Establishing the Value of Water for Different Economic Sectors Using a Regional Interindustry Model

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Obtaining estimates of the value of water to a region is important, especially in areas where the supply is limited[1] or unstable. Major financial commitments to water development projects are influenced by the public's perception of the value of water in its various uses. Because scarcity characterizes both water resources and taxpayers' capital, it is critical that water resource investments be evaluated properly. Comprehensive regional planning requires knowledge of factors that constrain economic growth and development. One such factor is the scarcity of a primary element of production such as water.

Scarcity of water, or of any other commodity, can be handled by managing demand or by allocating limited amounts among alternative uses. By implementing appropriate price and non-price measures, some of the perceived scarcity of water can be mitigated. Failing this, one must devise schemes for allocating the available water. Inefficient allocation can result when water is not allocated through a market mechanism at a price that reflects the value of the marginal product. Moreover, since regional economic development is of concern to regional governments, a technique for evaluating the impact of different levels of water resource availability on regional economic growth will have some merit for long-range planning.

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1. This study does not necessarily assert that water in Saskatchewan is becoming scarce. An examination of water use in various subregions of the province, however, suggests that scarcity is approaching, whereas in other regions scarcity is perceived during some periods, particularly during drought.

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The primary objective of this study is to estimate the maximum value of water for different economic sectors in the province of Saskatchewan. In seeking an appropriate evaluation technique, individual sectoral requirements must be viewed in the context of the total available supplies. All sectors in an economy are interdependent, and each sector depends on water availability. Thus, it is essential to develop a technique that not only facilitates estimation of the impact of water restrictions on economic growth, but also accounts for the interdependencies that exist. On the one hand, input-output models, based on the interrelationships of industries within a regional economy, can be used to derive implications for regional water resources if a given economic sector expands output levels, employment, or income.[2] Thus, input-output analysis can rank various sectors in terms of total water requirements, with no priorization of water use by one sector relative to other sectors. On the other hand, linear programming procedures provide a basis for allocating a scarce resource while maximizing a given objective function. Thus, one can combine input-output models and linear programming to derive an allocation of scarce water resources that maximizes regional value added, given the structure of the region and the technology of various industries.

Concept of Value

Natural resources, like commodities, command an economic value only when their availability relative to their use is limited. A notion of value is implicit in the use of (or inherent demand for) the commodity. As water becomes a scarce resource and as scarcity becomes a problem, it takes on a positive economic value because of competition for its use.

In a market system, prices serve as a guide to a commodity's value. One concept of value defines value as the amount a perfectly rational user of a good would be willing to pay for it rather than go without it. Thus, value is a measure of a user's willingness to pay, and it is a value in exchange. Another concept of value is that of "value in use". This value measures the importance of a good to its user but does not reflect what the item could bring on the market, as measured by "value of exchange".

According to Marglin (1968), however, the value of a resource has a meaning only in relation to the objective one has in mind. Thus, one way to define value is to measure the contribution of the resource to the

2. An example of such an application is provided by Kulshreshtha (1983) for Saskatchewan. Similar applications for the United States are found in Laurent and Hite (1971), Ching (1981), and Harris and Ching (1983).

objective function. Similarly, the value of water can be measured as such from an economic efficiency perspective or from a regional accounting stance. The value of water using the regional accounting approach may be estimated as the contribution made to value of new goods and services produced by an accounting entity—firm, sector, consumer—in a region during a specified period. Such a value is not directly comparable to the values obtained using either use or exchange criteria as it is neither the "value in use" nor the "value in exchange" of water. Instead, it is measured in terms of its contribution to the overall economic well-being of a region, using a set of well-defined, relatively restrictive assumptions.

Although use of the regional accounting procedure has been suggested (D'Arge 1970), the application of this procedure to allocative decisions has its limitations. The value of water obtained is a valid criterion for allocation only when the social opportunity cost of labour and other primary resources is zero. It is only under this condition that the maximum social productivity of the scarce water resource would be equivalent to maximum total value added. Furthermore, as Young and Gray (1972) have noted, this value of water may be close to the one obtained by the residual imputation approach[3] to determining value and may therefore be subject to the same limitations as that approach.[4]

One further caution in applying the regional accounting approach is that in this approach the economic well-being of the regions is measured by gross domestic product (GDP), which itself has some well-known deficiencies. First, the GDP is not expressed in per capita terms. Second, it only measures those goods and services that constitute market goods. Thus, non-market benefits such as the opportunity for home production and non-market costs such as the cost of environmental degradation are not included here. Third, it does not account for the opportunity costs of immigrant labour or borrowed capital.

Methodology

The model presented here was motivated by similar attempts to combine the input-output and linear programming methods and to apply them to the allocation of a scarce resource in a regional economy (Kelso et al. 1973; Henry and Bowen 1981; Harris and Rea 1984).

3. The residual imputation approach derives the value of water by substracting from the total output value the share of factors of production other than water.
4. Readers are cautioned that a number of significant differences related to the definition of value added may invalidate the equivalence of value using the two approaches.

The basic procedure incorporates the production function, based on the input-output model for various sectors, into a linear programming framework. The objective function is to maximize the regional gross domestic product, referred to here as the gross regional product (GRP). This GRP is maximized in the form of production constraints and a water constraint derived from current water-use coefficients. The control case is the current economic situation, with current levels of final demand and water use. The availability of water is then increased to the point that an additional unit (dam^3) of water will not further increase the GRP. And the availability of water is then decreased to find the point at which the solution is infeasible. In this manner the last unit of water is allocated to the industry that contributes most to the GRP.

The conceptual model can be represented mathematically as:

$$\text{maximize} \quad Z = C\,X \tag{1}$$

$$\text{subject to} \quad \bar{Y} \geq (I - A)\,X \geq Y \tag{2}$$

$$W'X \leq w_0 \tag{3}$$

$$X \geq 0 \tag{4}$$

where
- i is the sector number ($i = 1, \ldots, 64$);
- Z is the gross regional product;
- C is a 1×64 vector of the value-added coefficients obtained from the input-output model;
- X is a 64×1 vector of gross output;
- $\bar{Y}$ is a 64×1 vector of projected final demand;
- I is the identity matrix of order (64×64);
- A is a 64×64 matrix of technical coefficients derived from the input-output model;
- Y is a 64×1 vector of the final demand obtained from the input-output model;
- w_i is water intake per thousand dollars of gross output, obtained from the input-output model; and
- w_0 is the total available supply of water.

Water is assumed to be the only basic resource constraining regional value-added activity. Thus, the object of the exercise is to find the level of regional sectoral output (X vector) for which regional value added will be maximized, subject to the constraints that (1) sectoral water requirements cannot exceed total available supply, (2) total output must be at least capable of meeting the current level of final demand, and (3) sectoral output cannot be less than zero.

The above model can be used to generate two types of information. First, the primal solution can be used to predict the impacts of change in the level of resource availability on both the total output and the spatial allocation of that output among production sectors. Second, the dual solution can be used to generate shadow prices for the resources used in the production process.

The above procedure estimates the maximum value of water; for the net value of water, the opportunity cost of labour and capital must be deducted. Furthermore, the analysis is based on the assumption that all other primary inputs (1) do not constrain production; (2) have perfectly competitive input markets that display constant returns to scale so that prices are constant regardless of the quantity consumed; and (3) receive the appropriate value of the marginal product. This implies that the opportunity cost of all other primary resources is assumed to be zero.

Overview of the Underlying Transactional Table

The input-output linear programming model used in this analysis is based on a transactions table reflecting the 1984 levels of output and final demand for Saskatchewan. The initial model was based on 1979 levels of transactions, but through use of a non-survey updating procedure, it was updated to reflect 1984 conditions. The resulting transactions table is a 79 × 66 matrix in a sector-by-sector "square conformable" format, with 63 producing sectors listed down and 63 purchasing sectors listed across (plus households, other final demands, and exports). Items in this table are in producers' prices and reflect that part of the demand that is met through local production. A single (condensed) transactions table is shown in Table 1.

The two basic types of resource data required by the model are: (1) the labour required to produce a given level of output, derived as the average person-years of employment in a sector necessary to produce $1,000 worth of output in 1984 dollars, and (2) water-use coefficients, defined as the quantity of water used (in dam^3) to produce $1,000 worth of 1984 output in one sector. Water quantity is measured in terms of gross intake of water by a given sector. Gross water intake is defined as the total amount of water added to the water system to replace water discharged or consumed during production. Water consumption is water lost during the process. Discharged water is water returned to the environment in the form of water. Water discharge and water consumption (the effluent subsystem of a plant) are roughly equivalent to the total gross water intake of the plant (Tate and Scharf 1985). Ratios of the current average GRP to water use

TABLE 1 Saskatchewan Transactions Table, 1984 (million 1984 dollars)

Producing Industry Group	Purchasing Industry Group: Agri-culture	Mining	Agri-cultural Pro-cessing	Non-agri-cultural Manuf.	Con-struc-tion	Transpor-tation, Commerce, Utilities	Trade	Finance, Real Estate, Insur.	Services	Total Inter-mediate Sales	Final Demand: House-holds	Business Investment and Government	Exports	Total Output[a]
Agriculture	89	1	439	3	1	—	26	—	11	570	118	15	3,148	3,884
Mining	26	182	2	167	162	32	7	4	4	586	58	8	3,375	4,060
Agricultural processing	33	—	34	3	1	—	1	—	49	121	421	3	491	1,043
Non-agricultural manufacturing	95	27	6	56	153	41	25	5	58	466	284	47	879	1,690
Construction	90	314	2	16	4	185	22	374	13	1,020	23	1,818	7	2,892
Transportation, commerce, utilities	61	85	14	41	22	125	115	50	256	769	595	47	1,124	2,556
Trade	52	21	8	23	84	26	16	8	119	357	1,660	77	543	2,656
Finance, real estate, insurance	128	692	4	13	29	27	105	115	63	1,176	1,481	46	712	3,442
Services	156	258	51	83	152	122	216	157	293	1,488	1,068	213	714	3,510
Total intermediate demand	730	1,580	405	608	558	533	713	866	6,553	5,708	2,274	2,274	10,905	25,440
Wages and other labour income	1,851	791	190	465	1,065	1,117	1,610	1,152	906	9,232	419	989	0	10,670
Other value added	669	955	60	134	318	572	282	1,472	978	5,490	679	165	0	6,334
Imports	666	767	240	700	923	330	252	135	788	4,947	3,922	883	0	9,752

Note: Dashes denote less than $500,000.

a. Totals reflect rounding or residual error of estimation.

for various sectors are provided in Table 2. The last column in this table shows the level of gross regional product generated by one unit (dam^3) of water. But because these ratios show only the direct relationship, they are not very useful for allocation purposes.

Allocation of Available Water Supply through the Model

The relative value to the economy as a whole of the allocation of the additional supply of water is estimated through comparisons of optimal GRP levels of each sector under different levels of water supply. Value refers here to the contributions made to the general economic well-being of the economy through the relaxation of the water constraint. The marginal value of additional water supplies may be assessed by solving for the shadow price of water with respect to the change, which is the dual solution to equation (3).

For this purpose, the Saskatchewan economy was simulated under different levels of water availability. Water availability is not a constraint to regional production until it drops below 2.22 million dam^3. Water availability was reduced marginally by 1,000 dam^3 until meeting the present final demand facing Saskatchewan became infeasible.

The shadow price of water associated with various levels of water availability is shown in Table 3. As noted above, this shadow value is measured by the dual solution to equation (3). From this table, it can be seen that at 1.701 million dam^3, water becomes a constraint to GRP. Moreover, the shadow price of water at this point is approximately $17.47 per dam^3. By estimating the contribution of water to regional well-being, the shadow price indicates the "value" of additional water to the regional economy (see Figure 1 which depicts the relationship between shadow price and quantity of water). But if policy makers wish to allocate the constrained water supply among alternative economic sectors in Saskatchewan, a more precise tool of water allocation is required.

To develop a more precise allocative producer, the model was solved for four different water availabilities: first, for 1.7 million dam^3 and 1.701 million dam^3, and, second, for 2.223 million dam^3 and 2.224 million dam^3. By comparing sectoral GRP levels within each pair of water availabilities, an estimate of the value of water is obtained (see Table 4). A comparison of the sectoral GRP for water availability of 1.7 million dam^3 and 1.701 million dam^3 is of interest because at the latter level water availability becomes a constraint to regional development. If the water supply falls from 1.701 million

TABLE 2 Water Demand Input-Output Results

Sector	Description	Water/FD[a]	GRP/FD[b]	GRP/AFT[c]
1	DAIRY FARMS	0.02	1.00	63.67
2	CATTLE FARMS	0.02	0.98	62.72
3	HOG FARMS	0.02	0.94	60.37
4	POULTRY FARMS	0.02	1.02	65.58
5	WHEAT FARMS OF BROWN SOIL	0.02	1.03	65.36
6	WHEAT FARMS OF DARK BROWN SOIL	0.02	1.03	65.36
7	WHEAT FARMS OF BLACK SOIL	0.02	1.03	65.36
8	OTHER GRAIN FARMS ON BROWN SOIL	0.02	0.98	62.55
9	OTHER GRAIN FARMS ON DARK BROWN SOIL	0.02	0.98	62.53
10	OTHER GRAIN FARMS ON BLACK SOIL	0.02	0.98	61.90
11	FRUITS AND VEGETABLE FARMS	0.01	0.83	57.66
12	INTENSIVE IRRIGATION FARMS	7.60	1.08	0.14
13	BACKFLOOD IRRIGATION FARMS	6.12	1.11	0.18
14	FORESTRY	0.00	5.77	0.00
15	FISHING AND HUNTING	0.00	0.97	0.00
16	METAL MINING	0.01	0.89	91.62
17	MINERAL FUEL MINING	0.00	0.60	622.23
18	NON-METAL MINING	0.03	0.82	27.68
19	SERVICES TO MINING	0.00	174.76	0.00
20	SLAUGHTERING AND MEAT PROCESSING	0.00	0.73	212.24
21	POULTRY PROCESSORS	0.02	1.19	71.92
22	DAIRY FACTORIES	0.00	1.16	3221.82
23	FRUIT PROCESSORS	0.00	29.61	27143.10
24	FEED MANUFACTURERS	0.00	1.05	77483.34
25	FLOUR AND CEREAL MANUFACTURERS	0.01	1.27	101.77
26	BAKERIES	0.00	1.86	975.68
27	VEGETABLE OIL MILLS	0.01	0.58	7.41
28	MISCELLANEOUS FOOD MANUFACTURERS	0.05	2.30	47.90
29	SOFT DRINK MANUFACTURERS	0.00	7.34	2636.84
30	RUBBER AND PLASTIC	0.00	1.28	281.24
31	LEATHER AND LEATHER PRODUCTS	0.00	1.61	623.00
32	TEXTILE MANUFACTURERS	0.00	2.39	779.89
33	CLOTHING	0.00	1.10	47728.59
34	WOOD AND WOOD PRODUCTS	0.00	1.22	4273.78
35	FURNITURE MAKERS	0.00	7.74	63211.92
36	PULP AND PAPER	0.16	0.73	4.58
37	PRINTING AND PUBLISHING	0.00	5.31	697020.53
38	PRIMARY METAL INDUSTRY	0.00	0.83	566.51
39	METAL FABRICATION	0.00	2.02	1907.93
40	MACHINERY AND EQUIPMENT	0.00	0.98	664781.51
41	TRANSPORT EQUIPMENT	0.00	1.35	2793.87
42	ELECTRICAL PRODUCTS	0.00	1.13	818127.94
43	NON-METAL PRODUCTS	0.01	2.37	233.40
44	PETROLEUM AND COAL PRODUCTS	0.01	2.26	344.84
45	CHEMICAL PRODUCTS	0.02	0.88	52.78
46	MISCELLANEOUS MANUFACTURING	0.00	5.07	1410.72
47	CONSTRUCTION	0.00	1.26	171231.60
48	TRANSPORTATION	0.00	1.06	98065.40
49	COMMUNICATIONS AND INSURANCE	0.00	5.63	49835.96
50	UTILITIES	26.69	11.60	0.43
51	WHOLESALE TRADE	0.00	1.36	8804.17
52	RETAIL TRADE	0.00	14.67	138256.67
53	OWNER-OCCUPIED DWELLINGS	0.00	0.00	6366.42
54	FINANCE, INSURANCE, AND REAL ESTATE	0.00	2.71	85854.28
55	EDUCATIONAL AND HEALTH SERVICES	0.00	2.75	31051.17
56	AMUSEMENT AND ENTERTAINMENT	0.00	49.34	0.00
57	BUSINESS SERVICES	0.00	1.47	38250.71
58	ACCOMMODATION AND FOOD	0.00	8.24	6459.11
59	MISCELLANEOUS PERSONAL SERVICES	0.00	12.80	35224.51
60	TRANSPORTATION MARGINS	0.00	0.75	0.00
61	OPERATING, OFFICE AND LAB SUPPLIES	0.00	11.38	0.00
62	TRAVEL AND ADVERTISING	0.00	6.57	0.00
63	HOUSEHOLD INCOMES	0.12	5.02	42.34

a. Total water required per $1,000 of final demand.
b. Gross regional product per dollar of final demand

TABLE 3 Shadow Price of Water at Alternative Supply Levels

Water Supply (million dam^3)	Shadow Price ($/$dam^3$)	Optimum GRP (million 1984 $)
2.224	0.00	17,603
2.223	0.16	17,603
2.200	0.16	17,600
2.100	2.64	17,554
2.000	6.80	17,003
1.900	9.09	16,247
1.800	9.81	15,293
1.701	17.47	14,227
1.700	17.47	14,210

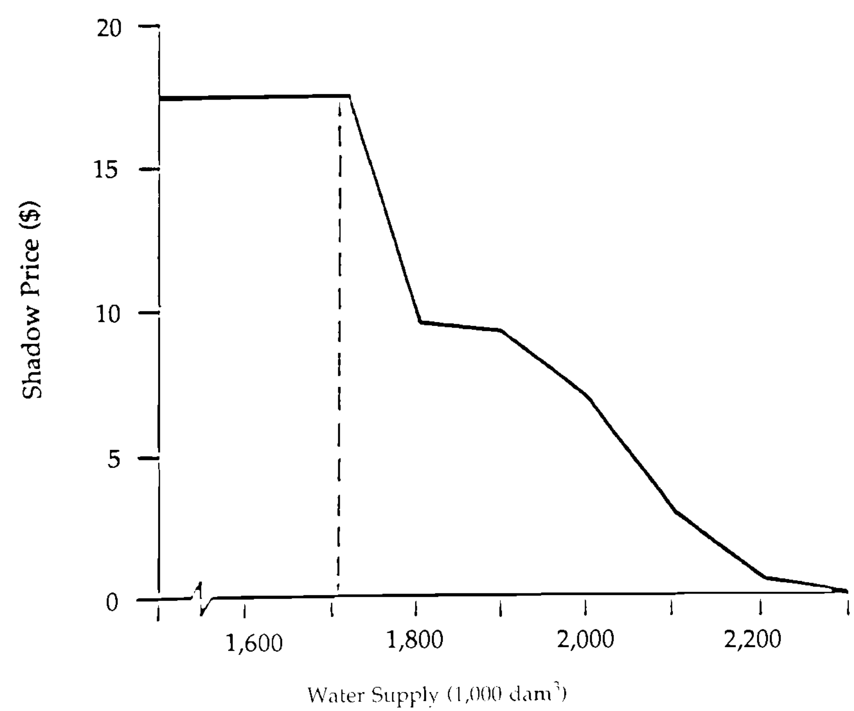

FIGURE 1 Shadow price of water at different water supply levels

TABLE 4 Value of Water in Terms of Contribution to Gross Regional Product, by Major User and Ranking of Various Sectors (dollars)

Sector	Level Low (water availability 1.700-1.701 million dam³)	Level High (water availability 2.223-2.224 million dam³)	Rank of Sector	
			Level Low	Level High
Agriculture	320.37	21.99	9	2
Mining	18,166.34	3.29	1	9
Agricultural processing	456.38	4.42	7	6
Other manufacturing	539.66	7.71	5	4
Construction	613.46	5.41	4	5
Communication	463.36	3.63	6	7
Utilities	338.28	3.72	8	8
Trade	1,711.80	16.07	3	3
Services	3,483.33	124.39	2	1

dam^3 to 1.7 million dam^3, different sectors will make different contributions to the GRP. This contribution will vary between $320.37 and $18,166.34. At this level of water availability, the mining sector is the leading beneficiary since it registers the largest decline in GRP.

Similarly, when water availability increases, the shadow value of water declines. A decrease from 2.224 million dam^3 to 2.223 million dam^3 results in water valued at between $3.29 and $124.39. At this level of change, the major beneficiary is the services and agriculture sector.

The agriculture and mining sectors—given current economic interdependencies, technology of production, and water-use efficiency—face the largest reductions in output if water availability is reduced because agriculture has a low value-added to water-use relationship. If agriculture could use water more efficiently, the effect of water curtailment would be lessened. If water-use efficiency does not improve, plentiful water supplies would see more water allocated to agriculture. But with reduced water availability, additional water should be allocated to the mining sector for the greatest increase in regional value added.

Summary and Limitations

The primary objective of this paper was to develop an input-output linear programming model based on the 1984 structure of the Saskatchewan economy. Such models can serve as a basis for resource planning, particularly decisions on the allocation of water. The model allocates water among competing economic sectors in such a way that

the regional level of gross domestic product is maximized, while constraints facing the regional economy are met. The model generates a marginal value of water for different users.

Results suggest that the shadow value of water varies between $0.16 per dam^3 at 2.223 million dam^3 to a maximum of $17.47 per dam^3 when water availability is only 1.701 million dam^3. Thus, if water availability is reduced by an average of 30.7 percent, no serious economic problems are anticipated. A more severe drought, however, would affect the economic performance of the region.

Findings also indicate that the agriculture and services sector would experience larger reductions at high levels of water availability, whereas the mining and services sectors would face reductions at low levels of water availability.

These results have their limitations, however. First, use of the input-output model necessarily implies that the relationship between inputs and outputs is linear, which may bias results. As water becomes scarcer, opportunities for conserving water may be developed, thereby leading to the substitution of other inputs for water. Second, water-use coefficients are assumed to be known and fixed, but, in fact, existing data are only crude approximations. Third, in the linear programming portion of the analysis the production function is constrained by an upper bound of final demand that must be estimated. If this upper bound changes, the results of the analysis will change. Fourth, the approach provides evidence of the impacts of a constrained supply of water on a regional economy and thus, in terms of GRP, subject to various limitations in approaching the true value of water.

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