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The Conceptualization and Quantification of a Water Supply Sector for a National Agricultural Analysis Model Involving Water Resources

Miscellaneous Report

THE CENTER FOR
AGRICULTURAL AND RURAL DEVELOPMENT
IOWA STATE UNIVERSITY • AMES, IOWA 50011

THE CONCEPTUALIZATION AND QUANTIFICATION OF A WATER SUPPLY SECTOR FOR A NATIONAL AGRICULTURAL ANALYSIS MODEL INVOLVING WATER RESOURCES

by

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Miscellaneous Report

The Center for Agricultural and Rural Development

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Introduction

Availability of water for agricultural use is one of the major factors determining agricultural production in the Western United States and this area's contribution to national production levels. In this publication the existing knowledge on water availability is drawn together to develop a consistent and dependable set of water supply projections for the Western United States for 1985 and 2000. This water supply data can then be used as a basis for analyzing the allocation and use of the nation's water resources under alternative national agricultural production and environmental quality policies.

Evaluation of alternative national policies and resource allocations as a means for achieving the goals of society is an area in which the economist can make a major contribution. Two tasks face the economist in pursuing this effort. One, he must conceptualize the problem and the physical relationships and interactions that pertain to the problem or contribute to the solution. Two, the economist faces the task of quantifying the relationships in physical terms and assigning economic weights to the variables.

In purely theoretical investigations the researcher must only satisfy his colleagues, but research in more applied areas must not only meet the professional standards of the discipline but must stand up under the scrutiny of decision makers and the general public. The demands of this dual audience often dictate that the assumptions made must conform more closely to reality, and the degree of aggregation and generalization must be more limited than would be desired in purely theoretical investigations. Any investigation of this type must be internally consistent and consistent with the real world.

The Water Sector

Water is obtained from two main sources--surface watercourses and ground water. The amount of surface water available is determined by the magnitude and distribution of the annual precipitation, the proportion of the precipitation that reaches the watercourses, and the availability of reservoir storage. The reservoir storage provides the ability to change the intertemporal allocation of the water. Excess water from wet periods can be held and then released for use in dry periods. This reallocation may occur within a given year or over a period of several years. The water in storage is subject to losses due to evaporation and percolation into the underlying ground strata. Reservoir projects are usually located so that percolation losses are minimized leaving evaporation losses as the major restriction on the quantity of water that can be made available for use through storage. The length of time water would have to be held in storage to even out the annual flows is determined by the variability in annual precipitation and runoff. The combination of the storage time required and the evaporation losses places an upper limit on the quantity of water that can be made available. If there were no storage losses, the mean annual runoff would represent the maximum quantity of water that could be made available for use over time.

Since losses do occur while water is in storage, the upper limit on water availability through storage will always be less than the mean annual runoff. The magnitude of the potential loss is a function of the annual evaporation losses and the length of time the water is held in storage. The storage time is directly related to the variability in annual precipitation. As the variability in precipitation increases, the storage time required to yield a uniform flow also increases.

Ground water supplies are obtained from both stock and flow resource endowments. Ground water pumped from closed basins or slowly recharged aquifers that have required hundreds to thousands of years to accumulate the existing supply are depletions of a stock resource. Pumping from aquifers that are readily recharged from infiltration and percolation of precipitation or deep percolation from streams, reservoirs, canals or irrigated land constitutes the utilization of a renewable flow resource. The ground water supply available in any given year represents the sum of the yields obtained from the renewable sources plus the depletion of the stock resource deemed desirable by society.

The basic interactions involved in the measurement or estimation of the total supply of water available for use in an area are expressed in the following set of equations:

$$W_T = f\,(W_S, W_G) \qquad (1)$$

$$W_S = F(NR, A, S_C, S_L) \qquad (2)$$

$$NR = f(P, V_P, G, B) \qquad (3)$$

$$S_L = f(E, V_P) \qquad (4)$$

$$W_G = f(Y_R, Y_D)$$

where:

W_T is the total available water supply;

W_S is the water available from surface sources;

W_G is the water available from ground water;

NR is natural runoff;

A is the area of the basin drained;

S_C is the storage capacity of reservoirs in the area;

S_L is the loss of water due to impoundment;

P is annual precipitation;

V_P is the variability in annual precipitation;

G is the affect of geological factors such as slope, soil type and texture, infiltration rate, etc.;

B is the affect of biological factors such as the retardation of runoff by plant cover, the use of water and loss by evapotranspiration by natural vegetation, etc.;

E is the net evaporation from reservoirs;

Y_R is the yield of ground water from rechargeable aquifers; and

Y_D is the depletion of ground water from nonrechargeable aquifers.

In order for this formulation to be useful for the development and evaluation of policy, planning, or resource allocation it must be empirically estimated. In this study water supplies are estimated for each of the 58 producing regions defined by the Center for Agricultural and Rural Development for use in the NSF-RANN studies which are contained within the nine river basins that drain the Western United States, Figure 1. The nine river basins include the Missouri, the Arkansas-White-Red, the Texas-Gulf, the Pecos-Rio Grande, the Upper Colorado, the Lower Colorado, the Great Basin, the Columbia-North Pacific, and the California-South Pacific basins. The producing regions containing irrigated crop activities are numbered consecutively from 48 through 105.

Surface Water Supplies

Consistency in computational procedure and data is one of the major problems encountered in developing water supply statistics. Although data for individual areas are available from numerous sources including state publications, comprehensive river basin studies and Type I studies, etc., the most complete and consistent source of data upon which to base the computation of water supplies is The Nations' Water Resources [79]. Even within this one source some variability exists in computational procedures for different river basins and some of the natural runoff data may not be directly tied to physical relationships. It is not possible to determine from the text or references which procedures were used in which regions. Therefore, since some of the data is derived from precipitation-evapotranspiration-runoff relationships and the data set appears to be internally consistent we will assume that the natural runoff data reflects the physical precipitation-runoff relationship existing in each region.

The preliminary data for the second national water assessment[1] contains a more recent estimate of water availability, but inspection

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[1]Memorandum to the NPA Committee (April 18, 1974).

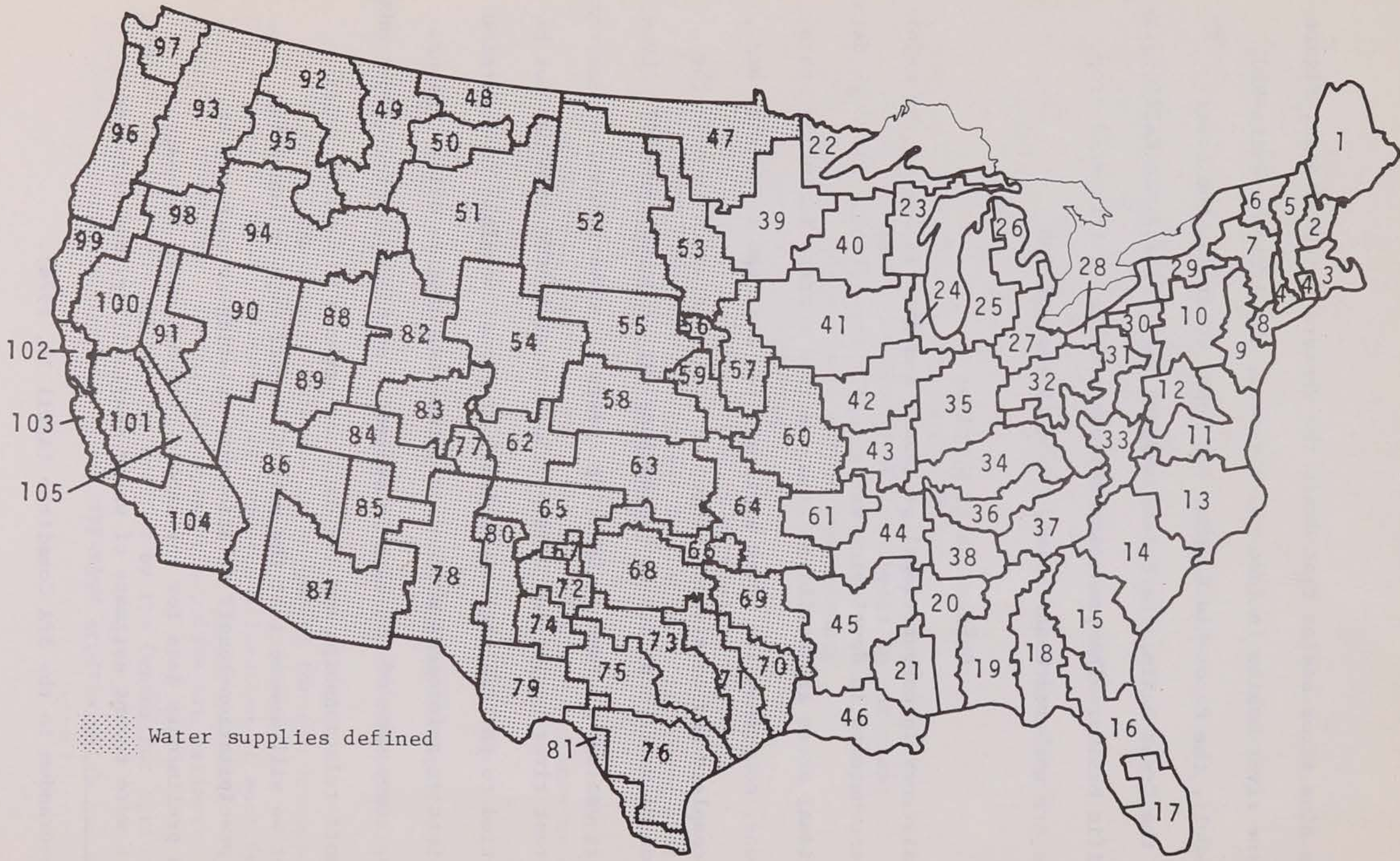

Figure 1. The 58 producing regions with water supplies defined

of the computational procedures for the agricultural water supplies raises the question whether the supplies reflect physical relationships between precipitation, percolation, surface runoff, and storage or whether they more nearly reflect historical water usage in the various regions.

Natural runoff

Natural or "virgin" runoff as reported in The Nation's Water Resources [79] is used as the basis for computing surface water supplies. The concept of natural runoff refers to that portion of precipitation which reaches surface watercourses. It is defined as the annual flow of water that would appear in surface streams if there were no upstream development [79].

Since the boundaries of the producing regions defined in this investigation are not consistent with the reporting areas in The Nation's Water Resources [79], it is necessary to transform the data to a basis consistent with the producing regions.

The annual natural runoff for each of the producing regions is computed as a weighted average of the natural runoff reported for the river basin subareas contained in each producing region. The weighting factors are area and average annual precipitation. The area of the producing regions and the area of each of the included river basin subareas, defined on a county boundary basis, are calculated from the acreages contained in the Conservation Needs Inventory [8]. The acreages are converted to square miles for ease of computation.

Average annual precipitation for each producing region is compiled from monthly average precipitation measurements for the 19 states which are either entirely or partially included in the nine western river basins [55-74]. Because producing regions are not contained within state boundaries, the average annual precipitation is a weighted average of the annual precipitation attributable to the state parts included in each producing region. The formula for computing average annual precipitation is:

$$P_i = \sum_{m \varepsilon i} \left(\frac{P_{m\varepsilon i} A_{m\varepsilon i}}{A_i} \right) \qquad \begin{matrix} i = 48, \ldots, 105 \\ m = 1, \ldots, n \end{matrix} \qquad (6)$$

where:

P_i is the average annual precipitation for the ith producing region;

A_i is the area of the ith producing region in square miles;

$P_{m\varepsilon i}$ is the average annual precipitation in the mth state part of the ith producing region; and

$A_{m\varepsilon i}$ is the area of the mth state part in the ith producing region.

After the natural runoff is computed for each producing region, the natural runoff statistics for all producing regions within a river basin are normalized in order to adjust for inconsistencies resulting from rounding errors and aggregation errors during computation. This makes the statistics consistent with the natural runoff reported for the river basin in the Nation's Water Resources [79].

The computational formula is:

$$NR_i = \frac{\sum_j \left(\frac{P_{j\varepsilon i} A_{j\varepsilon i}}{A_j}\right) NR_j}{\sum_{i\varepsilon k} \sum_j \left(\frac{P_{j\varepsilon i} A_{j\varepsilon i}}{A_j}\right) NR_j} NR_k \qquad (7)$$

where:

NR_i is the average natural runoff in the ith producing region;

$P_{j\varepsilon i}$ is the average annual precipitation in the portion of river basin subarea j which is in the ith producing region;

$A_{j\varepsilon i}$ is the area of the jth river basin subarea which is included in producing region i;

NR_j is the average natural runoff reported for river basin subarea j;

A_j is the area of river basin subarea j; and

NR_k is the average natural runoff reported for river basin k.

The average annual precipitation, the area in square miles, average natural runoff in inches per year and acre feet per square mile, and the average annual natural runoff for the producing regions with irrigation activities are listed in Table 1.

Reservoir storage

Mean annual runoff is the maximum amount of water then can be expected over a period of years. The variation in annual precipitation results in a distribution of years with above average runoff and years with below average runoff. In the western states reservoir development

Table 1. Average annual precipitation, area in square miles, and average natural runoff in inches per year, acre feet per square mile, and 1000 acre feet for each producing region requiring water supplies

Producing region	Average annual precipitation (inches)	Area (square) miles	Average natural runoff (inches)	Average natural runoff (acre ft. per sq. mile)	Average natural runoff (1,000 acre feet)
48	14.71	26439	1.15	61.3	1621.6
49	14.25	36205	3.15	168.0	6082.4
50	14.47	16855	1.15	61.3	1033.8
51	13.00	73998	2.54	135.5	10024.4
52	15.90	93657	.64	34.1	3196.8
53	19.49	36876	.71	37.9	1396.4
54	14.21	59516	1.50	80.0	4761.3
55	19.94	39889	1.67	89.1	3552.8
56	25.15	6455	2.66	141.9	915.7
57	30.94	22098	4.10	218.7	4832.1
58	21.16	40234	1.40	74.7	3004.1
59	31.83	14653	2.23	118.9	1742.7
60	40.64	40422	8.58	457.6	18497.0
61	46.86	19666	17.28	921.6	18124.1
62	15.28	24801	1.43	76.3	1891.5
63	19.60	46171	1.81	96.5	4457.0
64	41.73	39183	11.22	598.4	23447.0
65	16.75	30090	1.44	76.8	2310.9
66	26.59	16221	2.38	126.9	2059.0
67	16.91	4208	.23	12.3	51.6
68	22.73	35450	3.35	178.7	6333.7
69	43.09	25197	16.70	890.7	22442.0
70	42.93	16998	14.78	788.3	13398.9
71	32.72	26198	11.21	597.9	15659.8
72	15.78	13050	.12	6.1	80.7
73	25.73	33287	2.87	153.1	5095.1
74	13.23	14467	.09	4.8	69.4
75	19.51	31985	2.02	107.7	3445.8

Table 1. Continued.

Producing region	Average annual precipitation (inches)	Area (square) miles	Average natural runoff (inches)	(acre ft. per sq. mile)	(1,000 acre feet)
76	26.67	37905	2.99	159.5	6044.5
77	11.86	8185	1.40	74.7	611.1
78	11.06	58563	.92	49.1	2873.5
79	12.03	33206	.47	25.1	832.4
80	12.70	20362	.52	27.7	564.7
81	19.71	15884	.72	38.4	609.9
82	11.86	46171	2.44	130.1	6088.3
83	14.47	25656	4.80	256.0	6567.9
84	10.82	30536	1.53	81.6	2491.7
85	8.83	26537	.31	16.5	438.7
86	8.29	62783	.28	14.9	937.6
87	13.68	65017	.63	33.6	2184.6
88	14.88	24907	1.95	104.0	2590.3
89	9.42	20369	1.21	64.5	1314.5
90	8.67	73151	.41	21.9	1599.6
91	11.40	18061	1.14	60.8	1098.1
92	24.45	35720	15.48	825.6	29490.2
93	18.51	59434	7.29	388.8	23107.8
94	16.17	64972	4.61	245.9	15974.3
95	19.55	31690	12.52	667.7	21160.3
96	58.75	38427	51.04	2722.1	104602.8
97	62.34	15772	47.38	2526.9	39854.5
98	19.49	18400	1.05	56.0	1030.4
99	64.83	23534	23.97	1278.4	30085.7
100	32.84	31615	12.63	673.6	21295.7
101	19.29	32661	7.43	396.3	12942.4
102	44.67	6944	9.36	499.2	3466.4
103	20.29	11195	4.22	225.1	2519.6
104	6.80	42548	.93	49.6	2110.4
105	9.11	13842	.69	36.8	509.4

has been undertaken in an attempt to change the intertemporal allocation of water by storing water in years with above normal precipitation for release in years with below normal precipitation. Reservoir storage capacity has a direct affect on the quantity of water available and must be considered when developing water supply statistics.

Lof and Hardison (19) have developed a relationship between stream flow and reservoir storage capacity. Mean annual flow adjusted for evaporation losses from reservoirs is considered to be the maximum amount of water which can be made available for use through construction of surface storage. The storage required to provide any desired level of flow in 95 and 98 percent of the years is reported in their paper for each major river basin in the United States. Mean annual runoff is assumed to be equivalent to mean annual flow in using the Lof and Hardison technique. Storage to mean annual runoff ratios which will make various percentages for mean annual runoff available for use in 95 percent of the years are computed for all the river basins in the Western United States and are reported in Table 2.

Reservoir storage capacities for each of the producing regions in the irrigated areas have been computed from U.S. Bureau of Reclamation, U.S. Geological Survey, U.S. Army Corps of Engineer, and various state publications (9, 13, 20, 31, 51, 76, 78, 82). Active conservation capacity and joint use capacity for all reservoirs with a capacity of 5,000 acre feet or more which are completed, under construction or authorized are summed to obtain the total storage capacity for each

Table 2. Storage to mean annual flow ratios to make the indicated percent of mean annual flow available with 95 percent probability of adequacy (Source: 12)

	Percent gross mean annual flow available									
	10	20	30	40	50	60	70	80	90	95
Upper Missouri	0.035	0.075	0.138	0.225	0.349	0.522	0.725	0.988	1.750	-
Lower Missouri	0.085	0.160	0.235	0.355	0.542	0.822	1.215	1.740	3.250	-
Upper Ark.-White-Red	0.005	0.130	0.269	0.438	0.676	1.000	1.444	-	-	-
Lower Ark.-White-Red	0.100	0.190	0.305	0.455	0.590	0.762	1.015	1.475	2.370	-
Western Gulf	0.100	0.150	0.379	0.589	0.920	1.300	1.900	2.920	-	-
Upper Rio Grande & Pecos	0.025	0.070	0.115	0.175	0.260	0.400	0.580	0.840	1.500	-
Colorado	0.030	0.075	0.125	0.200	0.300	0.420	0.571	0.775	1.278	2.680
Great Basin	0.020	0.050	0.095	0.181	0.312	0.481	0.730	1.152	1.925	3.695
Pacific N.W.	0.030	0.070	0.115	0.175	0.260	0.374	0.449	0.574	0.900	1.622
Central Pac.	0.075	0.139	0.205	0.274	0.391	0.562	0.850	1.350	3.050	-
South Pac.	0.100	0.283	0.545	0.838	1.263	1.820	2.660	-	-	-

producing region, Table 3. All authorized reservoir projects are expected to be completed and in operation by 2000. Therefore, completed storage capacity is used in the computation of water availability for 1985, Table 9.a. And, total storage capacity, including authorized projects, is used in the computation of water availability for 2000.

Storage-natural runoff ratio

The storage-natural runoff ratio is computed for each producing region by dividing the reservoir storage by the mean annual runoff. Each producing region is located geographically by river basin and the computed ratio is interpolated into the proper row in Table 2 to get the proportion of mean annual runoff which is available with 95 percent probability of adequacy, Table 4. This proportion is multiplied by mean annual runoff, Table 1, to get gross dependable surface water supply.

Reservoir storage losses

Water is lost from surface storage through evaporation. Lof and Hardison (19) report evaporation losses for each river basin as a percentage of storage. Storage losses are computed by multiplying the reservoir storage capacity by the percent of evaporation loss. The gross supply is adjusted for evaporation losses to get net dependable surface water supplies attributable to storage, Table 4.

Table 3. Mean annual runoff, storage capacity, and storage-mean annual runoff ratio for the producing regions in the Western United States

Producing region	Mean annual runoff (1000 a.f.)	Storage capacity (1000 a.f.) Completed	Authorized	Total	Storage-maf ratio Completed	Total
		(Missouri Region)				
48	1621.6	201.0		201.0	.124	.124
49	6082.4	3054.7		3054.7	.502	.502
50	1033.8	13740.8		13740.8	2.360[a]	2.360[a]
51	10024.2	2324.9		2324.9	.232	.232
52	3196.8	34288.3		34288.3	2.769[a]	2.769[a]
53	1396.4	6048.0		6048.0	4.331	4.331
54	4761.3	6486.3	293.8	6780.1	1.362	1.424
55	3552.8	236.1	339.7	577.8	.163	.163
56	915.7					
57	4832.1					
58	3004.1	1461.3	25.3	1486.6	.486	.495
59	1742.7	1149.6	214.3	1363.9	.660	.783
60	18497.0	3863.2	232.9	4096.1	.209	.221
		(Arkansas-White-Red)				
61	18124.1	8208.0		8208.0	.453	.453
62	1891.5	1112.6	264.0	1376.6	.588	.728
63	4457.0	939.8	259.0	1198.8	.211	.270
64	23447.0	3154.4	739.9	3885.3	.134	.166
65	2310.9	1298.3	200.0	1498.3	.562	.648
66	2059.0	3207.2		3207.2	1.558	1.558
67	51.6	23.3		23.3	.452	.452
68	6333.7	1775.0	299.0	2074.0	.280	.327
69	22442.0	4999.8	337.2	5337.0	.223	.238
		(Texas-Gulf)				
70	13398.9	5370.6	2324.6	8055.2	.428	.601
71	15659.8	5420.8	2649.1	7889.9	.346	.504
72	80.7	41.8		41.8	.518	.518
73	5095.1	3152.4	2480.1	5632.5	.618	1.105
74	69.4	80.9		80.9	1.166	1.166
75	3445.8	3646.0		3646.0	1.058	1.058
76	6044.5	948.8	274.9	1223.7	.175	.202
		(Pesco-Rio Grande)				
77	611.1	239.5	100.8	340.3	.392	.557
78	2873.5	3794.6	59.3	3853.9	1.321	1.341

[a]Ratio includes runoff and storage capacity in all upstream regions.

Table 3. Continued.

Producing region	Mean annual runoff (1000 a.f.)	Storage capacity (1000 a.f.) Completed	Authorized	Total	Storage-maf ratio Completed	Total
79	832.4	364.5		364.5	.438	.438
80	564.7	300.3		300.3	.532	.532
81	609.9	6355.9		6355.9	2.473[b]	2.473[b]
(Upper Colorado)						
82	6088.3	5104.8	149.6	5254.4	.850	.875
83	6567.9	1766.8	786.9	2553.7	.269	.389
84	2491.7	22145.9	252.2	22398.1	1.926[a]	2.005[a]
(Lower Colorado)						
85	438.7	84.1		84.1	.191	.191
86	937.6	18097.4		18097.4	2.943[a]	2.943[a]
87	2184.6	6043.8		6043.8	2.767	2.767
(Great Basin)						
88	2590.3	3282.3	45.0	3327.3	1.267	1.285
89	1314.5	432.7		432.7	.329	.329
90	1599.6	276.9	223.1	500.0	.173	.313
91	1098.1	1517.7		1517.7	1.382	1.382
(Columbia-North Pacific)						
92	29490.2	11303.9		11303.9	.383	.383
93	23107.8	9705.7	11.5	9717.2	.420	.421
94	15974.3	8608.2	309.2	8917.4	.539	.558
95	21160.3	1160.3	204.0	1364.3	.055	.064
96	104602.8	2994.6	354.1	3348.7	.029	.032
97	39854.5	2581.2		2581.2	.065	.065
98	1030.4	96.3		96.3	.093	.093
(California-South Pacific)						
99	30085.7	3526.0	319.2	3845.2	.117	.128
100	21295.7	11787.6	833.8	12621.4	.554	.593
101	12942.4	9726.9	239.6	9966.5	.752	.770
102	3466.4	2745.3	1075.1	3820.4	.792	1.102
103	2519.6	1231.5		1231.5	.489	.489
104	2110.4	2133.7		2133.7	1.011	1.011
105	509.4	302.0		302.0	.593	.593

[b]Accounts for 1960.0 thousand acre feet of natural runoff from Mexico.

Table 4.a. Net flow made available with 95 percent probability of adequacy through flow regulating storage for 1985

Producing region	Storage / MAR	Proportion / MAR	Gross water supply (1000 a.f.)	% Evap. loss	Evap. loss (1000 a.f.)	Flow available through storage (1000 a.f.)
48	.124	.27777	450.4	4.44	8.9	441.5
49	.502	.58844	3579.1	4.44	135.6	3443.5
50	2.360	.95000	6760.4[a]	4.44	745.7	2571.2
51	.232	.40070	4016.7	4.44	103.2	3913.5
52	2.769	.95000	12560.0[a]	4.44	1625.6	7020.9
53	4.331	.95000	1326.6	4.44	268.5	1058.1
54	1.362	.84908	4042.7	4.44	288.0	3754.7
55	.163	.37126	1319.0	4.44	25.6	1293.4
56	.085	.10000[b]	91.6	2.45	1.9	89.7
57	.085	.10000[b]	483.2	2.45	10.1	473.1
58	.486	.57572	1729.5	4.44	64.9	1664.6
59	.660	.54214	944.8	2.45	28.2	916.6
60	.209	.26533	4907.8	2.45	94.6	4813.2
61	.453	.39867	7225.5	3.57	293.0	6932.5
62	.588	.46303	875.8	11.70	130.2	745.6
63	.211	.25827	1151.1	11.70	110.0	1041.1
64	.134	.13778	3230.5	3.57	112.3	3118.2
65	.562	.45210	1044.8	11.70	151.9	892.9
66	1.558	.70000	1441.3	11.70	375.2	1066.1
67	.452	.40588	20.9	11.70	2.7	18.2
68	.280	.30651	1941.3	11.70	207.7	1733.6
69	.223	.22870	5132.5	3.57	178.5	4954.0
70	.428	.32333	4332.3	8.31	476.2	3856.1
71	.346	.28559	4472.3	8.31	450.5	4021.8
72	.518	.36619	29.6	8.31	3.5	26.1
73	.618	.40876	2082.7	8.31	262.0	1820.7
74	1.166	.56474	39.2	8.31	6.7	32.5
75	1.058	.53632	1848.1	8.31	303.0	1545.1
76	.175	.20306	1227.4	8.31	78.8	1148.6
77	.392	.59429	363.2	9.16	21.9	341.3
78	1.321	.87288	2508.2	9.16	347.6	2160.6
79	.438	.62111	517.0	9.16	33.4	483.6
80	.532	.67333	380.2	9.16	27.5	352.7
81	2.473	.90000	548.9	9.16	582.2	410.7
82	.850	.81491	4896.2	5.86	299.1	4597.1
83	.269	.46900	3080.3	5.86	103.5	2976.8

[a]Includes water supply made available through storage in this and all upstream regions.

[b]Assume sufficient storage capacity available in reservoirs with less than 5,000 acre feet capacity to provide .10 of mean annual runoff.

Table 4.a. Continued.

Producing region	Storage MAR	Proportion MAR	Gross water supply (1000 a.f.)	% Evap. loss	Evap. loss (1000 a.f.)	Flow available through storage (1000 a.f.)
84	1.926	.92311	13909.3[a]	5.86	1700.4	4635.0
85	.191	.38800	170.2	5.86	4.9	165.3
86	2.943	.95000	15622.0[a]	5.86	2835.5	481.9
87	2.767	.95000	2075.4	5.86	354.2	1721.2
88	1.267	.81488	2110.8	8.20	269.1	1841.7
89	.329	.51006	670.5	8.20	35.5	635.0
90	.173	.39070	625.0	8.20	22.7	602.3
91	1.382	.82975	911.1	8.20	124.5	786.6
92	.383	.61200	18048.0	1.10	124.3	18023.7
93	.420	.66133	15281.9	1.10	106.8	15175.1
94	.539	.77200	12332.2	1.10	94.7	12237.5
95	.055	.16250	3438.5	1.10	12.8	3425.7
96	.029	.10000	10460.3	1.10	32.9	10427.4
97	.065	.18750	7472.7	1.10	28.4	7444.3
98	.093	.25111	258.7	1.10	1.1	257.6
99	.117	.16562	4982.8	1.11	39.1	4943.7
100	.554	.59532	12677.8	1.11	130.8	12547.0
101	.752	.66597	8619.3	1.11	108.0	8511.3
102	.792	.67986	2356.7	1.11	30.5	2326.2
103	.489	.27863	702.0	7.17	88.3	613.7
104	1.011	.44071	930.1	7.17	153.0	777.1
105	.593	.31638	161.2	7.17	21.7	139.5

Table 4.b. Net flow made available with 95 percent probability of adequacy through flow regulating storage for 2000

Producing region	Storage / MAR	Proportion / MAR	Gross water supply (1000 a.f.)	% Evap. loss	Evap. loss (1000 a.f.)	Flow available through storage (1000 a.f.)
48	.124	.27777	450.4	4.44	8.9	441.5
49	.502	.58844	3579.1	4.44	135.6	3443.5
50	2.360	.95000	6760.4[a]	4.44	745.7	2571.2
51	.232	.40070	4016.7	4.44	103.2	3913.5
52	2.769	.95000	12560.0[a]	4.44	1625.6	7020.9
53	4.331	.95000	1326.6	4.44	268.5	1058.1
54	1.424	.85722	4081.5	4.44	301.0	3780.5
55	.163	.37126	1319.0	4.44	25.6	1293.4
56	.085	.10000[b]	91.6	2.45	1.9	89.7
57	.085	.10000[b]	483.2	2.45	10.1	473.1
58	.495	.58439	1755.6	4.44	66.0	1689.6
59	.783	.58609	1021.3	2.45	33.4	987.9
60	.221	.28133	5203.8	2.45	100.4	5103.4
61	.453	.39867	7225.5	3.57	293.0	6932.5
62	.728	.51605	976.1	11.70	161.1	815.0
63	.270	.30072	1340.3	11.70	140.3	1200.0
64	.166	.17333	4064.1	3.57	138.7	3925.4
65	.648	.48824	1128.3	11.70	175.3	953.0
66	1.558	.70000	1441.3	11.70	375.2	1066.1
67	.452	.40588	20.9	11.70	2.7	18.2
68	.327	.33432	2117.5	11.70	242.7	1874.8
69	.238	.24174	5425.1	3.57	190.5	5234.6
70	.601	.40363	5408.2	8.31	669.4	4738.8
71	.504	.35952	5630.0	8.31	655.7	4974.3
72	.518	.36619	29.6	8.31	3.5	26.1
73	1.105	.54868	2795.6	8.31	468.1	2327.5
74	1.166	.56474	39.2	8.31	6.7	32.5
75	1.058	.53632	1848.1	8.31	303.0	1545.1
76	.202	.22271	1346.2	8.31	101.7	1244.5
77	.557	.68722	420.0	9.16	31.2	388.8
78	1.341	.87591	2516.9	9.16	353.0	2163.9
79	.438	.62111	517.0	9.16	33.4	483.6
80	.532	.67333	380.2	9.16	27.5	352.7
81	2.473	.90000	548.9	9.16	582.2	410.7
82	.875	.81988	4926.1	5.86	307.9	4618.2
83	.389	.57417	3771.1	5.86	149.6	3621.5

[a] Includes water supply made available through storage in this and all upstream regions.

[b] Assume sufficient storage capacity available in reservoirs with less than 5,000 acre feet capacity to provide .10 of mean annual runoff.

Table 4.b. Continued.

Producing region	Storage / MAR	Proportion / MAR	Gross water supply (1000 a.f.)	% Evap. loss	Evap. loss (1000 a.f.)	Flow available through storage (1000 a.f.)
84	2.005	.92593	13951.8[a]	5.86	1770.1	3942.0
85	.191	.38800	170.2	5.86	4.9	165.3
86	2.943	.95000	15622.0[a]	5.86	2835.5	439.5
87	2.767	.95000	2075.4	5.86	354.2	1721.2
88	1.285	.81721	2116.8	8.20	272.8	1844.0
89	.329	.51006	670.5	8.20	35.5	635.0
90	.313	.50059	800.7	8.20	41.0	759.4
91	1.382	.82975	911.1	8.20	124.5	786.6
92	.383	.61200	18048.0	1.10	124.3	18023.7
93	.421	.66267	15312.8	1.10	106.9	15205.9
94	.558	.78720	12575.0	1.10	98.1	12476.9
95	.064	.18500	3914.7	1.10	15.0	3899.7
96	.032	.10500	10983.3	1.10	36.8	10946.5
97	.065	.18750	7472.7	1.10	28.4	7444.3
98	.093	.25111	258.7	1.10	1.1	257.6
99	.128	.18281	5500.0	1.11	42.7	5457.3
100	.593	.61076	13006.6	1.11	140.0	12866.5
101	.770	.67222	8700.1	1.11	110.6	8589.5
102	1.102	.75040	2601.2	1.11	42.4	2558.8
103	.489	.27863	702.0	7.17	88.3	613.7
104	1.011	.44071	930.1	7.17	153.0	777.1
105	.593	.31638	161.2	7.17	21.7	139.5

Maximum net flows obtainable

The storage required to provide a given level of mean annual runoff increases at an increasing rate as the desired level of mean annual runoff increases. At some point the evaporation losses accruing from the increment of storage capacity necessary to deliver a higher level of mean annual runoff becomes greater than the projected increase in available water and a net reduction in usable water results. The maximum level of water availability is always less than the mean annual runoff. In regions where evaporation losses are high and where carry-over storage requirements are large the maximum maintainable flow is reached at lower flow levels than in the more humid regions where evaporation losses are lower and carry-over periods shorter. The relationships developed by Lof and Hardison (19) are used to compute the maximum net flow available from each producing region, the potential for developing additional supplies through construction of reservoir storage and the additional construction required to provide the maximum attainable net flow, Table 5.

Computations for several of the producing regions indicate that more water would be available if less storage capacity were available in the region. This stems from the fact that the storage capacity requirement is computed only for flow regulation. Storage requirements for maintaining a power head for hydroelectric generation, flood control, or other uses which require a discharge schedule other than for flow regulation are excluded. These requirements would generally be in addition to those for flow regulation. If the total storage requirements in a region exceed

Table 5. Maximum net flow attainable from flow regulating storage with 98 percent probability of adequacy, potential increase in supply and additional storage capacity required by region for 2000

Producing region	Maximum net flow % MAR	Maximum net flow 1000 AF	Potential Δ supply	Δ Storage required
(Missouri Region)				
48	.80	1297.3	890.6	3204.4
49	.80	4865.9	1694.6[a]	9718.3[a]
50	.80	2521.7	34.1[b]	(1851.5)[c]
51	.80	8019.4	4567.1[a]	20815.9[a]
52	.80	7124.5	303.5[b]	(8849.1)[c]
53	.80	1117.1	59.0[b]	(3115.6)[c]
54	.80	3809.0	210.8	3218.6
55	.80	2842.2	1799.2	6883.8
56	.78	714.2	624.5	3859.7
57	.78	3769.0	3295.9	20367.3
58	.80	2403.3	900.7	4047.3
59	.78	1359.3	479.3	6129.7
60	.78	14427.7	9888.5	75441.0
(Arkansas-White-Red)				
61	.79	14318.0	8072.7	46164.3
62	.48	907.9	207.2	2595.6
63	.48	2139.4	1172.6	8160.9
64	.79	18523.1	14769.9	66455.7
65	.48	1109.2	292.8	3354.6
66	.48	988.3	12.8	1116.7
67	.48	24.8	9.5	85.1
68	.48	3040.2	1476.8	11226.8
69	.79	17729.2	12822.2	61989.0
(Texas-Gulf)				
70	.50	6699.5	2865.9	28121.8
71	.50	7829.9	3765.3	34391.6
72	.50	40.4	19.2	176.1
73	.50	2547.6	541.9	8124.3

[a]Indicates a reallocation of supply, not an increase in total availability.

[b]Indicates magnitude of water lost due to onsite uses which require storage capacity in excess of that required for flow maintenance.

[c]Storage capacity in excess of that required for flow maintenance.

Table 5. Continued.

Producing region	Maximum net flow % MAR	Maximum net flow 1000 AF	Potential Δ supply	Δ Storage required
74	.50	34.7	6.6	106.5
75	.50	1722.9	395.5	5657.7
76	.50	3022.3	2045.3	15096.5
		(Rio Grande)		
77	.74	452.2	79.8	637.5
78	.74	2126.4	87.5	743.7
79	.74	616.0	141.8	967.3
80	.74	417.9	78.5	603.2
81	.74	451.3	40.6[b]	(5148.5)[c]
		(Upper Colorado)		
82	.81	4866.7	476.8[a]	6161.4[a]
83	.81	5320.0	1861.9[a]	9925.3[a]
84	.81	12205.0	291.6[b]	(1577.2)[c]
		(Lower Colorado)		
85	.81	355.3	190.1[a]	749.4[a]
86	.81	1241.1	675.5[b]	(17143.7)[c]
87	.81	1769.5	198.5[b]	(1893.1)[c]
		(Great Basin)		
88	.70	1813.2	106.2	1594.3
89	.70	920.2	375.9	2064.9
90	.70	1119.7	470.8	2539.2
91	.70	768.7	32.4	568.7
		(Columbia-North Pacific)		
92	.93	27425.9	10671.5	74217.7
93	.93	21490.3	7854.8	57295.6
94	.93	14856.1	3580.0	37408.1
95	.93	19679.1	15779.4	60000.6
96	.93	97280.6	86334.1	299999.4
97	.93	37064.7	29620.4	112996.8
98	.93	958.3	700.7	2891.9
		(California-South Pacific)		
99	.88	26475.4	21018.1	134549.0
100	.88	18740.2	5873.7	85338.8
101	.88	11389.3	2799.8	49568.5
102	.88	3050.4	491.6	12125.0
103	.44	1108.6	494.9	7083.2
104	.44	928.6	231.6	4830.6
105	.44	224.1	98.8	1379.0

the storage requirements for flow regulation then the maximum attainable flow cannot be reached. Onsite uses of water which have generally been considered as nonconsumptive have been transformed through their large storage requirements into consumptive uses. In the regions which show this characteristic the maximum attainable annual flow has been achieved and the onsite uses have a consumption component equal to the difference between the maximum attainable flow and the flow realized when all storage capacity is utilized.

Natural variability in precipitation and runoff

The variability and amount of precipitation are important factors in determining the quantity of storage capacity necessary to maintain a given level of mean annual runoff. A region with a high mean annual precipitation and uniform distribution of precipitation within and among years requires a much lower storage capacity to maintain flow adequate to satisfy demands than a region with less annual precipitation and greater variability over time.

In some regions the precipitation is uniform enough that the mean annual runoff occurring naturally exceeds the quantity indicated as being available through current storage capacities. Mean annual discharge and 95 percent probable discharge data provided by the U.S. Geological Survey[1] for the 99 aggregated subareas are used as a measure of the natural variability in runoff. The ratio of 95 percent probable discharge

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[1]Surface water supply statistics for 1975 National Water Assessment provided by the U.S. Geological Survey.

to mean annual discharge, Table 6, is compared with the proportion of mean annual runoff available through storage. In those regions where the discharge ratio is greater than the indicated proportion of mean annual runoff available it is assumed that discharge from the region is directly related to runoff, and that the proportion of mean annual runoff consistent with the proportion of mean annual discharge occurring with 95 percent probability represents the gross dependable surface supply available with 95 percent probability of exceedance. This gross supply is adjusted for evaporation losses from existing reservoirs to get a net surface water supply in these producing regions, Table 6.

Conveyance losses and net surface water supplies

In each region the 95 percent probable water supply available at the reservoir gate, Table 7, represents the larger of either the mean annual runoff provided with 95 percent probability of adequacy through storage or the mean annual runoff occurring 95 percent of the time due to the natural distribution of precipitation.

The crop and livestock water use coefficients used in the CARD-NSF model represent consumptive use or net diversions. Net diversion is the difference between the total amount of water diverted from the natural watercourse, and the amount available for reuse or return flow. This is a valid concept for evaluating the adequacy of water supplies. Howdever, using supplies computed at the reservoir or watercourse and demands on the basis of net diversions overestimates the number of units of land that can be irrigated unless it is assumed that there is no

Table 6.a. Water availability expected to occur with 95 percent probability without additional flow regulating storage for 1985

Producing region	Mean annual discharge (cfs)	95% probable discharge (cfs)	Ratio 95% prob. MAR	Surface water available naturally (1000 a.f.)
		(Missouri Region)		
48	10.8	6.3	.58333	937.0
49	8.4	4.6	.54762	3195.2
50	10.0	5.8	.58000	0.0[a]
51	12.0	6.8	.56667	5577.2
52	23.7	11.8	.49789	0.0
53	27.0	17.6	.65185	641.7
54	1.8	0.99	.55000	2330.7
55	7.1	4.4	.61972	2176.1
56	7.1	4.4	.61972	565.6
57	41.1	30.4	.73955	3564.0
58	6.6	2.0	.30303	845.4
59	6.6	2.0	.30303	993.1
60	70.8	28.3	.39972	7299.0
		(Arkansas-White-Red)		
61	24.6	11.6	.47154	8253.2
62	0.24	0.091	.37917	845.9
63	6.2	1.6	.25806	1230.3
64	39.8	11.1	.28274	6517.1
65	5.9	1.6	.27119	474.5
66	5.9	1.6	.27119	183.2
67	0.0	0.0	.00000	0.0
68	3.2	1.5	.46875	2761.2
69	30.5	10.1	.31500	6891.1
		(Texas-Gulf)		
70	15.4	4.7	.30519	561.1
71	11.6	2.2	.18965	2519.4
72	7.3	1.2	.16438	17.7
73	7.3	1.2	.16438	575.5
74	2.8	0.5	.17857	25.7
75	2.8	0.5	.17857	1024.4
76	6.1	1.0	.16393	912.1

[a]Evaporation losses greater than 95% probable flow occurring naturally within the region.

Table 6.a. Continued.

Producing region	Mean annual discharge (cfs)	95% discharge (cfs)	Ratio 95% prob. MAR	Surface water available naturally (1000 a.f.)
		(Rio Grande)		
77	0.53	0.084	.15849	75.0
78	0.53	0.19	.35849	682.5
79	0.9	0.32	.35556	262.6
80	0.21	0.027	.12857	45.1
81	0.0	0.0	.00000	0.0
		(Upper Colorado)		
82	5.9	2.8	.47458	2552.3
83	7.9	3.5	.44304	2806.3
84	15.4	6.0	.38961	0.0[a]
		(Lower Colorado)		
85	0.42	0.26	.61905	266.7
86	2.4	1.9	.79166	0.0[a]
87	0.0	0.0	.00000	0.0
		(Great Basin)		
88	0.0	0.0	.00000	0.0
89	0.0	0.0	.00000	0.0
90	0.0	0.0	.00000	0.0
91	0.0	0.0	.00000	0.0
		(Columbia-North Pacific)		
92	54.4	30.1	.55331	16192.9
93	195.0	140.0	.66667	15298.6
94	18.7	9.9	.52941	8362.3
95	56.2	38.2	.75467	15956.2
96	356.0	252.0	.69565	72734.3
97	52.0	36.4	.70000	27869.8
98				
		(California-South Pacific)		
99	40.3	17.2	.42680	12801.5
100	32.5	14.1	.43385	9109.1
101	35.6	12.7	.35674	4509.1
102	5.6	1.7	.30357	1021.8
103	2.3	0.25	.10870	185.6
104	0.69	0.08	.11594	91.7
105	0.0	0.0	.00000	0.0

Table 6.b. Water availability expected to occur with 95 percent probability without additional flow regulating storage

Producing region	Mean annual discharge (cfs)	95% probable discharge (cfs)	Ratio 95% prob. MAR	Surface water available naturally (1000 a.f.)
		(Missouri Region)		
48	10.8	6.3	.58333	937.0
49	8.4	4.6	.54762	3195.2
50	10.0	5.8	.58000	0.0[a]
51	12.0	6.8	.56667	5577.2
52	23.7	11.8	.49789	0.0
53	27.0	17.6	.65185	641.7
54	1.8	0.99	.55000	2317.7
55	7.1	4.4	.61972	2176.1
56	7.1	4.4	.61972	565.6
57	41.1	30.4	.73955	3564.0
58	6.6	2.0	.30303	844.3
59	6.6	2.0	.30303	987.9
60	70.8	28.3	.39972	7293.2
		(Arkansas-White-Red)		
61	24.6	11.6	.47154	8253.2
62	0.24	0.091	.37917	815.0
63	6.2	1.6	.25806	1200.0
64	39.8	11.1	.28274	6490.7
65	5.9	1.6	.27119	451.4
66	5.9	1.6	.27119	183.2
67	0.0	0.0	.00000	0.0
68	3.2	1.5	.46875	2726.2
69	30.5	10.1	.31500	6879.1
		(Texas-Gulf)		
70	15.4	4.7	.30519	367.9
71	11.6	2.2	.18965	2314.2
72	7.3	1.2	.16438	17.7
73	7.3	1.2	.16438	369.4
74	2.8	0.5	.17857	25.7
75	2.8	0.5	.17857	1024.4
76	6.1	1.0	.16393	889.2

[a]Evaporation losses greater than 95% probable flow occurring naturally within the region.

Table 6.b. Continued.

Producing region	Mean annual discharge (cfs)	95% probable discharge (cfs)	Ratio 95% prob. MAR	Surface water available naturally (1000 a.f.)
		(Rio Grande)		
77	0.53	0.084	.15849	65.7
78	0.53	0.19	.35849	677.1
79	0.9	0.32	.35556	262.6
80	0.21	0.027	.12857	45.1
81	0.0	0.0	.00000	0.0
		(Upper Colorado)		
82	5.9	2.8	.47458	2543.5
83	7.9	3.5	.44304	2760.2
84	15.4	6.0	.38961	0.0[a]
		(Lower Colorado)		
85	0.42	0.26	.61905	266.7
86	2.4	1.9	.79166	0.0[a]
87	0.0	0.0	.00000	0.0
		(Great Basin)		
88	0.0	0.0	.00000	0.0
89	0.0	0.0	.00000	0.0
90	0.0	0.0	.00000	0.0
91	0.0	0.0	.00000	0.0
		(Columbia-North Pacific)		
92	54.4	30.1	.55331	16192.9
93	195.0	140.0	.66667	15298.5
94	18.7	9.9	.52941	8358.9
95	56.2	38.2	.75467	15954.0
96	356.0	252.0	.69565	72730.4
97	52.0	36.4	.700000	27869.8
98				
		(California-South Pacific)		
99	40.3	17.2	.42680	12797.9
100	32.5	14.1	.43385	9099.9
101	35.6	12.7	.35674	4506.5
102	5.6	1.7	.30357	1009.9
103	2.3	0.25	.10870	185.6
104	0.69	0.08	.11594	91.7
105	0.0	0.0	.00000	0.0

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Table 7.a. Regional surface water supplies and conveyance losses for 1985

Producing region	Gross supply (1000 a.f.)	Conveyance losses %	Conveyance losses (1000 a.f.)	Net surface supply (1000 a.f.)
		(Missouri Region)		
48	937.0	.11979	112.2	824.8
49	3443.5	.11979	412.5	3031.0
50	2592.8	.11979	310.6	2282.6
51	5577.2	.12110	675.4	4901.8
52	7256.7	.28614	2076.4	5180.3
53	1131.1	.30063	340.0	791.1
54	3754.7	.14710	552.3	3202.4
55	2176.1	.28261	615.0	1561.1
56	565.6	.28261	159.8	405.8
57	3564.0	.28261	1007.2	2556.8
58	1664.6	.24957	415.4	1249.2
59	993.1	.24957	247.8	745.3
60	7299.0	.24957	1821.6	5477.4
		(Arkansas-White-Red)		
61	8253.2	.14945	1233.4	7019.8
62	845.9	.15863	134.2	711.7
63	1230.3	.19567	240.7	989.6
64	6517.1	.18026	1174.8	5342.3
65	892.9	.26012	232.3	660.6
66	1066.1	.19567	208.6	857.5
67	18.2	.09646	1.8	16.4
68	2761.2	.14606	403.3	2357.9
69	6891.1	.14719	1014.3	5876.8
		(Texas-Gulf)		
70	3856.1	.12240	472.0	3384.1
71	4021.8	.08289	333.4	3688.1
72	26.1	.08289	2.2	23.9
73	1820.7	.08289	150.9	1669.8
74	32.5	.08289	2.7	29.8
75	1545.1	.08289	128.1	1417.0
76	1148.6	.08289	95.2	1053.4
		(Rio Grande)		
77	341.3	.18094	61.8	279.5
78	2160.6	.23431	506.3	1654.3
79	483.6	.19346	93.6	390.0
80	352.7	.23431	82.6	270.1
81	494.0	.19346	95.6	398.4

Table 7.a. Continued.

Producing region	Gross supply (1000 a.f.)	Conveyance losses %	(1000 a.f.)	Net surface supply (100 a.f.)
		(Upper Colorado)		
82	4597.1	.12157	558.9	4038.2
83	2976.8	.11136	331.5	2645.3
84	4635.0	.11061	512.7	4122.3
		(Lower Colorado)		
85	266.7	.13971	37.3	229.4
86	481.9	.12934	62.3	419.6
87	1889.7	.14059	265.7	1624.0
		(Great Basin)		
88	1841.7	.11754	216.5	1625.2
89	635.0	.11754	74.6	560.4
90	602.3	.15445	93.0	509.3
91	786.6	.13176	103.6	683.0
		(Columbia-North Pacific)		
92	18023.7	.19639	3539.7	14484.0
93	15298.6	.14772	2259.9	13038.7
94	12237.5	.10949	1339.9	10897.6
95	15956.2	.10171	1622.9	14333.3
96	72734.3	.17509	12735.0	59999.3
97	27869.8	.10212	2846.1	25023.7
98	257.6	.19333	49.8	207.8
		(California-South Pacific)		
99	12801.5	.10546	1350.0	11451.5
100	12547.0	.10262	1287.6	11259.4
101	8511.3	.10262	873.4	7637.9
102	2326.2	.10262	238.7	2087.5
103	613.7	.10262	63.0	550.7
104	777.1	.10262	79.7	697.4
105	139.5	.10262	14.3	125.2

Table 7.b. Regional surface water supplies and conveyance losses

Producing region	Gross supply (1000 a.f.)	Conveyance losses %	Conveyance losses (1000 a.f.)	Net surface supply (1000 a.f.)
		(Missouri Region)		
48	937.0	.11979	112.2	824.8
49	3443.5	.11979	412.5	3031.0
50	2592.8	.11979	310.6	2282.6
51	5577.2	.12110	675.4	4901.8
52	7256.7	.28614	2076.4	5180.3
53	1131.1	.30063	340.0	791.1
54	3780.5	.14710	556.1	3224.4
55	2176.1	.28261	615.0	1561.1
56	565.6	.28261	159.8	405.8
57	3564.0	.28261	1007.2	2556.8
58	1689.6	.24957	421.7	1267.9
59	987.9	.24957	246.6	741.3
60	7293.2	.24957	1820.2	5473.0
		(Arkansas-White-Red)		
61	8253.2	.14945	1233.4	7019.8
62	815.0	.15863	129.5	685.7
63	1200.0	.19567	234.8	965.2
64	6490.7	.18026	1170.0	5320.7
65	953.0	.26012	247.9	705.1
66	1066.1	.19567	208.6	857.5
67	18.2	.09646	1.8	16.4
68	2726.2	.14606	389.2	2328.0
69	6879.1	.14719	1012.5	5866.6
		(Texas-Gulf)		
70	4738.8	.12240	580.0	4158.8
71	4974.3	.08289	412.3	4562.0
72	26.1	.08289	2.2	23.9
73	2327.5	.08289	192.9	2134.6
74	32.5	.08289	2.7	29.8
75	1545.1	.08289	128.1	1417.0
76	1244.5	.08289	103.2	1141.3
		(Rio Grande)		
77	388.8	.18094	70.3	318.5
78	2163.9	.23431	507.0	1656.9
79	483.6	.19346	93.6	390.0
80	352.7	.23431	82.6	270.1
81	494.0	.19346	95.6	398.4

Table 7.b. Continued.

Producing region	Gross supply (1000 a.f.)	Conveyance losses %	(1000 a.f.)	Net surface supply (100 a.f.)
		(Upper Colorado)		
82	4618.2	.12157	561.4	4056.8
83	3621.5	.11136	403.3	3218.2
84	3942.0	.11061	463.0	3506.0
		(Lower Colorado)		
85	266.7	.13971	37.3	229.4
86	439.5	.12934	56.8	382.3
87	1889.7	.14059	265.7	1624.0
		(Great Basin)		
88	1844.0	.11754	216.7	1627.3
89	635.0	.11754	74.6	560.4
90	759.4	.15445	117.3	642.1
91	786.6	.13176	103.6	683.0
		(Columbia-North Pacific)		
92	18023.7	.19639	3539.7	14484.0
93	15298.5	.14772	2259.9	13038.6
94	12476.9	.10949	1366.1	11110.8
95	15954.0	.10171	1622.7	14331.3
96	72730.4	.17509	12734.4	59996.0
97	27869.8	.10212	2846.1	25023.7
98	257.6	.19333	49.8	207.8
		(California-South Pacific)		
99	12797.9	.10546	1349.7	11448.2
100	12866.5	.10262	1320.4	11546.1
101	8589.5	.10262	881.5	7708.1
102	2558.8	.10262	262.6	2296.2
103	613.7	.10262	63.0	550.7
104	777.1	.10262	79.7	697.4
105	139.5	.10262	14.3	125.2

loss between the watercourse and the farm gate. Since this is not a reasonable assumption the water supplies are adjusted for conveyance losses to convert the water supplies to a farm gate basis. The water represented by conveyance losses is not completely unavailable for use since losses from canals and distribution systems represent a major contribution to ground water recharge and much of the water removed from the surface water supplies reappears in the form of ground water pumped from recharged aquifers.

Total diversions and conveyance losses are reported for irrigation organizations in the 1969 agricultural census (52). Dividing conveyance losses by total diversions gives the proportion of water lost between the point of origin and the point of use. In this model it is assumed that the total surface water supply is delivered either to points of use within the region or to the border of the region for export to other regions. Therefore, conveyance losses are computed for each region by multiplying the surface supply times the proportion of diversions loss by irrigation organizations as computed for that region, Table 7.

Surface water transfers

The model allows surface water to be transferred between producing regions within a river basin by natural flows and by man-made transfer facilities. Transfers between producing regions in different river basins are allowed where man-made diversion facilities now exist or are under construction. The interbasin transfers and the man-made intrabasin transfers are limited by the capacity of these facilities. The entire surface supply of water originating in a region may be transferred; therefore, demands for water in the region of origin are competing with demands in all downstream regions and any regions which may be the recipients of man-made transfers. Water transfer losses are computed for each transfer activity. These computations reflect the loss occurring in the importing region and all intervening regions through which the water passes, Table 8.

Ground Water Supplies

Ground water statistics have been compiled from comprehensive river basin studies, state publications, and background data for the second national water assessment[1] (1-7, 10, 11, 14-18, 21, 22, 24-30, 79, 81). Pumping rates which are less than recharge rates are considered dependable supplies and are treated as surface water except the water is not transferable between regions. Pumping rates in excess of recharge rates are considered depletions of ground water stock supplies. Maximum depletion rates allowed in those regions depleting ground water correspond to either the present rate of depletion, if the total ground water stock in storage is sufficient to sustain the current rate beyond 2000, or the projected rate of depletion in either 1985 or 2000 if that estimate is available.

Surface water supplies and ground water obtained from recharge are added to obtain an estimate of the dependable water supply. It represents the amount of water which will be equalled or exceeded in 95 out of 100 years. This estimate provides a basis for a long range planning horizon.

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[1]Water supply statistics provided by the Technical Committee for the 1975 National Water Assessment.

Table 8. Interregional water transfer activities, deliveries per acre foot exported, and activity cost

Region Exp.	Region Imp.	Deliveries (acre feet)	Cost	Region Exp.	Region Imp.	Deliveries (acre feet)	Cost
48	52	.71386	6.15	63	64	.81974	6.85
48	57	.51212	5.96	65	64	.60651	4.57
48	60	.38431	5.14	65	66	.73988	4.47
49	50	.88021	3.31	65	67[b]	.90354	6.14
49	48	.77477	6.48	65	67[b]	.90354	6.14
49	52	.55308	2.36	65	72[a]	.91711	8.48
49	57	.39677	2.29	66	64	.81974	5.62
49	60	.29775	1.97	67	68	.85394	9.70
50	48	.88021	7.36	67	69	.72825	8.93
50	52	.62835	2.36	68	69	.85281	12.25
50	57	.45077	2.29	72	73	.91711	9.20
50	60	.33827	1.97	74	75	.91711	9.21
51	52	.71386	2.16	77	78	.76569	5.77
51	57	.51212	2.10	77	79	.61756	5.29
51	60	.38431	1.81	77	81	.49809	4.89
52	53	.69937	2.24	78	79	.80654	5.29
52	57	.71739	2.65	78	81	.65051	6.39
52	60	.53835	2.28	79	81	.80654	7.92
53	57	.71739	2.65	80	79	.80654	5.18
53	60	.53835	2.28	80	81	.65051	6.39
54	55	.71739	9.39	82	84	.88939	2.66
54	56	.71739	9.06	82	86[a]	.77436	5.77
54	57	.51465	9.26	82	88[a]	.88246	4.77
54	60	.38621	7.98	82	104[a]	.76936	45.59
55	56	.71739	8.76	83	54[a]	.85290	11.05
55	57	.71739	8.95	83	62[a]	.84137	6.68
55	59	.75043	8.49	83	77[a]	.81906	3.77
55	60	.53835	7.92	83	78[a]	.62715	3.62
56	57	.71739	8.95	83	79[a]	.50582	2.46
56	60	.53835	7.72	83	81[a]	.40796	4.01
57	60	.75043	2.82	83	84	.88939	3.00
58	59	.75043	7.56	83	86[a]	.77436	5.77
58	60	.56315	6.87	83	104[a]	.76936	45.59
58	63[a]	.80433	9.44	84	86[a]	.87066	6.49
59	60	.75043	6.87	84	104[a]	.86612	51.31
62	63	.80433	8.64	85	86	.87066	7.44
62	64	.65934	6.85	86	104[a]	.99478	58.94

[a] Interbasin transfers.

[b] Intrabasin man-made transfers.

Table 8. Continued.

Region Exp.	Region Imp.	Deliveries	Cost	Region Exp.	Region Imp.	Deliveries	Cost
87	86	.87066	12.73	99	105[b]	.72265	2.85
92	93	.85228	2.30	100	91[a]	.86824	9.00
92	96	.70305	2.97	100	101[b]	.89738	6.33
93	96	.82491	3.48	100	102[b]	.89738	6.43
94	90[a]	.84555	4.91	100	103[b]	.80529	29.20
94	93	.76559	2.05	100	104[b]	.80529	47.71
94	95	.89829	4.87	100	105[b]	.80529	6.15
94	96	.63155	2.67	101	102[b]	.89738	6.60
95	93	.85228	3.12	101	103[b]	.89738	32.54
95	96	.70305	3.04	101	104[b]	.89738	53.17
99	100[b]	.89738	5.66	101	105[b]	.89738	6.53
99	101[b]	.80529	5.42	105	91[a]	.86824	5.74
99	102[b]	.89738	6.43	105	101[b]	.89738	6.03
99	103[b]	.72265	26.20	105	104[b]	.99478	58.94
99	104[b]	.72265	42.82				

planning horizon. The inclusion of a depletion component provides a more accurate estimate of the total water availability for any year prior to 2000 but cannot be included in calculations involving planning horizons extending beyond 2000, Table 9.

Water Prices

Prices for dependable water supplies

A consistent set of regional water prices, Table 10, has been developed from repayment and operation and maintenance charges assessed against irrigated land by Bureau of Reclamation projects in each of the producing regions. Since the Bureau of Reclamation charges are reported on the basis of an acre of land (76), and not on the basis of a unit of water, the cost per acre has been divided by the water deliveries per irrigated acre served by each project (75, 77). This cost represents the price paid by farmers per acre foot of water delivered by each project. The price for the region is a weighted average of the prices of the individual projects. Regions which do not contain Bureau of Reclamation projects have been assigned prices equal to the nearest upstream region with a bureau project. If no upstream projects exist in the basin the price represents an average of the prices in the closest regions with similar conditions. Regional prices are adjusted to a water consumed basis by dividing the regional price for water delivered by the field efficiency for the region, Table 10. The field efficiency for each region is the ratio of farm deliveries to net diversions, weighted for each crop and each subarea in the producing region.[1]

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[1]Soil Conservation Service, background data for the 1975 National Water Assessment.

Table 9.a. Dependable water supply and allowable ground water depletion by producing region for 1985

Producing region	Dependable supply Surface	Ground	Total	Allowable depletion
		(1000 acre feet)		
		(Missouri Region)		
48	824.8	30.1	854.9	-[a]
49	3031.0	37.9	3068.9	-[a]
50	2282.2	8.1	2290.3	-[a]
51	4901.8	124.0	5025.8	-[a]
52	5180.3	148.0	5328.3	-[a]
53	791.1	152.4	943.5	-[a]
54	3202.4	609.7	3812.1	609.7
55	1561.1	1666.1	3227.2	184.0
56	405.8	112.0	517.8	-[a]
57	2556.8	263.6	2820.4	-[a]
58	1249.2	932.1	2181.3	103.6
59	745.3	1471.5	2216.8	-[a]
60	5477.4	215.4	5692.8	-[a]
		(Arkansas-White-Red)		
61	7019.8	143.0	7162.8	-[a]
62	711.7	169.3	881.0	-[a]
63	989.6	1499.9	2789.5	1499.9
64	5342.3	118.5	5460.8	-[a]
65	660.6	232.2	892.8	1882.3
66	857.5	43.0	900.5	398.8
67	16.4		16.4	446.2
68	2357.9	257.0	2614.9	200.9
69	5876.8	88.0	5964.8	-[a]
		(Texas-Gulf)		
70	3384.1	177.4	3561.5	-[a]
71	3688.1	665.2	4353.3	-[a]
72	23.9		23.9	1996.3
73	1669.8	500.0	2169.8	1492.4
74	29.8		29.8	786.7
75	1417.0	347.9	1764.9	29.3
76	1053.4	953.1	2006.5	-[a]
		(Rio Grande)		
77	279.5	679.3	958.8	-[a]
78	1654.3	743.0	2397.3	-[a]
79	390.0	631.5	1021.5	-[a]
80	270.1	70.1	340.2	23.4
81	398.4	76.6	475.0	-[a]

[a]Ground water depletion not defined.

Table 9.a. Continued.

Producing region	Dependable supply Surface	Ground	Total	Allowable depletion
	(1000 acre feet)			
		(Upper Colorado)		
82	4038.2	55.6	4093.8	-[a]
83	2645.3	452.9	3098.2	-[a]
84	4122.3	46.0	4168.3	-[a]
		(Lower Colorado)		
85	229.4	52.0	281.4	-[a]
86	419.6	399.2	818.8	133.1
87	1624.0	1531.3	3155.3	2866.9
		(Great Basin)		
88	1625.2	221.9	1847.1	221.9
89	560.4	169.3	729.7	169.3
90	509.3	177.9	687.2	177.9
91	683.0	30.8	713.8	30.8
		(Columbia-North Pacific)		
92	14484.0	299.0	14783.0	-[a]
93	13038.7	607.3	13646.0	-[a]
94	10897.6	2957.9	13855.5	-[a]
95	14333.3	118.9	14452.2	-[a]
96	59999.3	594.3	60593.6	-[a]
97	25023.7	171.7	25195.4	-[a]
98	207.8	67.6	275.4	-[a]
		(California-South Pacific)		
99	11451.5	182.7	11634.2	
100	11259.4	1822.3	13081.7	2348.4
101	7637.9	7190.4	14828.3	3481.4
102	2087.5	329.3	2416.8	256.0
103	550.7	988.0	1538.7	217.8
104	697.4	1866.2	2563.6	1070.4
105	125.2	329.3	454.5	309.8

Table 9.b. Dependable water supply and allowable ground water depletion by producing region for 2000

Producing region	Dependable supply Surface	Ground	Total	Allowable depletion
	(1000 acre feet)			
		(Missouri Region)		
48	824.8	30.1	854.9	-[a]
49	3031.0	37.9	3068.9	-[a]
50	2282.2	8.1	2290.3	-[a]
51	4901.8	124.0	5025.8	-[a]
52	5180.3	148.0	5328.3	-[a]
53	791.1	152.4	943.5	-[a]
54	3224.4	609.7	3834.1	609.7
55	1561.1	1666.1	3227.2	184.0
56	405.8	112.0	517.8	-[a]
57	2556.8	263.6	2820.4	-[a]
58	1267.9	932.1	2200.0	103.6
59	741.3	1471.5	2212.8	-[a]
60	5473.0	215.4	5688.4	-[a]
		(Arkansas-White-Red)		
61	7019.8	143.0	7162.8	-[a]
62	685.7	169.3	855.0	-[a]
63	965.2	1499.9	2465.1	1499.9
64	5820.7	118.5	5439.2	-[a]
65	705.1	232.2	937.3	1896.5
66	857.5	43.0	900.5	672.2
67	16.4		16.4	333.6
68	2328.0	257.0	2585.0	167.7
69	5866.6	88.0	5954.6	-[a]
		(Texas-Gulf)		
70	4158.8	177.4	4336.2	-[a]
71	4562.0	665.2	5227.2	-[a]
72	23.9		23.9	1678.0
73	2134.6	500.0	2634.6	1489.6
74	29.8		29.8	713.5
75	1417.0	347.9	1764.9	24.9
76	1141.3	953.1	2094.4	-[a]
		(Rio Grande)		
77	318.5	679.3	997.8	-[a]
78	1656.9	743.0	2399.9	-[a]
79	390.0	631.5	1021.5	-[a]
80	270.1	70.1	340.2	23.4
81	398.4	76.6	475.0	-[a]

[a]Ground water depletion not defined.

Table 9.b. Continued.

Producing region	Dependable supply: Surface	Ground (1000 acre feet)	Total	Allowable depletion
		(Upper Colorado)		
82	4056.8	55.6	4112.4	-[a]
83	3218.2	452.9	3671.1	-[a]
84	3506.0	46.0	3552.0	-[a]
		(Lower Colorado)		
85	229.4	52.0	281.4	-[a]
86	382.3	399.2	781.5	133.1
87	1624.0	1531.3	3155.3	2866.9
		(Great Basin)		
88	1627.3	221.9	1849.2	221.9
89	560.4	169.3	729.7	169.3
90	642.1	177.9	820.0	177.9
91	683.0	30.8	713.8	30.8
		(Columbia-North Pacific)		
92	14484.0	299.0	14783.0	-[a]
93	13038.6	607.3	13645.9	-[a]
94	11110.8	2957.9	14068.7	-[a]
95	14331.3	118.9	14450.2	-[a]
96	59996.0	594.3	60590.3	-[a]
97	25023.7	171.7	25195.4	-[a]
98	207.8	67.6	275.4	-[a]
		(California-South Pacific)		
99	11448.2	182.7	11630.9	
100	11546.1	1822.3	13368.4	2348.4
101	7708.1	7190.4	14898.4	3481.4
102	2296.2	329.3	2625.5	256.0
103	550.7	988.0	1538.7	217.8
104	697.4	1866.2	2563.6	1070.4
105	125.2	329.3	454.5	309.8

Table 10. Water prices at the reservoir, field efficiency, water price at the farm and the maximum price for ground water depletion, by region

Producing region	Field efficiency	Water Prices (dollars/acre foot) Reservoir site	Farm delivery	Ground water depletion
		(Missouri Region)		
48	.5339	4.46	8.35	62.00
49	.5192	1.71	3.29	20.42
50	.5169	1.71	3.31	20.42
51	.5052	1.57	3.11	18.27
52	.7253	1.98	2.73	23.94
53	.8831	1.98	2.24	19.62
54	.5357	6.93	12.94	34.38
55	.7382	6.70	9.08	39.01
56	.7652	6.70	8.76	37.33
57	.7483	2.45	3.27	24.11
58	.6518	5.96	9.14	39.91
59	.7887	5.96	7.56	33.07
60	.8680	2.95	3.40	21.70
		(Arkansas-White-Red)		
61	.8791	2.95	3.36	12.50
62	.6886	5.46	7.96	35.79
63	.6316	5.46	8.64	39.01
64	.7965	5.46	6.85	17.96
65	.7889	3.64	4.61	26.11
66	.8149	3.64	4.47	14.58
67	.9024	6.14	6.80	36.02
68	.8790	9.98	11.35	27.19
69	.8146	9.98	12.25	29.59
		(Texas-Gulf)		
70	.9115	7.94	8.71	22.61
71	.9312	7.94	8.53	22.11
72	.8590	7.94	9.24	46.74
73	.8627	7.94	9.20	23.67
74	.7846	4.13	5.26	19.63
75	.8919	8.95	10.03	28.74
76	.8841	8.95	10.12	29.16

Table 10. Continued.

Producing region	Field efficiency	Water Prices (dollars/acre foot) Reservoir site	Farm delivery	Ground water depletion
		(Rio Grande)		
77	.9283	4.26	4.59	15.46
78	.7385	4.26	5.77	19.44
79	.8049	3.91	4.86	24.69
80	.8015	4.17	5.20	18.35
81	.9819	9.63	9.81	64.36
		(Upper Colorado)		
82	.4738	1.16	2.45	41.81
83	.5638	1.31	2.30	16.27
84	.4361	.81	1.84	28.06
		(Lower Colorado)		
85	.5713	4.36	7.63	24.46
86	.5858	4.36	7.44	15.19
87	.7270	7.46	10.26	12.23
		(Great Basin)		
88	.4762	2.57	5.40	12.91
89	.6254	5.04	8.06	16.11
90	.6134	3.56	5.80	13.36
91	.6201	2.13	3.43	26.09
		(Columbia-North Pacific)		
92	.6284	1.89	3.03	25.38
93	.8233	2.20	2.67	16.90
94	.4375	1.54	3.52	30.32
95	.4754	2.57	5.41	29.53
96	.8441	3.55	4.21	16.03
97	.6483	2.20	3.39	21.49
98	.4140	3.56	8.60	72.86
		(California-South Pacific)		
99	.6219	1.65	2.65	29.40
100	.8862	5.58	6.30	37.49
101	.8813	5.92	6.72	42.24
102	.8872	6.34	7.15	26.78
103	.8790	31.86	36.25	49.98
104	.9211	54.57	59.24	85.68
105	.9069	3.56	3.93	35.28

The formula for computing regional water prices is:

$$P^*_j = \frac{P_j}{(FE)_j} \qquad j = 48,\ldots,105 \qquad (8)$$

$$P_j = \sum_i \frac{(\frac{C_{ij}}{D_{ij}})TD_{ij}}{TD_j} \qquad i = 1,\ldots,r \qquad (9)$$

$$(FE)_j = \sum_{\substack{k\\1}} \frac{(\frac{(FD)_{klj}}{(ND)_{klj}})A_{klj}}{A_j} \qquad \begin{matrix} k = 1,\ldots,m \\ 1 = 1,\ldots,n \end{matrix} \qquad (10)$$

where:

A_j is the acres of irrigated land in the jth producing region;

P^*_j is the price per acre of water consumed in the jth producing region;

P_j is the weighted average price of an acre foot of water delivered to the farm in the jth producing region;

TD_j is the total delivery of water by Bureau of Reclamation projects in the jth producing region;

$(FE)_j$ is the field efficiency of irrigation water applied in the jth producing region;

C_{ij} is the repayment and operation and maintenance cost assessed per acre for water delivered by the ith Bureau of Reclamation project in the jth producing region;

D_{ij} is the acre feet of water delivered per acre of irrigated land served by the ith Bureau of Reclamation project in the jth producing region;

TD_{ij} is the total delivery of water to farms made by the ith Bureau of Reclamation project in the jth producing region;

FD_{klj} is the acre feet of water delivered to the farm for the kth crop in the lth subarea of the jth producing region;

ND_{klj} is the net diversion in acre feet required for the kth crop in the lth subarea of the jth producing region; and

A_{klj} is the acres of the kth crop grown under irrigation in the lth subarea of the jth producing region.

This price is applied to all water which is considered part of the dependable supply whether it is obtained from natural runoff or recharged ground water.

Prices for ground water depletion

Although surface water and rechargeable ground water prices should remain relatively constant over time, the cost of obtaining water through depletion of underground reservoirs changes as depletion progresses. Since there are no accurate estimates of how these costs will change for each of the producing regions an effort has been made to estimate a maximum price at which depletion would occur in each region. It is assumed that depletion will occur as long as it is profitable to deplete the reserve and utilize it in production. As long as the net return to land under irrigation is greater than the net return to the same land without irrigation then it will be profitable to continue utilizing the stock resource. In order to estimate this cut off point, the net return or rent differential between irrigated and dryland was computed for the nine river basins containing irrigation activities.[1] In adjusting the rent differential from an acre of land basis to an acre foot of water basis it is assumed that the

[1]The land rents used in computation are the shadow prices on irrigated and nonirrigated land as computed for the 1975 National Water Assessment model run E' 2000 with normal exports.

same amount of water would be released if the land were converted from irrigated to nonirrigated regardless of whether the water originated from surface sources or ground water depletion. The per acre net diversion computed on the basis of farm deliveries from Bureau of Reclamation projects adjusted for field efficiency is used to convert the rent differential to an acre foot basis. The computational formula is:

$$(PD)_{j\varepsilon k} = \frac{(LRD)_k}{(WR)_j} \tag{11}$$

$$(LRD)_k = \sum_{l} \left[\frac{(NRI)_{lk}(AI)_{lk}}{(AI)_k} - \frac{(NRD)_{lk}(AD)_{lk}}{(AD)_k}\right] \tag{12}$$

$$(WR)_j = \sum_{j} \frac{\dfrac{D_{ij}\ (TD)_{ij}}{TD_j}}{(FE)_j} \tag{13}$$

$j = 48,\ldots,105$
$k = 1,\ldots,9$
$l = 1,\ldots,9$
$i = 1,\ldots,n$

where:

$(PD)_{j\varepsilon k}$ is the price for water depletion in the jth producing region which is a part of the kth river basin;

$(LRD)_k$ is the land rent differential between irrigated and dry land in the kth river basin;

$(WR)_j$ is the water released by converting one acre from irrigation to dryland in the jth producing region;

$(TD)_j$ is the total delivery of water to farms by Bureau of Reclamation projects in the jth producing region;

$(NRI)_{lk}$ and $(NRD)_{lk}$ are the net return per acre from irrigated land and dryland for the lth land capability group in the kth river basin;

$(AI)_{lk}$ and $(AD)_{lk}$ are the acreages of irrigated land and dryland in the lth land capability group in the kth river basin;

$(AI)_k$ and $(AD)_k$ are the acreages of irrigated land and dryland in the kth river basin;

D_{ij} is the acre feet of water delivered per acre of irrigated land served by the ith Bureau of Reclamation project in the jth producing region;

$(TD)_{ij}$ is the total delivery of water to farms made by the ith Bureau of Reclamation project in the jth producing region; and

$(FE)_j$ is the field efficiency of irrigation water applied in the jth producing region.

Some river basins encompass such heterogeneous conditions that the computations for the basin do not adequately represent the situation in the individual producing regions. The land rent differential in those producing regions where conditions are represented more closely by relationship in adjacent river basins rather than the average for the river basin in which they are geographically located have been adjusted to reflect the relationships which most closely reflect actual conditions. The price per acre foot of water from depletion is given in Table 10.

Prices for converting irrigated land to nonirrigated

Activities have been included in the model that allow water to be released from agriculture and in effect convert irrigated land into nonirrigated. The scarcity of data on selling prices for water rights and the large speculative component in those prices that are available preclude a direct enumeration of market prices. Also, an estimate of the cost incurred in converting from irrigated to dryland would be more in keeping with the cost minimization framework of the linear programming model.

The cost of conversion to the farmer is composed of two components, the loss of net return and the decrease in the capital value of the land. The decrease in the net return is computed in the preceding section where it is used in the computation of costs for water depletion. The net return differential also represents the annual return to the capital asset land. Assuming that the land was purchased at the present value for irrigated land the cost of converting from irrigated to dryland would be two times the net return differential, Table 11.

Exogenous Agricultural Water Requirement

The CARD-NSF models include 12 crops: barley, corn, corn silage, cotton, legume hay, nonlegume hay, oats, sorghum, sorghum silage, soybeans, sugar beets, and wheat; and four categories of livestock: cattle feeding, cow-calf operations, dairy and hogs. All other crop and livestock activities are considered to be exogenous to the model. The water requirement for the exogenous crops, livestock and roughage must be satisfied before water can be made available for the activities in the model. The total requirement for each region is reported in Table 12.

Nonagricultural Water Consumption

Nonagricultural water consumption includes all domestic, municipal, industrial, steam electric generating, recreation, mining, and fish and wildlife consumptive uses of water. The 1965 nonagricultural demands for the river basin subarea in the Nations Water Resources (79) are weighted to the producing regions on the basis of population and value of production

Table 11. Water released per acre and the loss incurred in converting land from irrigated to nonirrigated

Producing region	Water released (a.f.)	Loss (dollars)	Producing region	Water released (a.f.)	Loss (dollars)
48	.56	69.44	77	2.54	78.52
49	1.70	69.44	78	2.02	78.52
50	1.70	69.44	79	1.59	78.52
51	1.90	69.44	80	2.14	78.52
52	1.45	69.44	81	.61	78.52
53	1.77	69.44	82	1.00	83.62
54	1.01	69.44	83	2.57	83.62
55	.89	69.44	84	1.49	83.62
56	.93	69.44	85	1.41	68.98
57	1.44	69.44	86	2.27	68.98
58	.87	69.44	87	2.82	68.98
59	1.05	69.44	88	1.19	30.72
60	1.60	69.44	89	.95	30.72
61	1.62	40.24	90	1.15	30.72
62	.97	69.44	91	2.15	112.20
63	.89	69.44	92	2.21	112.20
64	1.12	40.24	93	3.32	112.20
65	1.33	69.44	94	1.85	112.20
66	1.38	40.24	95	1.90	112.20
67	1.09	78.52	96	3.50	112.20
68	.74	40.24	97	2.61	112.20
69	.68	40.24	98	.77	112.20
70	.89	40.24	99	2.04	119.96
71	.91	40.24	100	1.60	119.96
72	.84	78.52	101	1.42	119.96
73	.85	40.24	102	2.24	119.96
74	2.00	78.52	103	1.20	119.96
75	.70	40.24	104	.70	119.96
76	.69	40.24	105	1.70	119.96

Table 12.a. Water requirements to satisfy exogenous agricultural and nonagricultural demands by producing regions for 1985 (1000 a.f.)

Producing region	Exogenous agricultural	Nonagricultural demand
48	352.8	48.4
49	1231.5	96.8
50	139.7	10.9
51	1470.3	195.8
52	251.4	120.3
53	4.4	104.1
54	1617.5	284.6
55	200.5	22.7
56	6.4	18.4
57	0.7	148.0
58	72.8	45.3
59	64.7	57.9
60	1.3	198.1
61	36.8	73.1
62	354.5	58.3
63	52.8	120.5
64	23.4	425.9
65	202.2	115.3
66	6.4	196.3
67	74.6	194.9
68	268.6	86.6
69	21.2	362.9
70	317.1	381.4
71	926.8	1901.9
72	548.3	60.7
73	206.7	264.1
74	244.4	220.0
75	834.4	343.6
76	560.8	491.1
77	749.8	17.6
78	649.3	109.0
79	65.9	85.7
80	67.1	34.2
81	835.5	74.4
82	1109.3	166.1
83	1041.9	48.2
84	300.7	86.4
85	37.6	48.9
86	288.1	214.2

Table 12.a. Continued.

Producing region	Exogenous agricultural	Nonagricultural demand
87	565.6	433.0
88	650.2	909.3
89	188.4	115.4
90	1704.6	122.6
91	688.8	371.4
92	755.5	109.1
93	2036.1	252.5
94	3211.0	190.0
95	431.3	73.9
96	277.1	547.8
97	7.6	232.2
98	259.0	109.6
99	394.9	289.6
100	4908.1	522.6
101	4487.7	726.6
102	525.0	759.3
103	802.4	199.8
104	2467.4	2164.8
105	315.8	63.6

Table 12.b. Water requirements to satisfy exogenous agricultural and nonagricultural demands by producing regions for 2000 (1000 a.f.)

Producing region	Exogenous agricultural	Nonagricultural demand
48	284.4	59.1
49	901.8	130.3
50	123.6	13.8
51	1309.9	264.0
52	244.4	225.1
53	4.5	118.5
54	1309.5	454.7
55	172.5	85.4
56	5.4	21.5
57	1.0	196.7
58	65.1	78.2
59	52.8	88.0
60	1.7	403.0
61	39.8	112.4
62	316.1	83.3
63	49.1	157.1
64	23.9	647.8
65	151.8	117.5
66	6.3	314.2
67	60.8	247.3
68	247.3	118.6
69	20.9	566.9
70	266.4	915.2
71	827.0	2636.4
72	477.7	75.7
73	173.3	371.9
74	216.1	299.9
75	733.9	547.7
76	460.0	715.5
77	648.3	18.8
78	493.1	166.9
79	58.0	80.1
80	52.1	36.5
81	706.6	106.0
82	1181.4	179.0
83	916.3	82.8
84	265.0	100.7
85	31.4	65.4
86	284.7	290.9

Table 12.b. Continued.

Producing region	Exogenous agricultural	Nonagricultural demand
87	560.2	644.2
88	556.6	1035.4
89	161.8	120.0
90	1570.1	137.9
91	663.0	409.4
92	597.2	141.3
93	1820.2	526.7
94	2858.8	172.3
95	361.6	109.1
96	264.0	1323.1
97	21.1	450.1
98	235.3	111.8
99	386.0	294.2
100	4576.8	621.9
101	2029.1	911.5
102	439.8	990.7
103	676.9	245.4
104	2310.2	2686.5
105	299.1	63.6

from industry, contract construction, and mining (53, 54). The per capita consumption of water for domestic uses and the water consumption per 1000 dollars of industrial output computed for each of the producing regions is multiplied by the projected population level and value of industrial production (80) to obtain the consumption demand for domestic, municipal, industrial, recreation and mining. These figures have been adjusted to reflect the increasing water demand for steam electric generation, fish and wildlife, and environmental concerns which have developed since the time period represented by the original relationships.[1] Total nonagricultural water demand for each region is listed in Table 12.

Legal Restrictions

Water rights and legally binding international agreements and interstate compacts with required minimum flows are the legal restrictions included in the model.

Water rights

Water rights indicate the ownership or the right to use water. Documentation of the distribution of water according to legally filed water rights in the western states has not been successful. Replies to a water rights questionnaire sent to 10 western states indicate that information quantifying the legal allocations of water is not available.

Since empirical data is not available, the limiting assumption is made that there is no transfer of water between the legal owner and the

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[1]Current and future annual water requirement statistics provided by the National Water Resources Council.

user. This assumption establishes the use of water at a point in time as an estimate of the legal allocation of water. The most recent estimates of agricultural water consumptive use are provided in the background data for the second national assessment for 1975.[1] These estimates, Table 13, are used in the model to indicate the amount of water legally tied to agriculture. This quantity must be used in agricultural production or released to other uses at a high cost, Table 11, by converting land permanently from irrigated to nonirrigated use.

Mandatory international transfers

International transfers are made between the United States and Canada and the United States and Mexico. Canada is allotted 45 thousand acre feet of natural runoff originating in the United States and entering the Milk River (23). Transactions with Mexico include the export of 1.5 million acre feet of water from the Lower Colorado Region to Mexico, export of 60 thousand acre feet from the Middle Rio Grande Region to Mexico and the import of 350 thousand acre feet of water into the Rio Grande Region in Texas from Mexico (79).

Mandatory interregional transfers

Within the United States interstate compacts have established legal requirements for transferring water. By 2000 the Garrison Division Unit will be transferring 1,086.6 thousand acre feet of water from the Missouri

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[1]Current and future annual water requirement statistics provided by the National Water Resources Council.

Table 13. Estimated 1975 agricultural water consumption by producing region

Region	(1000 a.f.)	Region	(1000 a.f.)
48	324.8	77	664.9
49	1470.0	78	1309.2
50	138.5	79	648.9
51	2273.6	80	645.6
52	547.1	81	1451.4
53	102.7	82	1179.2
54	3821.1	83	1198.1
55	3380.9	84	316.7
56	142.4	85	61.3
57	103.5	86	1067.0
58	1349.5	87	5113.2
59	1599.1	88	1352.6
60	47.9	89	617.3
61	69.3	90	1223.0
62	933.7	91	819.5
63	1853.6	92	787.2
64	147.8	93	4664.0
65	2498.8	94	6940.0
66	128.4	95	727.7
67	1421.3	96	539.8
68	1282.4	97	41.4
69	79.0	98	599.3
70	345.3	99	621.8
71	1063.6	100	4986.8
72	5321.6	101	12791.5
73	387.4	102	727.9
74	1663.5	103	986.2
75	1081.6	104	5631.7
76	877.1	105	77.5

Region to the Souris-Red-Rainy Region (79). The 1953 Sabine River Compact[1] requires the transfer of 26.3 thousand acre feet from Texas to Louisiana. The Arkansas River Compact[2], allocates flows in the Arkansas River resulting in a required minimum transfer of 169.8 thousand acre feet of water from Colorado to Kansas. The Big Blue River Compact[3] provides for a minimum transfer of 38.1 thousand acre feet from Nebraska to Kansas. The Upper Colorado Basin is required to deliver an average of 7.5 million acre feet at Lee Ferry, Arizona[4] for use in California, the Lower Colorado Basin and export to Mexico. Converting this average requirement to reflect the 95 percent probable flow results in a dependable delivery of 6.371 million acre feet. The implementation of the "1947 Condition" in the Pecos River Compact[5] results in a transfer of at least 129 thousand acre feet from New Mexico to Texas. Colorado must deliver Nebraska a minimum of 47.1 thousand acre feet under the South Platte River Compact.[6]

Voluntary interregional man-made transfers

Additional interregional man-made transfers exist which are not codified by interstate compact. By 2000 the Upper Colorado River Basin

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[1]Sabine River Compact, 1953, 68 Stat. 690, amended 76 Stat. 34.

[2]The Arkansas River Compact, 1948, 63 Stat.

[3]Big Blue River Compact, 1971, 86 Stat. 193.

[4]Colorado River Compact, 1922, 45 Stat. 1057, 1064.

[5]Pecos River Compact, 1948, 63 Stat. 159.

[6]South Platte River Compact, 1923, 44 Stat. 1509.

will have transfer facilities to export 660 thousand acre feet to the Missouri Region, 52 thousand acre feet to the Arkansas-White-Red Region, 110 thousand acre feet to the Rio Grande Region and 245 thousand acre feet to the Great Basin Region. California will receive up to 4.4 million of the 6.371 million acre feet transferred to the Lower Colorado River Basin. Since the boundaries of the regions are established by county lines and do not always coincide with actual divisions in drainage transfers of 1.1 million acre feet from the California-South Pacific Region to the Great Basin and 20 thousand acre feet from the Columbia-North Pacific Region to the Great Basin Region have been made to adjust for the natural runoff which has been credited to the inappropriate region during computation. The minimum water transfers required by international treaty and interstate compact are summarized in Table 14. The maximum water transfer requirements and canal capacities which restrict man-made interbasin and intrabasin transfers are listed in Table 15. The natural runoff which flows from Canada into the Columbia-North Pacific Region is not included in any of these computations.

Linear Programming Tableau

The concepts and interrelationships found in the water sector are brought together in a four region example, Figure 2. The coefficients in the example are derived by the methods described in this chapter. The example assumes a water price at the reservoir of $9, a field efficiency of .9, and a transfer loss of .2 for each region traversed.

Table 14. Minimum water transfers required by international treaty and interstate compact

Region From	Region To	(1000 a.f.)	Region From	Region To	(1000 a.f.)
48	Canada	45.0	Mexico	79	350.0
52	Souris-Red-Rainy	1086.6	80	79	129.0
			82	Mexico	
54	55	47.1	83	Mexico	1274.2
			84	Mexico	
58	63	38.1[a]			
			82	Mexico	
62	63	169.8	83	Mexico	
			84	Mexico	
70	Louisiana	26.3	82	86	
			83	86	6371.0
78	Mexico	60.0	84	86	
			82	104	
78	79	60.0	83	104	
			84	104	

[a]Also represents a canal capacity.

Table 15. Maximum water transfer requirements and canal capacities restricting man-made interbasin and intrabasin transfers

Region From	Region To	Capacity (1000 a.f.)	Region From	Region To	Capacity (1000 a.f.)
82	88	245.0	101	102	1048.0
83	54	660.0	99	103	
			100	103	158.0
83	62	52.0	101	103	
83	77		99	104	
83	78	110.0	100	104	2258.0
83	79		101	104	
83	81				
			99	105	
82	104		100	105	208.0
83	104	4400.0	101	105	
84	104				
			105	91	100.0
94	90	20.0			
			105	101	2.0
99	100				
99	101		105	104	472.5
99	103	1660.0			
99	104		99	101	
99	105		99	103	
			99	104	
99	102	167.0	99	105	10000.0
			100	101	
100	91	1000.0	100	103	
			100	104	
100	101	2065.0	100	105	
100	102	80.0			

	WBUY0001	WBUY0002	WBUY0003	WBUY0004	WN000001	WN000002	WN000003	WT001002	WT003004	WI001003	WI001004	WI002003	WI002004	WJ003004	WDEP0001	WDEP0003	WRRE0001	WRRE0002	WRRE0003	WRRE0004		RHSE2000
WSPLY001	1				1																L	Ag. Supply
WSPLY002		1				1															L	"
WSPLY003			1				1														L	"
WSPLY004				1																	L	"
WTR00001	1														1						E	Exog. Ag. Use
WTR00002		1						.8													E	"
WTR00003			1							.6		.8				1					E	"
WTR00004				1					.8		.5		.6	.8							E	"
WTT00001					1			-1		-1	-1										E	0
WTT00002						1						-1	-1								E	0
WTT00003							1		-1					-1							E	0
WRTRT001	1														1		2				G	1975 Ag. Use
WRTRT002		1						.8										.5			G	"
WRTRT003			1							.6		.8				1			.5		G	"
WRTRT004				1					.8		.5		.6	.8						1	G	"
WCAP0001										1	1										L	Canal Cap.
WCAP0003												.8									G	Compact Amt.
WCAP0004											.5		.6	.8							L	Canal Cap.
OBJ00001	10	10	10	10				9	9	9	9	9	9	9	10	20	40	40	40	40	N	
BND02000					U	U	U		L					U	U	U						

Assumptions: Reservoir water price $9
Field efficiency 90%
Transfer loss 20%

Land conversion cost $40
Water released by conversion 2, .5, .5, 1 in regions 001 through 004 respectively

Figure 2. Linear programming tableau of a sample water sector involving four regions

The financial loss from converting irrigated cropland to dryland is assumed to be $40 per acre. The conversion of one acre releases the water right restriction in region 001 by two acre feet, one-half acre foot is released in regions 002 and 003, while one acre foot is released in region 004. The tables containing the coefficients used in the water sector are listed as the row designations and activities are described.

Five row designations are used to indicate different constraints. The WSPLY rows delimit the amount of water originating in each region which is available for use by the crop and livestock activities in the model. The available water supply can be either purchased for use locally or can be transferred to other regions. The level of resource availability in each region as indicated by the right hand side is obtained by subtracting nonagricultural demands, Table 12, from the total dependable supply, Table 9. The WTR rows are the agricultural water balance rows for each region. These rows provide for interaction between the water sector and the crop and livestock production sectors. Enough water must be provided to satisfy the requirements of the crop and livestock activities in the model plus the demands for the exogenous agricultural uses which are included as the right hand sides for these rows. The exogenous agricultural water requirements are listed in Table 12.

The WTT rows form the basis of the water transportation network. The WRTRT rows define the water right restrictions. The 1975 agricultural water use level, Table 13, has been selected as the base for water use comparisons. The water right restrictions can be satisfied by using water from local sources, transferring water from another region, depleting ground water or releasing the water from irrigation by converting the land to dryland. The WCAP rows serve two functions. One, when used as less than constraints they reflect canal capacities. WCAP0001 represents a situation with the capacity constraint located in the exporting region. In WCAP0004 the capacity constraint is located in the importing region. And two, when used as greater than constraints they reflect legally binding interregional transfer obligations. The individual compacts and constraints are listed in the text and in Tables 14 and 15.

Five main categories of activities are included in the water sector. The WBUY activities purchase water from the local dependable supply and makes it available for use in the agricultural sector. The values in the objective function are the prices of water delivered at the farm from Table 10. The WN activities make local water available for transfer to other regions. The upper limit on these activities as indicated by the U in the bound section is equal to that portion of the local dependable supply originating from surface sources, Table 9. The WT, WI and WJ activities transfer water from one region to another. The WT designates natural transfers along a river system. The WI activities define man-made interbasin transfers and the WJ activities define man-made intrabasin transfers. The delivery coefficients obtained from Table 8, reflect the loss of water due to the transfer. The value in the objective function is the price of the water delivered to the farm in the importing region, Table 8.

A lower bound on one of the activities indicate a required interregional transfer, while an upper bound reflects the maximum capacity of the canal system involved in that transfer.

The WDEP activities provide for ground water depletion. The objective function values reflecting the maximum price at which depletion will occur are obtained from Table 10. The upper bounds establishing the maximum allowable depletion are listed in Table 9. The WRRE activities react only with the water right restrictions. These activities allow the relaxation of the previous agricultural water use level. The cost in the objective function reflects the loss of income and capital value associated with the conversion of irrigated land into nonirrigated cropland. These values are listed in Table 11.

The interrelationships built into the water sector and the source of all of the nonzero coefficients used to quantify the relationships are organized in tableau form in Figure 3.

Summary

Current knowledge of water availability is combined to project agricultural water supply data for the 58 producing regions defined in the nine river basins in the Western United States by the Center for Agricultural and Rural Development. The supplies are projected for 1985 and 2000. The relationships between precipitation, natural runoff, reservoir storage, rechargeable ground water, and ground water depletion are incorporated into the projected supplies.

	WBUYOZZZ	WBIYOZZZ	WBUYOZZZ	WBUYOZZZ	WNOOOZZZ	WNOOOZZZ	WNOOOZZZ	WTXXXIII	WTXXXIII	WIXXXIII	WIXXXIII	WIXXXIII	WIXXXIII	WJXXXIII	WDEPOZZZ	WDEPOZZZ	WRREOZZZ	WRREOZZZ	WRREOZZZ	WRREOZZZ		
WSPLYZZZ	1				1																L	Ag. Supply
WSPLYZZZ		1				1															L	Table 9 minus
WSPLYZZZ			1				1														L	Table 12
WSPLYZZZ				1																	L	
WTROOZZZ	1														1						E	Exog. Ag. Use
WTROOZZZ		1																			E	
WTROOZZZ			1								Table 8					1					E	Table 12
WTROOZZZ				1																	E	
WTTOOZZZ					1			-1		-1	-1										E	0
WTTOOZZZ						1						-1	-1								E	0
WTTOOZZZ							1		-1					-1							E	0
WRTRTZZZ	1														1						G	1975 Ag. Use
WRTRTZZZ		1																			G	
WRTRTZZZ			1								Table 8					1		Table 11			G	Table 13
WRTRTZZZ				1																	G	
WCAPOZZZ										1	1										L	
WCAPOZZZ											Table 8										G	Text and
WCAPOZZZ																					L	Tables 14 and 15
OBJ00001			Table 10								Table 8				Table 10			Table 11			N	
BND02000						Table 9					Test and Tables 14 and 15				Table 9							

Region designation: ZZZ
Transfer designation: Exporting XXX
Importing III

Figure 3. The tableau position and source of all nonzero coefficients in the water sector except plus or minus one

Water prices for renewable supplies are based on Bureau of Reclamation changes for project repayment and operation and maintenance costs. Costs for ground water depletion and for conversion of irrigated land to nonirrigated are based on projected net return differentials in order to estimate the maximum price in each region at which ground water depletion would continue or land would be kept in irrigation.

Legal restrictions are included to indicate the effects of existing water rights, international treaties, interstate compacts and water distribution agreements made in conjunction with the development of water storage and transfer projects.

The projections can be used in evaluating the allocation and use of water by society as a whole or only within the agricultural sector.

306, July 1963.

Outlook in 1974: Summary Report. California
esources Bulletin No. 160-74, November 1974.

ventory Committee. *National Inventory of Soil
n Needs 1967.* U.S. Department of Agriculture
61, January 1971.

Data for Selected Major Texas Reservoirs."
10 (October 1973); 24-25.

C.R.; Shater, G.H.; and Rettman, P.L.
*gation of the Ground Water Resources of the
exas.* Texas Water Commission Bulletin 6310,

n Observation Wells." *Water for Texas* 5, No.
1975): 34-35.

12. Heady, Earl O.; Madsen, Howard C.; Nicol, Kenneth J.; and Hargrove, Stanley H. Agricultural Water Policies and the Environment. Center for Agricultural and Rural Development, Iowa State University CARD Report 40T, June 1972.

13. Implementation of the California Water Plan. California, Department of Water Resources, The Resource Agency, Bulletin No. 160-66, March 1966.

14. Klemt, William B.; Duffin Gail L.; and Alvarez, Henry J. "Board's San Antonio Office Conducting Two Aquifer Studies." Water for Texas 2, No. 8 (September 1972): 5-10.

15. Lansford, Robert R.; Ben-David, Shaul; Gebhard, Thomas G., Jr.; Brutsaert, Willem; and Creel, Bobby J. An Analytical Interdisciplinary Evaluation of the Utilization of the Water Resources of the Rio Grande in New Mexico: Upper Rio Grande Region. New Mexico Water Resources Research Institute Report No. 021, November 1973.

16. ________. An Analytical Interdisciplinary Evaluation of the Utilization of the Water Resources of the Rio Grande in New Mexico: Middle Rio Grande Region. New Mexico Water Resources Research Institute Report No. 022, December 1973.

17. Lansford, Robert R.; Ben-David, Shaul; Gehhard, Thomas G., Jr.; Brutsaert, Willem; and Creel, Bobby J. An Analytical Interdisciplinary Evaluation of the Utilization of the Water Resources of the Rio Grande in New Mexico: Socorro Region. New Mexico Water Resources Research Institute Report No. 023, February 1974.

18. ________. An Analytical Interdisciplinary Evaluation of the Utilization of the Water Resources of the Rio Grande in New Mexico: Lower Rio Grande Region. New Mexico Water Resources Research Institute Report No. 024, March 1974.

19. Lof, George O.G. and Hardison, Clayton H. "Storage Requirements for Water in the United States: Water Resources Research 2, No. 3 (1966): 323-354.

20. Martin, R.O.R. and Hansen, Ronald L. Reservoirs in the United States. U.S. Department of Interior, Geological Survey, Water Supply Paper 1838, 1966.

21. Missouri Basin Interagency Committee. The Missouri River Basin, Comprehensive Framework Study: Volume IV, Appendix, Economic Analysis and Projections. Final Draft, June 1969.

22. Missouri Basin Interagency Committee. The Missouri River Basin, Comprehensive Framework Study: Volume VI, Appendix, Hydrologic Analysis and Projections. Final Draft, June 1969.

51. ________. Water Resources Development in Texas. Dallas, Texas: Author, January 1975.

52. ________. Census of Agriculture, 1969. Volume IV, Irrigation. Washington, D.C.: U.S. Government Printing Office, 1973.

53. U.S. Department of Commerce, Bureau of Economic Analysis and U.S. Department of Agriculture. Economic Research Service. 1972 OBERS Projections-Regional Economic Activity in the U.S. Series E E Population, Vol. 3, Water Resources Regions and Subareas. Washington, D.C.: Author, September 1972.

54. U.S. Department of Commerce, Bureau of Economic Analysis and U.S. Department of Agriculture, Economic Research Service. 1972 OBERS Projections-Economic Activity in the United States. Series C Population, Vol. 4, Water Resources Regions. Washington, D.C.: Author, September 1972.

55. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Arizona. National Climate Center, Asheville, N.C.: Author, July 1973.

56. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Arkansas. National Cimatic Center, Asheville, N.C.: Author, July 1973.

57. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, California. National Climatic Center, Asheville, N.C.: Author, July 1973.

58. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Colorado. National Climatic Center, Asheville, N.C.: Author, July 1973.

59. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Idaho. National Climatic Center, Asheville, N.C.: Author, July 1973.

60. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Kansas. National Climatic Center, Asheville, N.C.: Author, July 1973.

61. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Missouri. National Climatic Center, Asheville, N.C.: Author, July 1973.

62. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Montana. National Climatic Center, Asheville, N.C.: Author, July 1973.

63. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Nevada. National Climatic Center, Asheville, N.C.: Author, July 1973.

64. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, New Mexico. National Climatic Center, Asheville, N.C.: Author, July 1973.

65. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, North Dakota. National Climatic Center, Asheville, N.C.: Author, July 1973.

66. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Nebraska. National Climatic Center, Asheville, N.C.: Author, July 1973.

67. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Oklahoma. National Climatic Center, Asheville, N.C.: Author July 1973.

68. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Oregon. National Climatic Center, Asheville, N.C.: Author, July 1973.

69. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, South Dakota. National Climatic Center, Asheville, N.C.: Author, July 1973.

70. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Texas. National Climatic Center, Asheville, N.C.: Author, July 1973.

71. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Utah. National Climatic Center, Asheville, N.C.: Author, July 1973.

72. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Washington. National Climatic Center, Asheville, N.C.: Author, July 1973.

73. ________. Climatography of the United States No. 85. Monthly Averages of Temperature and Precipitation for State Climatic Divisions: 1941-70, Wyoming. National Climatic Center, Asheville, N.C.: Author, July 1973.

74. ________. Climatological Data Annual Summary 1970. National Climatic Center, Asheville, N.C.: Author, 1970.

75. U.S. Department of Interior, Bureau of Reclamation. Federal Reclamation Projects Water and Land Resource Accomplishments, 1969: Statistical Appendix. Washington, D.C.: Author, 1970.

76. ________. Federal Reclamation Projects Water and Land Resource Accomplishments, 1972: Statistical Appendix 3. Washington, D.C.: Author, June 30, 1972.

77. ________. Federal Reclamation Projects Water and Land Resource Accomplishments: Statistical Appendix 2. Washington, D.C.: Author, June 30, 1972.

78. ________. Water Supply Report. Denver, Colorado: Author, October 1973.

79. U.S. Water Resources Council. The Nation's Water Resources, The First National Assessment of the Water Resources Council. Washington, D.C.: U.S. Government Printing Office, 1968.

80. ________. 1972 OBERS Series E' Projections and Historical Data, Population, Personal Income and Earnings; Aggregated Subareas. Washington, D.C.: Author, June 1974.

81. Walker, Loyd and Taylor, Howard. "TWDB High Plains Study Shows 304 Million Acre-Feet of Water in 45-County Area." Water for Texas 5, No. 1-2 (January-February 1975): 20-22.

82. Water for California: The California Water Plan Outlook in 1970. California, Department of Water Resources, The Resource Agency Bulletin No. 160-70, December 1970.

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