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Missouri River Water Use in North Dakota

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HIGHLIGHTS

A literature review, Delphi study, and time-series analysis were conducted to record past and to project future Missouri River water use within the state of North Dakota. Data constraints did not allow for rigorous analytical time-series analysis. Response by Delphi panelists was limited because of the sensitive political nature of water allocation. For these reasons, the literature is limited to general projections of water use in North Dakota. In spite of these concerns, water resource planning requires estimates of future demands. North Dakota is expected to demand between 1.0 and 4.7 million acre-feet of Missouri River water by the year 2020. This is roughly two to four times current use.

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Overview

Recent popular and professional literature has proclaimed that water resource problems are among the most pressing natural resource issues (AWRA 1985). Leitch et al. (1983) surveyed natural resource experts to identify significant emerging natural resource issues in a study prepared for the U.S. Geological Survey. Water concerns occupied 9 of the top 30 most significant issues. Water quantity was described by Newsweek (Sheets et al. 1983) as the "crisis of the '80s." A recent survey of top-level Bureau of Reclamation personnel (Hitchcock et al. 1982) concluded that competition among uses and users will be the major water issue in the 1990s. Even a cursory examination of real world conditions affirms that these statements and studies identify serious, real concerns.

The Missouri River is the largest source of surface water in North Dakota. With an annual flow of 17 million acre-feet, it exceeds the combined flow of all other rivers and streams in the state (Figure 1). This study estimates future use of Missouri River water within North Dakota in order to facilitate fair and efficient allocation. The thought is not to plan for, nor anticipate, severe climatic conditions (e.g., drought), but rather to provide a first step in comprehensive water planning under expected "normal" water availabilty. The goal is to help the state identify its future water demands and thus develop efficient and equitable plans to meet those demands. This is a necessary prerequisite for subsequent planning for emergency water management and allocation under severe climatic conditions.

Legal Allocation of Interstate Water

Riparian rights and prior appropriation have been the major principles used in the *intrastate* allocation of water. Riparian rights are prominent with the eastern states, and prior appropriation is prominent with the western states, where it was developed. However, these principles have not been and perhaps cannot be applied to the *interstate* allocation of water. The U.S. Supreme Court ruled in Sparhase vs. Nebraska that water is an article of interstate commerce. Further, North Dakota and the other upper basin states have taken the position that Missouri River water has clearly been allocated in the O'Mahoney-Milliken amendment to the 1944 Flood Control Act. In spite of these positions, water will be the subject of controversy between and among states for years to come.

There are three major approaches to the allocation of *interstate* waters--equitable apportionment, congressional apportionment, and interstate compacts (Saxowsky 1984). When interstate water rights are brought before the

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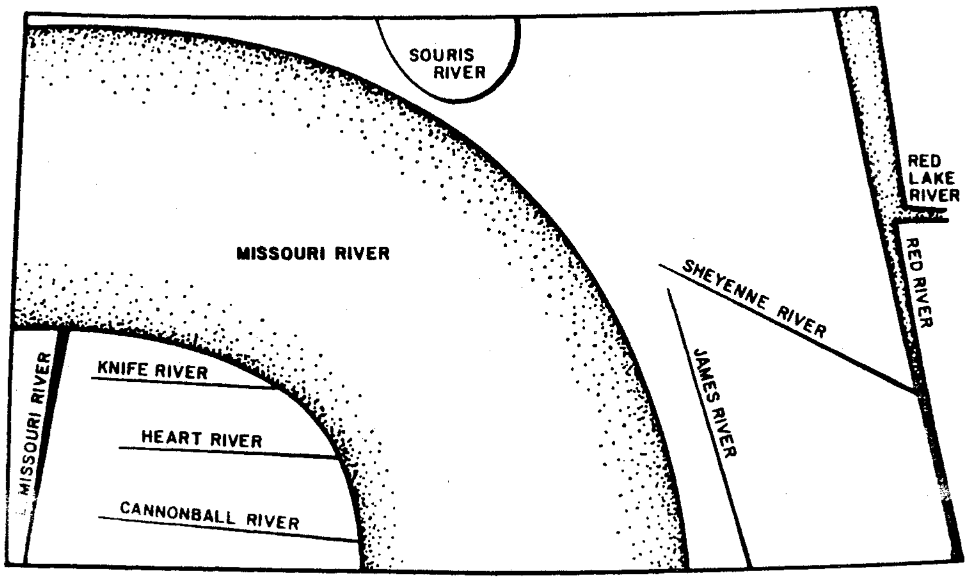

Figure 1. Schematic Presentation of Proportional River Flows in North Dakota.

SOURCE: North Dakota State Water Commission (1984).

courts for litigation, the usual solution is equitable apportionment, established by the Supreme Court in 1907. The courts determine equitable apportionment from criteria such as physical and climatic conditions, return flows, established uses, available storage, and wasteful uses. When the water has been allocated by the courts, a state can use its share any way it chooses as long as it does not exceed its court-established entitlement.

Almost by accident, a precedent for congressional apportionment of interstate water was established when Congress approved the Colorado River Compact which appropriated the water of the Colorado between the upper and lower basin states. The Supreme Court in 1963 ruled that this was effective congressional apportionment of interstate waters.

Interstate compacts are essentially negotiated agreements for water entitlements, which are approved by state legislatures and Congress. After approval by Congress, such compacts are federal law and cannot be altered unless they contain unconstitutional articles. Congressional approval is not automatic. The compact must not infringe on reserved federal or Indian rights. State entitlements, instream flows, and federal or Indian water rights are all issues to be addressed in allocation of interstate waters.

Objectives

The objectives of this study are (1) to estimate existing and historic uses of Missouri River water within North Dakota and (2) to project future North Dakota in-state use of Missouri River water (Figure 2).

Figure 2. Missouri River Basin

SOURCE: Missouri River Basin Commission (1977).

Methods

Objective 1 was accomplished by summarizing data contained in annual water use records maintained by the North Dakota State Water Commission Hydrology Division.

Objective 2 was accomplished using three methods: (1) a trend analysis that used as variables time-series data on past North Dakota uses of Missouri River water; (2) the Delphi method; and (3) synthesis predictions and projections of changes in uses or demands from current literature. The Delphi method relied on predictions from a panel of water experts. Current literature that predicts water use for North Dakota, water use for the West and the Northern Plains, and water use for the nation as a whole was reviewed. Two simplifying assumptions were made throughout the study: (1) no significant changes in water pricing will occur and (2) user mix, but not necessarily proportion, will remain constant (i.e., no new user groups or uses).

Trend Analysis. Since 1965 the North Dakota State Water Commission has required water permit holders[1] to annually report how much of the permit holder's allotment was used during the reporting year. This information was summarized according to use type (Table 1) and the hydrologic basin from which the water was withdrawn (Table 2 and Figure 3). These records represent only reported use, and not all permit holders report their use. However, it is the best historic and current use information available, and it is adequate to approximate a trend for predicting future use, assuming that the same permit holders report each year and that their use is representative of nonreporters' use. The number of annual observations for each of seven uses (Table 3) varied from seventeen for irrigation to three for flood control.

A simple linear regression equation where y = water use and x = time was used for the trend analysis. This assumes the relative price of water will not increase and new users will not enter the system. After statistical parameters were estimated, a simple regression model was generated to predict water use from 1965 to 2020 for each use and for total use.

Delphi Method. The Delphi method was used to predict future water use. The Delphi forecasting method is a systematic iterative survey technique based upon the independent contributions of a group of experts (Lindstone and Turoff 1975). Typically, Delphi topics are broad, amorphous events, rather than precisely defined empirical occurrences. The method is applicable to an inquiry regarding future expectations, such as the demand for water in North Dakota.

Delphi panelists knowledgeable about water resources in North Dakota were from government, private industry, and academic sectors (Table 4). They included private and industrial users and governmental bodies responsible for

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[1]The state requires a water permit for all withdrawals of surface water. With some possible exceptions, the state's water-permitting system--a very important water management tool--will determine water use. However, as the demands for water strain the administrative capacity to allocate water, other institutions may need to be developed.

TABLE 1. PERMITTED USE CLASSIFICATIONS USED BY THE NORTH DAKOTA STATE WATER COMMISSION

Bottling	Domestic	Industrial
Commercial	Institutional	Recreation
Power	Irrigation	Rural water
Flood control	Medical	Stock
Fire	Multiple use	Unused
Fish and wildlife	Municipal	

TABLE 2. MISSOURI RIVER SUBBASINS IN NORTH DAKOTA

Basin	Square Miles Drained
Eastern Direct Tributaries	14,550
James River	6,800
Little Missouri River	4,750
Cannonball River	4,310
Heart River	3,340
Western Direct Tributaries	2,800
Knife River	2,507
Grand River	890
Yellowstone River	750

Source: North Dakota State Water Commission (1983)

TABLE 3. USE TYPES EMPLOYED IN THE TREND ANALYSIS

Consumptive	Nonconsumptive
Irrigation	Recreation
Municipal	Flood control
Industrial[a]	
Rural domestic water	
Rural livestock water	

[a]Some of this will also be a nonconsumptive use; it includes thermoelectric (coal conversion) use.

Mainstem Missouri River

James River

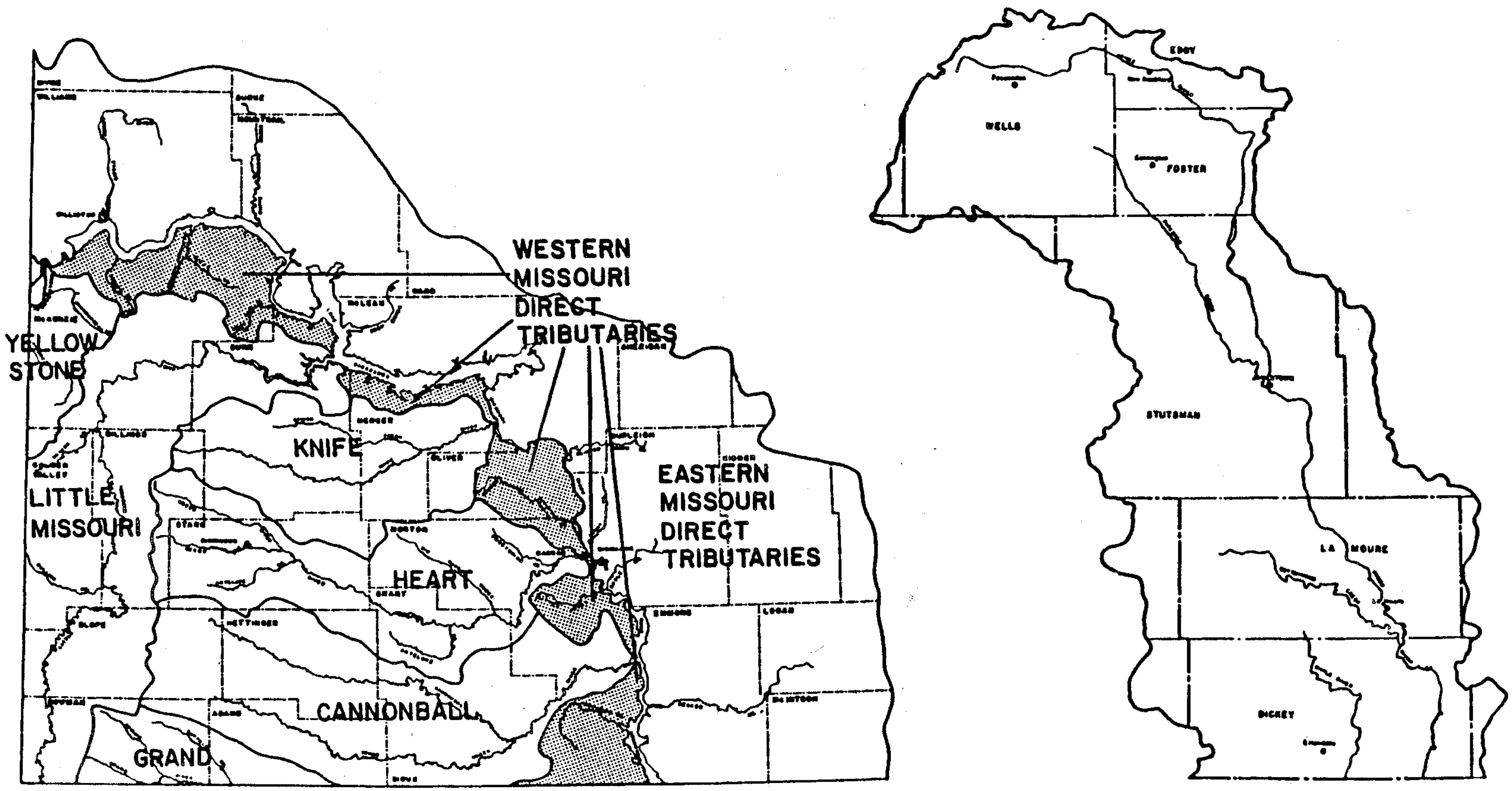

Figure 3. Missouri River Sub-basin Delineation in North Dakota

SOURCE: North Dakota State Water Plan (1983).

TABLE 4. SECTORS FROM WHICH DELPHI PANELISTS WERE CHOSEN

Sector	Number of Panelists
Government	
Federal	2
State	13
Local	5
Total	20
Private	
Industry	5
Agriculture	4
Associations	5
Total	14
Academic	
University of North Dakota	2
North Dakota State University	2
Total	4
TOTAL	38

water management. Iterations were planned to continue until an *a priori* selected level of consensus was reached. However, poor response and cooperation from panelists limited the Delphi to two rounds. Water use is an issue on which many panelists did not care to express an opinion, even with unanimity. However, Dalkey (1968) demonstrated that the majority of opinion convergence is achieved between the first and second Delphi rounds.

The Delphi survey instrument used in Round 1 requested the name and address of the panelist (Appendix A). It also listed nine use categories--seven consumptive and two nonconsumptive (Table 5)--and 1980 use figures in acre-feet. Panelists were requested to: (1) predict a percent increase or decrease for the years 2000 and 2020 using 1980 as a base; (2) list major legal, technical, economic, social, or political events that could alter their predictions; (3) give the probability of occurrence for each event for the years 2000 and 2020; and (4) list the names of other people knowledgeable about water resources in North Dakota.

A questionnaire was mailed to each panelist. After one month, only 8 of 38 questionnaires had been returned. A reminder and a copy of the questionnaire were mailed to panelists failing to respond. This brought only two more responses. Panelists were then contacted by telephone, which added one additional response. When it was determined that no more responses could be obtained in the first round, the data were compiled.

TABLE 5. USE TYPES AND BASELINE USES FOR THE DELPHI SURVEY

Use Type	1980
	acre-feet[a]
Consumptive	
Municipal	16,205
Other public[b]	77
Rural domestic, self-supplied[c]	4,810
Rural livestock, self-supplied	13,040
Irrigation	186,250
Industrial, self-supplied	4,480
Thermoelectric[d,e]	724
Nonconsumptive	
Thermoelectric	1,034,851
Recreation	336,496

[a]An acre-foot of water is one foot of water covering an area of one acre, 43,560 cubic feet, or 271,328 gallons.
[b]Includes trailer courts, businesses, parks, etc. which have their own source of water.
[c]Household uses.
[d]There is sufficient difference between consumptive and nonconsumptive thermoelectric uses to warrant delineation into separate categories.
[e]Coal conversion.

The second-round questionnaire was then mailed to the panelists. First-round results (mean and average) were included on the second-round survey instrument (Appendix B). Individual responses of each panelist who responded in the first round were provided to all panelists in the second round. Also in this iteration, the reported significant events were given along with their mean probability of occurrence. This was done to allow panelists to reevaluate their original positions and make new estimates or reaffirm their initial estimates. Twelve completed surveys were returned from a second-round mailing of 38. Predictions of Missouri River water use were made using the data from the two rounds of this Delphi survey.

Literature Review. A review of current popular and professional literature for water use projections provided the basis for a third projection. Very little forecasting of future water use has been reported specifically on the Missouri River in North Dakota. However, the literature does contain use forecasts for the entire Missouri Basin, the Northern Plains, the West, and the United States as a whole. In addition, the North Dakota State Water Commission has predicted water use in the North Dakota segment of the Missouri Basin to the year 2020 (North Dakota State Water Commission 1983).

Results

Historic Use

The use of Missouri River water since 1965 was summarized from Water Commission records. Water use peaked in 1977 and has since exhibited a small decrease (Table 6). However, this is reported use only, which unfortunately, may be an underestimate. The major water use increase in 1977 was due to thermoelectric expansion, and the slight decrease also can be attributed to a reduction in thermoelectric use.

TABLE 6. HISTORIC USE OF MISSOURI RIVER WATER IN NORTH DAKOTA, 1965-1982

Year	Total	Use: Industrial[a]	Irrigation	Municipal
	acre feet			
1-1965	1,056	0	1,050	0
2-1966	827	0	823	0
3-1967	2,153	1	2,133	19
4-1968	4,418	1	530	49
5-1969	5,896	1	1,617	0
6-1970	7,116	1	2,863	4
7-1971	8,074	1	2,477	99
8-1972	7,389	1	3,026	4,349
9-1973	83,669	61,221	8,259	8,190
10-1974	85,516	60,661	10,882	8,087
11-1975	492,186	474,006	10,293	7,337
12-1976	553,578	528,050	13,852	5,803
13-1977	1,173,269	1,144,076	15,243	9,650
14-1978	1,140,953	1,122,067	11,265	7,141
15-1979	1,063,378	1,045,372	8,435	9,131
16-1980	1,058,646	1,031,479	15,824	11,365
17-1981	1,041,058	1,020,695	9,466	10,879
18-1982	897,728	876,070	11,025	10,618

[a]Includes thermoelectric.

SOURCE: Hydrology Division, North Dakota State Water Commission.

Projections

All three projection methods indicated an increase in overall future use of Missouri River water, given current circumstances. Most increases tend to be relatively moderate. With the Missouri River's average annual flow of 17 million acre-feet at Bismarck and Garrison reservoir's storage of 18 million acre-feet, it appears that enough Missouri River water passes through or is stored in North Dakota to meet projected instate uses for the next 35 years.

Trend Analysis. Use of Missouri River water has been highly variable and subject to sudden changes due to shifts in agricultural prices and demand for thermoelectric power. Statistical analysis of trends proved to be an unsatisfactory means to characterize the data (Appendix C). Trends of the three major uses--municipal, irrigation, industrial--and the total use will be illustrated in graphs, and causal factors will be discussed.

Municipal use has followed an irregular pattern in recent years (Figure 4). Municipal use was insignificant until 1972 when consumption rose from 99 to 4,349 acre feet. Use doubled again in 1973 to 8,190 acre feet. Since 1973 water consumption varied with a gradual upward trend from a low of 5,803 to a high of 11,365 in 1980. The rapid rise in use coincided with a general economic boom in western North Dakota in the mid-1970s. Agriculture and energy experienced excellent economic returns that were reflected in employment and population increases in the region.

Irrigation based on Missouri River water began in the 1950s and has continued on a limited basis (Figure 5). The agricultural boom of the mid-1970s provided a strong economic incentive to increase production, and water from the Missouri provided the means for many farmers to increase their yields. As commodity prices first stabilized and later decreased, use of irrigation water from the Missouri also reached a plateau and has fluctuated around this plateau since 1977.

The dramatic and most significant increase in Missouri water use was stimulated by the rapid rise in thermoelectric facilities from 1973 to 1977 (Figure 6). Water use prior to 1973 was less than 10,000 acre feet and since 1977 has averaged over one million acre feet. Significant changes in water use were and will be tied to the number of large-scale thermoelelectric plants operating in the region.

As illustrated in Figure 7, total use of Missouri River water in North Dakota is nearly equal to the use by the thermoelectric industry. From 1978 to 1982, 98 percent of the consumptive use of Missouri River water in North Dakota was for industrial (i.e., thermoelectric) purposes. Any projections of water use essentially are projections of electrical energy demand from thermoelectric power. Barring the rebirth of Garrison Diversion on a large scale, no other use will have a significant effect in the next 20 to 40 years. An informal, "common sense" analysis of these trends would lead one to expect no major changes until the demand for electrical energy exceeds the capacity of current generating facilities.

Delphi. Delphi panelists were asked to predict Missouri River water use in North Dakota for irrigation, municipal, other public, rural domestic, rural livestock, self-supplied industrial, consumptive and nonconsumptive thermoelectric, and recreation purposes--seven consumptive and two nonconsumptive water uses. Results of the first round were not conclusive because the range of expert opinion was large, the coefficient of variation was large, and the sample size was small (Table 7).

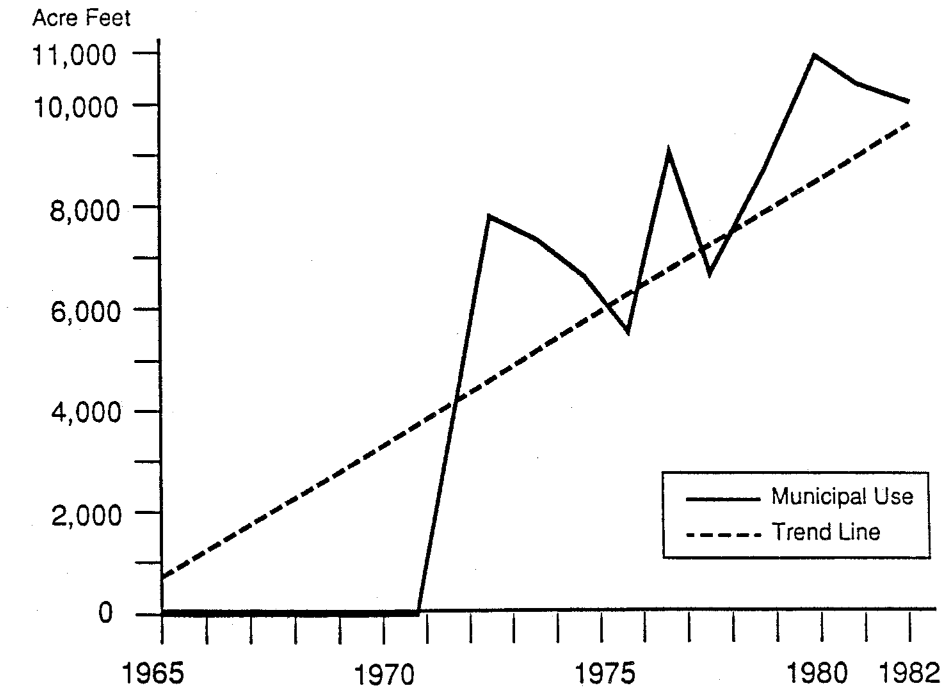

Figure 4. Use of Missouri River Water by North Dakota Municipalities, 1965 to 1982

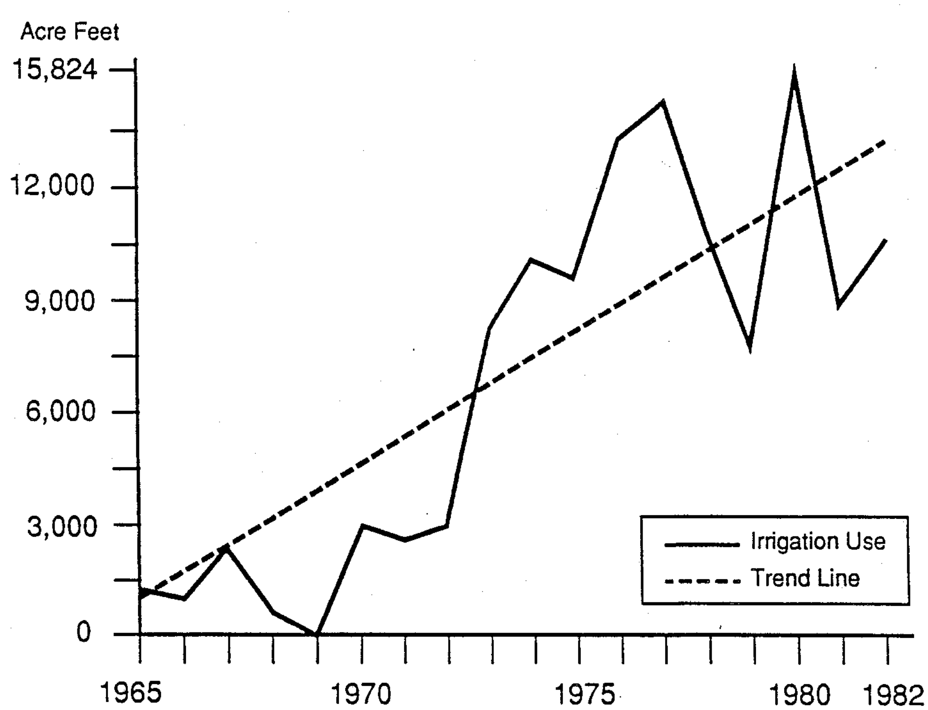

Figure 5. Use of Missouri River Water for North Dakota Agricultural Irrigation, 1965 to 1982

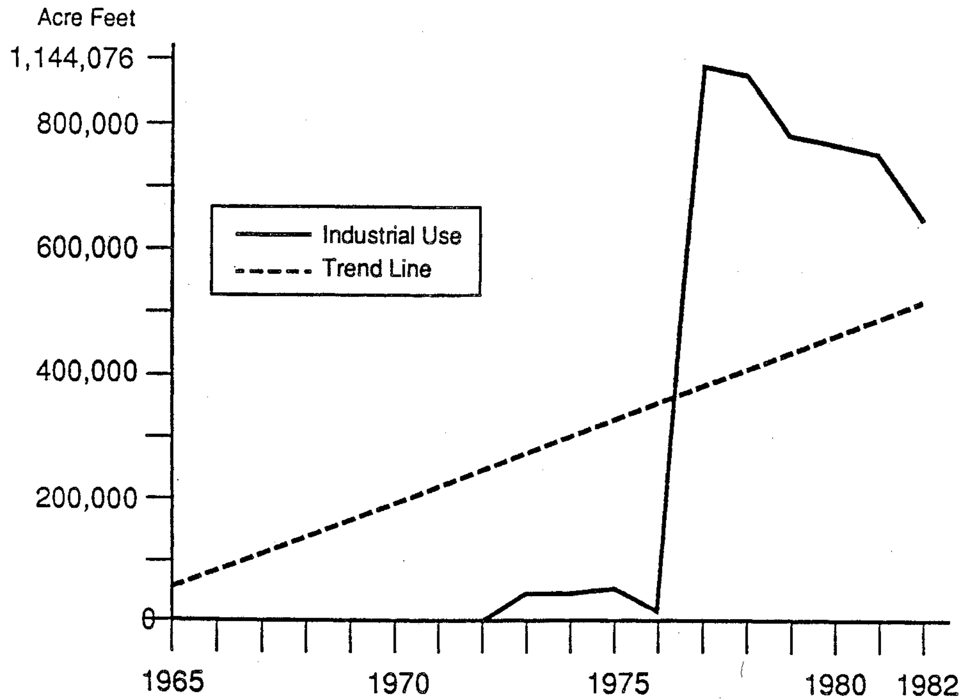

Figure 6. Use of Missouri River Water by North Dakota Industry, 1965 to 1982

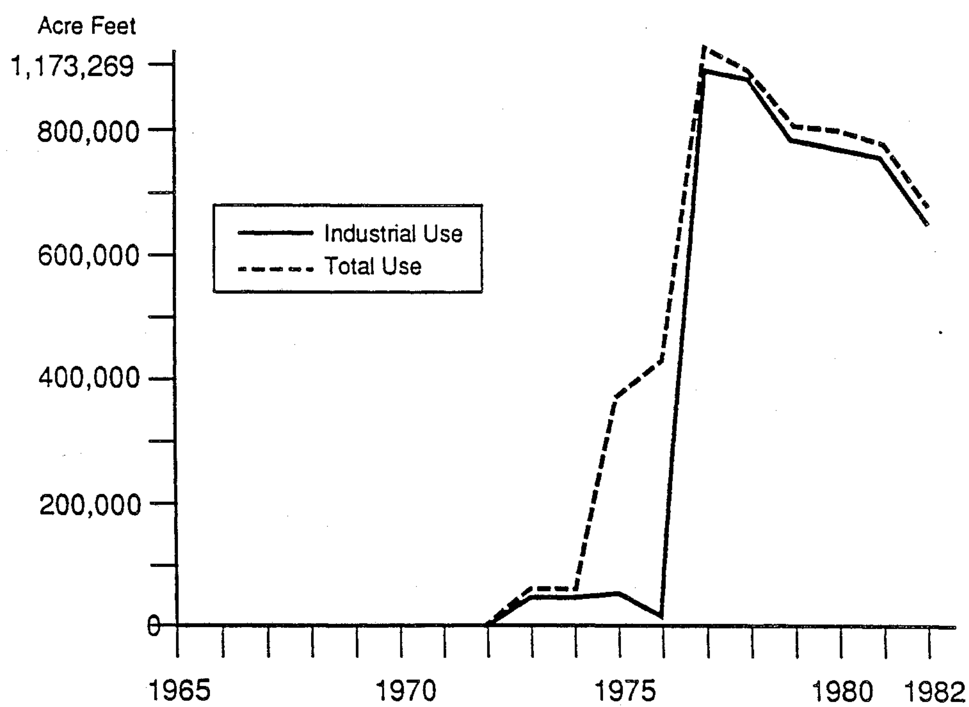

Figure 7. Total and Industrial Use of Missouri River Water in North Dakota, 1965 to 1982

TABLE 7. PERCENT CHANGE IN WATER USE PREDICTED BY DELPHI RESPONDENTS, ROUNDS ONE AND TWO, BY USE FOR THE YEARS 2000 AND 2020

Use	Mean		Range		Coefficient of Variation[a]	
	2000	2020	2000	2020	2000	2020
	------------------- percent increase -------------------					
			Round One			
Consumptive						
Municipal	17.78	36.67	10 to 50	15 to 100	71.86	67.50
Other public	13.13	26.11	0 to 50	0 to 100	112.50	114.80
Rural domestic	21.25	26.89	-20 to 200	40 to 200	342.50	280.37
Rural livestock	-4.06	-7.13	-25 to 10	-40 to 15	-302.96	-297.68
Irrigation	69.00	118.75	2 to 200	5 to 300	99.53	92.21
Industrial	32.75	76.75	-15 to 200	-20 to 200	209.25	224.27
Thermoelectric	41.67	74.56	5 to 200	65 to 400	159.76	171.91
Recreation	30.56	40.63	0 to 100	0 to 100	106.19	98.12
Nonconsumptive						
Thermoelectric	21.11	37.50	0 to 100	0 to 200	143.47	154.76
			Round Two			
Consumptive						
Municipal	20.67	37.08	10 to 40	10 to 50	43.74	32.73
Other public	12.33	20.00	10 to 25	-30 to 50	79.17	103.35
Rural domestic	9.42	13.92	-15 to 40	-15 to 50	177.28	174.34
Rural livestock	5.83	11.25	-2 to 10	5 to 25	39.93	54.02
Irrigation	37.75	73.67	5 to 100	20 to 150	78.94	66.81
Industrial	16.08	32.33	5 to 33	10 to 100	68.49	80.86
Thermoelectric	19.75	40.83	0 to 50	5 to 95	99.50	73.62
Recreation	37.92	54.58	0 to 100	0 to 100	76.78	56.12
Nonconsumptive						
Thermoelectric	9.09	10.91	0 to 35	100 to 60	129.73	374.50

[a]C.V. = standard deviation/mean. Coefficient of variation, because it is free of dimensions (e.g., dollars, pounds), allows more meaningful comparison than could be made with other statistics applicable to this data.

Second-round results brought about more consensus of opinion as shown by the reduced coefficients of variation (Table 8). Overall convergence of opinion for water use improved by 37 percent between the first and second rounds. If one extreme prediction is removed (a predicted 100 percent decrease in nonconsumptive thermoelectric use), convergence would show a 47 percent improvement.

The average increase and range of future predictions by the panelists for each use type and the predicted average for total use for the years 2000 and 2020 (Table 9) are considerably lower than the statistical analysis predictions (Appendix C). However, the Delphi predictions are "in the ballpark" with other studies as shown below.

Delphi survey results indicate use will nearly double between the years 2000 and 2020 for most uses. These predictions are made with the assumption that no major events to influence current trends will occur.

Delphi panelists were asked to list major events affecting water use, along with their subjective probability that the event would occur by the year 2000 or 2020. A majority of the respondents thought irrigated acres were almost certain to increase, at least by 2020. All respondents predicted an increase in industrial growth; however, the probability of occurrence ranged from .10 to 1.00. Construction and expansion of the Garrison Diversion Unit[5] were predicted by panelists to significantly increase water use, at least by 2020. For example, a 250,000-acre Garrison Diversion Unit would require 500,000 acre-feet of water annually, or about 3 percent of the annual average flow of the Missouri River through North Dakota (Garrison Diversion Unit Commission 1984). Increases in the amount of water used for recreation were projected to occur for several reasons, such as resort development along Lake Sakakawea, an increased number of public accesses, and an increase in the number of marinas.

A number of other significant, if not major, events potentially affecting water use were also suggested. Among these were the construction of the Southwest Pipeline,[6] a reduction in the amount of imported oil and/or natural gas, a relaxation of environmental standards and regulations, and an increase in the cost of crude oil.

There were also four events suggested that could decrease future water use: increased availability of Canadian hydroelectric power, advances in alternative energy sources, constraints imposed by downstream states, and increases in water use efficiency.

Literature Review. Forecasts of water use in current popular and professional literature are similar to the predictions of the trend analysis and Delphi survey, ranging from a slight decrease to a fourfold increase

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[5]The Garrison Diversion Unit Reformulation Act of 1986 authorizes federal participation on up to 130,000 acres of irrigation.

[6]The Southwest Pipeline is projected to use between 10,718 and 25,614 acre-feet per year (North Dakota State Water Commission 1982).

TABLE 8. REDUCTION IN COEFFICIENT OF VARIATION BETWEEN ROUND ONE AND TWO OF THE DELPHI SURVEY

		Coefficient of Variation		
	Year	Round One	Round Two	Percent Reduction
Consumptive				
Municipal	2000	71.9	43.7	39.1
	2020	67.5	32.7	51.5
Other public	2000	112.5	79.2	29.6
	2020	114.5	103.3	9.9
Rural domestic	2000	342.5	172.3	49.7
	2020	280.4	174.3	37.8
Rural livestock	2000	-302.9	39.9	113.1
	2020	-297.7	54.0	118.1
Irrigation	2000	99.5	78.9	20.7
	2020	92.2	66.8	27.5
Industrial	2000	209.2	68.5	67.3
	2020	224.3	80.9	63.9
Thermoelectric	2000	152.8	99.5	34.9
	2020	177.9	73.6	57.2
Nonconsumptive				
Recreation	2000	106.2	76.8	27.4
	2020	98.1	56.1	42.8
Thermoelectric	2000	143.5	129.7	9.6
	2020	154.8	374.5	-144.9
Average overall improvement				37.0

(Table 10). Projections for withdrawal in the years 2000 and 2020 are higher and more variable than for consumptive uses. There is some consensus on future consumptive uses, with the most common being a 23 to 33 percent increase. All but two studies predicted increases in total water use to the year 2000 and beyond.

Fredrick (1982) hypothesized that no significant increases in irrigation use would occur nationwide based on an assumption of higher water costs and limited access to new supplies. These limitations would encourage improvements in water use technology and management practices. Fredrick also forecast consumptive use for energy production to rise to 10 percent from a

TABLE 9. AVERAGE INCREASES IN MISSOURI RIVER WATER USES AS PREDICTED BY DELPHI PANELISTS

	Year (From 1980)					
	To 2000			To 2020		
Use	Average	Annual	Range	Average	Annual	Range
	percent increase					
Consumptive						
Municipal	20.7	.94	10 to 40	37.0	.79	10 to 50
Other public[a]	12.3	.58	-10 to 25	20.0	.45	30 to 50
Rural domestic[b]	9.5	.45	-10 to 40	13.9	.32	-15 to 50
Rural livestock	5.8	.28	2 to 10	11.2	.26	5 to 25
Irrigation	37.7	1.61	5 to 100	73.7	1.38	20 to 150
Industrial	16.0	.74	5 to 33	32.3	.70	10 to 100
Thermoelectric[c]	19.7	.90	0 to 50	40.8	.85	5 to 95
Recreation	37.9	1.62	0 to 100	54.6	1.09	0 to 100
Nonconsumptive						
Thermoelectric	9.0	.43	0 to 55	10.0	.23	-100 to 60
Overall average	16.0	.74		32.0	.69	

[a]Trailer courts, parks, businesses, etc. that have their own supply source.
[b]Household use.
[c]Coal conversion.

current 2 percent of total offstream use. However, the West will experience a rise to only 5 percent. Viessman and Welty (1985) reported that freshwater use in the United States rose 175 percent (4.12 percent annually) from 1955 to 1980. Because of probable higher costs in the future, increased environmental concerns, and a growing conservation movement, future rates of increase will be more moderate. Mather (1984) pointed out the difficulties in making such projections and said that, although none may be accurate, they show how water use can be influenced by different courses of action and how use can be modified by choosing different alternatives. He also pointed out that caution should be used in interpreting such projections.

Gray et al. (1979) predicted water use will increase in the upper Missouri River Basin and eastern Wyoming by 51 percent (11.35 million acre-feet annually) in the year 2000 (and) by 85 percent (13.91 million acre-feet) in the year 2020. Irrigation would account for 76 to 79 percent of total water use. By the year 2000 a 40 percent increase (1.35 percent annually) is expected from 1975 levels in the entire Missouri River Basin (Missouri River Basin Commission 1977). Irrigation is predicted to account for the majority of the increase. Consumptive use is projected to increase by 61 percent, with irrigation accounting for 90 percent of this increase. The North Dakota State Water Commission (1983) predicted total use for the entire Missouri River Basin in North Dakota (including the James River subbasin) would increase 27 percent from 1980 to 2000 and 43.5 percent by 2020 (1.2 and .84 percent annual increase, respectively). Current literature predicts an

TABLE 10. PUBLISHED PROJECTIONS OF FUTURE WATER USE IN THE UNITED STATES

Study Done By	Year of Study	Year 2000	Percent Change from 1975	Annual Percent Increase
		-----------million acre feet-----------		
Projected U.S. Water Withdrawals[a]				
Senate Select Committee	1961	994	117	3.14
Water Resources Council	1968	901	96	2.72
Resources for the Future	1971	437 to 949	-4 to 107	.83 to 2.95
National Water Commission	1973	660 to 1,477	44 to 222	1.46 to 4.78
Water Resources Council	1975	476	3	.11
Projected U.S. Consumptive Water Use[b]				
Senate Select Committee	1961	174	53	1.71
Water Resources Council	1968	143	26	.92
Resources for the Future	1971	140 to 192	23 to 69	.83 to 2.12
National Water Commission	1973	148 to 201	31 to 77	1.08 to 2.21
Water Resources Council	1975	151	33	1.14

[a]Withdrawals include any use in which water must be taken from its source. Estimated actual withdrawals in 1975 = 458.0 million acre feet per year.
[b]Consumptive uses include any use which precludes further use without additional expenditures. In 1975 estimated actual consumptive use = 113.68 million acre feet per year.

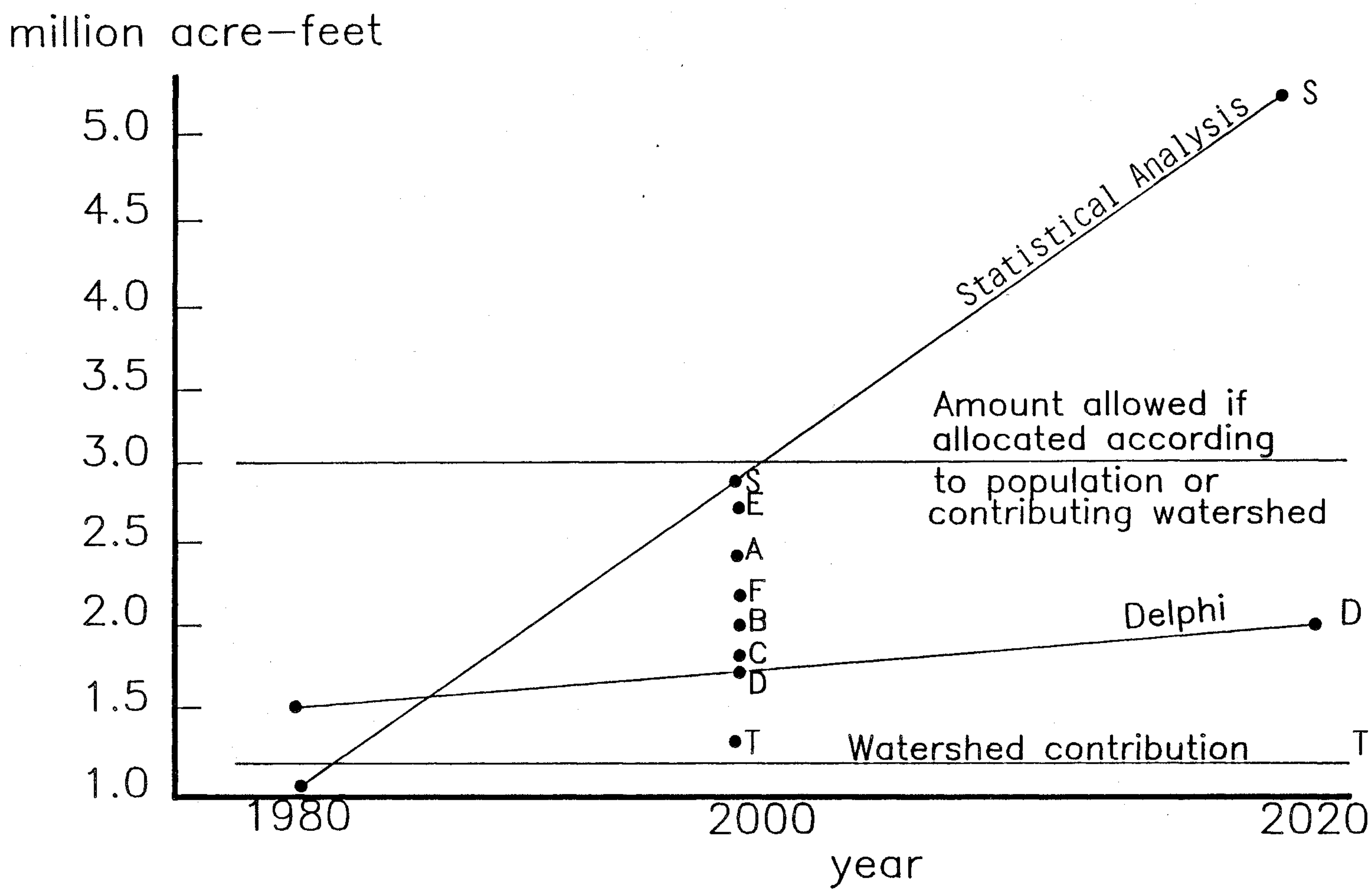
SOURCE: Viessman and Welty (1985).

increase in consumptive use of water between 12 and 70 percent, and the most likely increase is from 23 to 33 percent.

Two themes are common to all water use studies reviewed. First, as water demand increases, cost will also increase and have a moderating effect on use. Second, as costs increase and concern for the environment increases, better management practices, more efficient use, and recycling of water will become more economically feasible, politically acceptable, and socially demanded. This is in line with more recent predictions of less dramatic increases in future water use.

Comparison of Results

Figure 8 shows the results of this study and selected others. In most instances the statistical analysis projections are the highest because they



A=Senate Select Committee
B=Water Resources Council (1968)
C= Resources for the Future
D=Delphi Method
E=National Water Commission
F=Water Resources Council (1975)
S=Statistical Analysis
T=Trend Analysis

Figure 8. Comparisons of the Three Methods Used to Project Future Water Use in North Dakota

rely purely on time as the predictive element. Delphi and literature review results are similar to each other. This may have occurred because the experts that were selected are reading and perhaps contributing to the surveyed literature.

Neither statistical nor Delphi methods took into account an increase in the price of water.[7] As demand for normal economic goods increases, price also increases if supply remains unchanged; therefore, as price increases, quantity demanded decreases (or at least the rate of increase of quantity demanded decreases; absolute demand may continue to increase). It was suggested above that water is a normal good with several unique characteristics. If this is true, as use increases, price should also increase, and as price increases, use or rate of use should decrease. This ultimately leads to higher prices along with possibly higher use at a new market-clearing equilibrium.

While the State Constitution does not allow the State Engineer or the State Water Commission to charge for water use, this does not prohibit municipalities from charging residential, commercial, or industrial users. In addition, the "price of water" includes all costs incurred to use water, not just a per unit charge for water. Therefore, as it becomes necessary to develop deeper walls or provide more treatment for surface waters, the price of water will rise.

DeRooy's (1974) study of industrial response to increases in the price of water led to the conclusion that firms generally respond to increases in the real price of water by reducing the quantity of water used, because as the cost of water as an input rises, substitutes such as conservation become economically feasible. Hogarty and MacKay (1975) discovered that even temporary residential water rate increases can dramatically reduce domestic water use (i.e., demand is highly elastic). The reduction may be immediate and more or less permanent. Generally, most studies that have linked water demand and price have found that as the price (or cost) of water increases, the amount used per user decreases.[8] With this in mind, the preceding predictions, particularly the statistical analysis that predicts use as a function of time alone, should be used with much caution.

Summary

The objectives of this study were to quantify existing and historic use levels of the Missouri River in North Dakota and to predict future use of Missouri River water in North Dakota using several different methods. Two methods, statistical and Delphi, resulted in estimates that were quite

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[7]The Delphi panelists may have indirectly considered this factor, but it was not explicitly referred to in the questionnaire by either the panelists or the investigators except as an event separate from the regular predictions. Additionally, increasing costs are reflected in the available time-series data.

[8]Price is what a user pays per unit to use water, cost is what society pays per unit when someone consumes water or it can be considered the opportunity cost to a user.

different. However, when compared with national and regional outlooks in current literature, it was found that results of both methods enveloped projections of other studies. The Delphi analysis resulted in a lower bound and the statistical analysis in an upper bound.

Future water use estimates in the literature vary widely. The statistical analysis compared favorably with some studies, while the Delphi results compared favorably with others. It is clear, because of changing economic, technological, political, and social conditions, that no hard and fast predictions can or should be made. Authors of studies similar to this pointed out that any projections must be viewed with caution. Just as frequently, though, they pointed out that if any type of sensible allocation of water is to be achieved, such studies and projections must be made.

Enough water to supply even the highest estimated future use in North Dakota is physically available from the Missouri River under our initial assumptions. Realistically, however, North Dakota may face legal or institutional constraints on the amount that it can use. These may take a variety of forms and may be imposed by the courts, federal agencies, or by some type of multistate organization of Missouri River users. The Winters Doctrine, which provides for the beneficial use of water flowing through Indian Reservations, may be interpreted so that the state does not have access to all the water it could beneficially use. The semiarid Southwest may be allowed to use Missouri River water, again reducing the amount available for North Dakota. Because of their greater population and navigational use of the Missouri, states downstream may force North Dakota to reduce its use. If such constraints do occur, North Dakota must be able to allocate its share of the Missouri in an efficient and equitable way if it wishes to continue to maintain economic growth. Unfortunately, determining that share may be difficult.

One possible way to identify the state's fair share, as necessary for a mandated equitable apportionment, would be to allow North Dakota to have a percentage of water equal to the percentage of the basin it occupies. This would be about three million acre-feet per year, which is short by over one million acre-feet of the upper projection of the 2020 need but above the lower projection. Another possibility would be to allow North Dakota to use what it contributes to streamflow. This averages 1.1 million acre-feet per year (North Dakota use has exceeded this in past years). A third alternative for determining North Dakota's share could be according to population. North Dakota comprises about 6 percent of the total basin population. Approximately 6 percent of the total Missouri River flow would equal 3 million acre-feet per year. There are perhaps several other alternatives that could be employed to determine North Dakota's share. Whatever apportionment method is used, North Dakota will demand from 1.9 to 4.7 million acre-feet per year by 2020 to continue to maintain water-related economic growth.

Once its share has been determined, it will be up to North Dakota to decide how Missouri River water will be allocated within its borders. How much will municipal and industrial systems, recreation, the environment, and food and energy production receive? The development of more storage and conveyance facilities, conservation in use, and better management practices are all actions that may be implemented to insure adequate supplies for a variety of expanded uses. Implementation may be difficult because of resistance to nontraditional growth patterns and the failure to price water proportionate to its value in use. North Dakota should begin using projected water use figures (i.e., somewhere between 1.0 and 4.7 million acre-feet) in its planning process to establish baseline uses for interstate water allocations.

Further Study

During the past half century, the water use concerns of the United States and of many North Dakota residents have shifted from navigation and flood control to environmental enhancement and protection. Often, as with the Water Pollution Control Act of 1972, sweeping reforms are made; however, such actions sometimes are made without regard for practicality. To effectively plan for the future, an understanding of water availability, quantity and quality needed, time period needed, and use-type are all essential. Additionally, a state, regional, and basinwide evaluation of the resource base each possesses are needed as well as projections of population, agricultural, and industrial growth. Specifically, optimal patterns of water use must be sought and implemented. This will require technological advancement and perhaps institutional change. Options for water use, both current and future, must be analyzed and presented to North Dakota's decision makers. It is imperative that inter- and intragovernmental unit and agency cooperation and coordination schemes be developed at local, state, and federal levels. The effect of price on the quantity demanded in North Dakota should be looked at quite closely. The results of the studies and investigations suggested should be incorporated into forecasts of future use in order to refine and improve the projections to make better water management decisions for the future of North Dakota.

APPENDIX A

FIRST ROUND DELPHI SURVEY INSTRUMENTS

CONFIDENTIAL POLL OF EXPERT OPINION REGARDING
MISSOURI RIVER WATER USE IN NORTH DAKOTA

Name ______________________ Title ______________________

Organization ____

Address ______________________________ Phone ______________

(1) If the current trends in population, energy, economics, agriculture, technology, and politics continue into the future, how do you see Missouri River water use changing for each use category. Give estimates as an increasing or decreasing percentage of current (1980) use.

Category	Acre Feet[a]	2000	2020
Consumptive			
Municipal	16,205	± ____%	± ____%
Other Public	77	± ____%	± ____%
Rural Self-Supplied			
Domestic	4,810	± ____%	± ____%
Livestock	13,040	± ____%	± ____%
Irrigation (100,000 acres)			
Water-Required	186,250	± ____%	± ____%
Industrial			
Self-Supplied	4,480	± ____%	± ____%
Thermoelectric	724	± ____%	± ____%
TOTAL	225,586		
Nonconsumptive			
Recreation (Instream)	336,496	± ____%	± ____%
Thermoelectric	1,034,851	± ____%	± ____%
TOTAL	1,371,347		
TOTAL USE	1,596,933		

[a]Current (1980) use of Missouri River water in North Dakota (1980 North Dakota State Water Plan). One acre-foot = 325,851 gallons.

(2) Do you foresee any legal, technical, economic, social, or political events that would affect your estimates? If you do, what are these events? What is your subjective probability (0 to 100) these events will occur, and how would they modify Missouri River water use?

Probability of Occurrence

Event 1. ____________________ 2000 ______

____________________ 2020 ______

____

____

____

____

Event 2. ____________________ 2000 ______

____________________ 2020 ______

____

____

____

____

Event 3. ____________________ 2000 ______

____________________ 2020 ______

____

____

____

____

Event 4. ____________________ 2000 ______

____________________ 2020 ______

____

____

____

(3) Who do you feel are the three most knowledgeable and qualified individuals in North Dakota or nearby states to respond to this issue, its implications, and problems?

Name ______________________ Title ______________________

Address ____

____

Telephone ____

Name ______________________ Title ______________________

Address ____

____

Telephone ____

Name ______________________ Title ______________________

Address ____

____

Telephone ____

APPENDIX B

SECOND ROUND DELPHI SURVEY INSTRUMENT

COMBINED RESPONSES FROM INITIAL SURVEY ROUND
SPRING 1985

(1) If the current trends in population, energy, economics, agriculture, technology, and politics continue into the future, how do you see Missouri River water use changing for each use category? Give estimates as an increasing or decreasing percentage of current (1980) use.

Given the responses to the initial survey round, what are your revised forecasts for use of Missouri River water in North Dakota? The numbers penciled in represent your responses to the first round.

Category	2000			2020		
	Mean 15-Year Change	Range		Mean 35-Year Change	Range	
Consumptive						
Municipal	+18%	10-50	____	+37%	20-100	____
Other Public	+14%	5-50	____	+27%	10-100	____
Rural Self-Supplied						
Domestic	+28%	0-200	____	+39%	5-220	____
Livestock	+ 8%	1-25	____	+15%	1-40	____
Irrigation						
Water-Required	+63%	2-200	____	+104%	5-300	____
Industrial						
Self-Supplied	+33%	0-200	____	+73%	0-500	____
Thermoelectric	+41%	5-200	____	+82%	15-400	____
TOTAL						
Nonconsumptive						
Recreation (Instream)	+33%	0-100	____	+50%	0-100	____
Thermoelectric	+20%	0-100	____	+39%	0-200	____

Panel responses to: Do you foresee any legal, technical, economic, social, or political events that would affect your estimates? If you do, what are these events? What is your subjective probability (0-100) these events will occur, and how would they modify Missouri River use?

	Probability of Occurrence — Potential for Increased Use 2000 Mean	Probability of Occurrence — Potential for Increased Use 2020 Mean	Your Estimate of the Probability of Occurence 2000	Your Estimate of the Probability of Occurence 2020
Instream				
1) Increased Development of Public Accesses	75	NR*	____	____
2) Increased Development of Marinas	65	NR*	____	____
3) ______________			____	____
4) ______________			____	____
Withdrawals				
1) Reduction in Availability of Foreign Oil and/or Natural Gas	37	60	____	____
2) Construction of Coal Gasification Plants Within North Dakota	36	36	____	____
3) Construction of Garrison Diversion Project	63	57	____	____
4) Expansion of Garrison Diversion Project	0	50	____	____
5) Construction of the Southwest Pipeline	22	38	____	____
6) Industrial Growth	70	70	____	____
7) Increase in Irrigation	50	50	____	____
8) Changes in Environmental Attitudes & Policy (Relaxing of Standards & Regulations)	12	43	____	____

*No response.

	Probability of Occurrence: Potential for Increased Use (Continued) 2000 Mean	2020 Mean	Your Probability of Occurence: 2000	2020
9) Increase in North Dakota Population	85	NR*	___	___
10) Establishment of a Recreation Corridor from Garrison Dam to Bismarck (Both Instream & Withdrawals Increase)	65	NR*	___	___
11) Increase in Crude Oil Costs	33	67	___	___
12) ___			___	___
13) ___			___	___
14) ___			___	___
Withdrawals	Potential for Decreased Use			
1) Availability of Canadian Hydro-electric Power	10	50	___	___
2) Technological Advances in Alternative Energy Sources (e.g., solar, & wind power)	25	50	___	___
3) Downstream	20	50	___	___
4) Increases in Water Use Efficiency (Slow the Rate of Increase)	32	33	___	___
5) ___			___	___
6) ___			___	___

*No response.

APPENDIX C

STATISTICAL ANALYSES

Four uses (recreation, flood control, rural domestic, and rural livestock water) are particularly noticeable for their variability and resulting poor statistical fit. They also show considerable divergence in percentage increase in use from the other three uses and from each other.

Water quantities used or needed for recreation are extremely hard to measure. Recreation is usually an in situ use (e.g., fishing) which displays collective property characteristics. Because of this, it is hard to determine how much water is required for each recreational use. It can be assumed (because of current high excess capacity) that water needed for recreational uses will not increase as much as the trend line for water use projections indicates. There is very little information in the literature on measuring recreational use of water in terms of water quantity. Even studies that have focused on estimating final demand for water due to local or regional growth or decline fail to include recreational uses (e.g., Ching 1981; Harris and Ching 1983). This probably occurs because recreation use of water is a nonconsumptive, in situ use and does not compete with other uses until some critical low flow level is reached.

Projected rural domestic water use also displayed some anomalies, mainly its poor statistical fit. There may be several reasons for this. First and most significant, there are only a few observations on which to base the trend. Second, not all users report their use. Finally, as people leave the farm and as rural communities decline in population, there will be fewer people using rural water for domestic purposes. This may, however, be compensated for by an increase in municipal use. In reality, rather than showing an increasing trend as the model projects, rural domestic water use will probably decline.

Water used for livestock displays trend characteristics similar to rural domestic water. The majority of this water is used for red meat production. In recent years, demand for red meat has declined resulting in a subsequent drop in livestock numbers. However, whatever happens to rural domestic and livestock use is of little consequence overall. Both of these uses together account for approximately .00003 percent of total use of Missouri River water in North Dakota. It should be remembered, however, that in North Dakota as in most other states domestic uses have legal priority over all other uses.

Water retained upstream for flood control is another use that is difficult to quantify since it is available simultaneously for other uses such as power generation and recreation. This use is not likely to increase, because the majority of the Missouri River in North Dakota is already controlled.[1]

These four uses comprise less than .0004 percent of total Missouri River water use in North Dakota. When they were removed from the analysis, leaving only irrigation, industrial, and municipal uses, the results were essentially unchanged. Thus, it is evident from historic trends and future

[1]All but 70 miles of an original 365 miles of the Missouri River in North Dakota is impounded behind two dams.

projections that irrigation, industrial, and municipal uses have been and will continue to be the major users of Missouri River water in North Dakota.

Although the percentage increases in withdrawals for the three major uses for the years 2000 and 2020 are rather large (Table C1), they should be

TABLE C1. PERCENT INCREASE IN USE FROM 1980 LEVELS FOR THE THREE MAJOR USES OF MISSOURI RIVER WATER IN NORTH DAKOTA, 2000 AND 2020

	Percent Increase from 1980 Levels			
Use Type	Year 2000	Annual Increase	Year 2020	Annual Increase
Irrigation	153	4.75	317	3.63
Municipal	126	4.16	248	3.16
Industrial	128	4.21	322	3.66
Total	166	5.01	344	3.79

SOURCE: Trend Analysis

considered with caution, since the regression coefficients are heavily influenced by the 1973 to 1980 period, and price increases and technological improvements are not considered. Because water is a normal good, it can be safely assumed that as the cost (and price) of water rises (because of rising demand and stable supply), actual use will increase at a lower rate than projected or may decrease. Also, as water costs increase, the incentives for conservation and augmentation in all uses will increase. The supply of Missouri River water in North Dakota is physically limited to an annual average of 17 million acre-feet. It may be further limited by institutional constraints or legal claims of other interests.

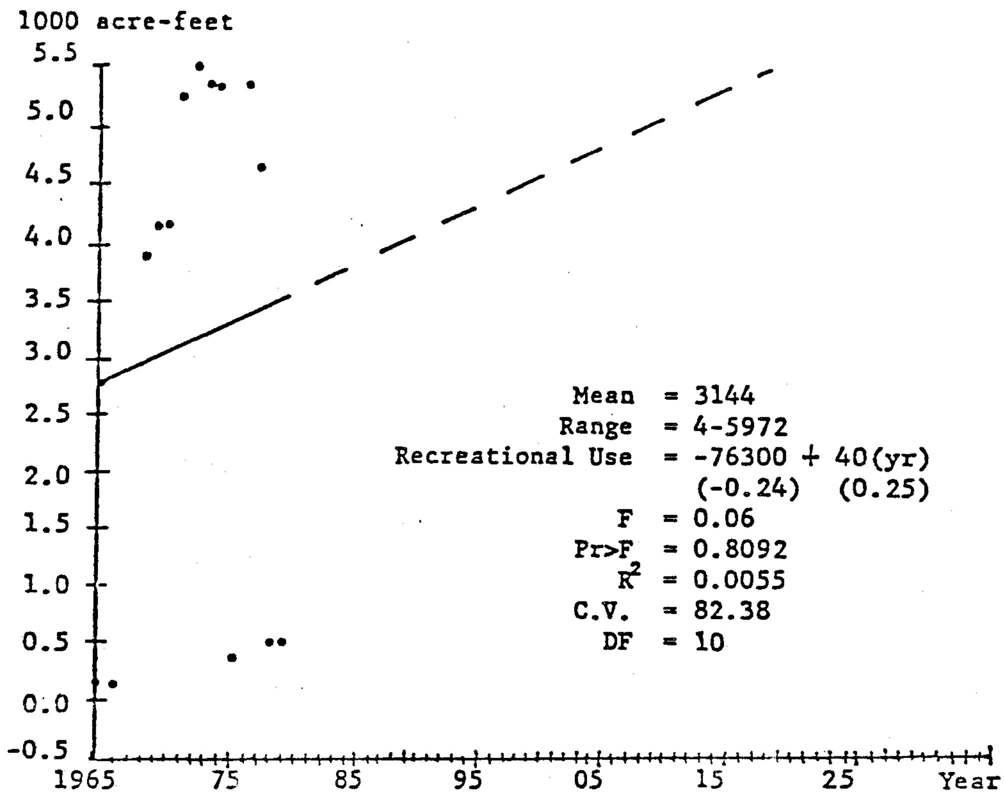

Figure C1. Recreational Missouri River Water Use Projections for North Dakota

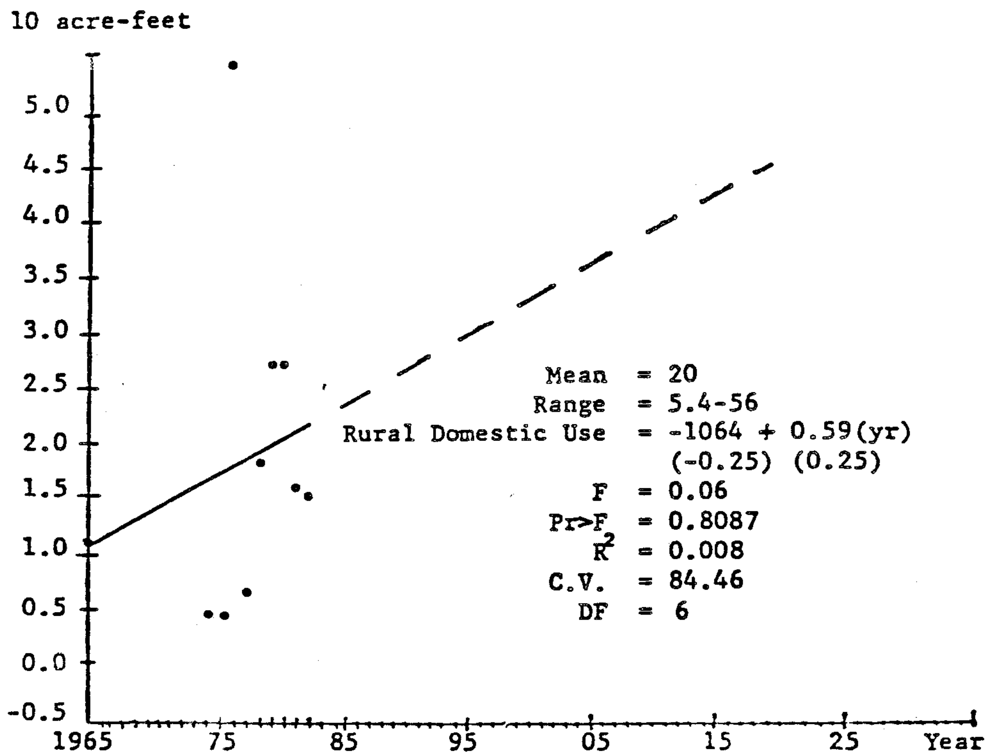

Figure C2. Rural Domestic Missouri River Water Use Projections for North Dakota

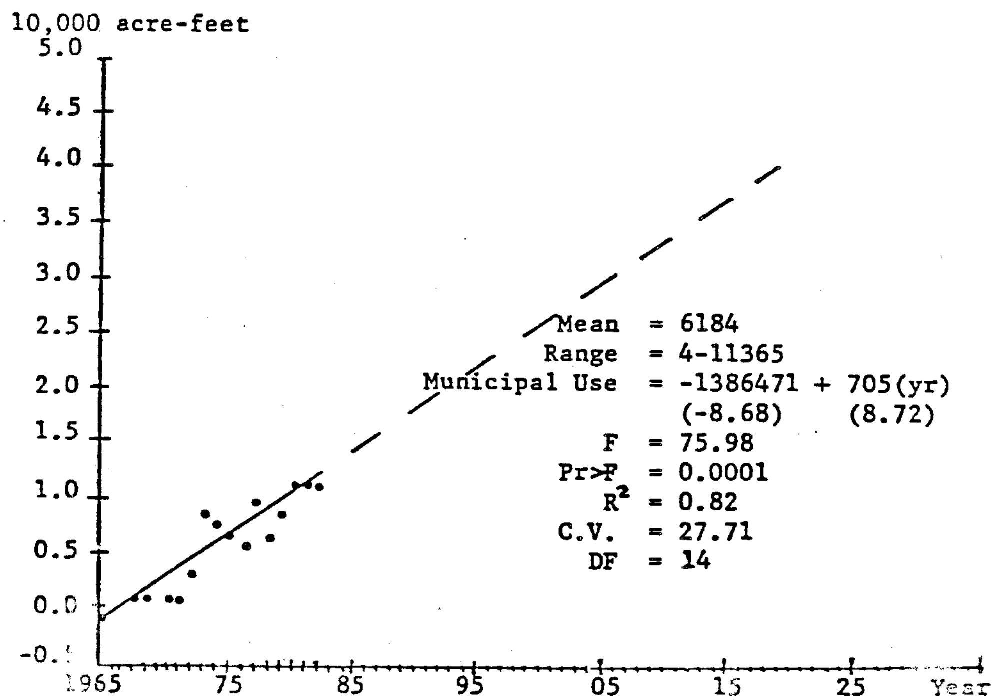

Figure C3. Municipal Missouri River Water Use Projections for North Dakota

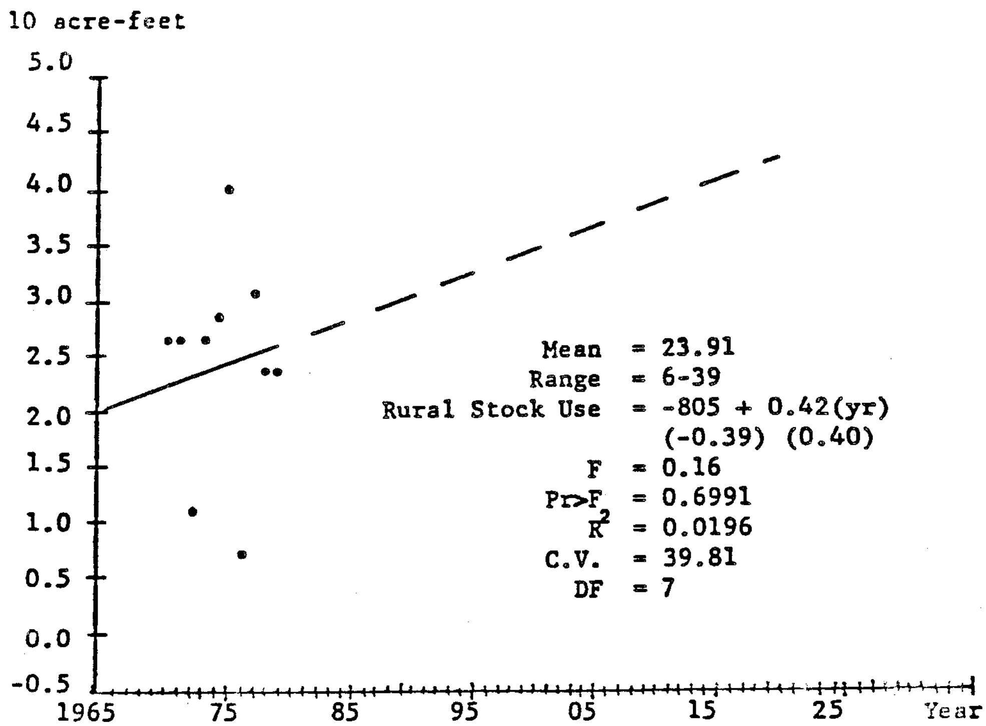

Figure C4. Rural Livestock Missouri River Water Use Projections for North Dakota

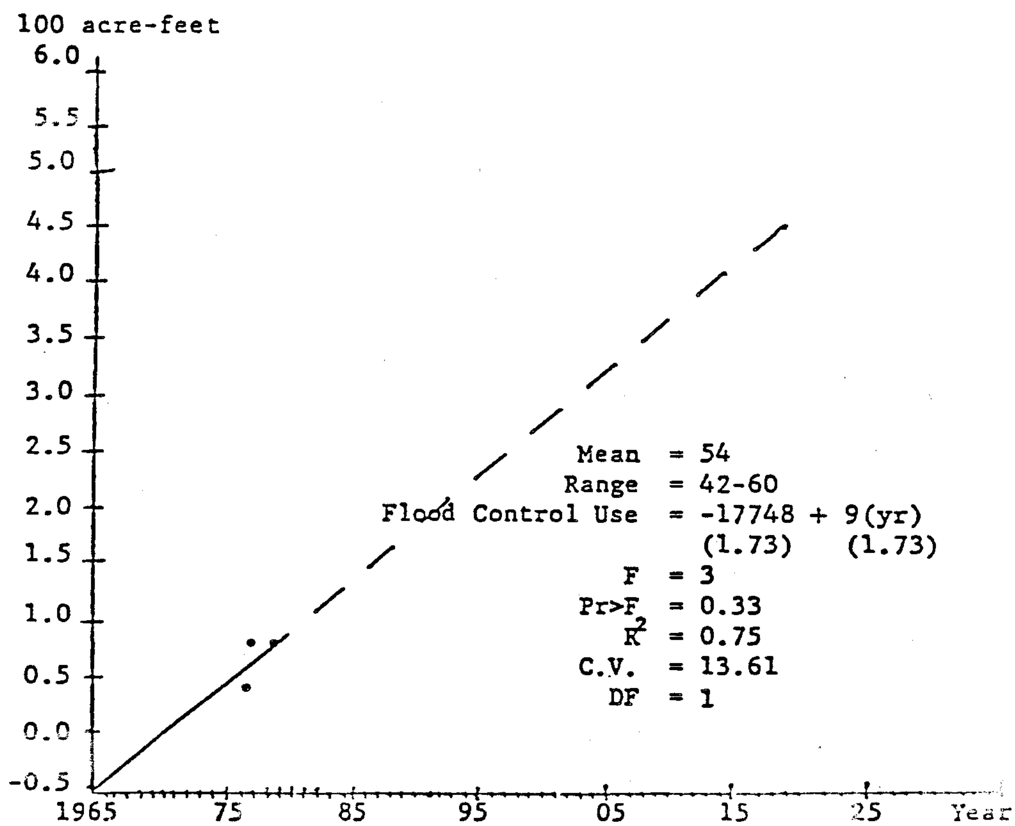

Figure C5. Flood Control Missouri River Water Use Projections for North Dakota

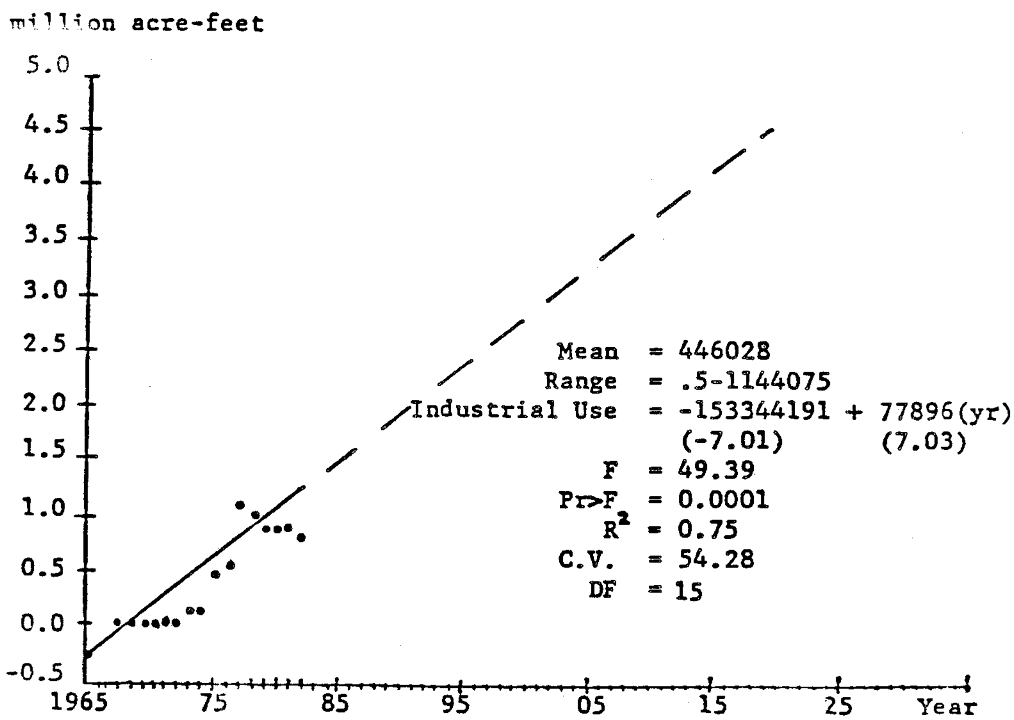

Figure C6. Industrial Missouri River Water Use Projections for North Dakota

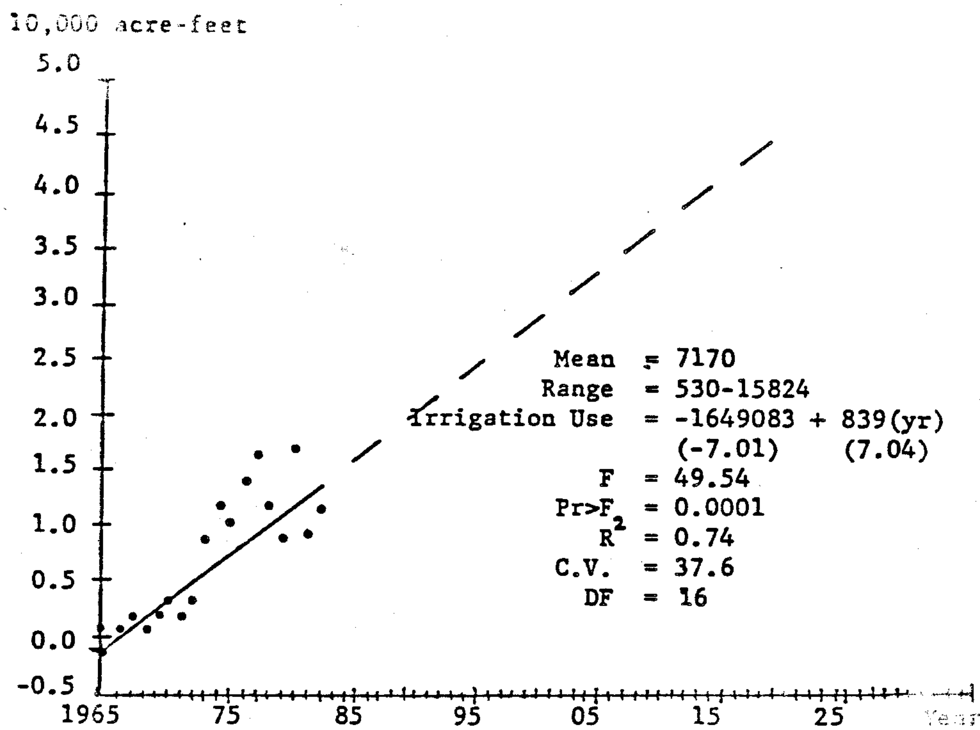

Figure C7. Irrigation Missouri River Water Use Projections for North Dakota

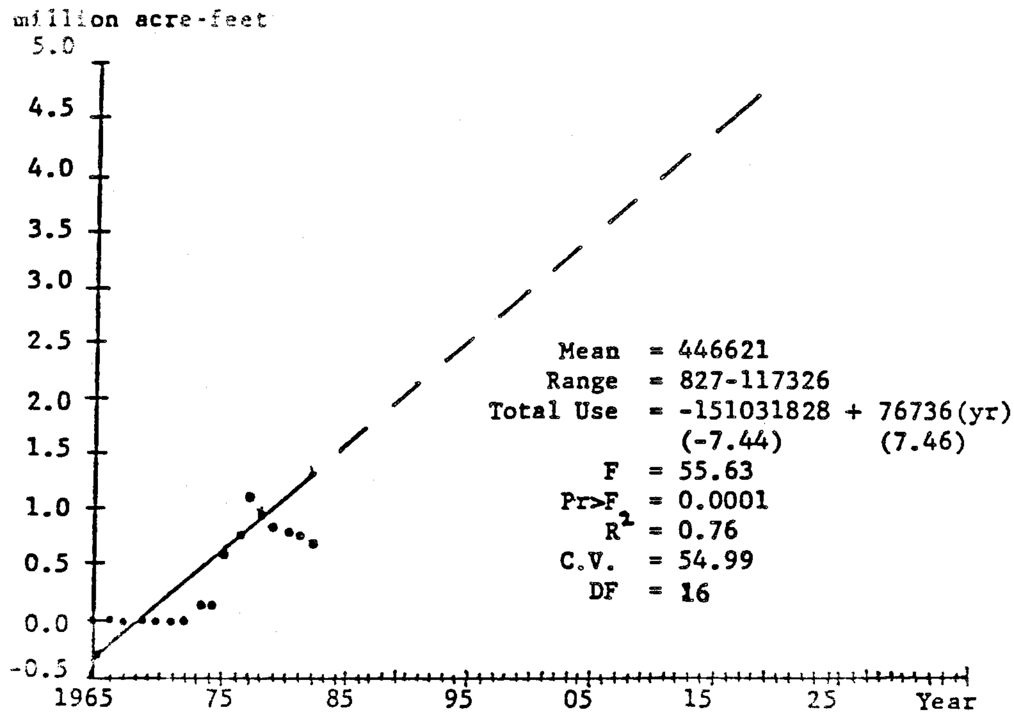

Figure C8. Total Missouri River Water Use Projections for North Dakota

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