0.05
Rural Sector			
domestic & livestock use	0.00966	0.6177	0.10
domestic & livestock consumption	0.00241	0.0420	> 0.20
Public Supplied Sector			
total water withdrawals	0.02340	0.6142	0.10
water withdrawal per capita	0.00561	0.0825	> 0.20
water delivered for:			
industrial & commercial use	0.01948	0.6780	0.05
domestic & public use	0.02416	0.5302	0.20
Self Supplied Industrial Sector			
total water use	0.04033	0.8954	0.01
total water consumption	0.09558	0.9019	0.01
thermoelectric use	0.03362	0.6985	0.05
thermoelectric consumption	0.15899	0.9265	0.01
other industry use	0.05167	0.8784	0.01
other industry consumption	0.05751	0.7381	0.05

Table 12: Farm Data Analysis for Wyoming

Category of Farm Data	X-coefficient	R-squared	level of significance
farms	-0.01170	0.7777	0.01
harvested acres	0.00099	0.0536	> 0.20
irrigated farms	-0.01242	0.8494	0.01
acres irrigated	0.00435	0.5906	0.01
irrigated cropland harvested	0.00267	0.4566	0.05

The sectors of most significant growth are public supplied and self supplied water uses, particularly in the domestic and public subsector of public supplied water use and the other industry subsector of self supplied water use. Rural use is increasing at a low rate.

The irrigation water use sector is growing, too (See Table 12). The amount of water used in this capacity is heavily influenced by several factors. Wyoming is indicating similar trends as Montana with respect to numbers of farms an irrigated farms. The number of irrigated farms is decreasing at the same rate as the total number of farms. As like Montana, the number of acres irrigated is increasing at twice the rate as the number of acres of irrigated cropland harvested.

The rate of increase in water use in Wyoming is stimulated largely by population growth and industrialization. The data indicate that the demand for water can be expected to continue rising slowly. There are no indications of a reduction of water use in any sector.

Colorado

The demand for water in Colorado is increasing at a low rate (See Table 13). Significant growth is occurring in the public supplied sector, particularly in the domestic and public subsector, and in the rural sector. The population is growing at a rate approximately twice that of water use thereby indicating per capita water use is decreasing. Population growth causes the majority of the increase in water use.

Irrigation water use is increasing slightly. The Farm Data indicate stabilization in the rate of irrigation water usage (See Table 14). The number of irrigated farms is decreasing at approximately the same rate as the total number of farms. Very similar to Wyoming and Montana. Additionally,

Table 13: Water Use Analysis for Colorado

Sector of Water Use	X-coefficient	R-squared	level of significance
General			
population	0.02467	0.9989	0.01
water use per capita	-0.01438	0.5075	0.20
total water withdrawals	0.01338	0.4200	0.20
total water consumed	-0.00866	0.2061	> 0.20
Irrigation Sector			
water delivered	0.01138	0.3439	> 0.20
water consumed	-0.01075	0.2385	> 0.20
Rural Sector			
domestic & livestock use	0.04739	0.5040	0.20
domestic & livestock consumption	0.03193	0.7673	0.10
Public Supplied Sector			
total water withdrawals	0.03581	0.9673	0.01
water withdrawal per capita	0.00816	0.6518	0.10
water delivered for:			
industrial & commercial use	0.01513	0.5197	0.20
domestic & public use	0.03937	0.9535	0.01
Self Supplied Industrial Sector			
total water use	0.15683	0.1255	0.01
total water consumption	0.04616	0.6287	0.10
thermoelectric use	-0.00807	0.1557	> 0.20
thermoelectric consumption	0.09065	0.6516	0.10
other industry use	0.02848	0.2415	> 0.20
other industry consumption	0.02498	0.5434	0.10

Table 14: Farm Data Analysis for Colorado

Category of Farm Data	X-coefficient	R-squared	level of significance
farms	-0.01525	0.8552	0.01
harvested acres	0.00083	0.0132	> 0.20
irrigated farms	-0.01649	0.8955	0.01
acres irrigated	0.00543	0.5268	0.02
irrigated cropland harvested	0.00578	0.4602	0.05

there is a strong relationship between the number of irrigated acres and the number of acres of irrigated cropland harvested. Suggesting that little unused irrigated acreage is not harvested or left for pasture.

No significant relationships exist suggesting any reason for change in irrigation water use. An apparent equilibrium level of water use is being reached. Water restrictions or shortages could contribute to this observation. The population-influenced uses of water are the primary sources of change in water demand in Colorado. As the population increases, so too should the rate of water use.

Summary of the Mountain States

Among the Mountain states several sectors have similar growth rates. These states have experienced moderate population growth from 1940 to 1987, ranging from 0.76 percent to 2.47 percent per year. Total water use has grown 1.34 percent to 2.38 percent per year. Rural water use has grown from 0.97 percent to 4.74 percent per year. The public supplied water use sector has grown between 1.71 percent and 3.58 percent per year. Both public supplied subsectors have similar growth patterns. The industrial and commercial subsector has increased water use by 1.51 percent to 2.78 percent per year, the domestic and public subsector has increased by 1.24 percent to 3.94 percent per year and the irrigation sector has increased its use of water by 1.24 percent to 2.56 percent per year.

Water use in the Mountain states is growing steadily. Population-affected growth in water demand causes a significant portion of this increase.

Comparison Between the Plains States and the Mountain States

Comparisons between the two regions, Mountain and Plains states, result in the following generalizations about each region that may be helpful in predicting future demand for water within the regions or within a state.

-- Population growth is greater in the Mountain states than in the Plains states.

-- Overall water withdrawals are increasing at a faster rate in the Plains states than in the Mountain states.

-- Irrigation water use is growing at a faster rate in the Plains states than in the Mountain states, but in absolute terms, the Mountain states use far more water than the Plains states.

-- Overall public supplied water use is growing at similar rates between the two regions, yet the industrial and commercial use of water is growing faster in the Plains states than in the Mountain states.

-- Public supplied industrial and commercial water use is uniformly strong in growth in the Mountain states, yet is varied among the Plains states.

The demand for water is increasing in all six states. Population growth, industrialization and commercialization, and irrigation are the primary forces behind continued increases in water use in these regions. Increases in demand for water, particularly in the Plains states, will be greatest in the irrigation sector due to the magnitude of the volume involved, over 15.6 million acre feet of water per year is consumed (Table 1). This accounts for approximately 94 percent of the consumptive use of water in the Upper Midwest.

A look at the raw data adds perspective to the analysis. The Mountain states have had a relatively constant ratio of irrigated farms to total farms since 1940. This ratio was 58 percent in 1940 and 55 percent in 1987 in Colorado. In Montana, the same ratio was 36 percent in 1940 and 39 percent in 1987. In Wyoming, the ratio was 58 percent in 1940 and 57 percent in 1987. Although there were slight changes in this ratio from year to year, the overall relationship remains unchanged. The census years from the mid 1950's to the mid 1960's were the peak period for all three states at approximately 61 percent in Colorado, 41 percent in Montana, and 65 percent in Wyoming. The initial years of growth in the ratio of irrigated farms to total farms must have occurred prior to 1940. The large increase in irrigation water supply resulted largely from the Bureau of Reclamation projects in the early 1900's.

In contrast, the Plains states are currently in the growth phase. The ratio of irrigated farms to total farms has increased in South Dakota from 1.3 percent in 1940 to 5.1 percent in 1987. In North Dakota, the ratio was 0.6 percent in 1940 and 2.3 percent in 1987, and in Nebraska, the 1940 rate was 5.7 percent and the 1987 rate was 37 percent. A four fold increase in the percent of farms using irrigation occurred in South Dakota and North Dakota, while a nearly seven fold increase in Nebraska occurred over this 47 year period of time. The ratio has been leveling off in the past three censuses, stabilizing in Nebraska at about 36-37 percent.

Nebraska has by far the most farms and irrigated farms among the two regions. North and South Dakota have the second and third most farms, yet by far the fewest irrigated farms. This tends to suggest that either the crops that are prevalent in the Dakotas require less water, precipitation levels are higher than in the other states (particularly Colorado and Wyoming where 50-60 percent of all farms use irrigation) or the structure of farms is more diversified in the heavily irrigated states (where many farms irrigate on only a small portion of the farm) in contrast to the less irrigated states (where fewer farms irrigate on a higher proportion of their land).

In the three Mountain states, irrigation accounted for over 90 percent of all water use from 1960 to 1985. In the three Plains states, irrigation accounted for 70-80 percent of all water use in Nebraska, 35-68 percent of all water use in South Dakota, and 13-50 percent of all water use in North Dakota, over the same 25 year period. This ratio fluctuates a great deal in North and South Dakota, probably as a reflection of varying precipitation.

Of the Plains states, Nebraska is most similar to Mountain states. North and South Dakota use far less water overall than the other four states, and a significantly lower percent of total water use is applied through irrigation.

Conclusions

The demand for water in all six states should be expected to increase in the future. The Mountain states should experience less drastic change in total water use as a result of the relatively stable relationship between total farms and irrigated farms. As a result of such a high ratio of total water use through irrigation, the stability in the irrigation sector should hold total water use levels fairly stable. The Plains states should experience considerable growth in both irrigation and total water use.

North and South Dakota are in a less mature stage of water development. Continual increases in the percent of farms using irrigation should result in increases in water use. The growth in total water use in North Dakota is occurring at a faster rate than irrigation water use. Additionally, a relatively low percent of total water use applied through irrigation indicates substantial increases in non-irrigation sectors of water use in North Dakota. The other sectors are better predictors of future water use in North Dakota than irrigation.

Irrigation water use in South Dakota is increasing in importance. Movement toward a higher level of both the ratio of irrigated farms to total farms and the ratio of irrigation water use to total water use, similar to the Mountain states and Nebraska, should be expected. A question is at what level. The demand for water in South Dakota will increase continuously until this stage is reached.

SUMMARY

Circumstances regarding water use are changing. Within the last several years, water shortages have occurred in urban communities and in a vast agricultural region. Even greater flexibility in water allocation will be necessary in the future, though, as demand continues to increase and supply remains relatively inelastic due to economic and technological infeasibility.

Within the Upper Midwest region the vast physical supplies of water can meet the expected demands for water for years to come if economic and technological limitations are overcome. Unless this occurs, the uneven distribution of supplies and varying quantities and qualities of water will persist in restricting the amount of water available for use.

Several approaches for dealing with this situation exist. One includes increasing the quantity of water supplied through water development. Limitations exist, though, particularly on large scale developments. Another approach is to reduce the quantity of water demanded. This could be accomplished by eliminating waste in current uses. These answers go to the heart of the problem: increase the available supply and decrease the demand, and shortages will occur less frequently. For circumstances where such supply and demand changes are expensive or impossible, alternatives are necessary. The use of economic principles to ration water may provide such an alternative. The most important change in the water laws and policies that can be made lie in increasing the mobility of the water rights and in reducing the impact such changes might have on third parties.

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