

WATER AS A CONSTRAINT TO ECONOMIC DEVELOPMENT IN WESTERN NORTH DAKOTA*

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Water, like many other natural resources, is becoming a scarce and very valuable commodity as man places ever increasing demands upon his physical environment. Although water related problems may not yet be as severe in North Dakota as in more industrially advanced or more arid regions, there may be potential for such problems to develop as the state strives for economic expansion via energy development, increased industrialization, or more intensive irrigation of agricultural lands. Future economic growth may conceivably be limited as a result of implicit and explicit constraints imposed by the availability of adequate water supplies.

Economic growth may of course be constrained by any of a combination of economic, demographic, political, geographical, cultural, or legal factors. This study, however, focuses merely upon the potential constraints to western North Dakota economic growth imposed by water availability. This does not imply that other factors are, or should be, considered unimportant.

Water availability as discussed herein refers to quantitative aspects only. This represents a considerable simplification since water quantity and water quality are interdependent phenomena. The timing and location of return flows, for example, may well affect water availability and water quality. Moreover, "quality" is rather nebulous in that acceptable levels vary among consumers. Although the present model structure is not amenable to the incorporation of water quality variables, it is conceivable that it could be modified via utilization of variants of models presented by Pfeifer [26].

The present investigation seeks answers to several broad quantitative questions. Fundamentally, will water become a constraint to western North Dakota economic growth? If so, at what level of activity will this constraint become apparent? Finally, how will the composition of economic activity affect the behavior of the constraint? Will vast increases in thermoelectric generation, for example, hasten the arrival of the constraint? Policy formulation in areas of water resource development, allocation, and use must logically encompass such broad considerations at a minimum.

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A comprehensive analysis of the economics of water resource necessitates a broad view of the economic structure of the region in question. This viewpoint was embraced by the United Nations Department of Social and Economic Affairs [34] some 25 years ago and more recently by such eminent economists as Howe [15] and Fox [13]. In essence, policy formulation with respect to water development, allocation, and use may be fundamentally incorrect if based upon a rather myopic view of the regional economic structure.

Each sector's water demands must be viewed in relation to total available supplies. Sector's compete for existing supplies but each sector's continued existence is partially dependent upon availability of water to competitors. A particular sector requires water as well as the output of other sectors as input into its productive facilities. Sectors are economically interdependent and each is dependent upon water availability. A shortage of water in a particular sector may thus manifest an aggregate shortage.

It is becoming increasingly evident that traditional partial equilibrium models (i.e., benefit-cost analysis) are inadequate tools for water resource economics. The inadequacy stems in part from the partial equilibrium assumptions regarding growth of effective demand and in part from associated technical problems.[1] Fortunately, general equilbrium models offer a viable alternative.[2]

The applications of the general equilibrium methods of input-output and linear programming are of relatively recent origin. Nevertheless, their fundamental role in water resources planning and development is quite well established. Stoevener and Castle [31] have quite possibly offered the most severe criticism yet were unable to refute the potential propriety of such methods.

Ciriacy-Wantrup [6, p. 25] first indicated the potential utility of input-output accounting schemes for analysis of public expenditures in water resources projects. Folz [12, p. 211] later noted the potential for input-output analysis of anticipated general growth patterns within a specified river basin. Nemchinov [23, pp. 180-181] suggested the use of interindustry models for calculation of regional resource profiles to facilitate resource development and allocation decisions, a concept later applied by Carter and Ireri [5].

Linear programming applications are of more recent origin. As indiciated by Maas [20], the Harvard Water Resources Group made extensive use of programming techniques in the formulation of design criteria related to river basin planning and development. Earlier models have been provided by Steiner [30], Eckstein [10], Eckstein and Krutilla [11], and McKean [22]. All were primarily of a benefit-cost nature.

More recent research has exhibited the joint use of input-output and linear

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[1] See Fox [13], Howe [15], and Margolis [21].

[2] Systems simulations (see Hamilton, et al [14] or Biswas [3]), although not of a purely economic nature, offer a third alternative which may complement partial or general equilibrium analysis.

programming techniques. This framework is quite beneficial to economists striving to determine efficient allocation of scarce resources among competing users, according to prescribed social objectives and within the technological structure of the economy. The work of Lofting and McGauhey [18, 19], Tijoriwala, et al [32], and Kelso, et al [16] is representative of such endeavors. Several theoretical and applied input-output linear programming models are provided by Richardson [28].

The theoretical advantages of such models are readily apparent. Input-output analysis is a neutral framework from a policy point of view. It merely offers an approximation of what is with respect to the technological structure of the economy; it cannot tell the regional planner "what should be" with respect to the efficient allocation of scarce resources among competing users. Once the pattern of final output is specified, there exists no choice among several possible production alternatives. A unique set of sectoral output levels is consistent with a specified pattern of final demand.

Utilization of linear programming variants of input-output models enables circumvention of this deterministic aspect of the Leontief system. Linear programming acknowledges the existence of many feasible production possibilities but allows the regional planner to select the one which optimizes chosen objectives. Thus, policy goals may be incorporated into an otherwise neutral analytical method via specification of an objective function and associated constraints.

THE CONCEPTUAL MODEL

The conceptual input-output linear programming model of the western North Dakota water economy is substantially based upon the California model constructed by Lofting and McGauhey [18, 19] and the Arizona model constructed by Tijoriwala, et al [32]. The model is essentially an optimization linear programming formulation whereby input-output techniques are used concomitantly to provide necessary coefficients in the objective function and constraints.

Surface and subsurface waters are not uniformly distributed either spatially or temporally; the result of complex interrelationships among factors such as topography, climate, groundwater geology, and a highly variable hydrologic cycle. The distribution of water may be quite variable even within a relatively small geographic area. Moreover, Landsberg [17, p. 122] indicates that most water problems are in fact local or regional as opposed to national, and that relative costs associated with the transportation of water are usually quite prohibitive.

Given the extreme variability with respect to the distribution of water within regions, a model constructed for each of separately defined regions within the study area as opposed to a single model constructed for the study area in the aggregate has greater appeal. The locational aspects of water availability are better captured. Restriction of geographic area, which is accomplished by utilizing models for separately defined sub-areas within the total study area, quite logically assures that the location of water supply and the location of water demand (i.e., point of use) are in closer proximity. This procedure is used in the formulation of the theoretical model of the western North Dakota water economy.

The North Dakota model requires six general components which are interrelated by the very nature of an input-output linear programming model. The essential components are: (1) a valid input-output table for the aggregate study area; (2) water use data indicating unit water use per dollar value of output for each sector; (3) volume of water (surface plus subsurface waters) available on an annual basis per region; (4) specified minimum acceptable or projected final demand vectors for each region; (5) labor requirements per dollar of output for each sector; and (6) data indicating labor availability per region.

The Objective Function

An objective function represents an explicit statement of the goal to be optimized, which in the present analysis is taken to be the level of Gross Regional Product (GRP) for each study region. GRP represents an indicator, albeit imperfect, of the economic performance of a regional economy and may be measured (estimated) by either of two theoretically equivalent approaches. All expenditures on final products within a given economy may be summed, or alternatively, value added by each producer for each product may be totaled.

The Constraints

The maximum attainable Gross Regional Product is limited by several complex and interrelated factors. The present analysis however is not an attempt to examine all potential constraints to western North Dakota economic growth. Primary emphasis is placed upon an examination of the potential constraints to economic growth imposed by water availability. Nevertheless, the model structure is quite flexible in that other resource constraints could be incorporated to satisfy other study objectives. The constraints included in the present model structure are discussed below.

The Technological Constraint. Input-output analysis provides a convenient method of expressing the constraint imposed by the technological structure of the economy. These constraints may be written in the usual matrix notation as $(I-A)\,X \geq Y$. For a specified final demand vector Y, the requisite gross output vector X may be determined. The elements of the technical or direct requirements matrix, A are found as $a_{ij} = \frac{X_{ij}}{X_j}$. Thus the technological constraint and the objective function are expressed in terms of the same variable X.

The Water Constraint. The existence of sectoral interdependencies with respect to water usage has been cited previously. In brief, sectors not only require water directly, but indirectly as well via their demands for the physical output of other sectors. Not merely a shortage of water in general, but also a shortage of water in particular sectors, could create adverse effects within the total economy. Input-output analysis again provides a means to mathematically state this interdependence phenomena and enables formulation of a water constraint.

The $(I-A)^{-1}$ matrix represents the direct plus indirect dollar requirements, on an interindustry basis, necessary per dollar of delivery to final demand. Conversion of the Leontief inverse matrix into a matrix indicating direct plus indirect water requirements per dollar delivery to final demand may be accomplished via multiplication of the Leontief inverse by a diagonal matrix of direct water intake coefficients. The resultant matrix is hereafter referred to as the W matrix and each element as w_{ij}.

Direct water intake coefficients are easily determined. Given (1) gross output per sector for a specified year, and (2) the volume of water withdrawn by the sector in the same year, a coefficient indicating water use per dollar of gross output is obtained by dividing (2) by (1). To achieve greater accuracy or reliability, data might be obtained for a number of years and a least-squares line estimated through the origin to derive an average coefficient.

Sectoral water use may be expressed as follows: (1) $W_i = \sum_{j=1}^{n} (w_{ij} \cdot X_j)$ where w_{ij} is an element of the water "multiplier" matrix described above. Then water use by sector i per dollar of output of sector i is: (2) $w_i = \frac{W_i}{X_i} = \frac{\sum_{j=1}^{n} (w_{ij} \cdot X_j)}{X_i}$. Total water use may then be represented as $\sum_{i=1}^{n} W_i$. If W_o represents the volume of surface and subsurface water available, the inequality $\sum_{i=1}^{n} w_i X_i \leq W_o$ must hold true. Thus, these equations enable formulation of a water constraint in terms of the output variable, X, appearing in the objective function.

The Labor Constraint. Although the present analysis is not concerned with an evaluation of the role of labor resources in the western North Dakota economy, a labor constraint is, however, included as a "safety valve". The technological constraint merely states that a specified final demand must be equaled or exceeded. No upper limit is specified.[3] It is, therefore, possible that the optimal solution could occur at unreasonably high levels of gross output. The labor constraint represents an attempt to prevent an obviously unattainable optimal solution.

Labor coefficients indicating employment per dollar of gross output need first be calculated. Given employment data and associated gross output, a direct labor requirements coefficient is determined via a procedure analogous to that used in determining the water intake coefficients. The individual sectoral coefficients are represented as l_i.

Given total labor availability (L_o) for the region, a labor constraint may

[3] It is conceivable that a maximum final demand vector (Y^1) might also be included such that the technological constraint would be expressed as $Y^1 \geq (I-A)\, X \geq Y$.

be formulated as $\sum_{i=1}^{n} l_i X_i \leq L_o$. Again, the variable in the constraint is consistent with the variable appearing in the objective function.

The elements appearing in the preceding discussion are integrated and summarized in convenient mathematical notation below. The model may be written as:

Maximize the objective function $Z = CX$

subject to

$$(I-A)\, X \geq Y$$

$$\sum_{i=1}^{n} w_i X_i \leq W_o$$

$$\sum_{i=1}^{n} l_i X_i \leq L_o$$

where

i (or j) = number of the sector

n = number of sectors

Z = Gross Regional Product

C = value added coefficients vector (dimension 1-n)

X = gross output vector (dimension n x 1)

(I-A) = identity matrix - matrix of Direct Requirements (both dimension n x n)

Y = final demand vector (dimension n x 1)

w_i = sectoral water intake per dollar of gross output

W_o = total water availability

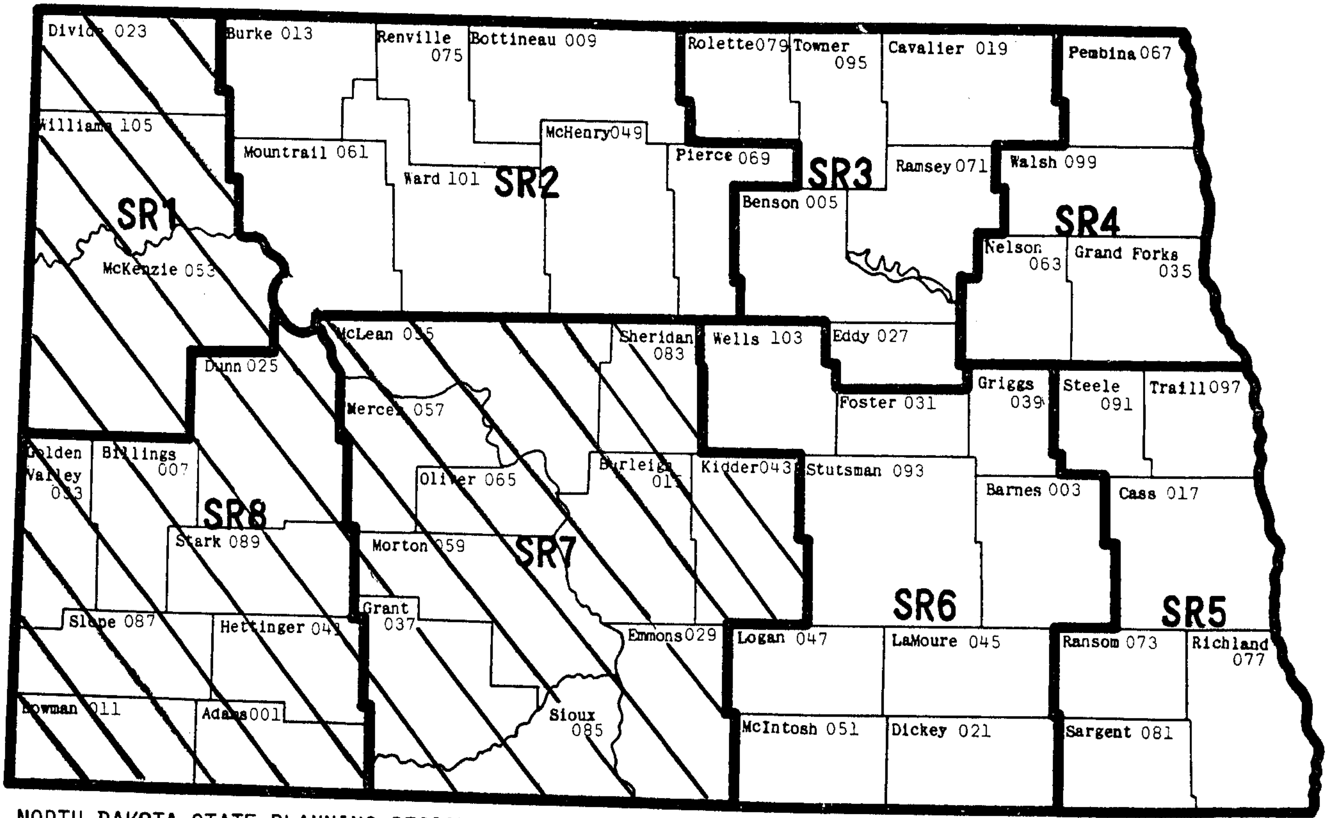
l_i = sectoral labor requirements per dollar of gross output

L_o = total labor availability

Upon apportionment of the aggregate study area into sub-areas, the model may be solved for each of these sub-areas. The aggregate input-output table, the water intake coefficients, and the labor requirements coefficients (all determined from aggregate data) are assumed to be equally descriptive of each sub-area. The other elements are unique for each study area.

The remainder of the discussion presents the empirical results obtained from solution of the models constructed for the western North Dakota economy and analyses thereof. The western North Dakota economy, for purposes of the present analysis, includes the 21-county area depicted in Figure 1. This aggregate study area was further subdivided into three distinct sub-areas

FIGURE 1: Study Area



NORTH DAKOTA STATE PLANNING REGIONS

-- Shaded area represents the study area (also shown in Figure 1) and the general model applied separately to each.[4]

THE EMPIRICAL FORMULATION

As shown in the theoretical model discussed previously, an input-output model is the cornerstone of an input-output linear programming formulation. Input-output offers an approximation of the technological structure of the economy which is instrumental in the specification of the constraints and objective function required in the linear programming format.

The coefficients in the objective function and technological constraint (given by the I-O data)[5] remain constant for all study regions. Regional differences are captured via the final demand vectors on the right hand side of the technological constraint. Similarly the water constraint and labor constraint must be specified for each study area.

The Water Constraint

Formulation of the water constraint requires knowledge with respect to the volume of water required per study region relative to the level of economic activity within that region, in addition to an assessment of the volume of water supplies available per region. These topics and associated estimation procedures are addressed below.

Water Requirements. The volume of water used in an economy is a function of the level of economic activity and the technology of water use. It is assumed, however, that technology of water use changes quite slowly, such that for purposes of the present analysis, it may be ignored.[6] Thus, a coefficient indicating water use per dollar of gross output (for each sector) is taken to be representative of a sector's water requirements relative to the level of economic activity. The direct water coefficients (W_i's) appear in Table 1. All coefficients indicate gross withdrawals.

Water Availability. Data indicating annual availability of water within the specified study regions are not presently available. Furthermore, water supply may be defined in a variety of ways. A common definition of water supply is the annual average surface runoff in the region of interest, although percentages of maximum dependable flow are also frequently used. In either case, groundwater must also be considered as a possible source of water supply. In

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[4]The three sub-areas correspond directly to Study Regions 1, 7, and 8 as established by the North Dakota State Planning Commission.

[5]The basic I-O model used is described in Thor Hertsgaard, et al, REAP Economic-Demographic Model: Technical Description, Bismarck: N. D. Regional Environmental Assessment Program, May 1977. The model was expanded to 17 sectors in an unpublished work by Hertsgaard.

[6]The same assumption is evident in the models constructed for the California and Arizona water economies.

TABLE 1: Direct Water Input Coefficients

(Acre-feet per $1,000 gross output)

Sector	Sector Name	Total Water Withdrawal Coefficient
1	Agriculture, Livestock	.057
2	Agriculture, Crops	.292
3	Sand and Gravel Mining	.002
4	Construction	.003
5	Transportation	.009
6	Communication and Utilities	.003
7	Wholesaling and Agricultural Processing	.002
8	Retail Trade	.001
9	Finance, Insurance, Real Estate	.001
10	Business and Personal Service	.004
11	Professional and Social Service	.005
12	Households	.069
13	Government	.007
14	Coal Mining	0.0
15	Electric Generation	1.813
16	Petroleum Extraction	.256
17	Petroleum Refining	1.751

Source: See B. Eggleston and M. Henry, An Input-Output Linear Programming Model of the Western North Dakota Water Economy. Bismarck; N.D. Regional Environmental Assessment Program, 1978.

the present analysis, regional water supplies are defined in terms of 50 percent of average annual runoff plus 25 percent of total groundwater availability as indicated in Bargur [2, p. 84]. The resulting values should be considered as upper limits and are not necessarily consistent with "political" or "legal" availability.

Average annual runoff (1903-1972) for 25 major stream gaging stations in western North Dakota was utilized to construct an 11-interval contour map via the computer routine SYMAP. Total runoff per study region was determined from the resulting map and 50 percent of each value was taken as representative of regional surface water supplies. Regional annual surface water supplies are then 3,675,639 acre-feet, 1,497,295 acre-feet, and 64,282 acre-feet for Study Regions 1, 7, and 8, respectively.

Groundwater data indicating volume available per specified region is also unavailable. Therefore, a "crude" map of aquifers and associated volumes of water contained therein was utilized as a gross approximation of groundwater availability.[7] The map indicates that 560,000 acre-feet and 1,725,000 acre-feet of groundwater are present in Study Regions 7 and 8, respectively. Thus an additional 140,000 acre-feet and 431,250 acre-feet (i.e., 25 percent of the preceding figures) are available for regions 7 and 8, respectively.

The Labor Constraint

The labor constraint is conceptually similar to the water constraint. Regional labor requirements must be linked to the level of economic activity within the region and labor availability per region must be specified. Although the labor requirements are partly a function of the technology of labor use, this factor is ignored since the assumption of very slow changing technology is again invoked. Sectoral labor coefficients indicating number of employees required per $1,000 of gross output were calculated via a procedure analogous to that used in the determination of sectoral water coefficients.

The application of an optimizing input-output linear programming model to a 21-county area within western North Dakota provides a means of examining water use (governed by the level of economic activity) relative to water supply (governed by the hydrologic conditions of the region). The analysis is of the general equilibrium type whereby each user's (sector's) requirements are viewed relative to the total economic system. Benefit cost analysis, the traditional approach to water resource evaluation, is lacking in this respect.

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[7] See the North Dakota State Water Commission [24, p. 49] for this map. Although incomplete for the aggregate study area as defined in the present analysis, this map represents the only available groundwater data for this region and was necessarily used. Although it is not explicitly considered herein, it is recognized that extensive strip mining of lignite can affect aquifer levels.

The model was applied to three sub-areas of the total area (denoted Study Region 1, Study Region 7, and Study Region 8 as defined in Figure 1). The results shown in Table 2 indicate 1985 water withdrawals (consumption) of 70,700 (70,700), 1,678,500 (383,300)*, and 333,300 (95,695)* acre-feet per year for Study Region 1, Study Region 7, and Study Region 8, respectively. Corresponding gross output requirements are $935,923,000, $3,946,470,000, and $1,411,538,000. For the aggregate 21-county area, this represents a 283 percent increase in water withdrawals and an 87 percent increase in gross output relative to 1973 baseline projections. Much of the increase in water requirements may, however, be attributed to the expected increase in thermo-electric generation which consumes a small percent of water withdrawn, about 0.5 percent. Regardless, these increases are necessary to satisfy the estimated 1985 final demand levels.[8]

SUMMARY

There are some basic limitations in using a static IO-LP model for long run forecasting. Over a period of time, technology and relative price changes exert strong influence on the technological structure of the regional economy. Trade patterns are subject to change over time and this is an especially acute problem for small regional economies faced with rapid development. Over the forecast horizon, it can be expected that the impact of a rapidly growing regional economy on basic political and social institutions may cause policy-makers to reevaluate existing norms which, in turn, may influence the future rate and composition of regional economic change.

Problems were also encountered with respect to water supply data. There exists no definite method of determining or even defining surface water supply. Thus, no figures for North Dakota are readily available, especially on the regional basis utilized herein. Knowledge with respect to groundwater supplies is even more limited and will likely remain so for some time. Thus, the SYMAP routine and crude groundwater maps were used. The accuracy of the SYMAP map might be improved by using minimum flows calculated from statistical distributions of extreme values, as opposed to average runoff.[9] This would enable a probability

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*Note that the large difference between Study Regions 7 and 8 water withdrawals and water consumption is because of the small (0.5 percent) proportion of water withdrawn by electric generation and gasification plants that is actually consumed.

[8]Final demand estimates were made by Hertsgaard, et al. See Footenote 5. Some modifications were made by Eggleston-Henry for Sectors 14-17. See the source cited in Table 1.

[9]The Gumbel Distribution is often utilized in analysis of extreme value data minimums. This distribution is highly skewed in a leftward direction. For a concise introduction to the topic, see United States Department of Commerce, National Bureau of Standards, Statistical Theory of Extreme Values and Some Practical Applications, by Emil J. Gumbel, Applied Math Series 33 (Washington, D. C.: United States Government Printing Office, 1954).

TABLE 2: Summary of Empirical Results: Study Region 1

Sector	Gross Output ($\$10^6$) 1973 (1)	1980 (2)	1985 (3)	Number of Employees 1973 (4)	1980 (5)	1985 (6)
1	31.802	35.724	37.344	1,272	1,429	1,494
2	73.988	96.437	111.550	1,406	1,832	2,119
3	1.055	1.452	1.754	42	58	70
4	17.066	22.995	27.422	700	943	1,124
5	2.201	3.251	3.912	348	514	618
6	13.783	21.539	28.210	496	775	1,016
7	33.020	40.115	45.703	1,222	1,484	1,691
8	104.970	154.312	195.698	2,099	3,086	3,914
9	34.706	75.765	121.958	694	1,515	2,439
10	10.169	15.577	20.256	966	1,480	1,924
11	9.846	14.872	19.277	1,014	1,532	1,983
12	148.887	224.240	289.852	0	0	0
13	12.902	19.376	25.082	2,813	4,224	5,468
14	.019	.020	.020	2	2	2
15	0	0	0	0	0	0
16	42.457	66.213	66.762	723	1,126	1,135
17	7.318	0	0	205	0	0
Total	544.189	791.888	994.800	14,000	20,000	25,000
Total Available	N/A	N/A	N/A	14,000	20,000	25,000

Sector	Water Withdrawals (Acre-feet) 1973 (7)	1980 (8)	1985 (9)	Value-Added ($\$10^6$) 1973 (10)	1980 (11)	1985 (12)
1	1,812.6	2,036.3	2,129.0	10.864	12.218	12.772
2	21,604.5	28,159.6	32,573.0	31.933	41.661	48.190
3	2.2	3.0	4.0	.452	.619	0.747
4	51.3	69.0	82.0	5.528	7.450	8.885
5	19.8	29.3	35.0	.926	1.369	1.753
6	41.4	64.5	85.0	6.211	9.469	12.638
7	66.0	80.2	91.0	1.420	1.725	1.965
8	105.0	154.3	196.0	18.674	27.468	34.834
9	34.7	75.8	122.0	24.141	52.656	84.761
10	40.8	62.4	81.0	3.759	5.763	7.495
11	49.0	74.5	96.0	5.567	8.403	10.880
12	10,273.2	15,472.6	20,000.0	10.169	15.248	19.710
13	90.3	135.8	176.0	0.0	0.0	0.0
14	0.0	0.0	0.0	.007	.007	.007
15	0.0	0.0	0.0	0.0	0.0	0.0
16	10,869.0	17,091.1	17,091.0	5.558	8.674	8.746
17	12,813.8	0.0	0.0	.221	0.0	0.0
Total	57,873.6	63,308.4	72,761.0	125.430	192.904	253.333
Total Available	3,635,639.0	3,635,639.0	3,635,639.0	N/A	N/A	N/A

TABLE 2: (Cont.) Summary of Empirical Results: Study Region 7

Sector	Gross Output ($\$10^6$) 1973 (1)	Gross Output ($\$10^6$) 1980 (2)	Gross Output ($\$10^6$) 1985 (3)	Number of Employees 1973 (4)	Number of Employees 1980 (5)	Number of Employees 1985 (6)
1	133.524	156.855	179.864	5,541	6,274	7,195
2	222.561	265.154	315.249	4,229	5,038	5,990
3	3:277	6.766	7.410	131	271	296
4	46.145	68.627	82.210	1,802	2,814	3,371
5	6.353	10.076	12.184	1,004	1,502	1,925
6	45.359	74.125	90.811	1,633	2,668	3,269
7	138.825	187.238	229.294	5,137	6,928	8,484
8	357.856	535.912	656.016	7,157	10,718	13,120
9	93.263	207.332	239.856	1,865	4,147	4,797
10	33.771	52.378	63.755	3,208	4,976	6,057
11	35.435	56.265	69.848	3,650	5,795	7,194
12	535.959	827.088	1,017.419	0	0	0
13	45.660	74.313	93.064	9,954	16,200	20,288
14	9.968	72.469	116.466	887	6,450	10,365
15	60.343	445.300	725.300	301	2,227	3,626
16	47.238	76.473	78.808	803	1,300	1,340
17	57.421	92.957	95.796	1,608	2,603	2,682
Total	1,877.958	3,209.328	3,946.470	49,000	80,000	100,000
Total Available	N/A	N/A	N/A	49,000	80,000	100,000

Sector	Water Withdrawals (Acre-feet) 1973 (7)	Water Withdrawals (Acre-feet) 1980 (8)	Water Withdrawals (Acre-feet) 1985 (9)	Value-Added ($\$10^6$) 1973 (10)	Value-Added ($\$10^6$) 1980 (11)	Value-Added ($\$10^6$) 1985 (12)
1	7,895.9	8,940.7	10,252.2	47.375	53.644	61.513
2	64,987.8	77,425.0	92,052.7	96.146	114.547	136.188
3	6.6	13.5	14.8	1.396	2.882	3.157
4	138.4	205.9	246.6	14.951	22.235	26.636
5	57.2	90.7	109.7	2.675	4.242	5.129
6	136.1	222.4	272.4	20.321	33.208	40.683
7	277.6	374.5	458.6	5.969	8.051	9.860
8	357.9	535.9	656.0	63.698	95.392	116.771
9	93.3	207.3	239.9	64.818	144.096	166.700
10	135.1	838.0	255.0	12.495	19.380	23.589
11	177.2	281.3	349.2	20.021	31.790	39.464
12	36,981.2	56,069.1	70,202.0	36.445	56.242	69.184
13	319.6	520.2	651.4	0.0	0.0	0.0
14	0.0	0.0	0.0	3.728	27.103	43.556
15	109,401.8	807,328.0	1,314,968.9	7.302	53.881	87.761
16	12,092.0	19,377.1	20,174.8	6.188	10.018	10.324
17	100,486.8	162,674.8	167,643.0	1.723	2.789	2.874
Total	333,545.4	1,136,305.3	1,678,546.3	405.251	679.500	843.389
Total Available	1,928,295.0	1,928,295.0	1,928,295.0	N/A	N/A	N/A

TABLE 2: (Cont.) Summary of Empirical Results: Study Region 8

Sector	Gross Output ($\$10^6$) 1973 (1)	1980 (2)	1985 (3)	Number of Employees 1973 (4)	1980 (5)	1985 (6)
1	74.517	77.275	86.463	2,981	3,091	3,459
2	127.068	149.237	175.452	2,414	2,836	3,334
3	1.638	12.461	13.917	66	498	557
4	21.329	24.534	29.133	874	1,006	1,194
5	3.231	3.749	4.419	510	592	698
6	24.376	29.895	33.713	878	1,076	1,214
7	68.247	78.052	96.839	2,525	2,888	3,583
8	183.648	223.528	259.183	3,673	4,471	5,184
9	91.016	108.743	88.580	1,820	2,175	1,722
10	17.960	22.290	25.241	1,706	2,118	2,398
11	17.509	21.265	24.989	1,803	2,190	2,574
12	261.928	318.221	367.614	0	0	0
13	23.287	28.185	33.759	5,077	6,144	7,359
14	3.723	10.200	32.895	331	908	2,928
15	0	0	136.500	0	0	683
16	19.957	.141	1.297	339	2	22
17	.063	.171	1.576	2	5	44
Totals	939.497	1,107.947	1,411.538	25,000	30,000	37,000
Total Available	N/A	N/A	N/A	25,000	30,000	37,000

Sector	Water Withdrawals (Acre-feet) 1973 (7)	1980 (8)	1985 (9)	Value-Added ($\$10^6$) 1973 (10)	1980 (11)	1985 (12)
1	4,247.5	4,404.7	4,928.4	25.485	26.428	29.570
2	37,103.9	43,577.2	51,232.0	54.893	64.470	75.795
3	3.3	24.9	27.8	.698	5.308	5.929
4	64.0	72.6	87.4	6.911	7.949	9.439
5	29.1	33.7	39.8	1.360	1.578	1.860
6	73.1	89.7	101.1	10.920	13.393	15.103
7	136.5	156.1	193.7	2.935	3.356	4.164
8	183.6	223.5	259.2	32.689	39.788	46.135
9	91.0	108.7	88.6	63.256	75.576	61.563
10	71.8	89.2	101.0	6.645	8.247	9.339
11	87.5	106.3	125.0	9.893	12.015	14.119
12	18.073.0	21,957.3	25,365.4	17.768	21.639	24.998
13	163.0	197.3	236.3	0.0	0.0	0.0
14	0.0	0.0	0.0	1.392	3.815	12.303
15	0.0	0.0	247,474.5	0.0	0.0	16.516
16	5,109.0	36.1	332.0	2.614	.018	.170
17	110.3	299.4	2,749.1	.002	.005	.047
Total	65,546.6	71,377.7	333,341.3	237.461	283.585	327.050
Total Available	204,282.0	204,282.0	364,000.0*	N/A	N/A	N/A

*The water constraint was incremented by 20,000 acre-feet increments until a solution was found that would meet specified minimum levels of final demand.

statement with respect to a particular volume of water available (e.g., a 95 percent dependable supply).

The input-output model may not represent the economic structure of the study regions with complete accuracy. However, when used concomitantly with linear programming techniques, it provides at least a broad framework within which water needs and available supplies may be compared. The figures cited earlier, though certainly not precise estimates, do give some indication that water distribution problems may be encountered with future economic development. For Study Regions 7 and 8, projected 1985 water withdrawals exceed average regional surface water flows. This indicates the need for further development of groundwater supplies, recirculation of industrial water, the transfer of water from other regions and increased utilization of water from Lake Sakakawea in Study Region 7. In fact, most coal related development must locate near Lake Sakakawea to draw on this reserve of water. The 16-18 million acre-feet capacity of Lake Sakakawea should easily supply water needed by potential coal related development through 1985.

One final point merits discussion. Even assuming water supplies are very "tight," economic growth need not necessarily be restrained. A change in the structure of the economy may allow continued growth with no increased pressures on water supply. Transfer of water from a sector utilizing large volumes of water but producing low value output to a sector utilizing small volumes of water and producing high value output may enable increased gross output with the same level of water use.[10] Political and social factors may obviously preclude such action.

[10] See Lofting and McGauhey [19, p. 75] or Kelso, et al [16, p. 223] for similar discussion.

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