INPUT-OUTPUT MODELING OF THE CACHE LA POUDRE WATER SYSTEM

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ABSTRACT

This report outlines the adaptation of the input-output modeling technique to a depiction of the Cache La Poudre River basin water resource system. The objective is to apply the methodology to a local regional scale, making it suitable for "tactical" level planning. It builds upon a previous study which applied the input-output model to the water resource system of the whole South Platte River basin, developed for the purpose of "strategic" planning. The methodology is developed by demonstration, using the empirical data of the water system of the Cache La Poudre River basin.

The study reviews the problems involved in adapting the model to the local regional scale, and it develops detailed documentation to underpin the 600 items of numerical data contained in the input-output water balance model of the Cache La Poudre River basin. The final product is an input-output matrix of the basin water resource system having a size 123 x 123. This ties together all water related components of the basin into a unified system. The system structure is implicit in the water transfers shown.

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I INTRODUCTION

This study has two facets: (1) further development of the methodology of input-output water balance modeling, and (2) case study demonstration. The basic methodology for the application of input-output modeling to water systems has been developed already for a macro-scale of resolution through previous studies, which utilized the whole South Platte River basin as the case demonstration (see Hendricks and De Haan, 1975 and Hendricks et al., 1977). This study adapts the input-output methodology to the micro-scale of resolution through a depiction of the water system of the Cache La Poudre River basin in northern Colorado, which is a subbasin of the larger South Platte River basin. Thus there is a natural "nesting" of the matrices developed for the two levels of resolution. The report can be used as a guide to input-output modeling for the micro-scale case. One should note how the model is constructed, the documentation developed in order to give the model validity, and its applications. In addition to providing guidance on modeling procedure, the report may also serve as a reference relative to the annual water transfers of the components of the Cache La Poudre water system. The model itself is a useful reference. In addition it provides an organizing framework for a large variety of water oriented data.

1.1 Literature Review

The following utilizes the literature review of DeHaan (1976) and Hendricks and De Haan (1975). It further summarizes work done at Colorado State University, e.g., Hendricks and De Haan (1975) and Hendricks et al., (1977), which precedes the present study.

1.1.1 The input-output idea. An input-output model documents with a matrix format the interdependent exchange of a commodity between suppliers and users. This model was first applied in displaying the cyclic transfer of money between the producing sectors of an economy and the sectors which utilize those commodities. The usefulness of an input-output model stems from its ability to organize and collate large amounts of complex data into an organized and understandable format. Applying input-output theory to the modeling of water resource systems is a relatively new and innovative use of concepts originally developed for economics.

A history of the development of the input-output idea will clarify the context of the present study. Input-output theory has its roots in the mid-eighteenth century. It was in 1785 that Francois Quésnay published his "Tableau Economique" which showed the interdependency of economic activities on a farm. In a later publication, he attempted to model the economy of that time in the same fashion, trying to demonstrate the self-perpetuating qualities of the economic order due to the circular flow of wealth (Davis, 1968).

After Quésnay, the evolution of input-output theory remained dormant until 1874. In that year, Leon Walras published his "Eléments de'Économie Politique Pure." Walras was a mathematician and developed a model consisting of simultaneous equations which would determine the prices for the transfer of goods in an economic system. He considered the computational requirements insurmountable. Because of this, he viewed his model as only a theoretical representation of an economic system.

In August, 1936, Professor Wassily Leontief of Harvard published his article "Quantitative Input-Output Relations in the Economic System of the United States," in the "Review of Economics and Statistics." In this publication, and others which followed (e.g., see Leontief, 1951, 1965), he developed a general formulation of the interdependent nature of production in an economic system. An example of the Leontief formulation is the matrix shown in Figure 1-1. In 1973 Leontief received the Nobel Prize in Economic Science for his work with input-output analysis.

In February 1971, Bishop and Hendricks published a paper illustrating the use of the "transportation model" (a special case of linear programming) as a means for evaluating regional scale water reuse planning alternatives. This model was really an input-output scheme, but was not referred to in this sense by their paper. The model used was a matrix portrayal of the simultaneous transfers of water from primary, secondary, and supplemental supplies to the various sectors of water demand within an agro-urban system. This matrix is shown in Figure 1-2.

Hendricks and De Haan (1975) adapted Leontief's concept of economic input-output modeling to the depiction of a water resource system based upon water transactions (vis a vis monetary ones). They attempted to retain the basic principles of Leontief's model of the United States economy in 1947, insofar as possible. The model which they developed was based upon empirical data for the South Platte River Basin. With their report, and the thesis by De Haan (1976), they were able to demonstrate that an input-output matrix can be useful in system wide water planning and administration as it can describe and analyze the total water resource system of a river basin. They developed a foundation of basic principles for the water resource input-output matrix concept. To elucidate the adaptation of the principle, an input-output matrix was assembled using the system of the South Platte River basin as a case study. Actually, the case study comprised a large portion of their work, since it provided the means to demonstrate the concept.

The application of the input-output model to real water resource planning was accomplished in 1977 by Hendricks, Janonis, Gerlek, Goldbach, and Patterson in a water supply planning study of the South Platte River basin for the Omaha District, U.S. Army Corps of Engineers. The study was carried out by the Environmental Engineering Program, Department of Civil Engineering, Colorado State University and is reported by Hendricks et al. (1977).

This study was an analysis of water supply management and development alternatives for the South Platte River Basin, 1970-2020. The syntax of the study was the *input-output model* of water transfers within the basin between water supply sectors and water demand sectors. The input-output model was used to provide a quantitative "picture" of the South Platte water resource and use system as a whole, for any given

INDUSTRY PURCHASING

FINAL DEMAND

INDUSTRY PRODUCING

Industry producing	1 Agriculture and Fisheries	2 Food and Kindred Products	3 Textile Mill Products	4 Apparel	5 Lumber and Wood Products	6 Furniture and Fixtures	7 Paper and Allied Products	8 Printing and Publishing	9 Chemicals	10 Products of Petroleum and Coal	11 Rubber Products	12 Leather and Leather Products	13 Stone, Clay and Glass Products	14 Primary Metals	15 Fabricated Metal Products	16 Machinery (Except Electric)	17 Electrical Machinery	18 Motor Vehicles
1 Agriculture and Fisheries	10.86	15.70	2.16	0.02	0.19	—	0.01	—	1.21	—	—	0.05	*	0.01	—	—	—	—
2 Food and Kindred Products	2.38	5.72	0.08	0.01	*	*	0.03	*	0.79	*	—	0.44	*	*	*	*	*	—
3 Textile Mill Products	0.06	*	1.30	3.92	*	0.29	0.04	0.03	0.01	*	0.44	0.09	0.03	—	0.01	0.02	0.05	0.15
4 Apparel	0.04	0.20	—	1.96	—	0.01	0.02	—	0.03	—	—	*	*	—	*	*	*	0.10
5 Lumber and Wood Products	0.15	0.10	0.02	*	1.09	0.39	0.27	*	0.04	0.01	—	0.02	0.02	0.06	0.06	0.09	0.05	0.05
6 Furniture and Fixtures	—	—	0.01	—	—	0.01	0.01	—	—	—	—	—	—	—	*	0.01	0.18	0.03
7 Paper and Allied Products	*	0.52	0.68	0.02	*	3.92	2.60	1.08	0.33	0.11	0.02	0.05	0.18	*	0.09	3.04	0.07	0.03
8 Printing and Publishing	—	0.04	*	—	—	—	—	6.77	0.02	—	—	—	—	—	0.01	0.91	0.01	—
9 Chemicals	0.03	1.46	0.80	0.14	0.03	0.06	0.18	0.10	2.58	0.21	0.08	0.13	0.12	0.18	0.13	0.08	0.29	0.11
10 Products of Petroleum and Coal	0.46	0.06	0.03	*	0.07	*	0.06	*	0.32	4.03	0.01	*	0.05	5.90	0.02	0.04	0.07	0.33
11 Rubber Products	0.12	0.01	0.01	0.02	0.01	0.01	0.01	*	*	*	0.04	0.05	0.01	*	0.01	0.13	0.02	0.50
12 Leather and Leather Products	—	—	*	0.05	*	0.01	—	*	—	—	—	1.04	—	—	*	0.02	*	0.01
13 Stone, Clay and Glass Products	0.06	0.25	*	*	0.01	0.03	0.03	—	0.26	0.05	0.01	0.01	0.43	0.21	0.07	0.97	0.12	0.19
14 Primary Metals	0.01	*	—	*	0.01	0.11	—	0.01	0.19	0.01	0.01	*	0.04	6.90	2.53	2.02	1.85	1.28
15 Fabricated Metal Products	0.08	0.61	*	0.01	0.04	0.14	0.02	*	0.13	0.08	0.31	0.02	*	0.05	0.43	0.02	0.34	0.97
16 Machinery (Except Electric)	0.06	0.01	0.04	0.02	0.01	0.61	0.01	0.04	*	0.01	—	—	0.01	0.07	0.28	1.15	0.17	0.63
17 Electrical Machinery	—	—	—	—	—	—	—	—	*	—	—	—	0.01	0.05	0.24	0.58	0.46	0.52
18 Motor Vehicles	0.11	*	—	—	*	—	—	—	—	*	—	—	*	*	0.03	0.03	0.01	4.48
19 Other Transportation Equipment	0.01	—	—	—	—	—	*	—	*	*	*	—	*	*	—	—	*	0.01
20 Professional and Scientific Equipment	—	—	—	—	—	*	0.01	0.03	0.01	—	—	—	*	*	0.04	0.04	0.01	0.07
21 Miscellaneous Manufacturing Industries	*	0.01	*	0.28	*	0.02	0.01	—	0.03	—	*	0.02	0.01	*	0.02	0.05	0.11	0.02
22 Coal, Gas and Electric Power	0.06	0.20	0.11	0.04	0.02	0.02	0.12	0.33	0.19	0.56	0.04	0.02	0.20	0.35	0.06	0.10	0.05	0.06
23 Railroad Transportation	0.44	0.57	0.09	0.06	0.14	0.05	0.22	0.07	0.29	0.27	0.04	0.04	0.15	0.52	0.13	0.16	0.07	0.23
24 Ocean Transportation	0.07	0.13	0.01	0.01	0.01	*	0.02	*	0.34	0.09	*	*	0.01	0.08	*	*	*	*
25 Other Transportation	0.55	0.30	0.08	0.03	0.14	0.04	0.12	0.03	0.10	0.47	0.01	0.02	0.07	0.16	0.03	0.04	0.03	0.07
26 Trade	1.36	0.46	0.73	0.37	0.06	0.06	0.18	0.03	0.17	0.02	0.05	0.06	0.05	0.36	0.20	0.26	0.14	0.06
27 Communications	*	0.04	0.01	0.02	0.01	0.01	0.01	0.04	0.02	0.01	0.01	*	0.01	0.02	0.02	0.03	0.02	0.02
28 Finance and Insurance	0.24	0.15	0.02	0.02	0.08	0.02	0.02	0.02	0.02	0.13	0.01	0.01	0.05	0.06	0.04	0.05	0.04	0.02
29 Real Estate and Rentals	2.39	0.09	0.03	0.10	0.02	0.02	0.03	0.06	0.03	—	0.01	0.02	0.02	0.06	0.03	0.04	0.33	0.02
30 Business Services	0.01	0.63	0.07	0.10	0.02	0.06	0.02	0.06	0.42	0.04	0.02	0.05	0.01	0.03	0.05	0.09	0.06	0.06
31 Personal and Repair Services	0.37	0.12	*	*	0.04	*	*	0.02	0.01	0.01	*	*	0.03	0.01	0.01	0.01	*	*
32 Non Profit Organizations	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
33 Amusements	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
34 Scrap and Miscellaneous Industries	—	—	0.02	—	—	—	0.25	—	0.01	—	0.01	—	0.01	1.11	0.02	0.25	*	—
35 Eating and Drinking Places	—	—	—	—	—	—	—	*	—	—	—	—	—	—	—	—	—	—
36 New Construction and Maintenance	0.20	0.12	0.04	0.02	0.01	0.01	0.04	0.01	0.04	0.03	0.01	0.02	0.03	0.10	0.03	0.05	0.02	0.04
37 Undistributed	—	1.07	0.30	1.00	0.73	0.27	0.17	0.50	1.49	0.65	0.27	0.27	0.47	0.32	1.14	1.71	0.08	0.41
38 Inventory Change (Depletions)	2.66	0.40	0.12	0.19	*	0.01	0.09	0.03	0.14	0.01	*	0.03	*	0.11	*	*	*	0.01
39 Foreign Countries (Imports From)	0.69	2.11	0.21	0.28	0.10	0.01	0.62	0.01	0.59	0.28	*	0.04	0.14	0.62	0.01	0.05	*	0.02
40 Government	0.81	1.24	0.64	0.38	0.34	0.11	0.50	0.34	0.78	0.78	0.11	0.14	0.32	0.82	0.48	0.77	0.40	0.06
41 Private Capital Formation (Gross)	DEPRECIATION AND OTHER CAPITAL CONSUMPTION ALLOWANCES ARE INCLUDED IN HOUSEHOLD ROW																	
42 Households	19.17	7.65	3.34	4.24	2.72	1.12	2.20	3.14	3.75	5.04	1.00	1.20	2.35	5.53	4.14	6.80	3.41	3.30
TOTAL GROSS OUTLAYS	44.26	40.30	9.84	13.32	6.00	2.89	7.90	6.45	14.05	13.67	2.82	3.81	4.94	18.69	10.48	15.22	8.38	14.27

Industry producing	19 Other Transportation Equipment	20 Professional and Scientific Equipment	21 Miscellaneous Manufacturing Industries	22 Coal, Gas and Electric Power	23 Railroad Transportation	24 Ocean Transportation	25 Other Transportation	26 Trade	27 Communications	28 Finance and Insurance	29 Real Estate and Rentals	30 Business Services	31 Personal and Repair Services	32 Non-Profit Organizations	33 Amusements	34 Scrap and Miscellaneous Industries	35 Eating and Drinking Places	36 New Construction and Maintenance	37 Undistributed	38 Inventory Change (Additions)	39 Foreign Countries (Exports To)	40 Government	41 Private Capital Formation (Gross)	42 Households	Total Gross Output
1 Agriculture and Fisheries	—	*	*	—	*	*	0.01	—	*	—	—	—	—	0.12	—	—	0.97	0.09	0.17	1.81	1.28	0.57	0.02	5.92	44.25
2 Food and Kindred Products	—	0.01	9.82	*	0.02	0.01	0.63	0.07	0.01	—	—	—	*	0.25	*	0.32	3.47	*	0.42	2.90	1.08	0.73	—	23.02	40.30
3 Textile Mill Products	0.01	0.05	0.56	0.47	—	0.01	0.01	0.03	*	—	—	*	0.03	*	—	6.61	—	0.35	3.51	9.06	0.52	0.10	0.02	1.47	9.84
4 Apparel	0.91	*	*	*	*	*	*	0.02	*	—	—	—	0.02	0.02	*	0.01	0.72	*	2.15	0.21	0.38	0.26	*	9.90	13.32
5 Lumber and Wood Products	0.03	*	0.06	0.06	—	0.01	*	0.03	*	—	0.14	*	*	*	—	0.11	0.01	2.33	2.25	0.17	0.17	0.07	0.04	2.07	6.00
6 Furniture and Fixtures	0.02	*	—	*	—	—	*	—	*	0.04	0.06	—	—	*	—	—	—	0.22	[illegible]	1.73	0.03	0.05	0.57	1.46	2.89
7 Paper and Allied Products	0.02	6.08	9.87	*	*	—	*	0.57	*	*	—	*	0.56	0.03	—	0.63	0.05	0.17	[illegible]	1.34	2.15	2.86	—	2.34	7.90
8 Printing and Publishing	—	*	—	*	0.04	*	0.02	0.10	0.03	0.21	—	2.45	0.03	0.17	0.01	0.01	0.03	—	[illegible]	*	3.37	0.16	0.09	4.49	6.45
9 Chemicals	0.02	0.05	0.17	0.08	0.03	0.01	0.02	0.07	*	*	—	0.01	0.20	0.22	*	0.43	0.04	0.54	[illegible]	0.38	0.07	0.19	—	1.96	14.05
10 Products of Petroleum and Coal	0.01	*	0.01	6.47	0.27	0.79	3.45	0.20	*	0.01	0.76	*	0.06	0.06	*	0.01	0.21	0.62	2.36	0.06	0.68	0.18	*	2.44	13.67
11 Rubber Products	0.01	*	0.04	*	*	—	0.13	0.05	*	0.01	*	—	0.07	*	—	*	*	0.55	0.47	0.08	0.17	0.02	0.01	0.71	2.82
12 Leather and Leather Products	*	0.01	0.01	*	—	—	*	*	—	—	—	—	0.03	3.01	—	0.01	—	*	0.79	0.11	0.08	0.05	0.02	2.05	3.81
13 Stone, Clay and Glass Products	0.01	0.93	0.06	0.02	0.01	*	*	0.34	*	—	—	—	0.02	0.01	—	*	0.06	1.74	0.36	0.19	0.21	0.02	0.01	0.34	4.84
14 Primary Metals	0.43	0.07	0.20	0.05	0.20	—	0.01	—	*	—	—	—	—	*	—	0.15	*	1.19	1.24	1.45	0.77	0.02	—	0.02	18.53
15 Fabricated Metal Products	0.10	0.07	5.84	*	0.03	*	0.01	0.06	*	—	—	*	0.03	0.01	—	0.66	0.32	3.55	1.44	2.21	0.35	0.05	0.20	0.95	10.48
16 Machinery (Except Electric)	0.22	0.03	*	0.03	0.66	—	0.01	0.01	—	0.02	—	—	0.15	*	—	0.07	—	0.37	2.24	3.71	1.76	2.18	5.82	1.22	15.22
17 Electrical Machinery	0.12	0.03	0.02	0.02	0.34	—	0.01	0.01	0.05	—	—	0.01	0.59	*	—	0.04	—	0.77	1.27	0.25	0.44	0.17	1.75	0.93	8.33
18 Motor Vehicles	*	—	—	0.01	*	—	0.13	0.02	*	—	*	—	1.05	*	—	0.07	*	0.94	[illegible]	2.46	1.22	0.15	2.98	3.13	14.27
19 Other Transportation Equipment	0.30	—	—	*	0.04	0.06	0.13	—	—	—	—	—	*	—	—	3.01	—	*	2.46	0.22	0.32	1.25	1.29	0.17	4.00
20 Professional and Scientific Equipment	0.02	0.18	0.02	*	—	—	*	—	*	—	—	0.01	0.03	0.18	—	0.01	—	0.02	0.24	0.22	0.10	0.08	0.76	0.62	2.12
21 Miscellaneous Manufacturing Industries	*	0.03	0.16	*	*	*	*	0.01	*	—	—	0.15	0.16	0.05	0.05	0.11	0.27	0.32	[illegible]	0.54	[illegible]	0.48	0.51	1.89	4.76
22 Coal, Gas and Electric Power	0.03	0.01	0.03	1.27	0.44	*	0.09	0.49	0.01	0.06	3.15	*	0.31	0.16	0.05	—	0.22	2.22	[illegible]	0.02	0.35	3.20	—	—	9.71
23 Railroad Transportation	0.04	0.01	0.03	0.15	0.41	*	0.06	0.08	*	0.01	0.42	0.03	0.03	0.05	*	0.03	0.25	[illegible]	[illegible]	1.28	0.59	0.37	0.27	2.53	9.95
24 Ocean Transportation	*	*	0.01	*	—	0.22	—	—	—	—	—	—	—	—	—	*	—	—	*	—	1.35	0.31	—	0.15	2.29
25 Other Transportation	0.01	0.01	0.01	0.03	0.19	0.04	0.25	0.31	*	*	0.13	0.03	0.01	0.02	*	0.02	0.18	0.27	[illegible]	0.54	0.72	1.25	2.10	4.77	9.96
26 Trade	0.37	0.04	0.05	0.05	0.03	0.01	0.42	0.20	0.01	0.04	0.75	0.14	0.37	0.29	0.01	0.09	1.06	2.52	[illegible]	0.25	1.96	[illegible]	2.34	26.92	41.98
27 Communications	0.01	0.01	0.01	0.02	0.02	*	0.04	0.33	0.06	0.09	0.06	0.43	0.12	0.07	0.01	—	0.07	0.94	[illegible]	—	0.64	2.15	—	1.27	3.17
28 Finance and Insurance	0.02	0.01	0.02	0.35	0.07	0.12	0.30	1.60	*	1.85	0.56	0.02	0.12	0.09	0.03	—	[illegible]	0.43	—	—	2.14	5.03	—	6.99	12.81
29 Real Estate and Rentals	0.02	0.01	0.03	0.05	0.02	0.01	0.15	1.96	0.05	0.21	0.21	0.05	0.71	0.40	0.18	—	0.39	4.29	—	—	—	2.22	0.08	[illegible]	28.86
30 Business Services	0.01	0.35	0.06	0.01	0.02	*	0.02	1.71	0.09	0.14	0.04	0.06	0.12	0.02	0.10	—	0.06	[illegible]	[illegible]	—	*	0.94	—	2.18	5.16
31 Personal and Repair Services	*	*	*	0.02	0.11	0.01	0.26	1.42	0.02	0.11	0.02	0.07	0.56	0.08	0.02	0.33	0.23	0.72	1.17	—	—	[illegible]	0.27	8.35	14.28
32 Non Profit Organizations	—	—	—	—	—	*	*	—	—	0.02	—	—	—	0.08	—	—	—	—	2.19	—	—	5.68	—	8.04	13.30
33 Amusements	—	—	—	—	—	—	—	—	—	—	—	—	—	0.01	0.39	—	—	—	[illegible]	—	0.12	—	—	2.40	2.94
34 Scrap and Miscellaneous Industries	—	*	—	—	—	—	0.04	0.39	0.01	0.11	0.03	0.02	*	*	0.01	—	—	*	[illegible]	—	0.30	*	—	—	2.13
35 Eating and Drinking Places	—	—	—	—	—	—	0.01	—	—	—	—	—	—	0.15	—	—	—	—	—	—	—	—	—	13.11	13.27
36 New Construction and Maintenance	0.02	0.01	0.02	0.27	1.12	*	0.13	0.10	0.16	0.02	4.06	*	0.06	0.34	0.02	—	0.07	3.01	—	—	—	5.25	15.79	0.15	28.48
37 Undistributed	0.34	0.19	3.07	0.25	0.10	0.04	0.03	2.59	0.01	0.71	0.36	0.31	1.13	9.91	0.22	—	0.56	0.43	—	—	—	—	—	—	21.98
38 Inventory Change (Depletions)	0.01	0.05	0.15	*	—	—	—	—	—	—	—	—	—	—	—	0.46	—	—	—	—	0.22	—	—	—	4.43
39 Foreign Countries (Imports From)	0.01	0.05	0.14	0.01	0.04	0.50	0.08	—	0.03	0.10	—	—	—	—	*	0.07	—	—	[illegible]	—	—	1.31	—	1.32	9.52
40 Government	0.12	0.13	0.19	1.14	0.01	0.26	0.77	3.30	0.44	1.11	4.00	0.21	0.50	0.17	9.32	6.07	1.41	0.47	2.19	0.54	2.93	3.46	0.22	31.55	63.63
41 Private Capital Formation (Gross)																									
42 Households	1.95	0.90	2.17	5.11	5.70	0.93	6.20	26.42	2.15	7.83	14.06	1.90	8.20	9.41	1.50	—	4.28	10.73	2.27	—	0.65	30.86	—	2.12	223.58
TOTAL GROSS OUTLAYS	4.00	2.12	4.76	9.21	9.95	2.29	9.86	41.66	3.17	12.81	28.86	5.10	14.30	13.39	2.94	2.13	13.27	28.48	[illegible]	5.23	17.21	51.29	32.29	194.12	

INTERINDUSTRY TABLE summarizes the transactions of the U. S. economy in 1947, for which preliminary data have just been compiled by the Bureau of Labor Statistics. Each number in the body of the table represents billions of 1947 dollars. In the vertical column at left the entire economy is broken down into sectors; in the horizontal row at the top the same breakdown is repeated. When a sector is read horizontally, the numbers indicate what it ships to other sectors. When a sector is read vertically, the numbers show what it consumes from other sectors. The asterisks stand for sums less than $5 million. Totals may not check due to rounding.

Figure 1-1. The Leontief Input-Output Matrix Demonstrating the Basis of the Input-Output Model (Leontief, W. W., 1951).

ALLOCATION ALTERNATIVES FOR WATER RESOURCE SYSTEM

Origins (1)	Destinations: Municipal (2)	Industrial (3)	Agricultural (4)	Recreation wildlife hydropower (5)	System outflow (6)	Category availabilities (7)
Primary supply						
Surface water	—[a]	—[a]	—[a]	—[a]	—[a]	annual outflow
Ground-water	—	—[a]	—[a]	—[a]	—[a]	annual recharge
Secondary supply						
Municipal effluent	recycle reuse	sequential reuse	sequential reuse	sequential reuse	sequential reuse	municipal waste system outflow
Industrial waste	sequential reuse	recycle reuse	sequential reuse	sequential reuse	sequential reuse	industrial wastewaters
Agricultural return flow	sequential reuse	sequential reuse	recycle reuse	sequential reuse	sequential reuse	irrigation return flows
Supplementary supply						
Imported water	—[b]	—[b]	—[b]	—[b]	—[b]	annual importation
Desalination of sea water	—[b]	—[b]	—[b]	—[b]	—[b]	annual desalination
Use sector require-ments	municipal diversion requirement	industrial diversion requirement	agricultural diversion requirement	miscellaneous diversion requirement	downstream outflow	Totals

[a] Initial allocation of primary supply.
[b] Allocation of supplementary supply.

Figure 1-2. Bishop and Hendrick's Water Reuse Matrix Presented as a Transportation Algorithm (Bishop and Hendricks, 1971).

combinations of supply-demand. The concept of "representing a system" is illustrated in Figure 1-3, which shows one of the matrices developed.

The study developed basin wide input-output models for the 1970 water year, and for the years 1980, 2000, and 2020. The input-output models for the future years assume a mix of conditions based upon selected combinations of supply and demand (e.g., average water year runoff or drought, high per capita use or low, high or low population series, etc.). The selections were made from an almost infinite number of combinations and were designed to impose possible future stress conditions on the system. The input-output model was then intended to determine what measures (e.g., projects, efficiency of use, etc.) would allow the system to respond adequately to meet demands for water. The important question was: does the system have the *capacity* to respond to such stress conditions without unacceptable social dis-benefits? This, of course, was a value-laden political question. Therefore, the study developed factual data on both the availability of future water supplies and projections of future demands from the basin-wide point of view.

The essential information relative to water supply and water demands (1970-2020) in the South Platte Basin was presented in a general report; detailed documentation and rather complete data were given in six technical appendices. Although these latter volumes were written to provide necessary data for the input-output water balance model, they also stand alone as individual reference documents on their respective topics.

One of these volumes, by Goldbach (1977), described the input-output water balance model in some detail. A computer program was also developed by Goldbach. Goldbach's program accomplishes the input-output display only; it does not consider the functional relationships of the system.

The above mentioned study is referred to in this report simply as "South Platte Study." Its major point of interest consists of the application of the input-output theory to a real management problem of a government water agency.

1.1.2 Investigations related to the Cache La Poudre River basin. The present study adapts input-output principles to modeling the Cache La Poudre River basin water system. The Cache La Poudre basin has been the object of many studies and surveys since the early development and settlement in the area. The area is presently undergoing a new stage of development, consisting of rapid growth of new industry and extensive urbanization. Because of this growth there is presently strong interest in more deliberate management of the local resource base. This is confirmed in a wide range of current investigations and projects. However, a strong federal push was provided by the "208" planning provision of the Public Law 92-500, the Water Pollution Control Act Amendments of 1972. The 208 Plan for the Larimer-Weld region is being developed by the "Larimer and Weld Regional Council of Governments" (LWRCOG).

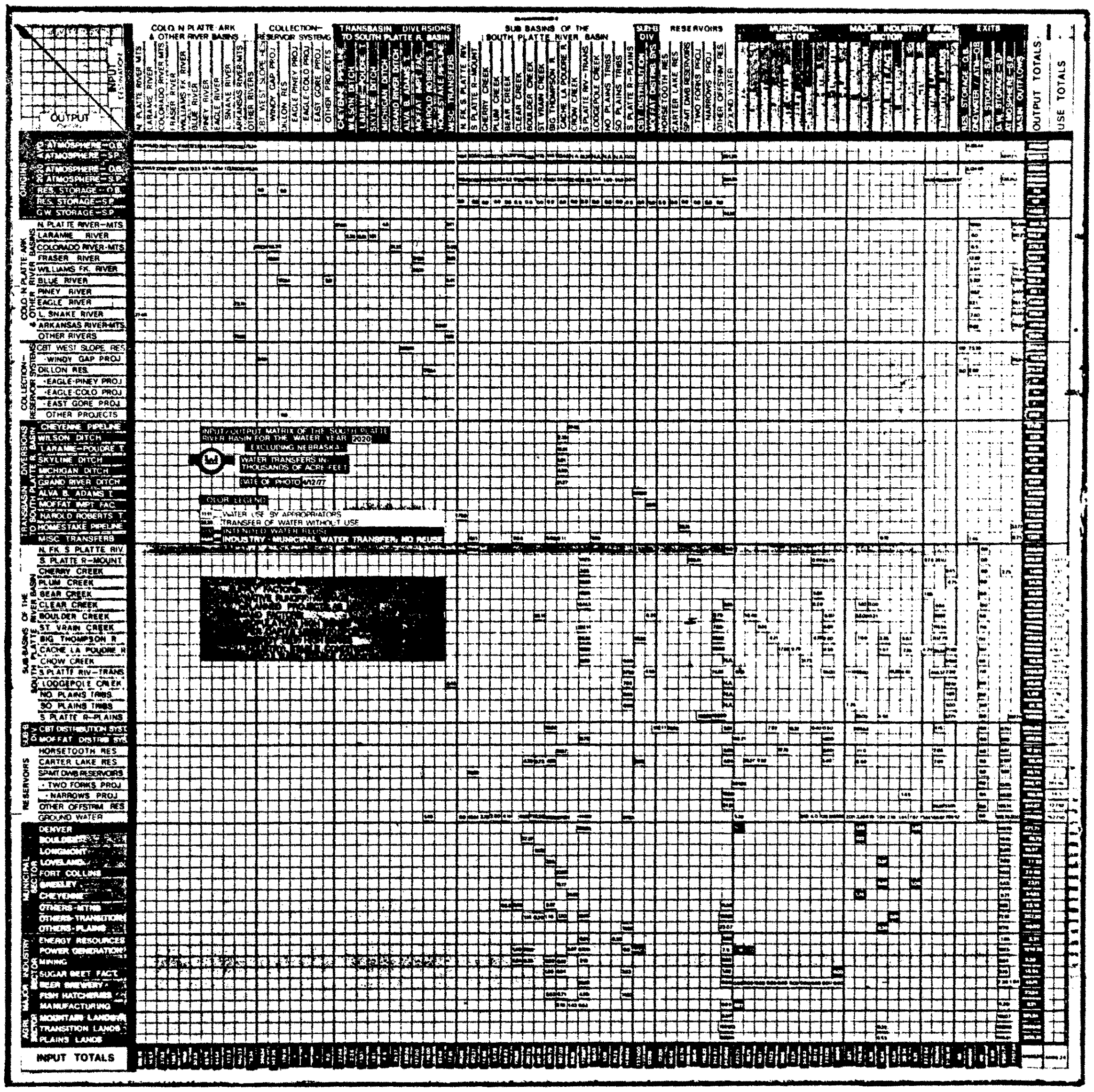


Figure 1-3. Input-Output Model for South Platte Basin Water Resources System. Magnetic Board Matrix Display (Hendricks, et al., 1977).

The early water related interest in the Cache La Poudre area is confirmed by E. S. Nettleton in his 1901 paper, "The Reservoir System of The Cache La Poudre Valley," published by the U.S. Department of Agriculture, and by the 1927 Thompson thesis, "A History of the Development of Irrigation in the Cache La Poudre Valley" (Colorado State Teachers College). Other surveys should be mentioned: "Groundwater Investigations in the Lower Cache La Poudre River Basin, Colorado" prepared by Hershey and Schneider as part of the program of the U.S. Department of the Interior for the development of the Missouri River basin (U.S. Geological Survey Water-Supply Paper 1669-X, 1964) and "Agricultural Land Use in the Poudre Valley," prepared by the Agricultural Engineering Department of Colorado State University for the Office of Water Resource Research of the U.S. Department of the Interior in 1973.

Investigations about planning for future development in the area, include: "Consolidation and Rehabilitation of Canals in Poudre Valley" by the Department of Agricultural Engineering of Colorado State University (Lurvey, 1973) and "Consolidation of Irrigation Systems," by the Environmental Resources Center of Colorado State University (Skogerboe, Radosevich and Vlachos, 1973). These two reports deal with the feasibility of consolidating the agriculture water distribution system of the Cache La Poudre area from both the physical and managerial points of view.

The activity of government agencies is indicated, for example, by two reports prepared by the U.S. Bureau of Reclamation (Region 7, Denver, Colorado). The first of the two is the "Concluding Report" about Cache La Poudre Unit, Colorado, investigating the proposed Idylwilde Dam project and the municipal and industrial water alternatives for the area (1966). The second one is the "Environmental Statement" about the proposed Long Draw Reservoir enlargement project (1972).

An environmental survey was provided in 1974 by the Department of Natural Resources, Colorado Division of Wildlife: "Environment of the Middle Segment, Cache La Poudre River, Colorado." This survey included geology, streamflow, water chemistry, aquatic biology, access and channel and banks as matters of concern.

Other studies include: the "Preliminary Report on Sanitary Sewerage System Improvements for Boxelder Sanitation District" prepared by M & I Inc. in 1973, and "Larimer County Comprehensive Sewer Study," prepared by M & I Inc. in 1971. Also, a thesis "A Preliminary Comparison of the Economics of Two Water Supply Alternatives for the City of Fort Collins" was submitted by Lau (1975) to Colorado State University.

A comprehensive study about the whole agricultural water system in the Cache La Poudre basin was prepared by Evans in 1971 ("Hydrologic Budget of the Poudre Valley") and submitted as a thesis to Colorado State University. A general hydrologic computer model was developed as part of the thesis.

While the above review is by no means complete, it illustrates the wide variety of water planning interests which are involved. Most of these reports provided information for the present study. More extensive literature reviews are found in the seven volume study by Hendricks et al. (1977), Janonis (1977), Janonis and Gerlek (1977), Gerlek (1977), Goldbach (1977) and in Hendricks and De Haan (1975).

1.2 Study Objectives

The South Platte water supply study of Hendricks et al. (1977), described previously, represents a development of input-output water balance modeling at large regional levels. The model was used to determine the various water supply planning alternatives, 1970-2020, for the South Platte River basin.

The type of insight obtained in a planning study is related to the scale of the planning. In the case of the South Platte, the emphasis was in insuring the basin wide water balance between resources and uses, while respecting certain constraining relationships defined under various scenarios about the future. A model of such a large scale has sufficient resolution for strategic investigations at the reconnaisance level only, while project oriented planning requires greater detail, providing, in turn, a tactical capability.

The regional planning in a large area such as the South Platte River basin is a fairly representative example of resource allocation planning and a study such as the one conducted by Hendricks et al (1977) is representative of a suitable approach. However, when dealing with local regional planning a basin wide model consisting of aggregated categories of water supply sources and uses is not adequate and a model having greater resolution detail (i.e., including conveyance, impoundment and treatment structures) is needed.

As with the larger South Platte River basin-wide model, demonstration is the best way to ascertain the applicability of the input-output model. The demonstration approach is felt to be more appropriate than to provide a general methodology algorithm. Therefore, the Cache La Poudre case study example of application is given. At this stage no theoretical generalization was pursued and the only preoccupation was just to deal with the real conditions and the real data of a case study.

1.3 Content of Report

This report comprises six chapters and nine appendices.

Chapter I describes the context and the objectives of the study. Previous works about input-output modeling were described in Section 1.1. Also prior studies about the water resources of the Cache La Poudre River basin were reviewed.

Chapter II is a review of the concepts of input-output modeling. These concepts were derived and interpreted by the writer from the available literature as mentioned in Section 1.1.

Chapter III is a presentation of the case study being used as a demonstrative example. The purpose of Chapter III is to develop information about the structure of the water system in its physical, human, legal and administrative dimensions. Such information provides a basis for determining the key elements of the system which are to be depicted in the input-output model.

Chapter IV is a presentation of the procedure which was used in developing the study. As it was anticipated in the "Objectives" (Section 1.2), no generalization of the approach methodology was pursued. However, a description of the empirical procedure which was used is attempted with the purpose of making more evident the type of problems which arose during the modeling process and the extent of the assumptions and decisions which were needed for providing the basic background of the numerical evaluations of the water exchanges. The selection of the representative key elements of the case study water system is herein described too.

Chapter V describes the water exchanges which occur among the selected representative key elements of the water system. The attainment of all the numerical evaluations of the water exchanges is herein described and the specific hypotheses used throughout the modeling process are presented too. This chapter is supported by the nine appendices of the report where the water mass-balances of all the selected representative key elements are individually depicted.

Chapter VI summarizes and interprets the main results of the study. These results fit into three categories:

- results related to the crude representation of the case study water system;
- results regarding the applicability of the input-output modeling for the representation of a local regional water system. (The advantages of the method are summarized and comments about its limitations are given).
- results regarding the suitability of the input-output modeling for planning study uses. The demonstration is given through case study related examples.

Points deserving further research were individuated throughout the study. These points relate to both the case study representation and the used methodology.

The appendices depict the water mass-balance of all the selected key elements of the case study water system. The figures included in the appendices are actually a form of input-output model representation of the system. Appendix A depicts the water entries into the system boundary. Appendices B to H depict the mass balances of the internal elements of the system of either one of the three types: transport, treatment, use. Appendix I depicts the water exits to the exit components of the system. The nine appendices contain much of the support data and documentation used in the study.

II INPUT-OUTPUT MODELING

This chapter outlines the concepts of input-output water balance modeling. The chapter content has been derived in part from a few key reports reviewed in Section 1.1, particularly Hendricks et al. (1977) and Goldbach (1977).

2.1 Description of the Input-Output Model

The basic idea of input-output water balance modeling is in the mass balance of each of the individual components of the modeled system. These system components may function as both origins and destinations of water flows. The water system is viewed then as an ensemble of components, which exchange water flows. These exchanges are subject to the constraints of the natural hydrology, of the physical facilities and of the water rights associated with each use.

The general structure of the input-output model can be described in terms of three categories of system components; these are: entry components, internal system components and exit components. The internal system components (transport, treatment, storage and use components) behave and are considered as both "origins" and "destinations" of water flows. Contrariwise, the entry components are viewed as "origins" only while the exit components are viewed as "destinations" only. The water flows enter the system through the entry components, circulate within the system through the internal system components and leave the system through the exit components.

The structural and functional characteristics of the system are represented in matrix form. The rows of the matrix consist of the "origin" components only (i.e., entry components and internal components). The columns of the matrix consist of "destination" components only (i.e. internal components and exit components). The presence of a datum at the crossing point between any row and column (i.e. a matrix "element") will indicate an interaction related to flow from the row-correspondent system component to the column-correspondent system component. The datum represents a characteristic of the interaction (e.g., actual flow, maximum possible flow, minimum critical flow, a quality index, a cost associated with the interaction etc.). The water flow can imply either simple conveyance or "use." Color coding can identify the nature of the transfer. The information will refer to a particular selected time interval. Additional matrices can be constructed to depict as many characteristics about the water transfers as desired.

The bottom row of the matrix consists of input totals (for each respective system component which serves as a destination), while the far right column consists of output totals (for each respective system component which serves as an origin). Further columns of totals of various sorts can be used, relating to specific interesting subsets of the water exchanges. The input totals in the matrix will coincide with the output totals for all the internal elements. This provides assurance of water balance for the system.

From the matrix display, one can grasp either the overall picture of the whole water system or the minute quantitative detail of the water exchanges among the individual system components. The format makes readily accessible a vast amount of data concerning any single item or group of items (e.g., water use by a single city, water use by a group of cities), or a whole system. The graphic display of a complex set of interactions easily conveys the concept of a system, and, in addition, it depicts the role of the individual system components relative to the whole system.

The selection of the key system components to be included in the model is probably the most perplexing task. They must be derived from a compromise between resolution and aggregation in order to keep the model meaningful and yet tractable in size. For example, how many tributaries should be displayed? How many stream reaches? Should irrigated land be disaggregated by sub-basins? Which cities should be included? Or should they all be lumped into a "municipal sector?" The answer to this question is a matter of individual judgment, keeping in mind the purpose which the input-output model is intended to serve.

The construction of an input-output model can be understood more easily by looking at a simple system depiction having only a few interactions. A simple illustrative example, adjusted from Hendricks et al. (1977), is reviewed here. Figure 2-1 is a block diagram of selected system components and their relevant interactions for the South Platte basin as it may have been at an early level of development (i.e. about 1890). The input-output matrix that corresponds to Figure 2-1 is shown in Figure 2-2. As seen in Figure 2-2, each of the system components acts as either origin of water (i.e. water is an "output" from the component), or as a destination of water (ile. water is an "input" to that component), or both. The internal system components have both outputs and inputs. In Figure 2-2, all the system components having "outputs" are shown as columns. The internal system components are in both rows and columns. Also, just as the block diagram of Figure 2-1 must have a numerical balance between outputs and inputs, so must the input-output matrix. For example, all inputs to the irrigation component in Figure 2-1 must be balanced by output from irrigation, i.e., both must add up to 1,868,000 acre-feet. These are sums along the column or the row in Figure 2-2. Also, the overall system, the entries (precipitation plus imports) are balanced by the system outflow plus evaporation and storage (17,177,000 acre-feet in total).

A comprehensive input-output model of water transfers for the whole water resource and use system in the South Platte River basin was shown previously in Figure 1-3. It was constructed by the principles outlined in the foregoing.

2.2 Using the Input-Output Model in Water Resources Planning and Administration

There is a wide variety of ways in which a water resources input-output model can be useful to a planner or administrator. These have been reviewed extensively by Goldbach (1977) and are reiterated here briefly. The applications discussed here are not fully developed. Rather they are intended to suggest ways in which a water resource input-output model can be used and to stimulate the imaginative process. Moreover, this is not a comprehensive discussion of all uses for

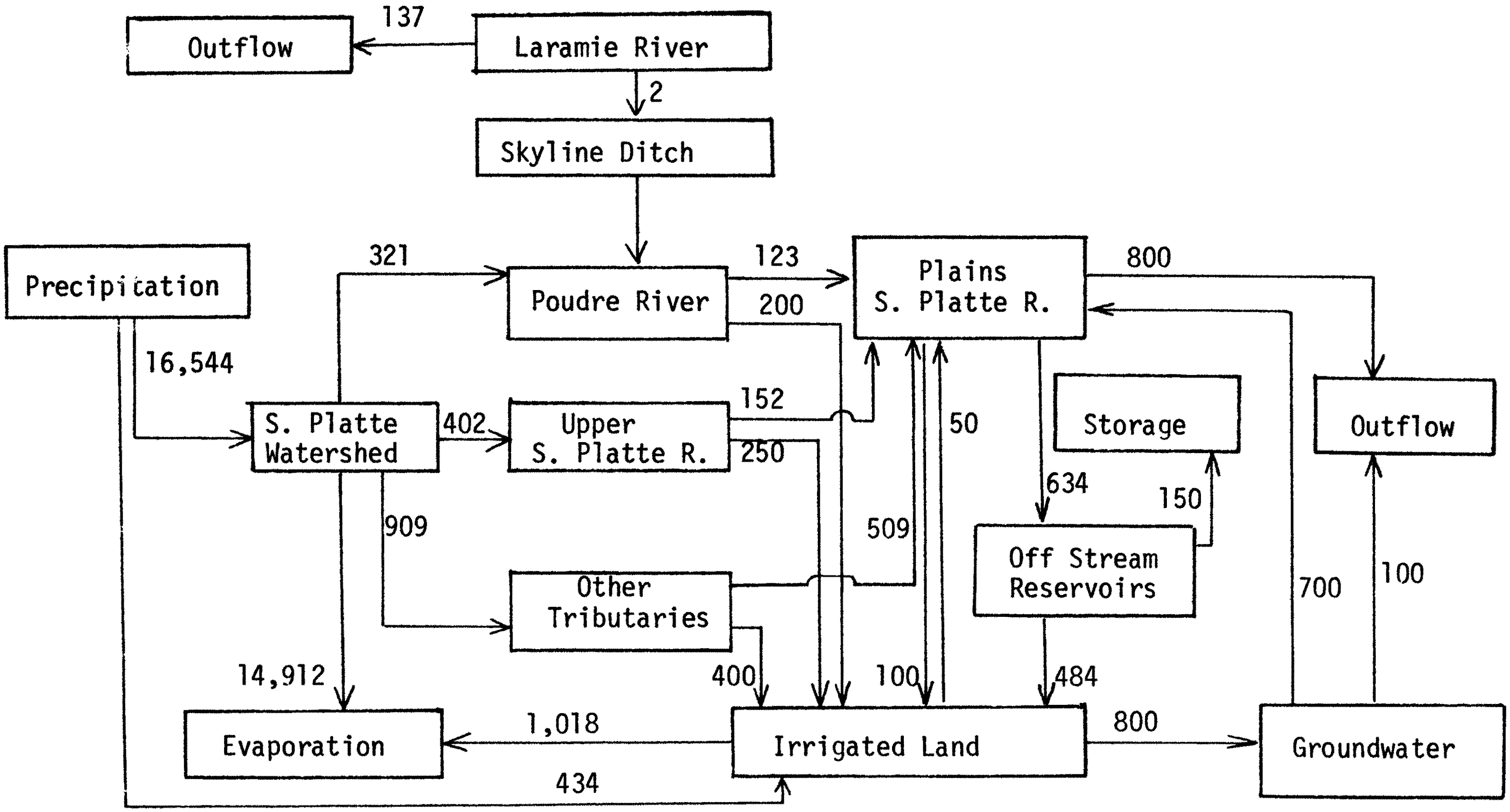


Figure 2-1. Block Diagram of Major Elements of Early South Platte Water Resources System Showing Roughly Estimated Annual Water Transfers in Thousands of Acre-Feet (Adjusted from Hendricks, et al., 1977).

	ORIGINS \ DESTINATIONS	INTERNAL COMPONENTS								EXITS			
		SKYLINE DITCH	POUDRE R.	UPPER S.PLATTE	OTHER TRIBS.	PLAINS S.PLAT.	IRRIGATED LAND	OFFSTREM RES.	G.W. RESERVOIR	EVAPORATION	OUTFLOW	STORAGE	TOTAL SUPPLIES
ENTR.	PRECIPITATION		321	402	909	0	434		0	14,912			16,978
	LARAMIE RIVER	2									137		139
INTERNAL COMPONENTS	SKYLINE DITCH		2										2
	POUDRE RIVER					123	200						323
	UPPER S. PLATTE					152	250						402
	OTHER TRIBUT.					509	400						909
	PLAINS S. PLATTE						100	634			800		1,534
	IRRIGATED LAND					50			800	1,018			1,868
	OFFSTREAM RES.						484					150	634
	G.W. RESERVOIR					700					100		800
TOTAL DELIVERED		2	323	402	909	1534	1868	634	800	15,930	1037	150	23,589

Figure 2-2. Input-Output Model of the South Platte Water Resources System as Illustrated in Figure 2-1. The Amounts are in Thousands of Acre-Feet (Adjusted from Hendricks, et al., 1977).

an input-output model. As familiarity with the model increases, new ideas on how to apply the model to the varied aspects of the planning and administrative processes will be germinated by the user.

An input-output model can be utilized to address questions having about three levels of sophistication: reconnaissance, internal functioning, and predictive. The reconnaissance level provides an understanding of where water is obtained, how it is conveyed, and what demands it must satisfy. The internal functioning level is a somewhat more involved level of understanding and is the comprehension of the function that each transfer has with respect to its positioning in the matrix and its relative importance with respect to all other transfers in the system. The highest degree of sophistication is reached at the predictive level with the ability to make projections of the behavior of the system under varied circumstances. A brief orientation is all that is necessary to use the model at the first level. Additional study and experience with the system are needed for the remaining two levels.

An input-output model is a *tool* which can be used by the engineer to assess the ability of a system to meet new water demand situations or disposal requirements. Since the model organizes a large amount of information about the system structure and displays it as well, it can provide utility in decision making by administrators and politicians too.

One of the biggest problems in evaluating a large and complex water resources system is to be sure that all aspects of it have been considered. Another is keeping an orderly record of the computations resulting from such an appraisal. The model provides the format to handle both problems.

Consider, for example, the process of determining a system's response to a drought situation. The seriousness of the drought will be reflected by the diminished surface flows and the length of the drought will be reflected by how much water can be brought "onto" the matrix through reservoir storage. Among the questions which the model can answer are: how much water will be available to industries and municipalities? Will agriculture water uses have to be reduced? Tentative answers to these questions and a description of the conditions to be modeled are formulated in what is called a *scenario*. According to the assumptions of the scenario all water transfers on a matrix are computed. The entire matrix might be brought into mass balance by the groundwater sector (for example). The resulting amount of water transferred to or from groundwater storage is compared with the policies set down in the scenario. If the withdrawal from storage is too large, then the demand for water must be reduced still further. But if there is a transfer to groundwater storage, then demands have been reduced more than was necessary. In either case, the system's behavior has been indicated. If a specific policy towards groundwater is to be imposed, a new scenario regarding water demand must be determined, the matrix reconstructed according to the new scenario, and the results reevaluated. Through this iterative process, the planner can examine a system in light of its physical, as well as institutional structure. In the meanwhile, the administrator will be assured that all components of the system are evaluated under the same conditions.

Changes in water demand by a single sector can also be studied with respect to the effect that they will have upon the entire system. Various supply alternatives can be traced by evaluating the current supply sources in terms of what additional water they are capable of supplying to a sector. Each preceding supply sector is in turn evaluated for the best method of routing water to meet an increased demand. Conversely, if a sector changes its point of discharge, those sectors previously depending upon that water would no longer be in a mass balanced condition. The points needing further attention are revealed by this fact. Thus, an input-output model can cause attention to be focused upon sectors affected in their water balances by policy changes.

The cost for each transfer may be displayed too by setting up a unit cost matrix, where unit costs of each contemplated transfer are shown in each of the matrix elements. With quantity and cost data together, the planner or administrator is able to use the input-output model as a method for determining the most economical way to deliver the required water. This was done by Bishop and Hendricks (1971) in a linear programming model.

Two properties of an input-output matrix make it suitable for storing information. First, the format is ordered and second, each bit of information contained in the model is uniquely identified. The kind of transfer which can be shown by an input-output matrix is not limited to quantities of water or unit costs. For example, the pounds of solids accruing to a river system are as easily modeled in the same manner as the transfers of water.

A further development of the input-output model could be for information storage. A classifying scheme could be established which is similar to the Dewey decimal classification for books. Such a scheme might designate original water sources as one hundreds, transbasin transfers as two hundreds, and so on. Then, the atmosphere as a source might have the specific category number of 110 and as a destination might have the category number of 990. To specify a transfer, the row category number, column category number and matrix number would be given. The matrix number tells which matrix displays the desired information. With this method of identification, several agencies could request water resource data from a central "data bank" in a simple and consistent fashion. Since the information required can be described numerically, a digital computer can be implemented easily as the storage and retrieval mechanism.

Communication is one of the biggest problems involved in the planning and administration processes. Often, complex and technical concepts must be conveyed to nontechnical people. The input-output model is an easy-to-understand method of communication. The model shows where water comes from, where it goes, and what is dependent upon each transfer in the modeled system. In one sense, the input-output model is a step backwards in that it moves away from the sophistication of computerization. On the other hand, large amounts of complex information are available through the model.

Another feature of the input-output model is that it provides an interesting display to look at. Much like reading a map, the more a person studies the model, the more information he gains from it. Because of its "mystique," the model is much more apt to hold someone's interest than is a set of tabular computations or complicated diagrams.

For oral presentation, the input-output model can serve as a visual aid too. The speaker is provided with a support to graphically illustrate the points he wishes to introduce. Also, for question and answer sessions, the model is usually able to provide a quantitative answer to questions about the system modeled.

2.3 Media for Display

An input-output representation of a water system is particularly effective when displayed using the matrix format. An input-output matrix can be constructed graphically on paper by typing, lettering, etc.

The display media used in the Environmental Engineering Program at Colorado State University for the South Platte study, reported by Hendricks et al. (1977), was a metal magnetic board measuring eight feet by eight feet, attached to a wall. The board supported magnetic strips indicating the denominations of sectors, and the elements containing the numerical data. The writing on the strips was done by use of transfer lettering. This method works quite well in that it facilitates the trial and error process of determining the appropriate sectors and sector components and their arrangement for the depicted water resources system. Once the system and the water exchanges were defined, a photograph of the board was taken for permanent record. The system component labels were on one-inch colored strip in order to make the board details easily readable in the pictures. One-inch squares were used for the numerical data. These strips and squares are magnetized rubber which attaches easily to the metal board. Color coding of element labels and water transfers were used to more easily identify the various types of information displayed. For example, all water transfers related to simple transportation were color coded yellow; if a water right (or by corollary, a use) was associated with the transfer, the color was white. The grouping of data was facilitated further by the bold lines separating the major sector interactions. The photograph in Figure 1-3 shows the magnetic board as constructed for the South Platte study (Hendricks et al., 1977).

Another format which can facilitate the construction of an input-output model display is derived from a computer output of the matrix. A computer program could be useful in several situations. First, in the early stages of model construction, when decisions on which system elements should be included and their position in the matrix are all in a state of flux, changes can be accomplished merely by punching new cards or rearranging their order. Second, the input-output display from the computer output may provide a useful format for making changes by hand to the numerical data within the matrix. Third, the computer gives the capacity to perform various types of arithmetic on the vast amount of numerical data contained within the matrix. Finally, the matrix display constructed by the computer is self-sufficient as an input-output model display by itself. A computer program serving this purpose has been developed by Goldbach (1977). That program had been used extensively in the South Platte study reported by Hendricks et al. (1977).

A more exotic display mechanism would have each number electronically displayed. Using a computer to control their value, the input-output model could serve as a "real time" indicator of how the modeled system is functioning.

III CASE STUDY: THE CACHE LA POUDRE WATER SYSTEM

As noted previously, the input-output model organizes a large amount of empirical data. The manner in which the concept is applied can be shown best by *demonstration*, using a case study. The Cache La Poudre Basin water system was selected as the case study.

This chapter reviews the characteristics of the Cache La Poudre River basin which are important in development of the case study. The structure of the water system in its physical, human, legal and administrative dimensions is outlined. This will provide a better understanding of the roles of the individual system components with respect to the functioning of the overall system. From this the abstraction of the input-output model is associated with the viability of a functioning system. In addition, the documentation of data used in the model is given a framework. The effects of changes from the 1970 situation can be assessed also, with the basic system description developed in the following sections.

3.1 Physical Characteristics of the Cache La Poudre Basin

Extensive description of the physical characteristics of the Cache La Poudre River basin is contained in various bulletins and reports. Extensive use was made in the following sections of material derived from these studies, particularly those of Evans (1971), Gerlek (1977) and Skogerboe, Radosevich and Vlachos (1973).

3.1.1 Location and physiography. The Cache La Poudre River is a fourth order tributary of the Mississippi River, the drainage system of the lower middle portion of the North American Continent. The Mississippi River drains approximately 1,250,000 square miles of the midwestern one third of the United States and extreme southern Canada. One of its major tributaries is the Missouri River which drains about 530,000 square miles of all or part of nine states and a small part of Canada. One of the major tributaries of the Missouri River is the Platte River. The Cache La Poudre River is a tributary of the South Platte River, which is one of the major tributaries of the Platte River. The South Platte River originates along the eastern slope of the Continental Divide. To the north, south and east lie tributary drainage areas of the Mississippi River Basin, specifically the North Platte, Arkansas, and Republican River. The inset in Figure 3-1 shows the location of the South Platte River basin with respect to its neighboring river basins. The Cache La Poudre River Basin is seen in the larger map of Figure 3-1 as one of the major drainages of the South Platte.

The drainage area for the Cache La Poudre River, which lies in northcentral Colorado on the eastern side of the Rocky Mountains, is shown in Figure 3-2. The eastern side of the Laramie and Medicine Bow Ranges forms the western drainage boundary, and the Mummy Range forms the southern drainage boundary with the Big Thompson River. The northern boundary is in the high plateau region of southern Wyoming. The Cache La Poudre discharges into the South Platte River on the eastern boundary near the city of Greeley. The river drains 1,877

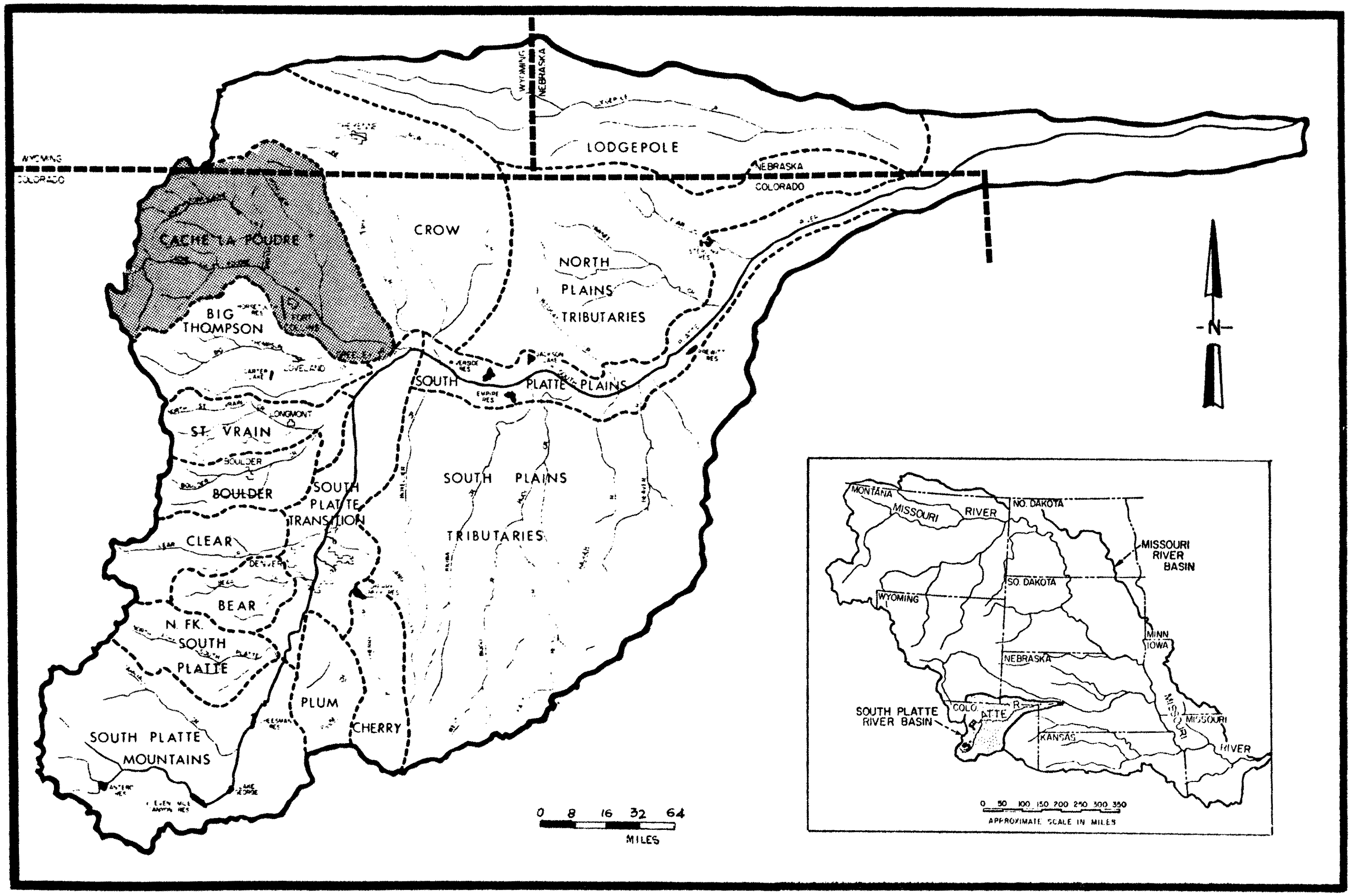


Figure 3-1. South Platte River Basin and Sub-basins (Adapted from Hendricks, et al., 1977).

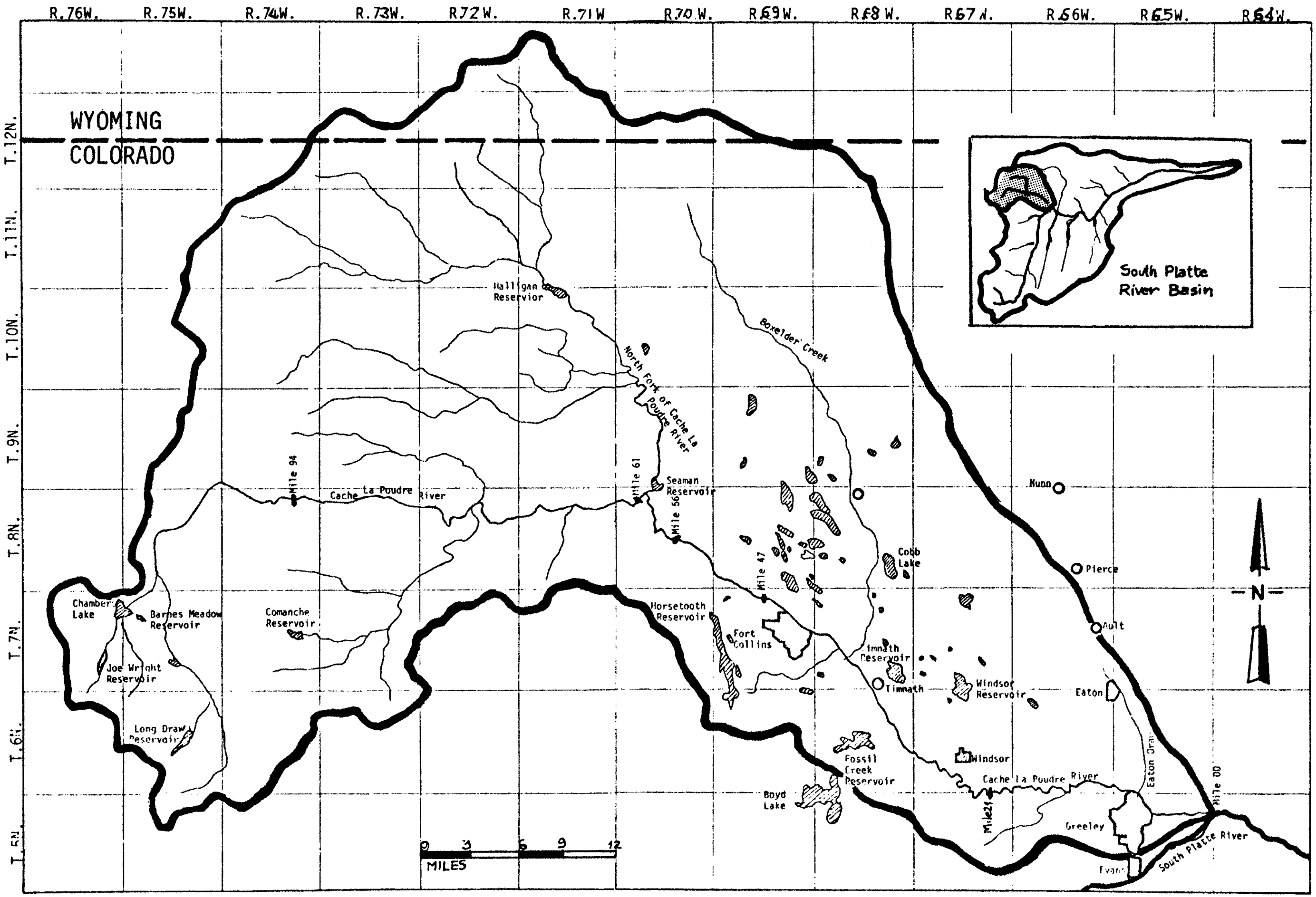


Figure 3-2. The Study Area: Cache La Poudre River Basin.

square miles. More than half of this area is mountainous, while the lower elevation portion is rolling plains. Most of the diversions, uses, and return flows are in the plains. A small portion of the sub-basin, about 150 square miles, is in Wyoming.

The Cache La Poudre River starts at Poudre Lake and several other places on the Continental Divide, which is about 12,000 feet elevation. But Chambers Lake is the beginning point of its identity as a river. From its headwaters, the Cache La Poudre River flows about 50 miles in a northeast direction to its canyon mouth. From this point it flows southeast over the open plains for about 35 miles until it meets the South Platte River just east of Greeley, at an elevation of 4,610 feet.

Most of the torturous mountain tributaries start among high mountain snowfields about 75 to 100 miles west of the plains. The principal mountain tributaries of the Cache La Poudre River are the North Fork, the South Fork, and Elkhorn Creek. Boxelder Creek, Fossil Creek and Eaton Draw originate in the foothills and join the Cache La Poudre in the plains below Fort Collins.

The topography of most of the lower area is rolling, a result of ancient winds. There are also numerous scattered lakes and reservoirs which are the result of wind action forming depressions in which the natural precipitation collected. Many of these lakes have been enlarged by constructing embankments to increase their storage capacity for irrigation purposes. These lakes and reservoirs are filled by canals which divert water from the river.

The agricultural portion of Poudre Valley lies mostly in the Colorado Piedmont section of the great plains province. The altitude above sea level for the agricultural area ranges from a minimum of 4,650 feet near Barnesville to about 5,800 feet near Livermore.

3.1.2 Climate. The climate of Cache La Poudre Basin, although varying with the location, is characterized by low annual precipiation, a high rate of evaporation, low humidity, an abundance of sunshine, frequent winds, and a wide range of temperatures. The summers are moderately hot and the nights are relatively cool. The winters are generally mild but have short periods of severe cold, and there are usually several heavy snowstorms. However, the snow does not accumulate in the valley.

Precipitation in the plains is generally sufficient to support a light cover of native grasses and shrubs, some winter grains, and a little hay. Most successful farming depends on irrigation for its water supply. Fall and winter precipitation is usually in the form of snow, while spring and summer precipitation usually occurs as thunderstorms. The mean annual precipitation is 14.19 inches at Fort Collins, 12.38 inches at Windsor, and 12.51 inches at Greeley. The maximum monthly precipitation usually occurs in May while the minimum usually occurs in January in the form of light snows.

The mountain agriculture, which is primarily hay and pasture, often has only a 90-day growing season. The average length of growing season in the irrigated area is from 175 to 185 days. Generally speaking, however, the growing season is sufficient to raise most temperate zone crops such as corn, sugar beets, potatoes, alfalfa, etc. The mean annual temperature at Fort Collins is 48.1°F, and 48.3°F at Greeley.

The major sources of atmospheric moisture for the Cache La Poudre River basin are from the Pacific Ocean and the Gulf of Mexico. Prevailing air currents which reach the basin from the west bring most of the atmospheric water that will end up as stream flows. However, because of the distance from the Pacific Ocean, the eastward moving storms lose much of their moisture in passage over mountain ranges to the west. Most of the precipitation in the basin occurs during the winter as snow in the mountains from these Pacific storms. Warm moist air from the Gulf of Mexico moves into the basin most frequently in the spring. It is carried northward and westward from the coast to higher elevations; the heaviest rainfall occurs on the plains during the April-July period. Figure 3-3 shows the distribution of mean monthly temperature and precipitation at Fort Collins and Greeley, respectively.

The mountain region has an alpine climate with heavy winter snows. Because of this the mountains are the most important water production area of the basin. Snow covered mountain parks and valleys often have very cold night temperatures in the winter. Summer temperatures in the mountains seldom exceed 90°F. At the summits of the Continental Divide, temperatures average less than 32°F over the entire year. Precipitation varies with the altitude and exposure and generally increases towards the higher elevations. The greatest precipitation — in excess of 50 inches annually — falls on the mountains of the Continental Divide that separate the watershed of the Cache La Poudre River and the Big Thompson River from the Colorado River Basin. The majority of this precipitation occurs in the winter as snow.

3.1.3 Hydrology. The Cache La Poudre River flows have been extensively altered from their natural hydrologic regime. Thus a man-controlled system stores water from season to season, imports foreign water, diverts it for use, and then returns a portion of it. In the Cache La Poudre Basin this man-controlled system completely dominates the natural hydrologic system creating a man-controlled and man-induced hydrology (e.g., man alters both the time distribution and the space occurrence of the flow).

To understand the present Cache La Poudre hydrology as altered by man, it is first useful to understand the natural hydrology. The natural system provides the basis for structuring and operating the man-altered system.

The native source of water of the river basin includes both surface water runoff and groundwater supplies. Native water supplies come from precipitation falling on the basin. The disposition of this precipitation is: as surface water runoff, seepage directly into the ground, and retention in the winter snowpack and glaciers. However, the largest part returns back to the atmosphere through evaporation from soil and water surfaces, through transpiration from plants, and through sublimation from the snow cover. The existence of the mountains causes an "island" of heavy winter precipitation. During the spring as air temperatures rise the spring runoff begins. This occurs mostly during the period May-July. The residual remains

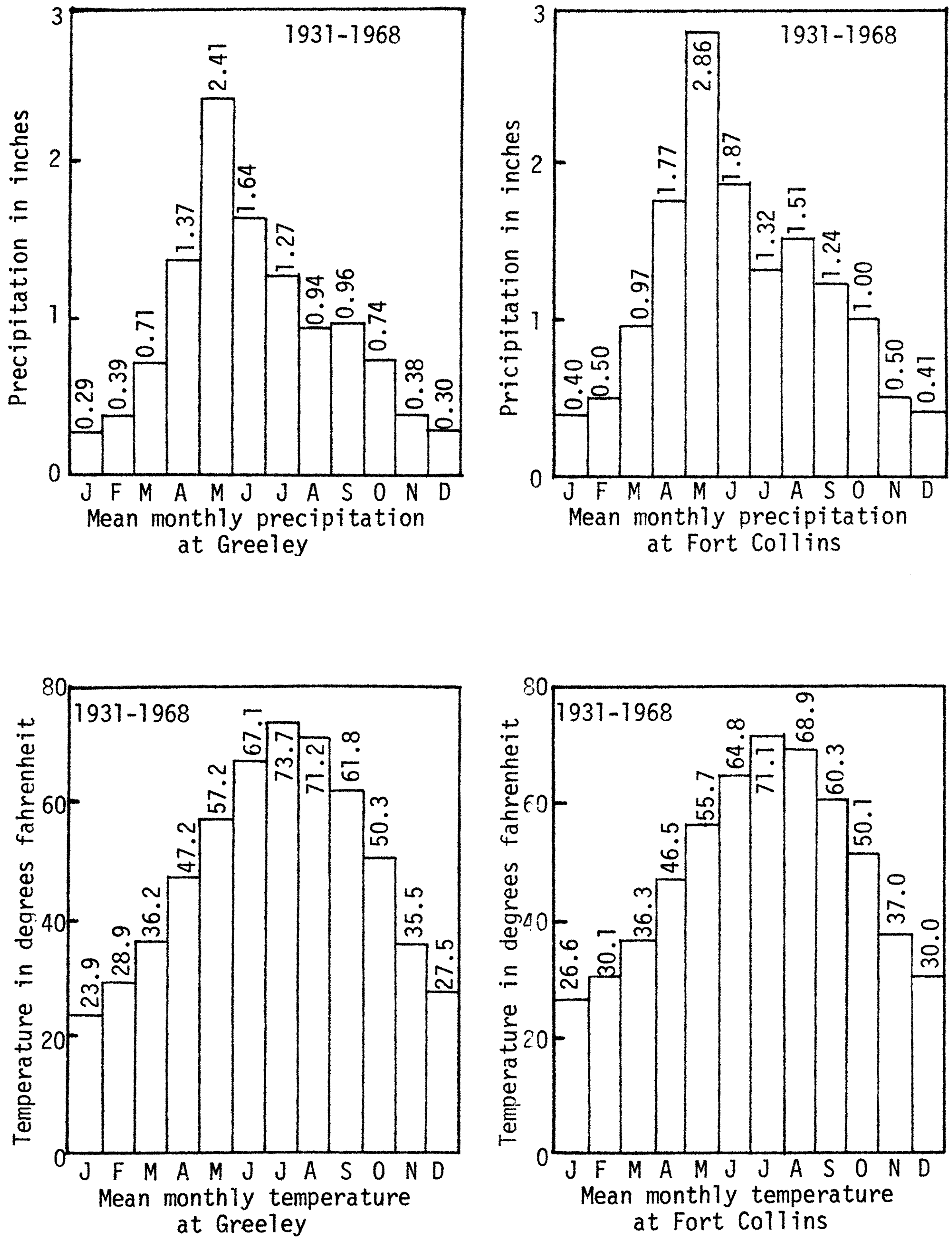


Figure 3-3. Mean Monthly Temperatures and Precipitations at Greeley and Fort Collins (adjusted from Evans, 1971).

behind in glaciers and large drifts and melts throughout the summer. Because the watersheds in this region are covered with rock, they are relatively impermeable and the melting snow quickly runs off the land. However, some will infiltrate, and emerge later as interflow. About 50 to 70 percent of the surface water runoff of Cache La Poudre River basin occurs during the period April-July as snowmelt from the mountain tributaries. During the four summer months July to October the interflow from the groundwater sustains these streams at lower flows. The flows may drop substantially during the fall and winter.

Nearly all of the surface water supply of this sub-basin is derived from melting snow pack in the mountains. Very little virgin water accrues to the surface flow of the Cache La Poudre River after it leaves it canyon. Boxelder Creek and Fossil Creek drain the low plains area. These streams are intermittent and contribute very little surface flow to the Cache La Poudre River. This surface water runoff is derived principally from summer thunder storms characterized by short intense rainfall and generally appears as short duration flash floods of a local nature. Because the plains are relatively flat and permeable, a good deal of this rainfall and subsequent runoff ends up seeping into the groundwater reservoir. The river valleys of the plains are underlain by valley-fill alluvium which provides an hydraulic connection with surface flows in the river.

Over the last century the Cache La Poudre has been changed from a natural drainage system to a highly complex water use system. Superimposed on the natural influences (e.g., snowfall and temperature), regulating the occurrence of runoff, is the human controlled water use subsystem (e.g., imports, reservoir storage and releases, diversions), and the man-induced return subsystem (e.g., point source discharges and non-point source discharges from irrigation return flows). Figure 3-4 depicts the overall basin and shows some of the structural features added.

A major element in the man-altered system are storage reservoirs. They have an aggregate capacity of about 350,000 acre-feet. With storage, water can be accumulated from year to year and released as "called" by the various water rights holders in the basin. Another significant element is imported water, which amounted to about 170,000 acre-feet in 1970. The USBR Big Thompson project, on line about 1947, and completed in 1958, is the largest project for water importation. This water is stored in reservoirs on both sides of the continental divide (e.g., Grand Lake and Shadow Mountain Lake in the Colorado River Basin and Horsetooth Reservoir in the Cache La Poudre Basin). Then it is released to various users through canals or through the river.

The resulting system of water resources development and associated uses completely dominates the natural system. In the upper reaches of the main stem this means that streamflows are affected by reservoir releases. In the plains reaches the water diversions and returns dominate streamflow patterns. Even in fall, winter and spring this is true, because when the water is not being applied directly to the land, it is being diverted to off-stream reservoirs. Diversions have a very strong effect on the flow in the Cache La Poudre River. They

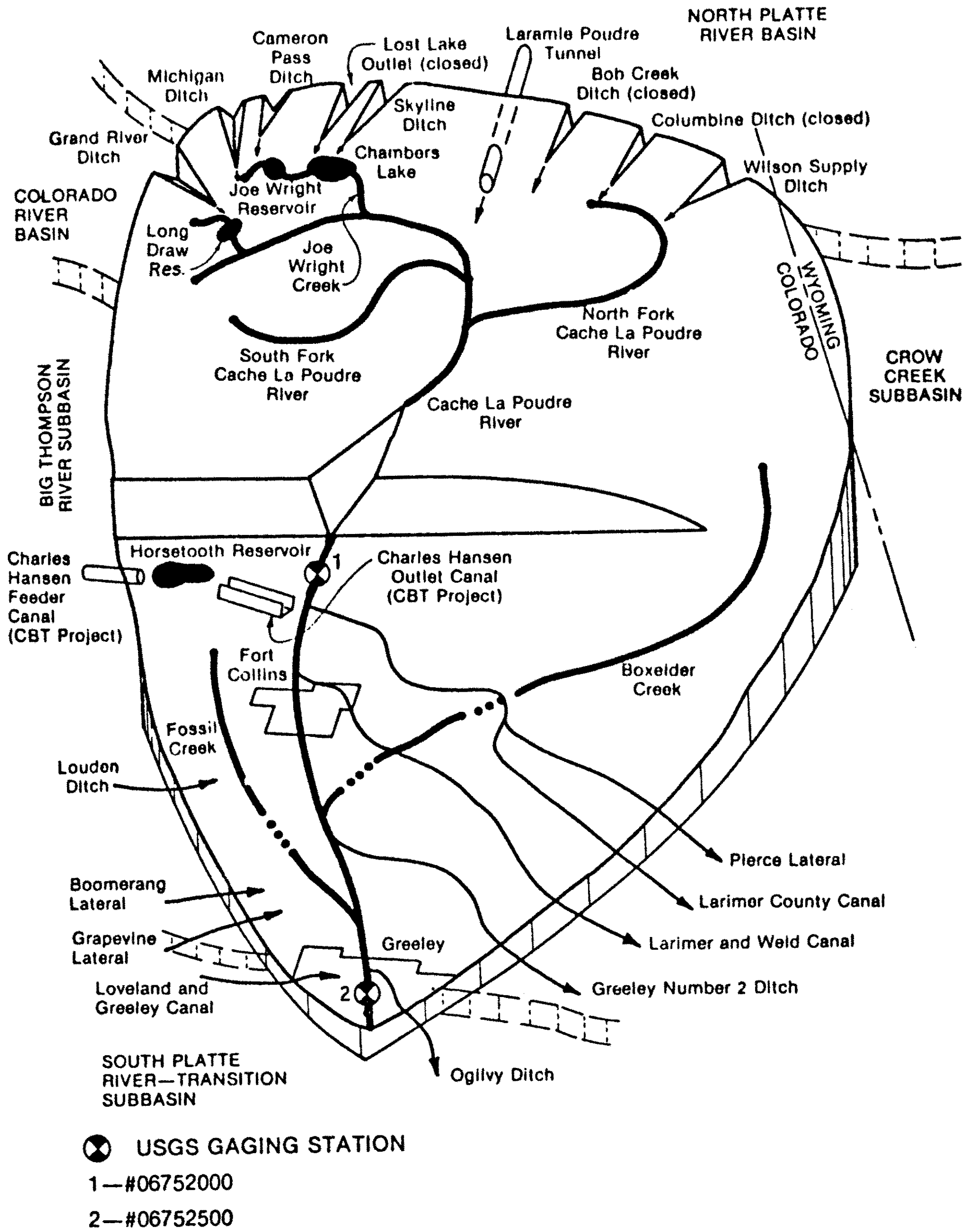


Figure 3-4. Schematic of the Cache La Poudre River Basin (Gerlek, 1977).

can be very large relative to the river flow and often zero flows occur below the diversion points. The flow is again restored by point source discharges and groundwater return flows from irrigation. Soon this water is diverted and another stretch of low flow occurs.

This balance between return flows and diversions has been affected very strongly in recent years by extensive pumping from the riparian aquifer. The pumping activity really got underway during the 1930's drought period. Evans (1971) indicated that 1,396 irrigation wells were active in the Cache La Poudre Valley in 1970. The well pumping has a serious effect on surface water diverters who are dependent on these groundwater seeps; the pumping has upset the equilibrium and effectiveness of the return flow mechanism. Occasionally, only a minor fraction of upstream reservoir releases reach diverters in the plains as the flows are not sustained in the river channel. Rather they infiltrate into the ground to replace the depletions of pumpage from the aquifer. Therefore, the practice of irrigation has severely affected and completely overridden the natural factors influencing the hydrology of the Cache La Poudre in its plains reaches. Evans (1971) studied the correlation between well pumping and annual virgin flow at the Cache La Poudre Canyon mouth. His results in Figure 3-5 show that, in order to ensure the supply, high rates of pumpage occur in those years when only little amounts of surface water is available at the mouth of the Cache La Poudre Canyon for use in the plains valley.

Historically, irrigation practices in the basin have not been efficient. Through custom, lack of capital to invest in scientific irrigation methods, and water laws which do not encourage the most efficient water use, much excess water is applied relative to the most efficient practices which are attainable today. In addition, there are seepage losses from the reservoirs and the unlined canals, ditches, feeders and laterals in the basin. As a result of these irrigation practices, water tables have risen over the years, making the plains reaches of Cache La Poudre River an effluent stream (i.e., it gains flow from the irrigation return flows). These return flows are in turn diverted, sometimes leaving a dry stream below the point of diversion. Thus the stream has an erratic flow-distance profile. This pattern of use and reuse extends all the way along the plains stem of the river.

Table 3-1 shows the average, maximum instantaneous, and minimum daily discharges (in cfs), and the average, maximum, and minimum yearly runoffs (in acre-feet) from records at the Fort Collins and Greeley Gaging Stations, respectively. The differences in flows between the two stations are indicative of the water use activity between Fort Collins and Greeley. The extremes of the records of the Fort Collins Gaging Station gives some indication of the natural variability of the surface water runoff of this river. However, there is rather substantial water resource development above this gaging station. Its flow records include imports from other basins and exclude the native runoff which is held back in reserviors and which bypasses the gaging station through ditches, canals, and pipelines. In fact, the maximum instantaneous discharge of the Cache La Poudre

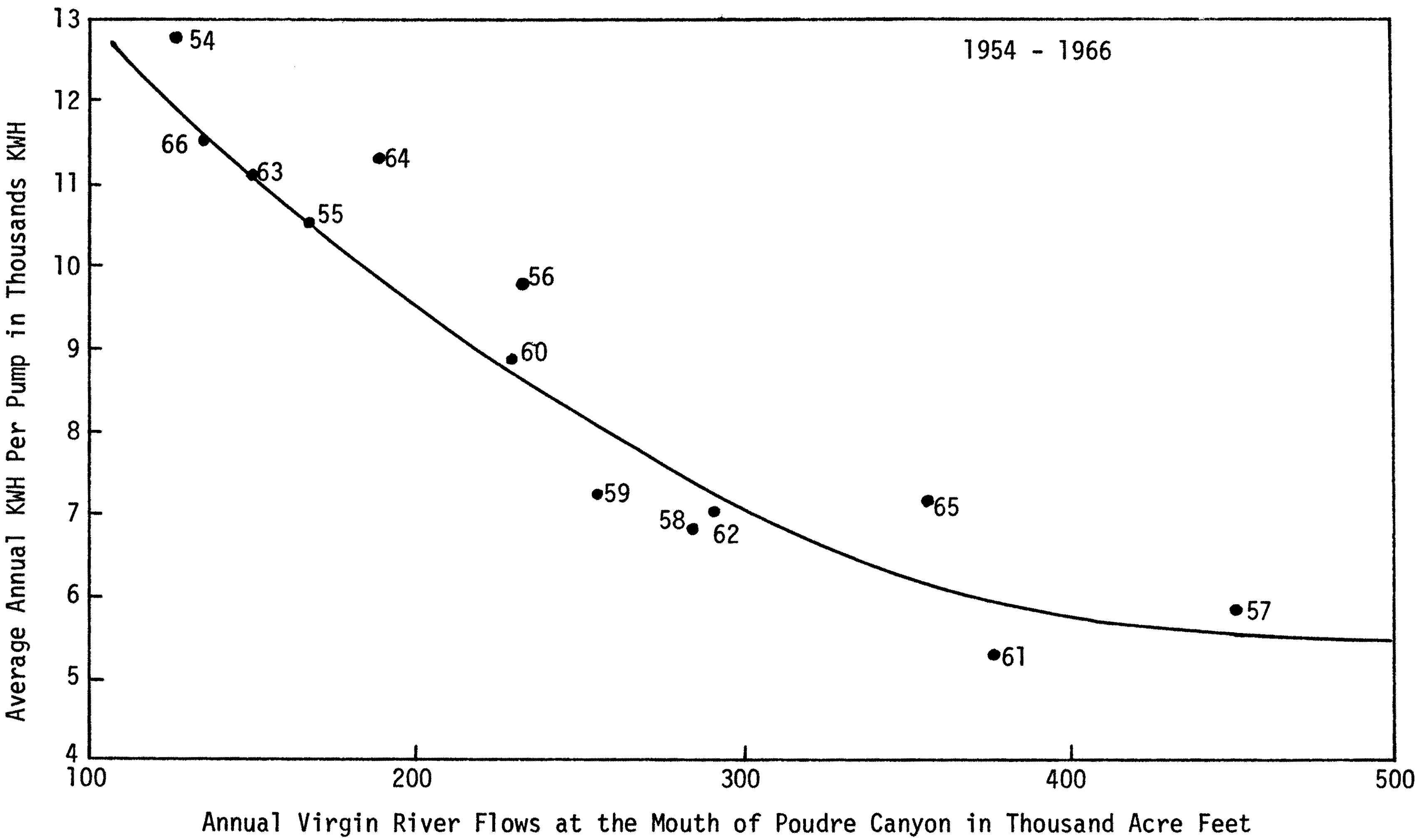


Figure 3-5. Annual Virgin Flows Versus Average Annual KWH per Pump from 1954 to 1966 (Evans, 1971).

Table 3-1. Surface Water Runoff Variability Within the Cache La Poudre River Sub-basin as Indicated by the Extremes of the Flow Records of Key Gaging Stations (adapted from Gerlek, 1977).

Flood discharges are: (first line) values used in multiple regression analysis, (second line) weighted averages.

Station Number	Station Name	Period of record, in years	Drainage area, in square miles	Gage datum, in feet above mean sea level	Basin slope, in feet per mile	Streambed slope, in feet per mile	Mean annual precipitation, in inches	10-year flood discharge, in cubic ft per second	50-year flood discharge in cubic ft per second	100-year flood discharge, in cubic ft per second	500-year flood discharge, in cubic ft per second	100-year flood depth, in feet
06748600	South Fork Cache La Poudre River near Rustic, Colo.	17	90.3	7597	220	74	24	924 857	1400 1290	1630 1490	2250 2020	4.5

River at this point was caused by the failure of Chambers Lake Dam and minimum daily discharge was caused by diversions of the Poudre Valley Canal half a mile upstream.

The flow at the mouth of the Caynon (i.e., at the exit from the mountain portion of the basin into the plains) plus the upstream diversions constitutes the gross surface water supply available for irrigation, municipal and industrial uses in the basin. These flows are shown in Table 3-2. The surface water outflow of the basin through the natural stream channel of the Cache La Poudre River contributes to the surface water supplies of the South Platte River-Transition sub-basin. These flows are measured at the USGS Gaging Station #06752500 near Greeley and are seen in Table 3-3. The 1915-19, 1924-75, 56 year average annual discharge recorded by this gaging station was 76,167 acre-feet. Gerlek (1977), indicates that the native surface water runoff of the basin during the 1953-56 four year drought period averaged, 158,066 acre-feet per year or 67% of the long term average.

3.1.4 Water quality. The Cache La Poudre River is classified as a B_1 stream from its headwaters to the intake of the Greeley Water Treatment Plant (Bellvue, river mile 54), and as a B_2 stream from that point to its confluence with the South Platte River below Greeley.

Available water quality records are very limited and sporadic for either surface or groundwater. The earliest records start in 1950 and continue to the present. However, there are several gaps in the records, one for a period of five years. Also, the data obtained have not been consistent with respect to sampling location or frequency of sampling. The samples may have been gathered in one year and at one location and not gathered at all or gathered at another location the next year. However, there have been limited studies on the water quality by McComas (1966) near Severance, and White (1964) on the Lower Boxelder Creek. Morrison (1978) has published the results of a sampling program on the lower Poudre River which continued during the period 1970 to 1977.

Existing records show that on January 17, 1950 the concentration of total dissolved solids (TDS) in the Poudre River near Greeley was 1,500 mg/L. On January 12, 1966 the concentration was 1,270 mg/L, indicating a relatively stable condition. These values compare with TDS concentrations on the order of 100 mg/L at the canyon mouth. At the time this study was conducted there were no suspended sediment records for comparison.

The water in Horsetooth reservoir is used for both domestic and irrigation purposes; however, for municipal use there may be a preference for water from the Cache La Poudre River due to the frequent occurrence of algae blooms in Horsetooth Reservoir. For industries also, water from the Cache La Poudre River is of high quality — a fact that figured prominently in the considerations for the establishment of Eastman Kodak in Windsor. This industry demands extremely high quality water and receives it through the Greeley Municipal Water Distribution System.

3.2 Population and Man-Related Activities

Information about the human community, the land use and the economic activities in the Cache La Poudre River basin was available

Table 3-2. Flow Records at USGS Gaging Station No. 06752000: "Cache La Poudre River at Mouth of Canyon, near Fort Collins, Colorado," (1).

Water Year	Discharge (Ac-ft)	Water Year	Discharge (Ac-ft)	Water Year	Discharge (Ac-ft)
1883	-	1914	406,000	1945	263,100
1884	675,000	1915	257,000	1946	214,300
1885	494,000	1916	281,000	1947	315,600
1886	318,000	1917	514,000	1948	225,300
1887	512,000	1918	317,000	1949	336,800
1888	192,000	1919	162,000	1950	212,700
1889	204,000	1920	364,000	1941	197,100
1890	244,000	1921	396,000	1952	273,500
1891	278,000	1922	206,000	1953	162,800
1892	216,000	1923	446,000	1954	100,100
1893	232,000	1924	447,000	1955	144,500
1894	321,000	1925	222,000	1956	216,000
1895	372,000	1926	381,000	1957	322,500
1896	236,000	1927	261,000	1958	240,700
1897	357,000	1928	302,000	1959	215,600
1898	201,000	1929	321,000	1960	205,500
1899	400,000	1930	222,000	1961	270,300
1900	496,000	1931	177,000	1962	273,400
1901	348,000	1932	261,000	1963	110,900
1902	166,000	1933	277,000	1964	160,700
1903	333,000	1934	135,200	1965	281,100
1904	375,000	1935	280,500	1966	98,280
1905	358,000	1936	294,400	1967	166,200
1906	296,000	1937	222,400	1968	212,100
1907	295,000	1938	259,400	1969	191,400
1908	261,000	1939	211,600	170	262,800
1909	468,000	1940	167,700	1971	311,100
1910	166,000	1941	224,000	1972	177,600
1911	253,000	1942	313,700	1973	321,500
1912	321,000	1943	349,200	1974	268,200
1913	221,000	1944	226,600	1975	221,400
Average for 92 years of record: 277,159 acre-feet.					

(1) Location: Lat 40°39'52", long 105°13'26" in NW¼ sec. 15, T.8N., R.70W., Larimer County, on left bank at mouth of canyon, 0.5 miles downstream from headgate of Poudre Valley Canal, 1.2 miles upstream from Lewstone Creek, and 9.3 miles northwest of courthouse in Fort Collins.

Drainage Area: 1,055 Square Miles

Period of Record: June to August 1881, May to July 1883, October 1883 to current year. Monthly discharge only for some periods. Records for Mar. 23 to Apr. 30 and July 4, to Aug. 20, 1883, published in WSP 9, have been found to be unreliable and should not be used. Prior to 1902, published as Cache La Poudre Creek or River at or near Fort Collins.

Gage: Water-stage recorder. Altitude of gage is 5,200 ft from topographic map.

Extremes: Maximum discharge not determined, occurred May 20, 1904; maximum discharge determined, 21,000 cfs June 9, 1891 (from reports of State Engineer of Colorado), caused by failure of Chambers Lake Dam; minimum daily discharge, 1.6 cfs Nov. 20, 28, 1948, caused by diversion of Poudre Valley Canal 0.5 miles upstream.

Accuracy: Natural flow of stream affected by reservoirs, transmountain diversions, diversions above station for irrigation, (most of which is below station) and diversions for municipal use.

Table 3-3. Flow Records at USGS Gaging Station No. 06752500: "Cache La Poudre River near Greeley, Colorado," (1).

Water Year	Discharge (Ac-Ft)	Water Year	Discharge (Ac-Ft)
1903	-	1945	38,680
1904	-	1946	36,140
1905	-	1947	90,290
1914		1948	43,020
1915	74,000	1949	100,500
1916	84,300	1950	30,650
1917	286,000	1951	45,220
1918	130,000	1952	65,970
1919	70,600	1953	39,780
1920	-	1954	28,410
1924	-	1955	25,950
1925	48,400	1956	37,870
1926	100,000	1957	83,400
1927	62,300	1958	160,800
1928	103,000	1959	76,560
1929	71,500	1960	57,060
1930	65,700	1961	165,300
1931	54,000	1962	161,800
1932	34,200	1963	63,430
1933	38,900	1964	46,180
1934	32,600	1965	111,400
1935	31,580	1966	52,890
1936	29,150	1967	81,140
1937	30,010	1968	52,420
1938	30,820	1969	63,440
1939	33,430	1970	129,000
1940	20,270	1971	179,700
1941	21,410	1972	96,700
1942	82,250	1973	156,400
1943	140,600	1974	122,800
1944	40,450	1975	106,000
Average for 56 years of record: 76,197 acre-feet			

(1) Location: Lat 40°25'04", long 104°38'22", in NW¼ sec. 11, T.5N., R.65W., R.65W., Weld County, on right bank 25 ft downstream from highway bridge, 2.9 miles east of courthouse in Greeley, and 3.0 miles upstream from mouth.

Drainage Area: 1,877 Square miles

Period of Record: March to October 1903, August to November 1904, January 1914 to December 1919, June 1924 to current year. Monthly discharge only for some periods.

Gage: Water-stage recorder. Altitude of gate is 4,610 ft (from topographic map). Prior to Apr. 4, 1916, staff gage and Apr. 4, 1916, to Dec. 17, 1919, water-stage recorder, at sites within 2 miles downstream at different datums. May 27, 1924, to Dece. 13, 1933, at present site at datum 0.51 ft higher.

Extremes: Maximum daily discharge, 4,200 cfs, June 24, 26, 1917; minimum daily, 0.8 cfs, Oct. 3, 1946.

Accuracy: Generally, records are good.

Remarks: Natural flow of stream affected by transmountain and trans-basin diversions, storage reservoirs, power developments, diversions for municipal supply, diversions above station for irrigation and return flow from irrigated areas.

from the technical report "Consolidation of Irrigation Systems" (Skogerboe, Radosevich and Vlachos, 1973). The content of this section was adapted from this report.

3.2.1 Population. The land area of the Cache La Poudre River basin is mostly contained within Larimer County and Weld County in northern Colorado. Both of these counties are fairly similar in terms of population, size, and composition. Agriculture is important in both counties and both are experiencing high rates of urban growth. A small portion of the basin is within the State of Wyoming but not much population dwells in this area, which is mountainous.

Larimer County, which is located on the west edge of the valley, with a population of 89,000 according to the 1970 census, has shown an increase of 68.53 percent population growth over the previous census done in 1960. The number of inhabitants of Larimer County classified as urban in 1970 were 59,557, with the remaining 23,644 classified as rural. However, Larimer lists only 2,167 persons as full-time employed in agriculture, which is a rather small porportion of the 34,094 persons gainfully employed in the county. The largest number of employed persons in any single category is to be found in manufacturing, followed by education and construction. The population of the county is rather young, with high in-migration and high levels of educational attainment.

The principal city in Larimer County is Fort Collins. Fort Collins has been growing much more rapidly than the rest of the county showing an increase of 72.2 percent between 1960 and 1970 for a total population of 43,337 inhabitants in 1970. It is rapidly become the populous pole in the emerging Colorado megalopolis stretching all the way from Fort Collins to the north to Pueblo in the south. As a matter of fact, projections to the year 2000 estimate an approximate population of 200,000 persons in the county with an even higher number of people by the year 2020 (estimated to about 355,000 inhabitants).

The urban growth of the City of Fort Collins is part of a rapidly growing suburban growth area contained between the cities of Fort Collins, Loveland, and Greeley (the last in Weld County) forming an "urban triangle." The population of this triangle, which is superimposed on Poudre Valley, is espected to increase to more than 400,000 people by the year 2020.

Similarly, Weld County which is located in the eastern part of the Poudre Valley is experiencing parallel trends of growth although not as pronounced as the ones in Larimer County. The population of Weld County according to the 1970 census was 89,297 inhabitants. This is a 23.43 percent increase over the 1960 census. Overall, Weld County is not growing as rapidly as the Larimer County region, but the agricultural land in this county is much more fertile and productive as compared to Larimer County. Indeed, the Weld County area was the earlier of the two areas of the Poudre Valley to be settled and the growth in this county has been much faster until the latest census which showed decreasing rates of increase for the entire county. This is particularly true for the urban population of Weld County which according to the latest census comprised 41,272 persons. Greeley, the major city of the county, grew by 48.8 percent between 1960 to 1970 (showing a total of 39,167 inhabitants according to the 1970 census).

However, not all the population of Larimer and Weld counties dwells within the Cache La Poudre basin area. Therefore, a different accounting was attempted for the sake of this study and is shown in Table 3-4. This table lists only the population of those Larimer and Weld counties sub-divisions which are covered by the study area according to the 1970 U.S. Census.

As can be seen, the total study area population was 118,040 inhabitants in 1970. About 60,163 of these inhabitants dwelled in Larimer County, while the remaining portion (57,877 inh.) dwelled in Weld County. About 82,239 of the total population was concentrated in the two large cities of Fort Collins and Greeley. The rest of the population (35,801 inh.) was spread over the plains and along the Cache La Poudre Canyon up in the mountains. Small concentration of population were found in the communities of Livermore, Wellington, Ault, Nunn, Pierce, Eaton, Severance and Windsor. The communites of Pierce, Nunn and Evans are geographically located out of the Cache La Poudre basin boundary, but are included in the study area since their water systems are tied to the entire Cache La Poudre water system.

3.2.2 Land use and economic activities. The rapid urban growth of Poudre Valley represents a situation where a great deal of agricultural water is being transferred to municipal and industrial uses. This has been stimulated, to a large degree, by the high rate of industrial growth in the Poudre Valley. The Eastman Kodak plant at Windsor, established in 1970, is the largest industrial activity in recent years. Undoubtedly it has stimulated other industries to locate in the area also.

Other large industry establishments include "Woodward Governor" and the "Ideal Cement," which maintain fairly large facilities in the Fort Collins area. Other manufacturing industries include those involved in sand and gravel production (e.g., the Greeley Sand and Gravel Co.) and in sugar production (Great Western sugar beet factories of Greeley and Eaton). Fish hatcheries represent a minor industry, but they divert substantial amounts of water. Hewlett-Packard began a large plant in 1977 in Fort Collins, which may employ eventually up to four thousand persons. The growth of service industries in the area has been significant also; no data are available for this sector.

The Cache La Poudre Valley is an area of widely diversified agriculture ranging from native hay to corn and sugar beets to carrots, potatoes and cucumbers. Alghough many crops grow well in this area, the three major crops are corn, sugar beets, and alfalfa. The principal agricultural industries are general farming, livestock feeding and dairying. The alfalfa and corn are usually raised for consumption in the area by the large number of feeder cattle and sheep. Sugar beets are sold to Great Western Sugar Company, and the tops and pulp are used to supplement the livestock industry. The small grains such as oats and barley are consumed primarily in the area.

The farming in the area is of two types: irrigated, and dry farming. Dry farming is found mostly in the plains areas which are too

Table 3-4. Resident Population of Cache La Poudre Basin in 1970 (1).

Larimer County		Weld County	
County Sub-divisions	Pop.	County Sub-divisions	Pop.
Fort Collins Division	43,637	Ault Division	3,747
Fort Collins City	43,337	Ault Town	841
		Nunn Town	269
Fort Collins North Div.	7,346	Pierce Town	452
Fort Collins West	1,693		
		Eaton Division	4,905
Fort Collins South Div.	4,911	Eaton Town	1,389
		Severance Town	59
Livermore Division	764		
		Evans Division	7,358
Timnath Division	1,166	Evans Town	2,578
Timnath Town	177	Garden City Town	142
		Rosedale Town	66
Wellington Division	2,339		
Wellington Town	691	Greeley Division	38,902
		Greeley City	38,902
		Windsor Division	2,785
		Windsor Town	1,564
Total Larimer County	60,163	Total Weld County	57,877
Total Area Population = 118,040			

(1) The source of information is the U.S. Bureau of the Census, 1971. U.S. Census of Population, 1970. Number of Inhabitants, Colorado U.S. GPO, PC(1)-A7-COLO, Washington, D. C.

(2) The communities of Pierce, Nunn and Evans are geographically located out of the Cache La Poudre basin boundary, but are included in the study area since their water systems are tied to the entire Cache La Poudre water system.

high for delivery of irrigation water, or for which the soil was deemed marginal. These dry farm plots are primarily used for small grains. The crops grown on the irrigated land include sugar beets, small grains, corn, alfalfa and some soy beans. The amount of land which is irrigated is really "water limited."

The cash value of agricultural crops during 1967 for Larimer and Weld counties was $9,600,000 and $43,600,000 respectively. Of the total cash value of $53,200,000, the value of crops from irrigated lands was $47,000,000. Thus, the average cash value of crops from irrigated lands was approximately $190 per acre.

3.3 Development of Water Use in the Cache La Poudre Basin

The development of water uses and the water rights information in the Cache La Poudre River basin is given in Evans (1971), Skogerboe, Radosevich and Vlachos (1973) and Gerlek (1977). These sources were the basis for this section.

3.3.1 History of water development. The area along the Cache La Poudre River was one of the first large areas to be developed for irrigation in Colorado. One of the first attempts to raise crops in the Poudre Valley was at La Porte in 1860. Vegetables, small fruits, native hay and oats were raised. The ditches were small and irrigation was on the "first bottom" of land, where the labor and the expense of operation were minimal, and easy cultivation of the alluvial soils was possible.

The stimulus for more rapid development of the Cache La Poudre River began with the completion of the Union Pacific Railroad and the coming of the Union Colony to the Greeley area in 1870. The Colony, under the leadership of Nathan C. Meeker and under the patronage of Horace Greeley, was founded on the belief that the higher lands above the river could be successfully adapted to cultivation with irrigation. Prior to the settlement of the Union Colony, there were only about 1000 acres under cultivation, with several small irrigation ditches conveying water to the lands along the margin of the river. The Greeley No. 2 Canal, constructed by the Colony, was the first large canal in the state designed to irrigate the terraces above the river.

The leaders of the Union Colony planned a number of canal systems designed to irrigate the lands of the benches above the river. The Greeley No. 2 Canal was begun in the fall of 1870. Greeley Canal No. 3 was the first built after the arrival of the colonists on the south-side of the river near Greeley.

The next large canal constructed, which involved the enlargement and lengthening of an existing ditch, was the Larimer and Weld Canal. This canal was constructed during the period 1879-1881, when it was enlarged to carry 571 cfs, which is the largest canal diverting water from the Cache La Poudre River. It's point of diversion is just north of Fort Collins, and it runs to Crow Creek near Barnesville.

The Laramie-Poudre Canal was another ditch located in this vicinity above the Larimer and Weld Canal. This canal ran discontinuously for a few years until 1928 when it was abandoned. In addition, to the above large canals, several smaller ditches were constructed during the earlier period also.

When various irrigation companies were originally established they were usually rather small with their participants being the original settlers of the valley. Such settlers would form an irrigation company, build the diversionary structures, and begin farming. When a later group of settlers would come, they would also go through the same process and file rights which would be "junior" to the previous group. Such a process would continue, even past the point when the flows of the river had been exceeded.

The original companies at the time of their organization were very small, but as time progressed and more modern machinery became available the increasing activities in the various projects affected also the structure, form, and size of these companies. The canal system would become larger and the amount of land under cultivation would grow also, but within the limits of the amount of water which constituted the water right.

Since snow-fed mountain streams delivered excess water in the spring and inadequate amounts later in the growing season a reservoir system started to be developed too. To augment the total flow, however, it became necessary also to divert the drainage from adjacent watersheds into the Cache La Poudre System. Chambers Lake was a key element in the early schemes to furnish more irrigation water. Chambers Lake lies on the divide between the upper watersheds of Larimer River (North Platte basin) and Cache La Poudre River with the outlet on the side of Cache La Poudre basin. The first measure, taken in 1887, to improve the available river flow, was to dam the outlet of the lake and thereby increase the lake's capacity to store the spring water excess for later release. The dam was washed out in 1891, but it was rebuilt soon and more substantially. At the same time measures were taken to increase the total flow by shunting some Laramie River drainage into the Cache La Poudre basin. The Skyline Ditch was the first of the transmountain diversions (1894). Other transbasin diversion structures include: Grand River Ditch, importing Colorado River water, built in 1895, Lost Lake Outlet, built in 1898, Cameron Pass Ditch, built in 1913, Laramie-Poudre Tunnel, built in 1914, Michigan Ditch, Wilson Supply Ditch, Bob Creek Ditch, Columbine Ditch built later. The most ambitious endeavor, the Colorado-Big Thompson project, was started in 1939 and completed in 1959.

According to Rohwer (1953) the first irrigation well in the Cache La Poudre area and in the state was dug in 1885 east of Eaton by E. F. Hudrle, who later dug two other wells nearby. The pumps were probably drive by a steam tractor engine and later converted to gasoline.

In 1912, Comstock reported 27 wells for irrigation in the Cache La Poudre Valley. In 1941, Code (1943) stated that there were 593 irrigation wells. In Water Supply Paper 1669-X (USGS, 1964), Hershey and Schneider indicated that there were about 1300 irrigation wells pumping an estimated 85,800 acre-feet. Evans (1971) indicated that about 1,400 wells were active in 1970 pumping an approximate annual volume of 200,000 acre-feet. The U.S. Bureau of Reclamation reported (1966) that the most rapid development of the groundwater resource occurred during the 8-year period 1947-1954. Table 3-5 summarizes the results of the U.S. Bureau of Reclamation studies (1966) about the groundwater utilization in Cache La Poudre Basin from 1947 to 1961.

Table 3-5. Groundwater Pumpage in Cache La Poudre Basin (USBR, 1966).

Year	Amount (1,000 Ac-ft.)	Year	Amount (1,000 Ac-ft.)
1947	64.1	1955	191.7
1948	104.9	1956	182.5
1949	85.1	1957	100.1
1950	129.7	1958	121.5
1951	101.6	1959	145.7
1952	133.6	1960	182.8
1953	150.9	1961	108.2
1954	221.2	Average	134.9

3.3.2 Water law, water rights and water administration. The primary principle of the appropriation doctrine is priority in right. This principle has been stated as "first in time is first in right" and means, basically, that when a water deficit occurs, the allocation of diversions among users is in priority order, i.e., the latest allocation right granted is the first to be closed. The second principle of appropriation is that the water in question must be the subject of a diversion. A third principle of appropriation is that a beneficial use must be made of the water appropriated. A beneficial use is defined as that amount of water that is reasonable and appropriate under reasonably efficient practices to accomplish without waste the purpose for which the diversion is lawfully made; it shall include the impoundment of water for recreation purposes, including fishery or wildlife. The fourth principle is that a valid appropriation of water is a right in real property. This property right is not absolute but is, rather a usufruct in a stream consisting in the right to have the water flow so that some portion of it may be reduced to possession and be made the private property of the individual during the period of possession. Finally, an appropriative right in water must exist for a definite amount. This is known as a "duty of water" and serves to quantify the doctrine of beneficial use by setting a maximum consumption which will be recognized as a reasonable beneficial use. The right or duty of water is usually expressed in terms of quantity of flow per second but may also be stated in acre-feet/time or season of the year or the amount of beneficial use which can be made of the water.

The appropriation doctrine is recognized in Colorado, as well as in the other western states. The Colorado constitution in fact incorporates the principle, stating that "the right to appropriate water for a beneficial use shall never be denied." Prior appropriation applies as well to underground waters not adjacent to any natural streams. A water right is defined as a right to use in accordance with its priority a certain portion of the waters of the state by reason of the appropriation of same. From this it can be seen that it is usufructory in nature. A conditional water right is the right to perfect a water right with a certain priority upon completion with reasonable diligence of the appropriation upon which the right is based.

Once a tributary water starts back to the stream, it is public water and is not subject to recapture by the original user. For example, a city cannot recapture its own waste water for further use; however, it could be done by another appropriation. The courts have held that an appropriator has only the right of use and that surplus water must be returned to the stream.

Failure to use a water right for a beneficial purpose for a period of ten years creates a presumption of abandonment. The question of abandonment of water rights is one of intent that must be shown by clear and unequivocal evidence. Mere lapse of time does not constitute an abandonment though it may be relevant to show intent.

As a result of the recognition of the prior appropriation doctrine in 1881 the Office of State Hydraulic Engineers was created, water divisions and districts were formed, and the vehicle for the administration of water in Colorado was set in motion. The South Platte River basin is contained within Colorado Water Division No. 1. The boundaries of Cache La Poudre basin closely coincides with the Water District No. 3. The first steps taken in Colorado to obtain definite information concerning its natural water supplies were also initiated during this early period. The State Engineer was given general supervisory control over the public water supplies of the State. The office was also charged with the collection of data and information regarding snowfall for the purpose of predicting probable runoff and with the duty of making measurements of the flow of public streams of the state.

Any person who desires a determination of a water right or a conditional water right and the amount and priority thereof will file an application with the water clerk setting forth facts supporting the ruling sought. Opposition, if any exists, must be filed by the last day of the second month following application. Rulings on applications and oppositions will be made within sixty days of filing of opposition arguments by the referee of the water district and these rulings may be appealed to the district water judge.

The imported waters into the Cache La Poudre basin are administered within the framework of interstate compacts and litigations. The first interstate water compact was the 1922 Colorado River Compact. It came about as a result of the contemplated acquisition of Colorado River water by Southern California cities and irrigation districts. Upper basin states feared that if the doctrine of prior appropriation applied, the fast developing southern California region would pre-empt the rights of the upper basin states to Colorado River Water (i.e., when their development was sufficient to require the water, it would not be available). The Colorado River Compact was hammered out then in exchange for the political support of the basin states for the Boulder Canyon Project Act, which passed Congress in 1928. This compact and the 1948 Upper Colorado River Compact, and the 1944 Mexican Treaty, has permitted the upper basin states to develop at their own pace, with the certainty that the allotted amount of water can be used. The Colorado River compacts and treaties are the basis for whole river basin programs.

Litigations are another form of interstate document. The Laramie River Decree of 1957 deals specifically with the question of trans-basin diversions to the South Platte basin (precisely through its Cache La Poudre sub-basin). It limits exports from the the Laramie River Basin in Colorado to 19,875 acre-feet of water in any calendar year. The North Platte River Decree of 1945 limits the exports of water from Jackson County to 60,000 acre-feet in any ten year period.

The Colorado River water imported through the Cololorado-Big Thompson project facilities are distributed by the Northern Colorado Water Conservancy District. The endogenous Cache La Poudre waters are administered under the control of the State Engineer office under the doctrine of "Prior Appropriation." The organizations which distribute the Cache La Poudre water are cities, water districts, irrigation companies and other individuals. Some of these entities distribute water only. Other of these entities treat and distribute water. The municipal and industrial used water are collected and treated before disposal by the cities or the industries itself or by sanitation districts.

In 1959 the U.S. Bureau of Reclamation reported that there were 32 separate irrigation canal systems and 70 major decreed direct flow rights for the native surface water runoff of the Cache La Poudre basin. These appropriations totaled 6,200 cfs which is equivalent to approximately 4,488,800 acre-feet per year.

The 1974 revised tabulation of Colorado Water Rights lists about 370 absolute and conditional direct flow rights decreed to the surface water runoff of the Cache La Poudre's drainage area. Water from the mainstem of the Cache La Poudre River is decreed to 144 ditch rights and 13 pipeline rights, while 31 ditch rights are decreed to waters of the North Fork. Boxelder Creek is appropriated by 14 decreed ditch rights. The remaining rights are supported by the various other tributaries, springs, seepages, and sloughs within this drainage area. A list of the existing direct diversion rights is given in Table 3-6.

A reservoir decree will permit the filling of a reservoir once each year; this can be done again the same year with another priority right. Reservoirs are filled during periods of high runoff when there is no call upon the river by other appropriators having senior priorities. In 1959 the U.S. Bureau of Reclamation reported that there were about 75 reservoirs whose rights were dependent on the native surface water runoff of the Cache La Poudre River basin. Their decrees ranged from 90 to nearly 18,000 acre-feet; the total storage decrees amounted to about 200,000 acre-feet.

The 1974 revised tabulation of Colorado Water Rights lists over 200 absolute and conditional storage rights decreed for the native surface water runoff of this sub-basin. Water from the mainstem of the Cache La Poudre River is decreed to 55 of these storage rights, while North Fork water is decreed to 40 storage rights. Runoff from Boxelder Creek supports 19 decreed storage appropriations. The remainder are for water from various other tributaries, springs, seepages, and sloughs within this sub-basin.

Table 3-6. List of Water Rights by Irrigation Companies (From Skogerboe, Radosevich, and Vlachos, 1973).

Canal Name	Priorities	Amount (cfs)	Date (1800's)
Ames Canal (Cap. 20 cfs)	25	17.97	10-1-67
Arthur Ditch (Cap. 110 cfs)	2	0.72	6-1-61
	19	2.165	7-1-66
	29	2.165	6-1-68
	32	1.67	6-1-69
	38	31.67	4-1-71
	52	18.33	7-20-72
	66	52.28	4-1-73
B.H. Eaton (Cap. 40 cfs)	9	29.10	4-1-64
	18	3.33	6-1-66
	53	9.27	7-25-72
Boxelder (Cap. 60 cfs)	15	32.5	3-1-66
	23	8.33	5-25-67
	30	11.93	7-1-68
Greeley #3 (Cap. 185 cfs)	35	52.0	4-1-70
	46	41.0	10-1-71
	50	63.13	7-15-72
	59	16.66	5-15-73
Chaffee (Cap. 22 cfs)	48	22.38	3-10-72
Coy (Cap. 32 cfs)	13	31.63	4-10-65
Jackson (Cap. 60 cfs)	3	11.67	6-10-61
	36	14.42	10-21-70
	67	12.13	9-15-73
Jackson	91	12.70	7-15-79
Ft. Collins Pipeline	1	3.5	6-1-60
(Cap. 28 cfs)	5	2.5	3-1-62
	6	7.0	3-15-62
	12	2.78	9-15-64
	14	4.5	5-1-65
Greeley Pipeline (Cap. 30 cfs)	6	5.0	8-1-62
	6½	7.5	
Jones Ditch (Cap. 25 cfs)	24	15.52	9-1-62
Lake (Cap. 165 cfs)	54	158.35	3-1-62
Larimer County Canal	5	10.77	3-1-62
(Cap. 500 cfs)	12	13.89	9-15-64
	28	4.66	3-15-68
	56	4.0	3-20-73
	84	7.23	4-1-78
	100	463.0	4-25-81
Larimer County #2	14	3.5	5-1-65
(cap. 180 cfs)	57	175.0	4-1-73
Larimer & Weld (Cap. 850 cfs)	10	3.0	6-1-64
	16	1.47	4-1-66
	21	16.67	4-1-67
	45	75.0	9-20-71

Canal Name	Priorities	Amount (cfs)	Date (1800's)
Larimer & Weld (Continued)	73	54.33	1-15-75
	88	571.0	9-18-78
Little Cache La Poudre	31	62.08	
(Cap. 125 cfs)	58	20.42	
Munroe Canal - North Poudre	199	250.0	
(Cap. 250 cfs)			
Greeley #2 (Cap. 600 cfs)	37	110.0	10-25-70
	44	170.0	9-15-71
	72	184.0	11-10-74
	83	121.0	9-15-77
New Mercer (Cap. 105 cfs)	25	7.03	10-1-67
	33	4.17	9-3-69
	47	8.33	10-10-71
	49	15.0	7-1-72
	98	136.0	2-15-80
North Poudre Canal	2	.72	7-20-72
(Cap. 125 cfs)	17	4.75	8-15-73
	19	2.165	5-15-74
	29	2.165	2-1-80
	40	4.0	3-1-83
	52	15.0	10-1-84
	60	7.2	10-1-88
	61	9.38	2-20-90
	63	3.32	5-1-94
			Date (1900's)
	66	11.0	4-30-00
	69	3.32	8-1-01
	77	6.72	5-15-03
	79	6.72	11-1-04
	80	6.72	11-2-04
	82	2.85	12-31-24
North Poudre Canal	97	307.0	
Ogilvy (Cap. 70 cfs)	122	91.0	7-1-81
Pleasant Valley & Lake	4	10.97	9-1-61
(Cap. 138 cfs)	11	29.63	6-10-64
	51	16.50	7-10-72
	92	80.83	8-18-79
	102C	-----	10-10-81
Poudre Valley Canal	--		
(Cap. 450 cfs)			
Taylor & Gill (Cap. 20 cfs)	17	12.17	4-15-66
Whitney Ditch (Cap. 70 cfs)	7	48.23	9-10-71
	43	12.95	

There are no major reservoirs located outside of the Cache La Poudre River basin that have storage rights to its native surface water runoff. However, there are several minor ones located in the Crow Creek basin which store some of the water transported there by agricultural ditches and canals. These include, among others, Saxton Lake (which is fed by the Greeley #2 ditch) and Briscoe and Faber Reservoirs (which are fed by the Eaton Ditch). Therefore, the bulk of the existing storage capacity available to the native surface water runoff of the Cache La Poudre River basin is located within the basin.

Twenty-two reservoirs with a combined capacity of 50,511 acre-feet are located in the mountains of the Cache La Poudre basin. These range in size from the 69 acre-feet Bellaires Lakes to the 10,128 acre-feet Halligan Reservoir (USBR, 1966); most are owned by irrigation companies but some are owned by the cities of Greeley and Fort Collins. However, the difficulties and expenses of operation and maintenance of these high mountain storage facilities has lead to the near abandonment of some, especially the smaller ones (U.S. Bureau of Reclamation, 1966).

Horsetooth Reservoir has no absolutely decreed storage rights for the surface flows of the Cache La Poudre River sub-basin. It does however, have a conditional storage appropriation for 96,000 acre-feet of water from Soldier Creek. The appropriation date, of the right is October 15, 1935 (Wilkinson, 1974).

Excluding Horsetooth Reservoir whose function is to store imported CBT water, there are over 90 reservoirs in the plains portion of the Cache La Poudre Basin. Some 56 have a total decreed capacity of 161,300 acre-feet; they range in size from less than 100 acre-feet to the 22,300 acre-feet Cobb Reservoir (USBR, 1966). Many of these reservoirs have been operating at less than decreed capacity due to sediment buildup, phreatophytic growth, and deterioration of the facilities (Evans, 1971). The total decreed storage capacity within the entire Cache La Poudre River basin (excluding Horsetooth Reservoir) is approximately 211,811 acre-feet. This represents about 90.2 percent of the estimated long term average annual native surface water runoff of the basin (Gerlek, 1977). The total actual storage available within the basin, including Horsetooth, is about 350,000 acre-feet.

Even in an extremely wet year, a great deal of these water rights are not satisfied. However, the decreed amount includes conditional decrees some of which will never come to fruition. In addition, water users in the basin do not consumptively use 100 percent of their diversions. Agriculture, which places the greatest demand on water in the basin, consumptively uses only about 4.1 acre-feet for every 10 acre-feet of water diverted, (Gerlek, 1977). The unused portion of the diversion is return flow, and it generally seeps through the ground and accrues back to the surface flow where it is used again and again — or, in the Plains it may be pumped. In this manner, water users with decrees for several times the actual volume of water available are all satisfied as each passes his residual for further consumption by a downstream appropriator. However, even accounting for this fortuitious reuse, the system is overappropriated.

The Cache La Poudre River has more land available for irrigation than there is water to supply it. Igorning the contribution of the Colorado-Big Thompson water which started in 1951, it was the above conditions which caused the evolvement of an intricate exchange system.

The Cache La Poudre sub-basin, of all the sub-basins in the South Platte River basin, is perhaps the most intricately developed with regards to "exchanges" by water users. All of the canals and most of the reservoirs are tied together in a complex network of ditches and pipelines that can permit the exchange of water between any two parties that may wish to do so. Therefore, the diversions of water in this sub-basin can be somewhat deceiving at first glance. In many instances, the water flowing in a ditch or being held in a reservoir is not necessarily the yield of the water right associated with the facility. For example, Fort Collins may transfer some of its CBT water in Horsetooth Reservoir "up to" its storage facility in the mountains, Joe Wright Reservoir. Or, an irrigation company may divert out of priority to upstream lands by replacing it with stored water at lower elevations to satisfy the senior appropriator who is calling the river. In both cases, of course, compensation for carriage losses over the distance of the exchange is made so as not to injure a third party.

Anderson (1963) has stated that the existing exchange system for this area was possible for three major reasons: (1) company ownership of water rights; (2) development of private and corporate storage reservoirs, and (3) the contribution of the Colorado-Big Thompson Project (CBT).

Company ownership of waters removes the restriction that a water right is appurtenant to a specified tract of land and allows the water to be moved between several parcels of land. The reservoir system made possible a dependable water supply late in the summer. The CBT, under its charter, can easily transfer water anywhere within the Northern Colorado Water Conservancy District (NCWCD) from any one use to any other use.

There are three basic types of transfers which have evolved along the Cache La Poudre River: (1) exchanges between stockholders in a company; (2) exchanges between companies; and (3) exchanges of CBT water. Transfers involving persons belonging to a ditch company are handled by the company office, if the canal is large; or, if it is a small ditch or private reservoir, on an individual agreement-payment basis. The large companies often maintain a service to facilitate the "rentals" by having a list of those who have surpluses and how much water is surplus; and, when any stockholder requests additional water, the company can effect the transfer with a minimum of difficulty. Many companies set a fixed rate of exchange while others leave the price up to the seller.

Transfers between irrigation companies usually take place when ditch rights versus reservoir rights are involved. The main reason for the exchanges is that the ditch companies with high priority and no reservoirs wish to ensure themselves of a late water supply, while the other junior rights just need to ensure themselves of a water supply. The process gained legal acceptance in 1897 when the following law was enacted legalizing the exchange and providing for the measurement of waters:

> CRS 1963, 148-6-4 When the rights of others are not injured thereby, it shall be lawful for the owner of a reservoir to deliver stored water into a ditch entitled to water or into the public stream to supply appropriations from said stream, and take in exchange therefore from the public stream higher up an equal amount of water, less a reasonable deduction for loss, if any there be, to be determined by the state engineer. Provided, that persons or company desiring such exchange shall be required to construct and maintain under direction of the state engineer measuring flumes or weirs and self-registering devices at the point where the water is turned into the stream or ditch taking the same or as near such as is practicable so that the water commissioner may readily determine and secure the just and equitable change of water.

There are some other values of the transfer system besides the more economical use of water. There is the fact that it does not involve lengthy and costly litigation for changes in points of diversion. Also, the use of water on the upper portions of a stream for irrigation will increase the natural flow of the stream by return flows later in the season and prevent low stages which would occur without the regulatory action of subsurface return flows. In time, the return of seepage flows will ensure the lower portion of the drainage a steady supply and thereby enable larger acreages to be farmed or cultivated.

Municipalities and industries have competed for any CBT water being sold, even if it is not immediately needed, thus raising the price to a point where, if a farmer no longer wants CBT water, it will invariably go to a municipality because agriculture cannot afford to pay for it. Although the municipal and domestic water districts have acquired almost 23 percent of the CBT water, the loss of agriculture is not as great as it would seem at first glance for three reasons: (1) the cities have expanded and taken over land previously used for agriculture; (2) there are much larger return flows from cities than from a corresponding agricultural area, even though the same amount is approximately needed on a per acre basis for both uses; and (3) at the present time, the cities have surplus water and are "renting" it to agricultural and industrial users.

IV ADAPTATION OF THE INPUT-OUTPUT MODEL TO THE CACHE LA POUDRE CASE

This chapter outlines the general procedures used in the study. In addition, it describes some of the problems involved and general assumptions made in adapting the empirical data to the requirements of the input-output model.

4.1 Input-Output Representation of the Cachle La Poudre Water System

4.1.1 Boundaries. The selection of the boundaries of the water system to be modeled was the first operational problem of the study. The need for a boundary proceeds from the necessity of setting a limit to the extent of the analysis.

Since the analysis was performed in terms of a "system representation," the word "boundary" is here meant to be the "system" boundary. The selection of the "system" boundary proceeds from the selection of the "geographical" boundary of the study area. Then, considerations about the purpose of the modeling and the nature of the water exchanges lead to understand the relevance of the various components of the *real* system; from this process one can select the appropriate components to be introduced in the *modeled* system.

The Cache La Poudre River basin geographical boundary was set as a rough tentative boundary for the *modeled* system. Within this geographical boundary, and external to it as necessary, the components of the water system must be specified. The specification of system components should generally derive from the particular purposes or uses of the model. Here, however, just a general depiction of the water system was pursued, since the "use" of the model is subject to the purpose of the user. The "in basin" water users and water structures (transfer, storage and treatment) were considered within the system. However, since a considerable source of supply for the Cache La Poudre basin is from out of basin import, all the import structures were included in the modeled system.

The imports from the Colorado River and the North Platte River basins occurred through transmountain diversion structures (Colorado-Big Thompson Delivery System Grand River Ditch, Michigan Ditch, Cameron Pass Ditch, Skyline Ditch, Laramie-Poudre Tunnel and Wilson Ditch). Other imports occurred through irrigation ditches originating in the Big Thompson Basin. These are Louden Ditch, Oklahoma Ditch, Boomerang Lateral and Grapevine Lateral. All these structures were considered as components of the study area water system. The neighboring basins where these import waters originated (i.e., Colorado River basin, North Platte River basin and Big Thompson River basin) were considered out of the system; they were introduced as "entries" to the system, and no insight into their characteristics was developed. On the other hand, some water is exported from the Cache La Poudre River basin through irrigation ditches (Larimer and Weld Canal, Pierce Lateral, Collins Lateral and Greeley No. 2 Canal). These structures were considered part of the water system too, but the basins where this water was delivered were excluded from the system (Crow Creek Basin and Other South Platte Sub-basins) and were considered as "exits" solely.

Particular attention had to be given to the urban structure of the study area since the expanding urbanization is likely to become one of the critical factors of the water uses in the future. Also some rural water districts, located wholly or partially outside the basin, are supplied with water originating in the Cache La Poudre Basin and delivered through facilities within the basin. Moreover, the territorial planning in these areas falls in the same unit as the Cache La Poudre Basin municipalities. Therefore, it was felt appropriate to include some "rural" establishments within the Cache La Poudre Water System. These are Ault, Pierce and Nunn (Crow Creek Basin) and Evans (Big Thompson Basin); they were introduced in the modeled system as part of the "Cache La Poudre Rural Domestic Users." However, their wastewaters were considered exiting the system and discharged to "exit" elements as "Out of Basin Aquifers" and "Other South Platte Sub-basins."

4.1.2 Selection of the key components of the Cache La Poudre water system. The system components used in the model were classified as *entry components, internal components,* and *exit components.* Those system components from which entry of water to the system occurs are "entry" components. Those from which exit of water from the system occurs are "exit" components. Those which permit or facilitate water transfers within the system are "internal" components. The selection of those system components to be included within the model was based upon judgment according to what seemed relevant for the system operation from both the structural or quantitative point of view. From this, the internal components selected included major municipal and domestic water user entities in the basin, major irrigated areas, the major water and sewage treatment plants and urban collection and distribution systems, the major reservoirs, the major irrigation ditches, the major industries, the major conveyance structures to or from the river reaches, major tributaries, and river reaches. A total of 109 internal components were included in the model. These components were classified in seven groups: "Transbasin Diversions," "Cache La Poudre Reaches and Tributaries," "Reservoirs and Lakes," "Ditches and Canals," "Municipal Sector," "Industrial Sector," and "Agriculture Sector and Other Lands."

Seven transbasin diversion structures were included in the first group. These are all the transmountain diversion structures importing water into Cache La Poudre River basin. Four other structures importing irrigation water from Big Thompson River basin were considered as "Ditches and Canals."

The Cache La Poudre River was divided into six reaches, defined by the mileages at their respective extremities, starting from the confluence with the South Platte River. The three upper reaches (Source-Mile 96, Mile 96-Mile 61, Mile 61-Mile 56) lay in the mountain portion of the Cache La Poudre basin (above the mouth of Poudre Canyon). The lower reaches (Mile 56-Mile 47, Mile 47-Mile 21, Mile 21-Mile 00) lay in the plains valley. The availability of the flow and diversion data in the six reaches helps in the evaluation of water use, reuse and discharge and would help in the assessment of environmental considerations. Three tributaries of the Cache La Poudre River were given identity as individual components of the water system; they included: The "North Fork of Cache La Poudre," "Eaton Draw" and "Boxelder Creek." The "North

Fork of Cache La Poudre" was included because of the quite relevant diversions occurring on it and because it receives some import water. "Boxelder Creek" and "Eaton Draw" were considered relevant not because of their natural flow (it is really negligible) but because they receive treated sewage discharged by the "Wellington Sewage Treatment Plant" and the "Eaton Sewage Treatment Plant." Other tributaries actually delivered their waters to Cache La Poudre River, but since no particularly interesting operation role was involved, their runoff was included within the land runoff from "Mountain Lands" and "Unirrigated Plains" to the river or the reservoirs.

Twenty-five relevant "Reservoirs and Lakes" were included in the system. Some reservoirs were grouped together into aggregated entities. All the geological aquifer formations underlying the Cache La Poudre basin were unified into one single entity referred as "Aquifer." The "Aquifer" was included in the "Reservoirs and Lakes" group too. Some small lakes and reservoirs were not considered, since their effect on the total water system was deemed negligible.

The "Ditches and Canals" group had thirty-four components. These comprise a near complete accounting of the irrigation diversion structures in the area.

The "Municipal Sector" contains twenty components. These include domestic water users, treatment plants, water distribution systems, and sewerage systems. Only two major municipal users, the "City of Greeley" and the "City of Fort Collins," were given individuality; the rest were aggregated as one single component under the name of "Cache La Poudre Rural Domestic Users." This group included also some smaller rural municipalities such as Windsor, Wellington, Timnath, Eaton, Pierce, Ault, and Nunn. Five water treatment plants and eight sewage treatment plants are included in the model. The sewage treatment plants considered are those discharging into basin streams or reservoirs. The discharges from land disposal treatment facilities were considered to flow directly from the users to the "Aquifer" (by infiltration) or to the "Atmosphere" (by evaporation). The Fort Collins and Greeley water distribution and sewerage systems were given individuality too, as components of the "Municipal Sector."

Ten "Industries" were identified in the system. Nine of these are individual plants. The tenth element lumps together the "minor industries" of the area.

The "Agriculture Sector and Other Lands" includes: The "Mountain Lands" and the "Unirrigated Plains" as runoff formation areas and the "Upper Cache La Poudre Irrigated Areas" and "Lower Cache La Poudre Irrigated Areas" as use elements. These four types of land cover the whole Cache La Poudre basin area. The Foothills area is quite small and was split between the "Mountain Lands" and "Unirrigated Plains" for the sake of the input-output modeling. The "upper" and "lower" classification for the irrigated areas was established according to the possibility of reusing municipal treated water for irrigation purposes. This possibility occurs in the "lower" portion only.

Besides the "internal" components of the system, eight "Entry" elements and six "Exit" elements were indicated. The "Entry" elements included: The "Atmosphere" as the source of the precipitation over the basin, the "Reservoir Storage" and "Groundwater Storage" to take into account the volumes kept in storage from a prior year and currently withdrawn and introduced into the system, the "Out of Basin Aquifers" to take into account the underground inflows from other basins. Also, three neighboring basins export water into Cache La Poudre Basin ("Big Thompson Basin," "Colorado River Basin" and "North Platte Basin"). Finally, "Other Origins," is an entry component identity created to take into account other water additions to the Cache La Poudre water system, originating from sugar beets.

The "Exit" elements include: the "Atmosphere" as destination of evaporation and evapotranspiration water, the "Reservoir Storage" and "Groundwater Storage" as destination of some water savings for release in later years, the "Out of Basin Aquifers" for taking into account the groundwater outflows and finally "Crow Creek Basin" and "Other South Platte Sub-basins" to take account of the river discharge to South Platte River, of irrigation exports, and of some out-of-basin domestic discharges.

4.1.3 Time horizon. Two different time-related problems arise in the input-output modeling of a water system. The first relates to the time unit to be used, the second to the calendar time position of the selected unit. For planning purposes, a time unit too short has little practical utility and too many iterations would be required to cover a cycle of system fluctuations. These fluctuations occur in both resource availability and use demand; they are more relevant for the demands, since the storage capacity within the basin smooths the natural hydrologic fluctuations. However, to prepare entire sets of input-output models for short time increments to account for flow variations would be very time consuming (and beyond the scope of this demonstration). It could be done through an operation study where such transient information is needed and where the input-output modeling would provide an adaptive format for the management of the cyclic data, eventually by means of some computerized algorithm.

An annual basis was selected for this demonstration since the annual cycle characterizes a system adequately for planning purposes. Of course, the operation detail is lost but the model is fairly representative for planning use. However, sometimes it was needed to go through the monthly or daily operation in order to "construct" or derive the yearly information. Thus, using the same time basis as in the "South Platte Study" (Hendricks et al., 1977) provides a common dimension for comparisons and deductions. The input-output model of the whole South Platte River basin used the year 1970 as the base model; this study used the year 1970 also.

The 1970 year was considered representative of the system structure as determined by Hendricks et al. (1977). This observation solves to a great extent the question of the representativeness of the model over a longer time horizon but still leaves the problem of what can happen under drought conditions. Then, it is recommended that at least another input-output representation, under drought scenario, would be coupled to the average condition representation when dealing with an actual planning problem.

4.1.4 Use and transfer units. The input-output modeling of a water system is based upon the mass balance of each system component and therefore implies a consistent unit for the water exchanges to be used throughout the representation of all the transfers. The numbers representing the water transfer should be intended as "gross" transfers among the system elements. Introducing "net" transfers would deform the meaning of the model representation and would overshade much information. Refer, for clarity, to an example in the Cache La Poudre water system. The "Fort Collins - Poudre Water Treatment Plant" diverted 9,701 acre-feet from the Cache La Poudre River (Mile 61-Mile 56) in 1970. Of this amount, 784 acre-feet were returned to the river as backwash water. This makes a "net" exchange of 8,917 acre-feet from the river to the water treatment plant. However, representing the water exchange as 8,917 acre-feet would be inexact. It could lead to the conclusion that an amount of 8,917 acre-feet available in the river could satisfy the water treatment plant demand, and it is not true, since the operation of the plant requires the further "circular" exchange of 784 acre-feet for its backwash. Then, the interaction between river and water treatment plant has to be represented by an amount of 9,701 acre-feet flowing from the river to the plant and by an amount of 784 acre-feet flowing from the plant to the river. Another typical case requesting attention is the industrial recycle. If an industry diverts a certain amount of water for its use and then recycles it for internal reuse, an indication of the net exchange between source and industry (i.e., withdrawal) wouldn't be sufficient, since the process water needed by the industry wouldn't be represented by this transfer. A transfer from the industry to the industry itself should be marked.

In order to achieve a proper mass-balance and make sure that water is not improperly represented as lost or gained, the magnitude of the smallest transfer will determine how many significant figures must be carried throughout the model. The unit which was selected for representing the water exchanges is the acre-foot and all the figures were rounded to this unity. The acre-foot is indeed an unit small enough to represent even the minor exchanges with suitable precision.

It could be objected that the acre-feet is an unit too small for representing the biggest water exchanges within the Cache La Poudre water system, in some cases amounting to hundreds of thousands of acre-feet. Then the last digits for the biggest water exchanges would be purely fictious. Actually, precision is not claimed for the last digits of the biggest figures — especially those such as groundwater related transfers. An approximation within 10 percent is estimated for all the water exchanges unless otherwise noted. Thus deviations in the hundreds or even thousands of acre-feet might exist for the biggest exchanges; however, this is still acceptable compared with the order of magnitude of the exchange. Because of this, the biggest water exchanges were used as necessary as "slack variables" for absorbing unavoidable inconsistencies in data. This was done more extensively for the case of exchanges related to the aquifer. These exchanges can be expected to include the strongest inaccuracies, say

25 percent as an estimated order of magnitude. However, the last digits can't be dropped even in the biggest exchanges if the mass-balance with the smallest has to be maintained. The maintenance of the significant figures also facilitates documentation of data.

4.1.5 Matrix representation. As soon as the key elements of the Cache La Poudre water system were selected, they were displayed in the input-output matrix format, as labels to rows and columns, and positioned according to the selected grouping as explained in paragraph 4.1.2.

The matrix representation was used even throughout the process of selection of the key elements, in order to provide the framework to fit these elements and to check their particular meanings and rules within the system representation of the water exchanges being developed. Moreover, the matrix provided help in the iterative process of the selection of those particular components which could be significant in the model as a representation of the system.

Finally, an ultimate setting for the matrix rows and columns was determined (i.e., system components and groups were definitely selected), the final elements and their grouping "settled" in the matrix and the water exchanges were determined as illustrated in Chapter V according to the process presented in the paragraph following (4.1.6).

Two color codes were used for the numbers in the transfers: yellow when simple transportation was involved, white when the exchange implied use. A "star" was used to mark those column elements having a "use" role in the water system.

4.1.6 Mass balance of the water exchanges. The complete matrix of the water exchanges in an input-output model representation will satisfy the water mass balances of all system components and the system as a whole. When all of the individual mass balances are satisfied, the whole water system representation can be considered "balanced" and complete.

The problem in using the available data was to assemble and complete them in such a way as to "fill" the whole network of water exchanges in the system with historically realistic figures and so that the mass balances could be satisfied. The information was not available in such a proper organized pattern and therefore extensive preparation work was required.

The input-output matrix actually provided an organized format for seeking needed data. The first step was to mark those elements in the matrix which contained water transfers. From this, a first collection of data was pursued. This first set of data was then put on the matrix in the appropriate matrix elements. The mass-balance procedure was able to determine what was needed in additional data.

The use of the input-output matrix helped considerably in managing the mass balances. As soon as the value of an input or an output for an element was determined and introduced in the matrix, an output or an input was automatically assigned to the other system element which was the "partner" in the water exchange.

When at any time during this iterative process only one exchange for an element remained unknown, it was soon computed by means of the mass-balance procedure and introduced in the matrix. This procedure was followed through repeated iterations until the whole matrix was completed.

4.2 Information Management

4.2.1 Data requirements. The procurement of the data about the amounts of water flowing in each water exchange within the system required searching, estimating and adjustment of data from various sources. All the information was of course related to the 1970 water year or calendar year as explained in paragraph 4.2.3. The need of "filling" the whole set of water transfers required an extensive procurement of data, covering the whole field of operation of the selected key components of the Cache La Poudre River basin water system. The type of data needed for each of the categories within each sector are described in Table 4-1. This table demonstrates how broad the field to be covered by the information searching is if a depiction of a "total" water system is pursued.

4.2.2 Source of the basic information. The information described in Table 4-1 was only partially available in the same format or assembly as needed for use in the intput-output model. Most data needed some adjustments or derivation. Three types of data were used: data from available records (provided by the related water organizations), estimated data, and data derived by computations. The data obtained from available records is discussed here.

The information about population and its distribution within the study area was provided by the "1970 U.S. Census of Population." The values were available in easily usable form from the "Larimer County, Colorado" information book (Colorado State University, 1973).

Municipal and other domestic water use information was provided to some extent by city records. This information was not enough to cover the whole field of the municipal and domestic water sub-system. Estimates from the knowledge of the populations and per capita use were needed also. In addition to city records, data were provided by the administrations of the water districts operating in the study area, and by operators of water and wastewater treatment plants. Some of these data were already partially organized by Janonis (1977).

The water import quantities were provided by USGS records (Water Resource Data for Colorado, 1970) and were obtained also from the compilations of Gerlek (1977). The USGS records reported all the amounts entering the basin study area through transmountain diversion structures. Gerlek reported the imports from Big Thompson River basin through irrigation ditches. Precipitation data in selected rain gages were available through the U.S. Department of Commerce, Weather Bureau reports.

Records about river diversions to irrigation ditches and canals were provided by the Commissioner for Water District No. 3, Colorado State Engineer Office. The Commissioner was able to provide data about reservoir inflows and outflows and about storage levels.

Table 4-1. Data Requirements for the Input-Output Model of Cache La Poudre Basin Water System.

Sector	Required Information
Entries	Precipitation over the basin; aquifer depletion; reservoir depletion; out of basin aquifer inflows; sugar beet water; imports through trans-mountain diversions; imports through irrigation ditches.
Municipal Sector	Diverted amounts to water treatment plants; water treatment plant back-wash water uses; amounts distributed to the various users or to distribution systems by the water treatment plants; amounts distributed by the water distribution systems to municipalities and industries; municipal and other domestic return flows to sewer systems, sewage treatment plants, aquifer and atmosphere; infiltrations into sewer systems; amounts delivered by the sewer systems to the wastewater treatment plants; amounts discharged by the wastewater treatment plants into rivers, aquifer, lakes or evaporated.
Industrial Sector	Amounts supplied to each industry by municipal water distribution systems; amounts diverted from the river; amounts pumped from aquifer; amounts of water entering or leaving the industry together with the raw water or the products; amounts discharged to aquifer, to river, to wastewater treatment facilities and to urban sewer systems; consumptive uses.
Cache La Poudre Reaches and Tributaries	Diversions from each reach or tributary to agricultural ditches, water treatment plants, industries; amounts flowing into reservoirs and lakes; municipal and industrial discharges; agricultural ditch discharges; river flows at each reach extremity and at tributary confluences; surface basin runoff; groundwater runoff.
Agriculture Sector and Other Lands	Total precipitation over each type of land; evaporation; evapotranspiration; surface runoff to the river or its tributaries, reservoirs and lakes; aquifer infiltration; groundwater irrigation, surface water irrigation.
Reservoirs and Lakes	Aquifer infiltrations from lands, ditches, canals, lakes and reservoirs; amounts discharged by sewage treatment plants and rural septic tanks; total aquifer depletion or volumes received to storage; groundwater runoff to the river reaches and tributaries; aquifer agriculture withdrawals; aquifer domestic withdrawals; river flows to reservoirs and lakes; inlet flows to reservoir and lakes; transbasin diversion inflows; municipal discharges to reservoirs and lakes; reservoir stored and released amounts; reservoir and lake infiltrations into aquifer; reservoir releases to river, to irrigation ditches or to other reservoirs; reservoir municipal diversions.
Ditches and Canals	Diverted amounts; aquifer infiltrations; evaporation losses; releases to other ditches and canals or to reservoirs; amounts released to irrigation; amounts released to other river basins.
Exits	Evaporation from urban and rural domestic uses; industry consumptive use; evaporation from wastewater treatment plants; reservoir evaporation; ditch and canal evaporation; row land evaporation; agriculture evapotranspiration; amounts put in reservoir and groundwater storage; groundwater flows to other basins; irrigation deliveries to other basins; out of basin deliveries by the Cache La Poudre water distribution systems and water treatment plants; Cache La Poudre discharge into South Platte River.

The information about industry water uses and return flows were mostly derived from Patterson's analysis (1977), and personal conversations. The agriculture water consumptive uses were derived from the analysis of Gerlek and Janonis (1977).

Other data were derived by estimates or computations. No quanitative data were found about groundwater uses and return flows. However, all the needed derivations were based upon related real information. Reports prepared by engineering consulting firms for local water organizations were used also.

4.2.3 Interpretation, evaluation and completion of the available data. Much of the available data needed to be adjusted or interpreted before input-output model use. This was mainly due to four reasons: (1) some data were not complete or were available just sparsely on monthly or daily basis, (2) some data were not available for the 1970 year, (3) some of them were available in different aggregation units than the acre-foot and (4) some inconsistencies occurred when more than one source was available.

Some liberties were taken to make these data usable. Flow data in the format of uniform average flow through the year, was converted into acre-feet. When the available information didn't refer to 1970 but to another year, it was considered for acceptance. An assessment was made of the reliability of such data for 1970. When the needed data was sparsely available for shorter time units than the year, the data for the missing periods were interpolated.

The data inconsistencies where different sources of information were available didn't really give too much trouble. The order of magnitude of the data from the various sources was usually the same. In such cases the selection of a particular datum was arbitrary. The coincidence of the orders of magnitude and the relative small relevance of the adjustments were considered a guarantee not to affect the total exchange framework.

Another problem relates to the assemblage of the directly available 1970 data as established and aggregated by the various water organizations. Some of these data referred to the 1970 calendar year, while others referred to the 1970 water year (October 1969 - September 1970). Information from any of the two types of source was freely used without providing adjustments. Actually, it was assumed that the differences between the water exchanges in the October - December 1969 and 1970 periods were not going to sensibly affect the whole exchange framework.

Much data were estimated or computed, especially those data in the groundwater related exchanges and the rural domestic water uses. It was a general policy to obtain the estimates from somebody who had familiarity with the related part of the water system. Of course, absolute reliability of these estimates is not guaranteed, but the method promised to be reliable and was applied whenever possible. The persons who provided such estimates are cited, as appropriate, throughout the report.

V DOCUMENTATION OF DATA

This chapter describes how the water exchanges which occur among the selected key components of the water system were evaluated quantitatively. The manner in which this was achieved is described herein. The chapter is supported by nine appendices where the water mass balances of all the selected key components are individually depicted by diagram.

The work is consistent, as possible, with the "South Platte Study," reported by Hendricks, et al. (1977); the case study part of this research could be considered as a "zoom" on a sub-basin of that study, focusing with larger resolution upon the Cache La Poudre River basin.

The assemblage of the information needed for establishing the mass balance of the whole Cache La Poudre water system was started with the determination of the water uses by municipal, industrial and agriculture sectors and the respective return flows. After these sectors were balanced, their interaction with the river subsystem was automatically established.

The second phase was the mass balance of the main "resource" components internal to the system; i.e., the river and the aquifer. The river subsystem lays partially in the mountain area of the basin and partially in the plains. Different procedures were used for each portion. For the mountain stream, the aquifer runoff to the river was first computed and the surface runoff was then determined through the mass balance of the stream. In the plains stream, however, the surface runoff is negligible. Thus, the surface runoff was assumed zero and the aquifer runoff was computed through the mass balance of the plains stream.

The mass balance of the land was established in the third phase. The surface runoff to the river had been already determined; the aquifer infiltration was evaluated by the mass-balance procedure. The fourth and last phase was the mass balancing of the aquifer. All the withdrawals and recharges were already determined; the net exchange with the neighboring out of basin aquifers was determined also through the mass-balance procedure. The calculations show a net groundwater outflow from the basin.

5.1 Origins of Water in the Cache La Poudre Water System

All the water being exchanged within the Cache La Poudre water system originated from the eight components comprised under the "entries" classification. Some of these entries refer to water withdrawals from basin storage held over from the previous year, i.e., "Groundwater Storage" and "Reservoir Storage." The "Groundwater Storage" was assumed not to be active in 1970, however, some water originated from "Reservoir Storage." This water was held in reservoirs or lakes since the previous year and was withdrawn in 1970. The existence of such an entry is detected by a reservoir or lake level being lower at the end of the year than at the beginning. This type of entry is fully discussed in paragraph 5.4.2.

Some water was introduced in the water system as internal moisture in industrial raw materials. This was the case with respect to water derived from sugar beets during the pulping process. Such water was accounted as originating from "Other Origins." The amount was large enough in that the mass balance of the sugar beet factory required that it be included.

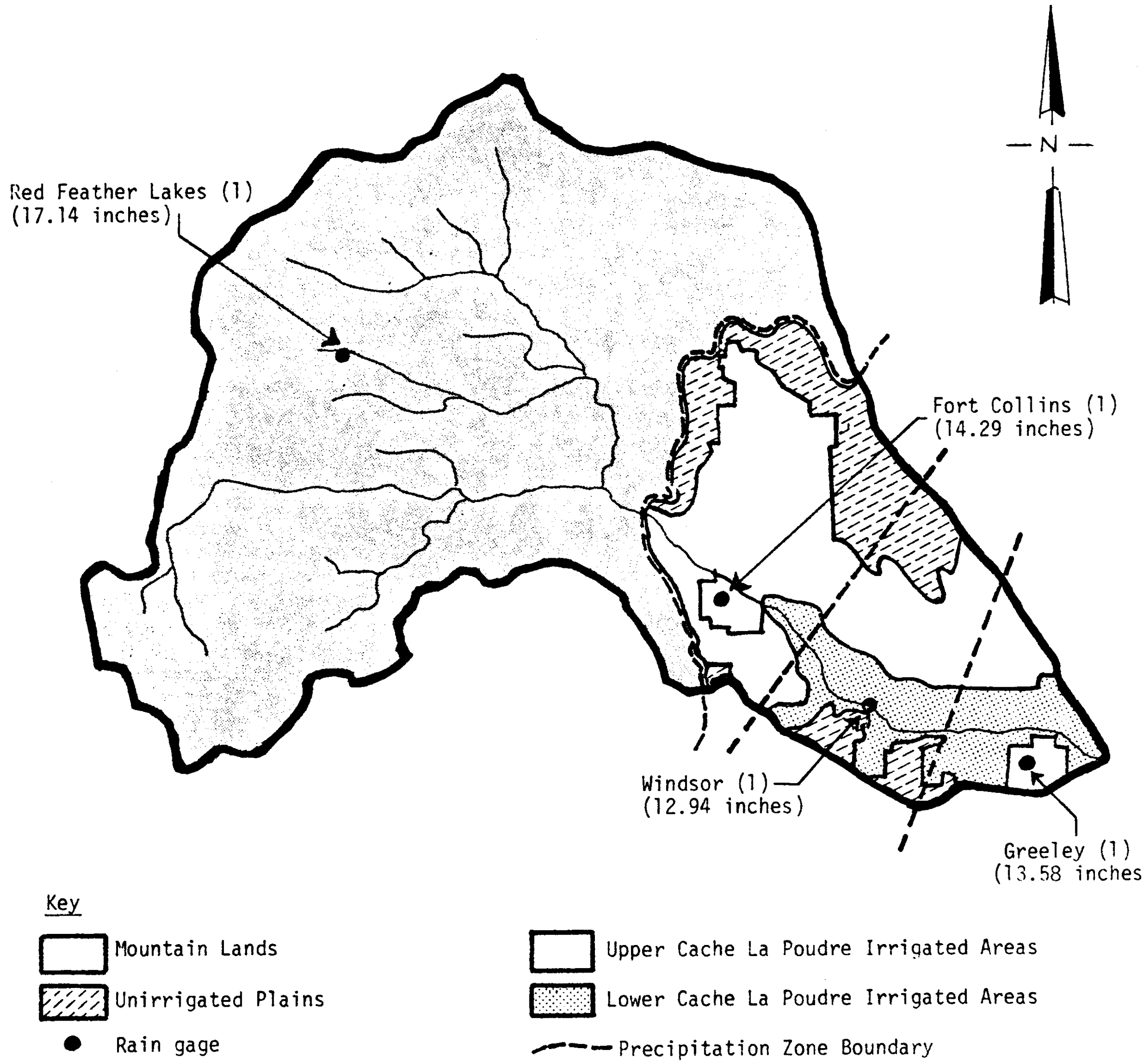
The rest of the water (the greatest amount) originated from the "Atmosphere" through precipitation, or from imports from other basins. These sources are discussed in the paragraphs 5.1.1 and 5.1.2, respectively.

5.1.1 Precipitation over the study area. The information about precipitation over the Cache La Poudre River basin was derived from the records of the Weather Bureau, U.S. Department of Commerce. Four rain gages within the Cache La Poudre River basin were selected as representative of the precipitation over portions of the basin. The gages are identified as: Red Feather Lakes, Fort Collins, Windsor and Greeley. The respective locations of these selected rain gages are shown in Figure 5-1. All the four mentioned gaging stations reported records for 1970 as follows: 17.14" at Red Feather Lakes; 14.29" at Fort Collins; 12.94" at Windsor; 13.58" at Greeley.

Four "precipitation areas" were determined over the basin according to the estimated area representation of the four rain gages. The Red Feather Lakes rain gage was considered representative of the precipitation over all the mountain portion of the basin. This mountain portion was defined as all the basin area laying at high elevation west and north of the 5,600 feet contour line. This boundary was determined by the definite drop of altitude which occurs quite suddenly at this contour. Then the Thiessen method (Ven Te Chow, 1964) was used to estimate area-wide precipitation for the plains precipitation zone, using the data from the three plains gages. The bisecting perpendicular lines to the straight line connections between the Fort Collins, Windsor and Greeley gages were assumed as boundaries of the area coverage representative of each gage. In this way four precipitation areas were determined. These four areas are seen in Figure 5-1. Their boundaries are represented by dotted lines.

The area of the Cache La Poudre basin was divided in four land zones, each of them considered as an individual component of the Cache La Poudre water System; they were designated as "Mountain Lands," "Unirrigated Plains," "Upper Cache La Poudre Irrigated Areas" and "Lower Cache La Poudre Irrigated Areas." They are seen in Figure 5-1 also.

The total precipitation volumes occurring over each of the four land areas were calculated and summed as shown in the tabular format of Figure 5-1. The respective precipitation volumes were: 1,263,728 acre-feet over the "Mountain Lands," 103,314 acre-feet over the "Unirrigated Plains," 220,239 acre-feet over the "Upper Cache La Poudre Irrigated Areas," and 65,340 acre-feet over the "Lower Cache La Poudre Irrigated Areas." The total precipitation volume over the entire basin was 1,652,621 acre-feet. Some 76 percent of this total precipitation occurred over the "Mountain Lands."



Type of land	Area Within Each Precipitation Zone (Acres)				Total Precipitation on each type of land (acre-feet)(2)
	17.14 in.	14.29 in.	12.94 in.	13.58 in.	
Mountain Lands	884,757				1,263,728
Unirrigated Plains		59,520	30,080		103,314
Upper Cache La Poudre Irrigated Areas		102,039	55,343	15,566	220,239
Lower Cache La Poudre Irrigated Area		4,369	28,946	21,300	65,340
Total Precipitation over Cache La Poudre Basin					1,652,621

(1) U.S. Department of Commerce, Weather Bureau.
(2) These are the summations of the products of the areas in each precipitation zone times the precipitation in each zone times the factor 1/12 to transform inches of precipitation in feet.

Figure 5-1. Precipitation Over Cache La Poudre River Basin in 1970.

The "destinations" of the precipitation were surface runoff to reservoir or surface drainage, infiltration into aquifer, evaporation or evapotranspiration. A 70 percent of the precipitation over the "Mountain Lands" and a 75 percent of the precipitation over the "Unirrigated Plains" was assumed to return to the atmosphere as evaporation, amounting to 884,610 acre-feet and 77,485 acre-feet respectively. The remaining amounts (379,118 acre-feet and 25,828 acre-feet) produced surface runoff to the surface drainage and reservoirs, or infiltrated into the aquifer. The surface runoffs are shown in Appendix H (Figures H-1) and H-2) and are justified in paragraph 5.4.2 (runoff to reservoirs and lakes), 5.5.1 and 5.5.2 (runoffs to the mountain reaches of Cache La Poudre River and to the North Fork). However, no direct surface runoff to the river from the "unirrigated plains" was considered, being actually negligible according to the opinion of Mr. John Neutze, Water Commissioner for Cache La Poudre basin. The total runoffs from "Mountain Lands" and "Unirrigated Plains" to the surface drainage, reservoirs or lakes amounted to 282,201 and 22,287 acre-feet respectively, as can be computed from the individual runoff values to the various destinations shown in Appendix H, Figures H-1 and H-2. The mass-balance of these two areas yielded aquifer infiltration amounts of 96,917 acre-feet from the "Mountain Lands" and 3,542 acre-feet from the "Unirrigated Plains."

An amount of 9.07 inches of the precipitation over the irrigated areas was considered "effective" (i.e., usable) for crop consumptive use. This value was estimated by Gerlek and Janonis (1977) and accepted in this study. The evapotranspiration rates times the acreage of the "upper" and "lower" irrigated areas give evapotranspirated volumes of 130,720 and 41,280 acre-feet respectively. More complete details about the deposition of the precipitation over the irrigated areas are given in paragraph 5.4.3.

5.1.2 Water imports into Cache La Poudre River Basin. Extensive information about water imports into the Cache La Poudre River basin was available from the "South Platte Study" (Gerlek, 1977). The material presented herein was partially derived from this source and completed as needed for use in the Cache La Poudre input-output water model.

Four different types of water imports into the Cache La Poudre Basin water system can be listed: (1) Colorado-Big Thompson Project water imports through the Horsetooth reservoir, (2) Colorado-Big Thompson project water imports through the Loveland Lake for municipal use by the City of Greeley, (3) irrigation ditch imports from the Big Thompson River basin, and (4) other transmountain diversions occurring at the headwaters of the Cache La Poudre River.

<u>The Colorado Big-Thompson Project</u> - At the present time, the largest imported source of "foreign" water into the Cache La Poudre drainage is the Colorado-Big Thompson Project (CBT). The facilities of the project collect water from the watershed of the Colorado River and transport it through a 13.1 mile tunnel (Gerlek, 1977, p. 8-19) beneath Longs Peak into a tributary of the Big Thompson River. Water deliveries were begun in 1947. Approximately 46 percent of CBT water is delivered

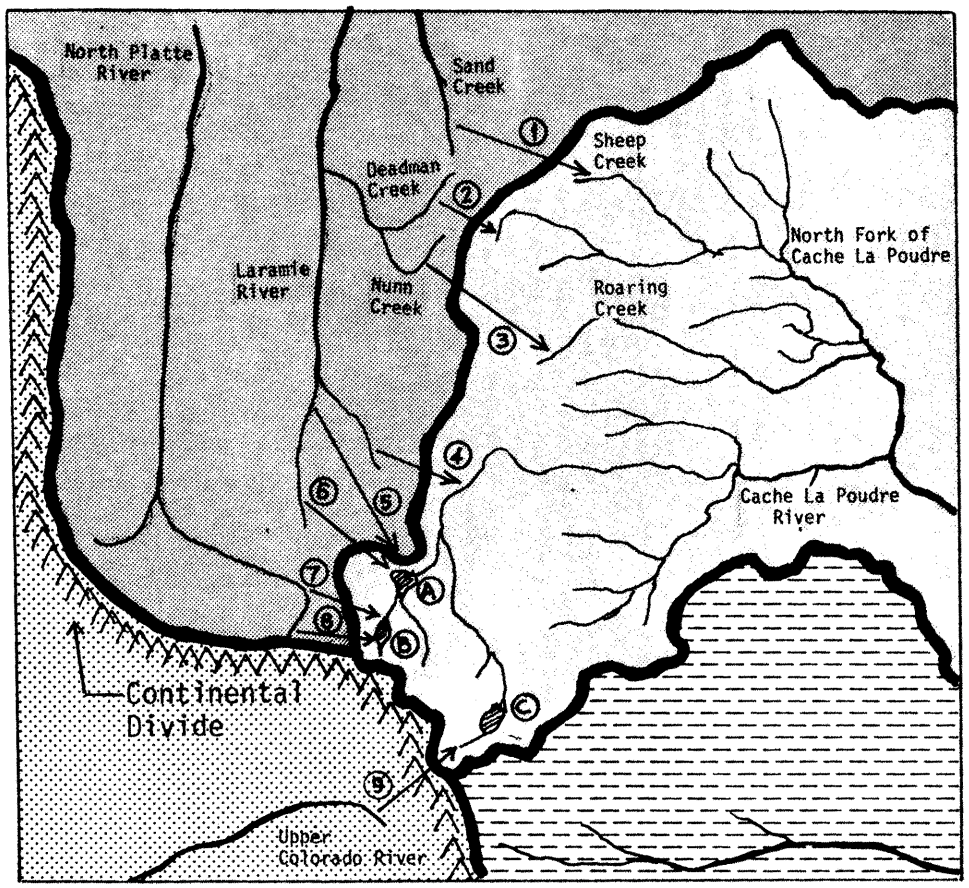
to the Cache La Poudre area (Evans, 1971). Horsetooth Reservoir, with a capacity of 151,752 acre-feet, is the main facility in the Cache La Poudre area. The reservoir supplements agricultural and domestic water users, and it has a recreational function as well.

The key west slope storage facility is Lake Granby. Water is pumped from Lake Granby to Shadow Mountain Lake, flowing then to Grand Lake, the intake for the Alva B. Adams Tunnel. Water levels, of both Shadow Mountain Lake and Grand Lake are maintained about constant, and so these lakes serve the project as "conduits" for CBT water. Green Mountain Reservoir was built in the Blue River drainage as a part of the CBT project to provide replacement storage to maintain flows of the Colorado River, satisfying prior water rights (e.g., the Shoshone right) and providing sufficient residual water for future development of the west slope. From Grand Lake, the CBT water flows by gravity beneath the Continental Divide through the 13.1 mile Alva B. Adams Tunnel to the eastern slope, emerging in the Big Thompson River basin, about 4 - 1/2 miles southwest of the twon of Estes Park. Here this water, augmented at times by flows from the Big Thompson River, is conveyed through canals, conduits, tunnels, regulating reservoirs, and hydroelectric power plants to Horsetooth Reservoir and Carter Lake, the principal east slope storage facilities. Water is released from these reservoirs for distribution through supply canals to the Cache La Poudre, and Big Thompson, St. Vrain, Boulder and South Platte-Transition and plains sub-basins. From these streams the CBT water is then diverted through existing canal systems to provide supplemental irrigation water to some 720,000 acres of land included in the NCWCD service area (Gerlek, 1977).

The Colorado-Big Thompson Project is capable of supplying about 720,000 acre-feet of water to the Colorado eastern slope area. However, even before the project was entirely completed, it was supplying water to the eastern slope. For example, 1954 was an extremely dry year and even though the project was not completely finished, it was able to supply well over 300,000 acre-feet of water which saved many of the crops that particular year (Skogerboe, Radisevich and Vlachos, 1973).

The total diversions of Colorado River water through the Colorado-Big Thompson project facilities amounted to 204,600 acre-feet in 1970 (Gerlek, 1977). A large portion of this amount (105,815 acre-feet) was delivered to Horsetooth Reservoir. This value was computed through the mass balance of inputs and outputs in Horsetooth reservoir (see Appendix D, Figure D-9). The rest of the diverted water (98,785 acre-feet, see Appendix B, Figure B-1) was assumed to be delivered to "Other South Platte Sub-basins."

<u>Transmountain ditches</u> - The natural flow of the Cache La Poudre River is augmented by a number of transbasin diversions (see Figure 5-2). The Cache La Poudre is over appropriated as are most streams in Colorado and the imported water was developed to supplement the supply. However, the direct importation is limited by Colorado water rights which are superposed on the limitations of the Laramie River Decree, the Colorado River Compact, and the North Platte River Decree.



Key

TRANSBASIN DIVERSION STRUCTURES:

1 Wilson Supply Ditch
2 Columbine Ditch (Closed)
3 Bob Creek Ditch (Closed)
4 Laramie-Poudre Tunnel
5 Skyline Ditch
6 Lost Lake Outlet (closed)
7 Cameron Pass Ditch
8 Michigan Ditch
9 Grand River Ditch

RESERVOIRS:

A Chambers Lake
B Joe Wright Reservoir
C Long Draw Reservoir

Colorado River Basin
North Platte River Basin
Big Thompson River Basin
Cache La Poudre River Basin

Figure 5-2. Transbasin Diversion Structures Importing West Slope Water Into Cache La Poudre River Basin.

Nine diversion structures have been built to import water directly to the Cache La Poudre Basin from watersheds outside of the South Platte River basin. These are listed in Figure 5-2. Only six of these structures are still in operation. They import water from the Colorado River basin, the North Platte River basin and the Laramie River basin. The Laramie River is a tributary of the North Platte river. No individuality was given to Laramie River basin as an entry element and the water diverted from this river was considered as originating in the "North Platte Basin."

The Grand River Ditch is the oldest operating transbasin diversion between the Colorado and the Cache La Poudre Basins. The structure intercepts the very high altitude runoff just under and along the west side of the Continental Divide and transports the water collected across the Continental Divide via La Poudre Pass, at an elevation of 10,190 feet, discharging into Long Draw Reservior on the Cache La Poudre River. The North Feeder of the Grand River Ditch is 15 miles long, winding around the East Slope of the Never Summer Mountains; it has collection points on Baker Gulch and Red Gulch and on Mesquito, Lost, Big Dutch, Little Dutch, Saw Mill, Lulu, Lady, and Bennett Creeks. The South Feeder of the Grand River Ditch is two miles long and it diverts water from Specimen Creek. The water rights for this ditch total 524.6 cfs (Johnson, 1976). Construction on this ditch began in 1890. It was generally cut by hand into steep hill sides with the excavated material used to form the lower or outside bank. The first water was diverted in 1892. By 1908 the North Feeder extending to Dutch Creek was almost half complete. Long Draw Reservior was completed in 1929 with a capacity of 4,400 acre-feet. The North Feeder was further extended in the 1930's. In 1975 parts of the Ditch were lined and the capacity of Long Draw Reservoir was increased to 10,800 acre-feet. The Grand River Ditch is owned by the Water Supply and Storage Company.

The Cameron Pass ditch diverts waters from tributaries of the Michigan River in the North Platte basin and transports them through Cameron Pass at an elevation of 10,300 feet to Joe Wright Creek, a tributary of the Cache La Poudre River. The diverted water is regulated by the Joe Wright Reservoir and then further regulated in Chambers Lake for subsequent release. In the input-output model these imports are considered as to be delivered directly to Joe Wright reservoir. Diversions prior to the North Platte River Decree (1945) averaged 260 acre-feet per year, and 107 acre-feet per year thereafter. Much of this decrease can be attributed to the expense of maintenance. The Cameron Pass Ditch is owned by the Water Supply and Storage Company which uses the imported water for irrigation. There are presently no plans to increase diversions through this ditch (Johnson, 1976).

The Michigan Ditch formerly known as the Rist and McNab Ditch, also diverts water from tributaries of the Michigan River and transports it through Cameron Pass to Joe Wright Creek. In addition, storage is provided by the same facilities used by the Cameron Pass Ditch, i.e., Joe Wright Reservoir and Chambers Lake. The Michigan Ditch has a water right for 121.0 cfs, which was adjudicated in 1908 with a priority of July, 1902, (United States Bureau of Reclamation, 1959). The Michigan Ditch deliveries are considered to flow directly to the Joe Wright Reservoir in the input-output model. Diversions prior to the North Platte River Decree (1945) averaged 3,389 acre-feet per year and 1,190 acre-feet per year thereafter. Again, much of this decrease can be attributed to the expense of maintenance.

The Wilson ditch, formerly known as the Sand Creek System or as Sand Creek ditch, diverts water at 8,600 feet from Sand Creek and at times from Deadman Creek, a tributary to Nunn Creek in the North Platte Basin. It delivers this water to Sheep Creek, a tributary of the North Fork of the Cache La Poudre. In the input-output model this water is considered to flow directly to the North Fork of Cache La Poudre. Diversions from Deadman Creek are subject to the provisions of the 1957 Laramie River Agreement. Diversions have averaged 834 acre-feet per year since 1957 and 987 acre-feet per year prior to 1957. Diversions from Sand Creek are not constrained by this decree and have averaged 1,919 acre-feet per year over the period in which records are available. The Wilson Supply Ditch is owned by the Divide Reservoir and Supply Company, an irrigation water supplier (Neutze, 1976). Construction of the ditch is believed to have commenced in 1899 and the first recorded diversions of water occurred in 1902 (United States Bureau of Reclamation, 1959).

The Columbine Ditch was built by the Mountain and Plains Irrigation Company, a company chartered in the early 1900's. Water was first brought through this ditch in 1921. Exports averaged 121 acre-feet per year until the ditch was discontinued in 1957 by Court Order from the case Wyoming vs. Colorado, 289 U.S. 573. This ditch diverted water at 10,300 feet from Deadman Creek, a tributary to Nunn Creek, to the North Fork of the Cache La Poudre River. The Columbine Ditch is now owned by the City of Greeley (Evans, 1971).

The Bob Creek ditch diverted at 9,900 feet from Nunn Creek in the North Platte Basin, to Roaring Fork, a tributary of the Cache La Poudre River. Water was first brought through this ditch in 1920. Diversions averaged 358 acre-feet per year until the ditch was discontinued in 1957 by Court Order from Wyoming vs. Colorado, 289 U.S. 573. The Bob Creek Ditch was also built by the Mountains and Plains Irrigation Company and it is presently owned by the City of Greeley (Evans, 1971).

The Laramie-Poudre tunnel, sometimes known as the Greeley-Poudre Tunnel, was the first tunnel constructed in the South Platte River Basin for the transbasin diversion of water. It diverts water at 8,570 feet from tributaries of the Laramie River, via the Rawah and Lower Supply Collection Ditches, to the Cache La Poudre River about eight miles downstream from Chambers Lake. The tunnel is 7.5 feet wide, 9.5 feet high, 11,306 feet long and has a capacity of 1,000 cfs. (United State Bureau of Reclamation, 1959). As a consequence of the disputes between Colorado and Wyoming over the apportionment of the Laramie River, the original 1902 priority date given to this tunnel by the Colorado State Supreme Court was changed to 1909 by the United States Supreme Court in 1922. The initial diversion through the tunnel was made in 1914. Prior to the Laramie River Decree (1957) the Laramie-Poudre Tunnel diverted an average of 9,657 acre-feet per year. Presently they average 15,630 acre-feet per year. Construction of this tunnel began in 1909. Although it was completed in 1911, diversions did not begin until 1914 because of the Laramie River apportionment disputes between Wyoming and Colorado. The ownership of this tunnel and its water rights are split between the Water Supply and Storage Company, which owns two-thirds interest, and the Windsor Reservoir and Canal Company which owns one-third interest.

The Skyline Ditch diverts water from the west branch of the Laramie River and from Two and One-half Mile Creek to Chambers Lake. The Skyline Ditch is located at an elevation of 9,100 feet, is five miles long, and has the physical capacity to deliver 400 cfs. (United States Bureau of Reclamation, 1959). In 1891 heavy rains washed out Chambers Lake Dam which had been used up to that time to impound native Cache La Poudre flows for irrigation. Construction of the Skyline Ditch was started with reconstruction of the dam. Diversions prior to the 1957 Laramie River Decree averaged 14,128 acre-feet per year, and 1,707 acre-feet per year, respectively. The Skyline Ditch is owned by the Water Supply and Storage Company. Since 1957 they have diverted by exchange through the Laramie Poudre Tunnel (which they own part interest in) some water previously exported through this ditch. The constraints of the Laramie River Decree cut down their previous import amounts and by transferring the water from Skyline to the Laramie Poudre Tunnel they are aboe to make the most effective use of what they have been allocated (Johnson, 1976).

The Lost Lake Outlet was built in 1898. Water was first brought through the ditch in 1899. It diverted water from the Laramie River at 9,180 feet to Chambers Lake. Exports averaged 215 acre-feet per year till it was ordered closed by the State Engineer of Colorado in 1950 (Evans, 1971).

These transmountain diversion structures are listed in Table 5-1 together with their 1970 imports, as reported by the USGS in "Water Resource Data for Colorado, 1970." The table lists also the source and destination of water and the periods of operation for each structure. The input-output mass balances of these import structures are presented in Appendix B.

Imports through irrigation ditches - Some water is imported into the Cache La Poudre basin through irrigation ditches. There are four ditches delivering water originated from Big Thompson River rights. These are "Louden Ditch," "Oklahoma Ditch," "Boomerang Lateral" and "Grapevine Lateral." Gerlek (1977) estimated a total import of 31,344 acre-feet in 1970 through these ditches. Gerlek's values were accepted in this study. These structures and their 1970 estimated imports are listed in Table 5-1. An 8 percent of these imports was assumed to be lost to the aquifer by seepage. The remaining amounts were delivered to "lower Cache La Poudre Irrigated Areas." The mass balances of these four agriculture ditches importing foreign water are depicted in Appendix E, Figures E-31, E-32, E-33, and E-34.

Direct municipal imports - Janonis (1977) reported that some Colorado-Big Thompson Project water is delivered directly to the

Table 5-1. Transbasin Diversions Importing Water into the Cache La Poudre River Basin (1).

	Transb. Diversion Structures	Source	Destination	Years of operation (2)	1970 Imports (acr.-ft.)(3)
Imports through Transmountain diversions	Colo.-Big-Thomp. Deliv. Sys.	Colorado Basin	Horsetooth Res.	1947-Present	105,815
	Grand River Ditch	Colorado Basin	Long Draw Res.	1892-Present	12,830
	Michigan Ditch	North Platte Basin	Joe Wright Res.	1905-Present	0
	Cameron Pass Ditch	North Platte Basin	Joe Wright Res.	1913-Present	0
	Skyline Ditch	North Platte Basin	Chambers Lake	1893-Present	1,550
	Laramie-Poudre Tunnel	North Platte Basin	CLP(4)Source-Mile 94	1914-Present	14,990
	Wilson Ditch	North Platte Basin	North Fork of CLP(4)	1902-Present	2,910
	Columbine Ditch	North Platte Basin	North Fork of CLP(4)	1921-1956	0
	Bob Creek Ditch	North Platte Basin	North Fork of CLP(4)	1920-1956	0
Imports from Big. Thomp.Bas.	Louden Ditch	Big Thompson Basin	Irrig. System (5)	Unknown	9,541
	Oklahoma Ditch	Big Thompson Basin	Irrig. System (5)	Unknown	6,900
	Boomerang Lateral	Big Thompson Basin	Irrig. System (5)	Unknown	7,806
	Grapevine Lateral	Big Thompson Basin	Irrig. System (5)	Unknown	7,097
Total Imports to Cache La Poudre River Basin (1)					169,439

(1) 1740 ac-ft supplied by the Big Thompson Basin to Greeley are excluded from this Table.
(2) Hendricks, et al, 1977.
(3) USGS, Water Res. Data for Colo., 1970.
(4) Cache La Poudre River.
(5) Actually, To lower CLP irrigation & aquifer seepage.

"Greeley Boyd Lake Water Treatment Plants" without passing through the Horsetooth reservoir. This amount was reported as 1,740 acre-feet.

This Colorado-Big Thompson water is reported in the input-output model as originating in the Big Thompson basin. Actually these 1,740 acre-feet are among the 98,785 acre-feet (see Figure B-1) which were delivered by the Colorado-Big Thompson Delivery System to "Other South Platte Sub-basins" (in particular Big Thompson River basin).

In summary, a total of 171,179 acre-feet was imported into the Cache La Poudre River Water System in 1970. Of these, 105,815 acre-feet were imported through the Coloado-Big Thompson Delivery System and the Horsetooth reservoir, 32,280 acre-feet through other trans-mountain import structures from Colorado and North Platte river basins, 31,344 through irrigation ditches from the Big Thompson Basin and 1,740 acre-feet of Colorado-Big Thompson Water directly to the "Greeley Boyd Lake Water Treatment Plants."

5.2 Municipal Sector

Three major municipal water users of the Cache La Poudre Water System are: the "City of Fort Collins," the "City of Greeley," and the "Cache La Poudre Rural Domestic Users." The "City of Fort Collins" and the "City of Greeley" get their water from Fort Collins and Greeley distribution systems. The "Fort Collins distribution system" is in turn supplied by the two Fort Collins water treatment plants: "Fort Collins-Poudre" and "Fort Collins-Horsetooth." The Fort Collins and Greeley distribution systems supply also some industrial water. The "Greeley Distribution System" is supplied by the "Greeley-Poudre" and "Greeley-Boyd Lake" water treatment plants. The "Cache La Poudre Rural Domestic Users" get their water from the "Soldier Canyon Water Treatment Plant," the "Aquifer" and the Fort Collins and Greeley distribution systems. No individuality was given in the input-output model to the rural domestic water distribution systems. However, this water is administered by the several water districts established in the study area.

The return flows of the two main towns of the area are collected by the "Fort Collins Sewer System" and the "Greeley Sewer System." The Fort Collins sewer system collects also some wastewater from some minor rural establishements included in the "Cache La Poudre Rural Domestic Users" and some industrial return flows. The "Fort Collins Sewer System" delivered its wastewater to the two Fort Collins wastewater treatment facilities usually refereed to as "No. 1" and "No. 2." The effluents were then discharged into the Cache La Poudre River or stored in Fossil Creek Reservoir for later agriculture use. The "Greeley Sewer System" delivered its effluent to the "Greeley Wastewater Treatment Facilities" and in turn to the Cache La Poudre River. The "Cache La Poudre Rural Domestic Users" wastewaters were partially collected under the administration of several sanitation districts. These sanitation districts delivered their water to the "Fort Collins Sewer System" or to their own sewage treatment plants. These include the Boxelder Sanitation District Sewage Treatment Plant, South Fort Collins Sanitation District Sewage Treatment Plant, Wellington Sewage Treatment Plant, Windsor Sewage Treatment Plant, and Eaton Sewage Treatment Plant. Some of the smallest sewage treatment plants use lagoon or land disposal treatment processes. These plants were not given individuality as elements of the system and are not mentioned in this report. Their correspondent discharges were represented as flowing directly from the "Cache La Poudre Rural Domestic Users" to the "Aquifer" or the "Atmosphere."

5.2.1 Fort Collins water system. The City of Fort Collins is located adjacent to the Cache La Poudre River, on the plains just east of the foothills and approximately 28 miles south of the Colorado-Wyoming border. It is one of the fastest growing cities in the nation. Census figures show that the Fort Collins population has grown from 25,000 in 1960 to 43,337 in 1970 (Colorado Division of Planning, 1976). It is ranked as the largest municipality within the study area according to the 1970 population estimate. The Fort Collins Distribution system supplies also the "West Fort Collins Water District," serving a rural population of 800 inhabitants in 1970.

Fort Collins has very little "water intensive" industry. A 1975 study estimated that the total industrial use amounted to less than 0.1 mgd (Toups, 1975). The major employer of area residents is Colorado State University, which has a student population of approximately 16,800 (Janonis, 1977).

Water supply - Fort Collins uses direct flow and storage rights to satisfy its water supply needs. The direct flow rights amount to 19.94 cfs from the Cache La Poudre River (Toups, 1975). The storage rights are for 10,291 shares of Colorado-Big Thompson Project water from Horsetooth Reservoir.

Fort Collins also has rights in a number of ditch companies. Much of this water has been acquired through city ordinances relative to original water service, but is rented back to the irrigation companies.

The city owns no high mountain storage and relies mostly on direct river flow or exchange for its supply. Water from Horsetooth Reservoir is used during periods when the demand exceeds either what can be satisfied by river diversion or the treatment capaicty of the "Poudre" treatment plant. This period is generally from April to October.

A tabulation of Fort Collins water rights is shown in Table 5-2. The water yield from these rights can never be totally realized because of low river flows. The yield from the Cache La Poudre water rights has averaged 10,867 acre-feet for the period 1969 to 1975. This is about 75 percent of the decreed direct flow rights.

Water treatment and distribution - Fort Collins has two water treatment plants located in Poudre Canyon and on La Porte Avenue below Horsetooth Reservoir, respectively. The "Poudre" water treatment plant is located in the Poudre Canyon and diverts water from Cache La Poudre river in the reach between miles 61 and 56. The "Horsetooth" Water Treatment Plant is located near the Soldier Canyon Dam; it diverts water from the "Horsetooth Reservoir." This water from the Colorado-Big Thompson project is delivered to the treatment plant through the "Dixon Feeder Canal" (Northern Colorado Water Conservancy District, Summary of Delivery Operations for 1970). The "Poudre" water treatment plant has

Table 5-2. City of Fort Collins Water Rights (1).

Type and location of Water Right	Amount	Appropriation Date	Basin Rank
I. Direct Flow Rights from Cache La Poudre River (2)	3.50 cfs. 2.16 cfs. 7.00 cfs. 2.78 cfs. 4.50 cfs.	6/01/1860 3/01/1862 3/15/1862 9/15/1864 5/01/1865	14 56 58 126 140
II Colorado Big Thompson Project (3)	10,291 units	—	—
III Irrigation Water Rights by Ditch Co. (3)			
North Poudre	4,723 ac.ft.	—	—
Pleasant Valley	3,782 ac.ft.	—	—
Arthur	187 ac.ft.	—	—
Larimer Co. No. 2	706 ac.ft.	—	—
New Mercer	177 ac.ft.	—	—
Warren Lake Res. Co.	347 ac.ft.	—	—
Water Supply & Storage	1,061 ac.ft.	—	—

(1) Derived from Janonis, 1977.
(2) Colorado State Engineer's Records for Water Division No. 1, Revised Priority List, 10/10/1974.
(3) Toups, 1975.

a present peak treatment capacity of 20.0 mgd., while the Horsetooth plant has a 24.0 mgd peak treatment capacity (Liquin, 10/8/76).

Janonis (1977) shows that 11,147 acre-feet were supplied by both plants to the "Fort Collins Distribution System" in the 1970 water year. City records for the "Horsetooth Water Treatment Plant" show that 2,230 acre-feet were supplied by this plant. The remaining 8,917 acre-feet were supplied by the "Poudre" plant. For each treatment plant more water was treated than actually delivered to the "Fort Collins distribution system," because of backwash water requirements. At the Poudre plant the backwash water was immediately discharged back to the river. Bluestein and Hendricks (1975) gave an average backwash flow of 0.7 mgd in 1971. Assuming that this value is valid for 1970 a total discharge of 784 acre-feet results.

At the Horsetooth water treatment plant the backwash water was discharged to settling and evaporation ponds before being recycled into the head of the plant (Janonis, 1977). The Dixon Feeder Canal diverted to the plant 2,506 acre-feet in 1970 (Nothern Colorado Water Conservancy District, Summary of Delivery Operations for 1970). Since 2,230 acre-feet were supplied to the Fort Collins Distribution system, the difference, 276 acre-feet, was assumed to be evaporated from the ponds. The water mass-balances for the two Fort Collins water treatment plants are shown in Appendix F, Figures F-7 and F-8.

The "Fort Collins Distribution System" supplied the "City of Fort Collins," some industries and the "Cache La Poudre Rural Domestic Users" through the West Fort Collins Water District. An amount of 107 acre-feet was supplied through this district (information received by direct telephone conversation). Janonis (1977) reported that 936 acre-feet were supplied to industries: 825 acre-feet to the "Fort Collins Power Plant" and 111 acre-feet to "Minor Industries." Then the mass balance of the "Fort Collins Distribution System" shows that a total amount of 10,104 acre-feet was directly supplied to the "City of Fort Collins" for domestic uses (see Appendix F, Figure F-10).

<u>Wastewater collection</u> - The Fort Collins sewer system collects the city wastewater, some industrial return flows and some "Rural Domestic Users" wastewater. Janonis (1977) estimated that the only industrial return flow to the "Fort Collins Sewer System" was from the "Minor Industries," amounting to 111 acre-feet. The only discharge from the "Cache La Poudre Rural Domestic Users" into Fort Collins sewers is the one delivered by the Mountain View Sanitation District estimated to be 118 acre-feet (see paragraph 5.2.3). Table 5-3 shows the distribution of flows in the Plant No. 2 for 1970. The total flow for 1970 was 8,315 acre-feet.

A considerable amount of groundwater infiltration into the Fort Collins sewer system is known to occur. An estimate by Mr. Chuck Inghram, Superintendent of the Fort Colins Sewage Treatment Plant No. 2 is that 50% of the summer flows and 10% of the winter flows in the sewer system were due to external infiltration. Based upon this assumption, and upon the data in Table 5-3, a computation of the infiltrated amounts was possible, and is shown in Table 5-4. The total annual sewage flow of 8,315 acre-feet was distributed among the various months, and then the

Table 5-3. Daily Records of the Flows Through the Fort Collins Sewage Treatment Plant No. 2 (1).

		Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Calendar Day	1	2.8	-	2.1	2.3	2.4	-	6.9	4.6	-	3.4	-	-
	2	2.3	2.1	-	-	-	3.3	-	-	3.9	-	-	-
	3	2.6	-	-	-	2.3	-	-	-	-	-	-	-
	4	2.7	-	2.3	2.5	-	3.0	-	4.7	4.0	-	-	-
	5	2.8	2.2	-	-	-	-	-	-	-	-	-	-
	6	1.9	-	-	2.9	2.4	-	5.3	-	-	-	-	-
	7	1.2	-	2.2	-	-	-	-	4.5		3.0	-	-
	8	1.2	2.2	-	-	-	-	-	-	-	-	-	-
	9	1.3	-	2.1	2.6	2.5	3.3		-	3.6	-	-	-
	10	2.7	-	-	-	-	-	-	4.7	3.5	-	-	-
	11	2.8	2.2	-	2.5	2.3	-	-	-	-	-	-	1.9
	12	2.3	-	2.2	-	-	9.8	-	-	-	-	-	-
	13	2.7	2.3	-	-	-	-	-	-	-	-	-	-
	14	2.4	-	-	2.5	2.4	-	-	-	-	-	-	-
	15	2.4	-	2.3	-	-	-	6.2	-	3.5	6.7	-	2.5
	16	2.4	2.0	-	2.4	-	4.7	-	-	3.3	-	-	-
	17	2.3	-	-	-	2.4	-	5.1	-	-	-	-	-
	18	2.3	-	2.3	-	-	-	-	4.5	4.3	-	-	-
	19	2.3	2.2	-	2.4	-	-	-	4.3	-	-	-	-
	20	2.4	-	2.2	-	2.6	-	-	-	-	-	-	-
	21	2.3	-	-	2.6	-	-	-	4.4	-	-	-	0.8
	22	2.3	2.1	1.9	-	-	-	-	-	-	5.6	-	0.8
	23	2.6	-	-	-	-	7.4	5.3	-	5.3	-	-	-
	24	2.3	-	-	2.4	-	-		-	3.8	-	-	-
	25	2.3	2.3	-	-	-	7.2	-	-	3.1	1.5	-	-
	26	2.1	-	2.2	-	3.1	-	-	4.5	-	1.8	-	-
	27	2.4	-	-	2.2	-	-	-	4.8	-	3.3	-	-
	28	2.3	2.1	2.3	-	3.1	-	-	-	-	3.5	-	-
	29	2.3		-	-	-	-	5.7	-	-	-	-	1.2
	30	2.3		2.0	2.6	-	-	-	-	-	-	-	-
	31	2.3		-		-		-	-		-		-
No. of Records		31	10	12	12	10	7	6	9	10	8	0	5
Monthly totals		71.3	60.9	67.5	75.0	79.5	165.7	178.5	141.4	114.9	111.4	77.6 ( )	43.8

(1) Information supplied by Mr. Chuck Inghram, Superintendent, Fort Collins Sewage Treatment Plant No. 2. All the amounts are in millions of gallons. The winter flows, i.e. from September to April were discharged to Fossil Creek Reservoir inlet and were stored for summer irrigation use (622 MG, i.e. 1,893 Ac-ft). The summer flows (May to August) were discharged to Cache La Poudre River, between mile 47 and mile 21 (565 MG, i.e. 1,724 Ac-ft). 3617 Acre-feet were totally treated at the plant in 1970. A flow equal to the average over the days showing records was assigned to the days where no record was available in order to compute the monthly totals.

Table 5-4. Aquifer Infiltration into Fort Collins Sewer System in 1970.

Months	Monthly percent of year flow (1)	Monthly Inputs to Sewer System (Ac.-ft)(1)	Aquifer Originated percents of flow (2)	Aquifer Infiltrations into Sewer System (Acre-feet)
Jan.	6.0	499	10	50
Feb.	5.1	424	10	42
Mar.	5.6	466	10	47
Apr.	6.3	524	10	52
May	6.6	549	50	275
June	14.0	1,164	50	582
July	15.2	1,264	50	633
Aug.	11.9	989	50	494
Sept.	9.8	815	10	81
Oct.	9.4	782	10	78
Nov.	6.5	540	10	54
Dec.	3.6	299	10	30
Totals	100.0	8,315		2,418

(1) The distribution of Fort Collins Wastewaters was assumed equal to the flow distribution in Ft. Collins Sewage Treatment Plant No. 2 (See Table 5-3). The total amount through the sewer system in 1970 (8315 ac-ft) was assumed to be distributed along the year according to these percentages.
(2) These values were estimated by Mr. Chuck Inghram, Superintendent, Ft. Collins Sew. Tr. Pl. No. 2.

monthly infiltration values were computed as indicated in Table 5-4. This gives a total 1970 infiltration of 2,418 acre-feet. Janonis (1977) reported that the Fort Collins Sewer System delivered 4,698 and 3,617 acre-feet respectively to the two Fort Collins Sewage Treatment Plants. Then, the mass-balance of the "Fort Collins Sewer System" indicated (Appendix F, Figure F-13) that 5,668 acre-feet were discharged by the "City of Fort Collins." The "City of Fort Collins" mass balance (Appendix F, Figure F-11) showed that 4,436 acre-feet were lost to atmosphere as consumptive use.

Wastewater treatment and disposal - Fort Collins has two wastewater treatment plants in operation. The older one (Fort Collins Sewage Treatment Plant No. 1) is located just north of Highway 14 on the Cache La Poudre River.

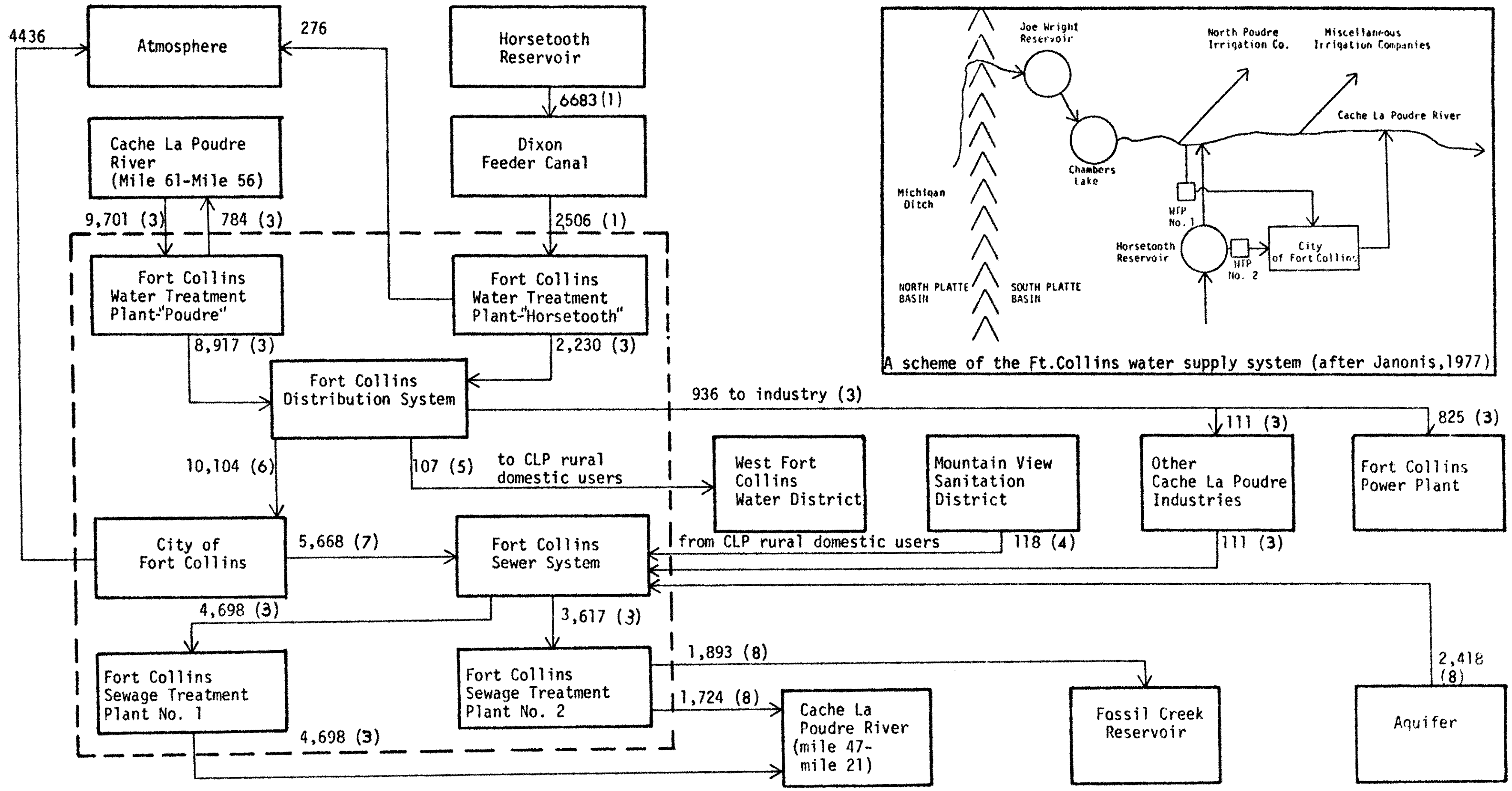
It is a 5.0 mdg (average design flow) trickling filter plant made over into an activated sludge wastewater treatment plant. The newer plant (Fort Collins Sewage Treatment Plant No. 2), located west of the Cache La Poudre River on Drake Road, became operational in December 1968. The original plant No. 2 has a 4.8 mgd average design flow capacity; it operates on the activated sludge process. The enlargements are located on Drake Road just north of the original plant. This enlargement has a 16.0 mgd average design flow, also operating on the activated sludge process. It became operational only in January 1977.

Data taken from city records and reported by Janonis (1977) show that 4,698 acre-feet of wastewater were treated by the "Fort Collins Sewage Treatment Plant No. 1." Data for sewage treatment plant No. 2 were taken from Tuck (1971) because the city records are incomplete due to a breakdown in the metering system. Tuck estimated these flows. His work gives a flow of 3,617 acre-feet for Sewage Treatment Plant No. 2 in the 1970 water year.

The Fort Collins Sewage Treatment Plant No. 1 discharged its effluent into Cache La Poudre River, in the reach between miles 47 and 21. Its water balance is given in Appendix F, Figure F-14. The Plant No. 2 discharged its effluent into the Cache La Poudre River (miles 47-21) during the summer (May to August); this amounted to 1,724 acre-feet (see the computation in Table 5-3). The rest of the flow, 1,893 acre-feet, was discharged into the "Fossil Creek Reservoir Inlet." The flow was stored in that reservoir for later summer agriculture reuse. The mass balance for Fort Collins Sewage Treatment Plant No. 2 is shown in Appendix F, Figure F-15.

An assemblage of the 1970 water exchanges in the Fort Collins water system was also prepared. It is shown in Figure 5-3.

5.2.2 Greeley water system. The City of Greeley is located on the Cache La Poudre River at an elevation of 4,663 feet. Greeley is the most eastern of the study area municipalities, located about 24 miles east of the foothills and 40 miles south of the Colorado-Wyoming border. According to the 1970 population data, Greeley is the second largest municipality within the study area, with a population of 38,902 (Colorado Division of Planning, 1976).



(1) Northern Colorado Water Conservation District,Summary of Delivery Operations for 1970.
(2) Computed through mass balance of Fort Collins Water Treatment Plant -"Horsetooth".
(3) Janonis,1977.
(4) Estimated on the basis of a served population of 750,using 200 gallons/capita-day.Only 70% of the used water is assumed to reach the sewers.
(5) Information supplied by West Fort Collins Water District.
(6) Janonis(1977)gives a total distributed amount equal to 10,211 acre-feet.107 ac-ft.go to Cache la Poudre Rural Domestic Users and the remaining portion goes to the City of Fort Collins.
(7) Computed through the mass balance of the Fort Collins Sewer System.
(8) Estimated on the basis of the information supplied by Mr.Chuck Inghram,Superintendent,Fort Collins Sewage Treatment Plant No.2

Figure 5-3. City of Fort Collins Water System and 1970 Water Balance (Amounts in Acre-Feet).

<u>Water supply</u>. The City of Greeley owns rights to the surface flows of the Cache La Poudre River and owns shares of water from the Colorado-Big Thompson Project. The Cache La Poudre direct flow rights are considered senior rights and total 12 1/2 cfs (Toups, 1975). In addition, Greeley also owns storage rights in a number of mountain lakes and reservoirs tributary to the Cache La Poudre River which total about 5,000 acre-feet per year. Greeley presently owns 17,888 shares of the Colorado-Big Thompson Project water (Alleman, 10/29/76).

The high mountain storage is an important facet in supplying water to Greeley water system because it provides control and flexibility in the use of water. Greeley currently owns Hourglass, Comanche, Twin Lake, Barnes Meadow, and Peterson Lake Reservoirs. Seaman Reservoir, which is located in the foothills at an elevation of about 5,600 feet, was acquired by the City in 1940 (Toups, 1975). The total storage capacity of these reservoirs is 13,219 acre-feet (Janonis, 1977).

<u>Water treatment and distribution</u> - The Greeley water system includes three water treatment facilities. One of these plants is located on the Cache La Poudre River at Bellvue. The other two are located near Boyd Lake, east of Loveland. These two plants were given unique individuality as a single element in the Cache La Poudre Water System under the name of "Greeley Boyd Lake Water Treatment Plants." However, one of the two Boyd Lake plants was not yet operating in 1970.

The "Bellvue" water treatment plant, which was built in 1901, diverts water from the Cache La Poudre River reach between miles 56 and 47. This water is treated by rapid sand filtration without coagulation. The plant presently has a capacity of 18.0 mgd (Alleman, 10/29/76). Treated water is used in backwashing the filters. Currently, all backwash water is reclaimed. In 1970 it was discharged back to the river.

Construction of Boyd Lake Water Treatment Plant No. 1 was completed in the spring of 1976. This plant is located on the south end of Boyd Lake. Boyd Lake Water Treatment Plant No. 1 treats Colorado-Big Thompson Project water diverted from Lake Loveland. Its present treatment capacity is 20.0 mgd (Alleman, 10/29/76). Treated water is used for filter and microstrainer backwash. The waste backwash water is recycled back to the head end of the plant preventing a waste discharge.

The Boyd Lake Water Treatment Plant No. 2, which is the oldest of the two Boyd Lake plants, was completed in 1969. This plant, located south of Boyd Lake, treats Colorado-Big Thompson Project water from Lake Loveland. The treatment consists of microstrainig, coagulation, and filtration of raw water. The plant presently has a capacity of 10.0 mgd (Alleman, 10/29/76). Treated water is used for filter and microstrainer backwash. Prior to January 1977 the waste backwash water was discharged to Boyd Lake (EPA Permit No.: CO-0001881, 1973). Now all backwash water is recycled to the head of the plant.

Data for the Greeley diversions in 1970 were available on the calendar year basis. Data from the city records show that a total of 14,025 acre-feet was delivered in 1970 to the "Greeley Distribution System." Janonis (1977) reports that of this water, 1,740 acre-feet was delivered by Boyd Lake Water Treatment Plant No. 2; the remaining 12,285 acre-feet was delivered by the Bellvue plant.

The Bellvue treatment plant diverted and treated more water than was actually delivered as product water because the waste backwash water was discharged to the river from the plant. The average discharge from the Bellvue plant to the Cache La Poudre River was 0.6 mgd (672 acre-feet) in 1971 (EPA, 1974). Assuming this figure is valid for 1970, then the Bellvue plant diverted 12,957 acre-feet (Janonis, 1977). The mass balance of "Greeley Bellvue" water treatment plant is shown in Appendix F, Figure F-1.

The Boyd Lake Plant No. 2 discharges its waste backwash water to Boyd Lake where it is settled. This system is essentially a recycle type system. For the purpose of this study, it was assumed to be a closed system and that the water treated and delivered by the Boyd Lake plant No. 2 was equal to its diversion. Thus, Boyd Lake plant No. 2 was assumed to have delivered 1,740 acre-feet in 1970 (Janonis, 1977). The mass-balance of Greeley "Boyd Lake" water treatment plants is shown in Appendix F, Figure F-2.

The "Greeley Distribution System" delivers the 14,025 acre-feet received by the Greeley Treatment plants to the various users. These include the "City of Greeley," some small municipalities within the "Cache La Poudre Rural Domestic Users" (Evans, Windsor and Timnath), three water districts also included among the "Cache La Poudre Rural Domestic Users" (Crestview, Harris and Sharkstooth) and three industries: "Montfort" (Meat Packing), "Eastman Kodak" and "Greeley G. W. Sugar Beet Factory." These industries were assumed to receive 617, 32 and 276 acre-feet respectively, according to Janonis (1977). The deliveries to the water districts amounted to a total of 80 acre-feet, as stated by Mr. Tom Ullman, Water Department, City of Greeley (Crestview: 70 acre-feet; Harris, 5 acre-feet; Sharkestooth: 5 acre-feet). The minor municipalities of Windsor, Evans and Timnath received respectively 350 acre-feet, 600 acre-feet, and 39 acre-feet. These values were estimated on the basis of populations of 1,564 inhabitants for Windsor, 2,570 inhabitants for Evans and 177 inhabitants for Timnath (as shown in Table 3-5, after 1970 U.S. Census) using 200 gallons per capita/day. Then, the total deliveries to "Cache La Poudre Rural Domestic Users" amounted to 1,069 acre-feet in 1970. The remaining amount (12,031 acre-feet as can be seen in the mass balance of Greeley Distribution System" in Appendix F, Figure F-3) was assumed to be delivered to the "City of Greeley."

Wastewater collection, treatment and disposal - The "Greeley Sewer System" collects the wastewater from the "City of Greeley" and an industry effluent (Monfort). Prior to 1973, Monfort discharged into the "Greeley Sewer System" (Alleman, 7/14/75). At that time Monfort's industrial wastewater treatment facility became operational. This plant utilizes anaerobic lagoons, extended aeration and polishing ponds for treatment. The plant now discharges to Lone Tree Creek about one mile north of its confluence with the South Platte River (Toups, 1974).

Greeley presently has two wastewater treatment plants in operation. The South Side First Avenue Plant, built in 1936, is located just south of the Cache La Poudre River on First Avenue. This plant is a high rate trickling filter plant which has a design capacity of 2.0 mgd (Toups, 1974). The North Side First Avenue Plant, built in 1965, is located just north of the Cache La Poudre River on First Avenue. The latter is an activated sludge process plant which has a design capacity of 7.0 mgd (Toups, 1974). The two plants were lumped together for the sake of the input-output modeling under the name of "Greeley Sewage Treatment Facilities."

As far as can be determined no records were kept for the wastewater treatment plants of Greeley prior to 1971. Janonis (1977) estimated a total wastewater flow of 8,190 acre-feet in 1970. This effluent was discharged into Cache La Poudre (miles 21-00) after treatment. The mass balance of "Greeley Sewage Treatment Facilities" is shown in Appendix F, Figure F-6. The industrial discharge from "Monfort" to the "Greeley Sewer System" was reported by Janonis (1977) to be 1,792 acre-feet. (This amount is higher than the delivery by the "Greeley Distribution System" since "Monfort" has other supply sources too.) The mass balance of the "Greeley Sewer System" (Appendix F, Figure F-5) determined a 6,398 acre-feet return flow from the "City of Greeley." In turn, the mass balance of the "City of Greeley" determined that 5,633 acre-feet were lost to atmosphere as consumptive use, assuming that no other supply or exit existed for the city (see Appendix F, Figure F-4).

A pictorial frame of the water supply facilities for the City of Greeley is shown in Figure 5-4. The numerical evaluations of the water exchanges are assembled and graphically represented in Figure 5-5.

5.2.3 Rural Cache La Poudre domestic water system. Even if the majority of the population in the study area lives in the two major cities of Fort Collins and Greeley, still a large portion (35,801 over 118,040) is spread over the countryside. This population is partially concentrated in several small towns lying almost entirely in the plains valley of the Cache La Poudre Basin. These towns are Wellington, Livermore, Ault, Nunn, Pierce, Eaton, Evans and Windsor. Some of these rural municipalities are undergoing a fast population increase mainly related to the establishment of large industries in the area. However, many persons in this population are still dedicated to farming activities.

Some of the small mentioned municipalities are actually located out of what is considered the geographical boundary of the Cache La Poudre River basin. These are Pierce and Nunn in the Crow Creek basin and Evans in the direct South Platte drainage. These communities were included in the study area anyway, since their water supply, distribution, or disposal systems are tied to the other Cache La Poudre basin exchanges.

Some of the Fort Collins and Greeley peripherial population is also considered as "rural." For the purpose of the input-output modeling, the total study area population besides the Fort Collins and

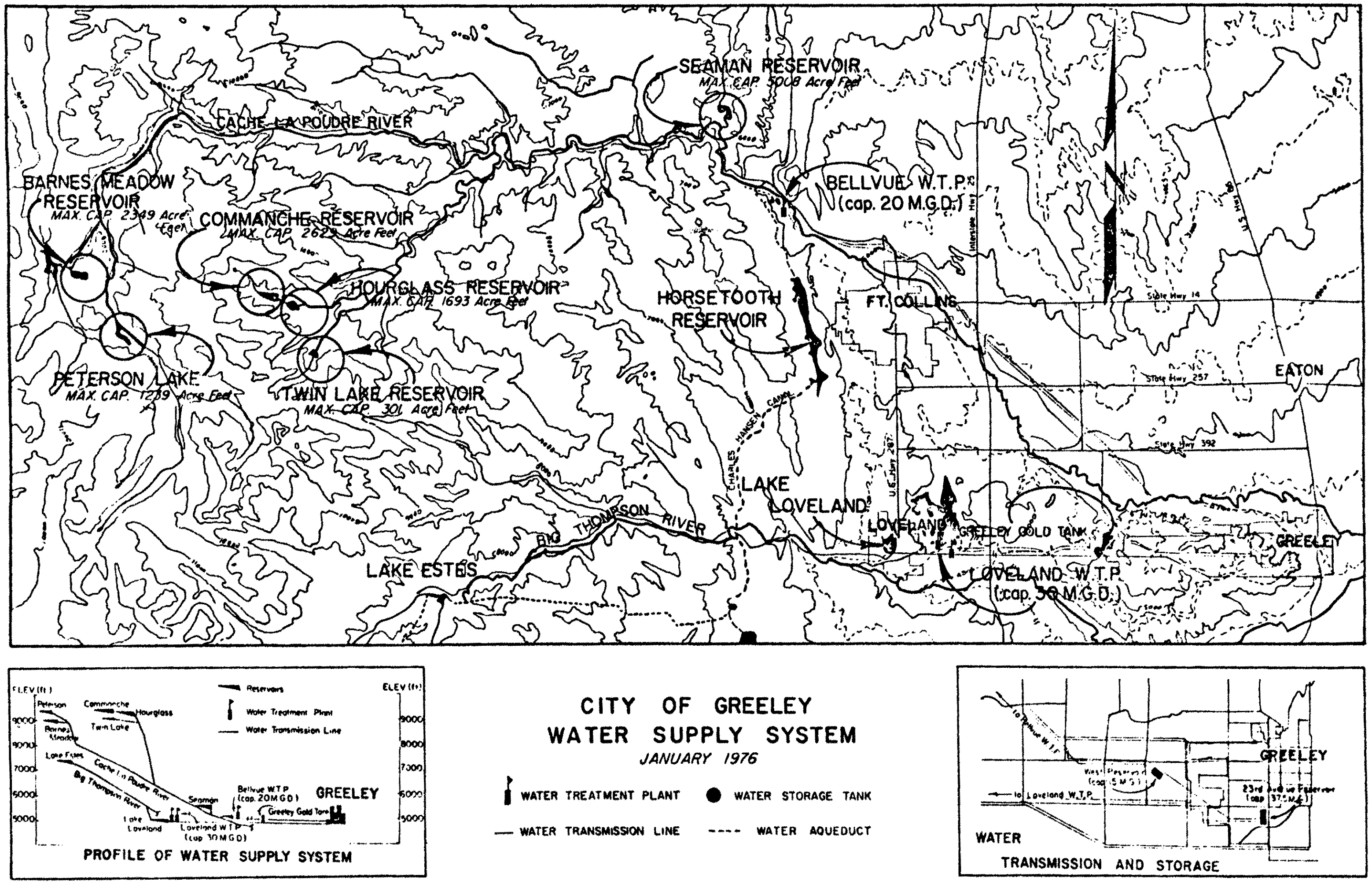
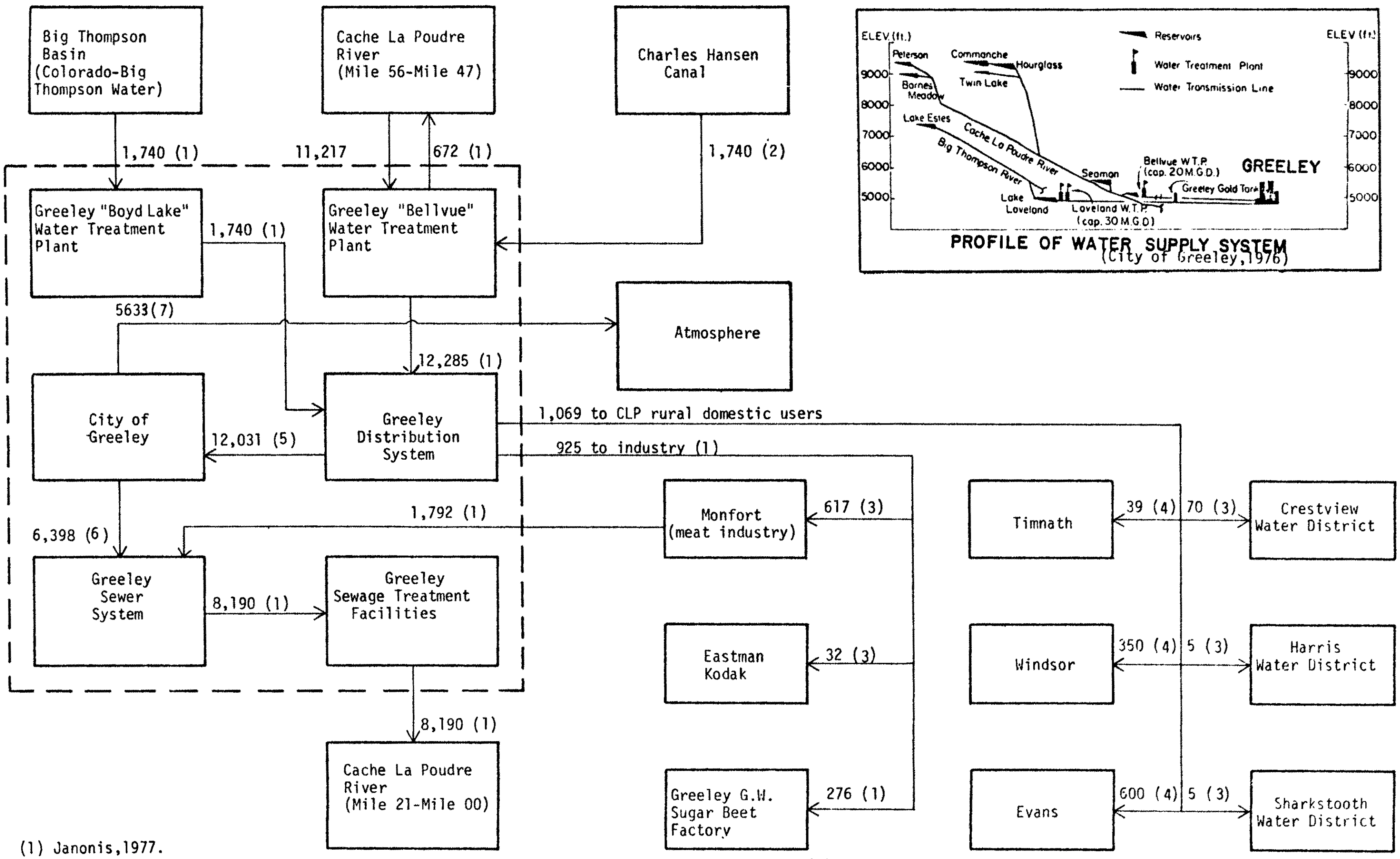


Figure 5-4. City of Greeley, Water Supply System (City of Greeley, 1976).



(1) Janonis, 1977.
(2) Northern Colorado Water Conservation District, Summary of Delivery Operations for 1970.
(3) City of Greeley records.
(4) Estimated on the basis of a pro capita use of 200 gal./day.
(5) Computed through the mass balance of Greeley Distribution System.
(6) Computed through the mass balance of Greeley Sewer System.
(7) Computed through the mass balance of the City of Greeley.

Figure 5-5. City of Greeley Water System and 1970 Water Balance (Amounts in Acre-Feet).

Greeley residents, was considered as a single user and was introduced as an individual element of the Cache La Poudre water system under the name of "Cache La Poudre Rural Domestic Users."

Water supply and distribution - Almost 50 percent of the water supply to "Cache La Poudre Rural Domestic Users" was found to be from groundwater. The rest of the supply is from the Fort Collins and Greeley distributions systems or is Colorado-Big Thompson Project water, treated through an autonomous water treatment plant (i.e., Soldier Canyon). The administration of the deliveries to the "Cache La Poudre Rural Domestic Users" is almost entirely under the control of the several water districts existing in the area (seen in Figure 5-6). These are: West Fort Collins Water District, East Larimer County Water District, Spring Canyon Water Association, Fort Collins-Loveland Water District, North Weld County Water District and Northern Colorado Water Association. The Northern Colorado Water Association delivers groundwater from its own wells. The other districts deliver water from Fort Collins or Greeley Distribution systems or from the "Soldier Canyon Water Treatment Plant" (Colorado-Big Thompson water). Part of the Cache La Poudre Rural Population is out of the coverage of any water district. This population was assumed to be supplied by private wells.

The evaluation of the water uses by the "Cache La Poudre Rural Domestic Users" is based on information supplied by the related water organizations, coupled with estimates as necessary.

The "Fort Collins Distribution System" supplied 170 acre-feet in 1970 to the West Fort Collins Water District, serving a population of 800 (information supplied by direct telephone conversation with the District Office). The "Greeley Distribution System" supplied 70 acre-feet to Crestview Water District, 5 acre-feet to Harris Water District and 5 acre-feet to Sharkstooth Water District serving an estimated population of 400. This information was provided by Mr. Tom Ullmann, Water Department, City of Greeley. The "Greeley Distribution System" apparently supplied also 350 acre-feet to Windsor, 600 acre-feet to Evans and 39 acre-feet to Timnath. These values were estimated on the basis of respective populations of 1,564 inhabitants, 2,570 inhabitants, and 177 inhabitants (1970 U.S. Census, Table 3-5) and of a per capita use of 200 gallons/day. This yields a total supply of 1,069 acre-feet from Fort Collins and Greeley distribution systems to a rural population of 5,511. The rest of the rural population (35,801 - 5,511 = 30,290 inhabitants) was assumed to use 300 gallons/capita-day. This per capita use was estimated (the City of Greeley resulted to use 278 gallons/capita-day, and Fort Collins 208 gallons/capita-day. A lower value for the rural users seemed appropriate). Then, this remaining portion of the population should have used a computed amount of 6,788 acre-feet. About 368 acre-feet of groundwater were delivered through the Northern Colorado Water Association (information provided by Joann Keener, Northern Colorado Water Association) and 2,887 acre-feet were delivered from the "Souldier Canyon Water Treatment Plant" through East Larimer County Water District, Fort Collins-Loveland Water District and North Weld County Water District (information supplied by Duane Davis, Manager of the Soldier Canyon Water Treatment Plant). The remaining quantity (6,788 - 368 - 2887 = 3,533 acre-feet) was assumed to be supplied through private wells.

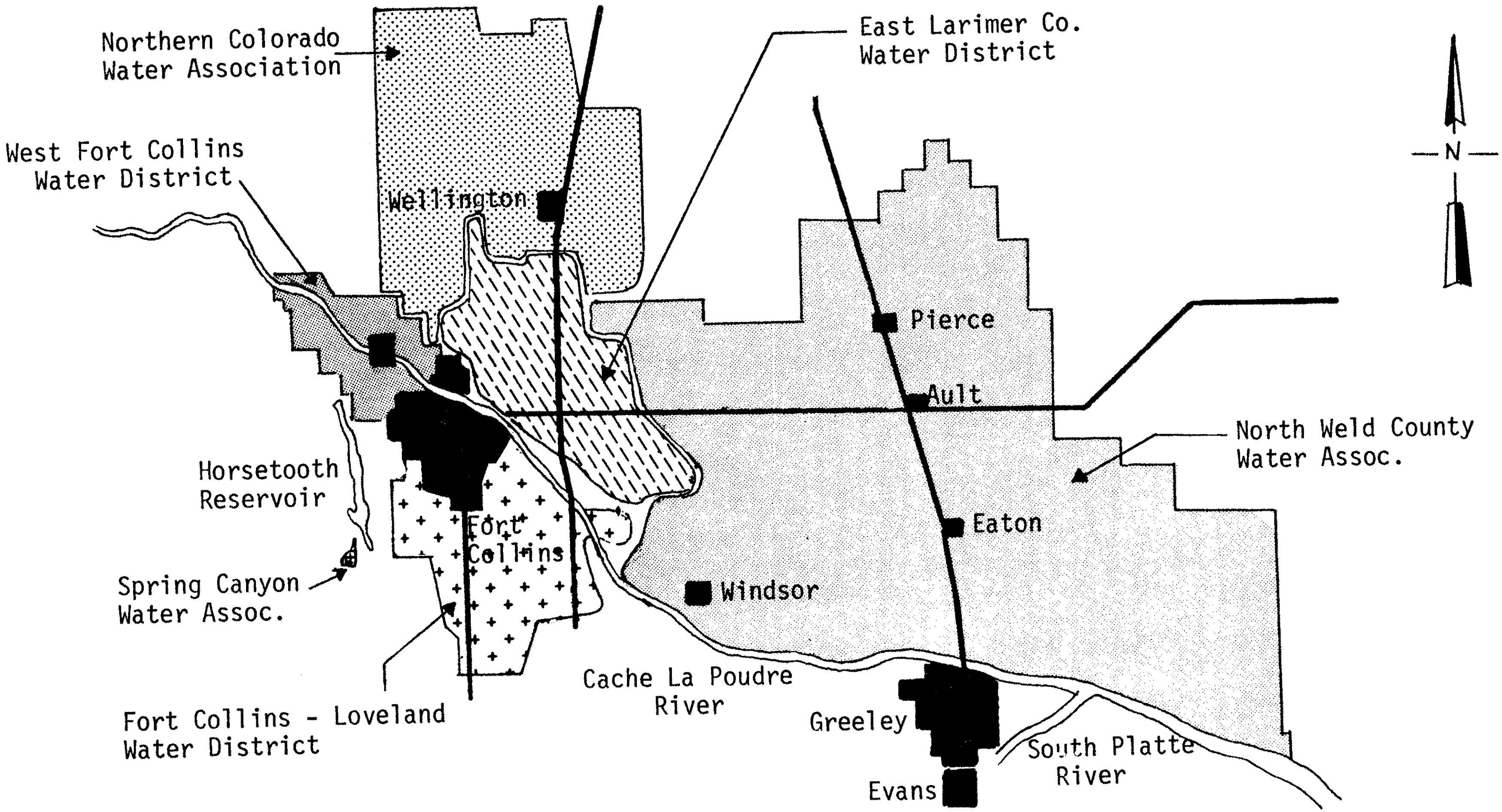


Figure 5-6. Major Water Districts Supplying Water to the Cache La Poudre Rural Domestic Users (Some smallest water districts, i.e., Sharkstooth W.D., Harris, W.D. and Crestview W.D., are not shown in this map.

Then, as a matter of input-out interactions, the "Cache La Poudre Rural Domestic Users" were considered to receive 107 acre-feet from "Fort Collins Distribution System," 1,069 acre-feet from "Greeley Distribution System," 2,887 acre-feet from "Soldier Canyon Water Treatment Plant," and 3,901 acre-feet from the aquifer (private wells and Northern Colorado Water Association Wells). The total supply was 7,964 acre-feet.

The total picture of the water supply in the study area is presented in Table 5-5. It includes City of Fort Collins and City of Greeley.

The "Soldier Canyon Water Treatment Plant" treated a total of 3,034 acre-feet of water in 1970, according to Duane Davis, Manager of the plant. A certain amount of this water was supplied for industrial use to the "Eaton G. W. Sugar Beet Fractory." Patterson (1977) stated that 147 acre-feet of water were supplied to the Eaton G. W. Sugar Beet Factory by the town of Eaton. However, since this water originated from the Soldier Canyon Plant, it was considered to flow directly from the plant to the plant, just for the sake of the input-output modeling. The mass balance of the "Soldier Canyon Water Treatment Plant" is shown in Appendix F, Figure F-9. The inflow to the plant is delivered through the "Dixon Feeder Canal" (Northern Colorado Water Conservancy District, Summary of Delivery Operations for 1970). This Colorado-Big Thompson Project water was in turn diverted from the Horsetooth Reservoir.

Wastewater collection, treatment and disposal - There are several collection systems which gather the wastewater from "Cache La Poudre Rural Domestic Users" to treatment site and disposal. Some of these collection systems are administered by small municipalities in the area (Windsor, Eaton, Wellington). Others are administered by the local sanitation districts, organizations having a certain coverage of rural area and collecting the discharges within it (Boxelder Sanitation District, Laporte Sanitation District, South Fort Collins Sanitation District). Some of these organizations have their own sewage treatment plant. Others deliver the sewage to the Fort Collins sewer system for treatment in the Fort Collins plant. Some of these small plants discharge their treated effluents into the Cache La Poudre River or its tributaries. Other plants use lagoon or oxidation pond treatment processes and eliminate their effluents through land disposal (Pierce, Ault, Continental West Subdivision, Colorado State University, Pingree Park, Red Feather Lakes). The final destinations of their effluents are the aquifer and the atmosphere. However, no individuality as system components is given to these sewage treatment facilities. For the modeling purpose their discharges were considered as flowing directly from the "Cache La Poudre Rural Domestic Users" to the "Atmosphere" or the "Aquifer."

Five sewage treatment plants serving the area rural population discharged directly or indirectly into the Cache La Poudre River: "Boxelder Sanitation District Sewage Treatment Plant," "South Fort Collins Sanitation District Sewage Treatment Plant," "Wellington Sewage Treatment Plant," "Windsor Sewage Treatment Plant," and "Eaton Sewage Treatment Plant." These plants were introduced in the model as individual components. Their characteristics and their 1970 operation are

Table 5-5. Water Supplies for Domestic Use in Cache La Poudre Basin Area in 1970.

Source of Water	Supplying Facility	Domestic Users	Served Population (1970)	Supplied Amount (Ac-ft) (1970)	Pro Capita Use (gal./day)
Cache La Poudre River and Horsetooth Res.	Fort Collins Distribution System	City of Fort Collins	43,337(1)	10,104(5)	208
		Cache La Poudre Rural Domestic Users (through West Ft. Collins Water District)	800(2)	107(2)	120
Cache La Poudre River and Colorado-Big Thompson System	Greeley Distribution System	City of Greeley	38,902(1)	12,031(6)	278
		Cache La Poudre Rural Domestic Users (Windsor Town)	1,564(1)	350(7)	200
		Cache La Poudre Rural Domestic Users (Evans Town)	2,570(1)	600(7)	200
		Cache La Poudre Rural Domestic Users (Timnath Town)	177(1)	39(7)	200
		Cache La Poudre Rural Domestic Users (Through Crestview Water District)	350(4)	70(3)	180
		Cache La Poudre Rural Domestic Users (Through Harris Water District)	25(4)	5(3)	180
		Cache La Poudre Rural Domestic Users (Through Sharkstooth Water District)	25(4)	5(3)	180
Horsetooth Reservoir	Soldier Canyon Water Treatment Plant	Cache La Poudre Rural Domestic Users (Through East Larimer Co. Water Dist.)	4,368(4)	979(8)	200
		Cache La Poudre Rural Domestic Users (Through Ft. Collins-Loveland Wat. Dist.)	3,253(4)	729(8)	200
		Cache La Poudre Rural Domestic Users (Through North Weld Co. Wat. District)	5,262(4)	1,179(8)	200
Aquifer	Northern Colorado Wat. Assoc. Wells	Cache La Poudre Rural Domestic Users (Through Northern Colorado Wate. Assoc.)	1,642(4)	368(9)	200
Aquifer	Other Wells	Other Cache La Poudre Rural Domestic Users	15,765(10)	3,533(10)	200
Averages or Totals			118,040	30,099	227

(1) U.S. Bureau of the Census, 1971. U.S. Census of Population, 1970. Number of Inhabitants, Colorado U.S. GPO, PC(1)-A7-COLO, Washington, D.C.
(2) Information supplied by the West Fort Collins Water District.
(3) Information supplied by Mr. Tom Ullmann, Water Department, City of Greeley.
(4) This value was estimated.
(5) See water balance of Fort Collins Distribution System, Appendix
(6) See water balance of Greeley Distribution System, Appendix
(7) These values were estimated assuming a pro-capita water use equal to 200 gal/day.
(8) Information supplied by Mr. Duane Davis, Manager, Soldier Canyon Water Treatment Plant. The plant supplied also 147 acre-feet of water to the Eaton G.W. Sugar Beet Factory.
(9) Information supplied by Mrs. Joann Keener, Northern Colorado Water Association.
(10) The Fort Collins and Greeley distribution systems serve a total population of 87,750 inh. The rest of the study area population (118,040-87,750=30,290 inh.) is assumed to use 200 gal/capita-day, i.e. a total amount of 6,788 acre-feet in 1970. Soldier Canyon Water Treatment Plant supplied 2,887 acre-feet and the Wells of Northern Colorado Water Association supplied 368 acre-feet. The remaining portion of the 6,788 acre-feet (6,788 - 2,887-368=3,533 acre-feet) was assumed to be supplied by other wells. The population served by these wells is the remaining population of the Study Area.

described in Table 5-6, together with the Fort Collins and Greeley major facilities. The effluent amounts were estimated on the basis of the served population, assuming a 70 percent return flow and a 200 gallon per capita water use. An addition of 22 acre-feet to the Windsor Sewage Treatment Plant takes account of the Eastman-Kodak discharge (Janonis, 1977). The type of treatment performed at these plants consisted mostely of aerated lagoons and polishing ponds. About 30 percent of the plant flow was assumed to be lost in the plant (i.e., 20 percent to the aquifer and 10 percent to the atmosphere). The remaining 70 percent was considered to be discharged to the receiving water bodies after treatment. The Cache La Poudre River (Miles 47-21) received discharges from "Boxelder Sanitation District Sewage Treatment Plant" and "Windsor Sewage Treatment Plant." The "Fossil Creek Reservoir" received discharges from the "South Fort Collins Sanitation District Sewage Treatment Plant" for later agriculture reuse. Then "Boxelder Creek" (tributary of Cache La Poudre River, Miles 47-21) received discharges from the "Wellington Sewage Treatment Plant." Finally, "Eaton Draw" (tributary of Cache La Poudre River, Miles 21-00) received discharges from the "Eaton Sewage Treatment Plant" (Toups, 1974). The individual mass-balances of all of these plants are shown in Appendix F (Figures F-16, F-17, F-18, F-19, F-20).

Of the total rural supply, (2,389 acre-feet) 30 percent was assumed lost to atmosphere by the water users (2,389 acre-feet). The remaining 70 percent (5,575 acre-feet) was assumed discharged to the mentioned sewage treatment plants or to "Fort Collins Sewer System," to "Crow Creek Basin," to "Other South Platte Sub-basins" or was disposed through septic tanks. The discharge to "Fort Colins sewer system" amounted to 118 acre-feet (by computation). These wastewaters were collected and delivered through the Mountain View Sanitation District. The amount of 118 acre-feet was computed on the basis of an estimated served population of 750, using 200 gallon/capita day and returning 70 percent of the used water. Some 790 acre-feet were computed to be discharged to the five small sewage treatment plants. Then about 688 acre-feet was lost from the internal Cache La Poudre Water System to "Other South Platte Sub-basins." This amount was discharged by Evans, one of the out-of-basin towns included in the system. This amount was computed on the basis of an estimated served population of 4,500 (Toups, 1974) using 200 gallons/capita day and returning 70 percent of the used waters. The 222 acre-feet Pierce and Nunn discharges, computed in the same way, on the basis of a population of 1,450 (Toups, 1974), left the system to the "Crow Creek Basin." Then, the remaining amount of return flow (5,575 - 118 - 790 - 688 - 222 = 3.757 acre-feet) was assumed to be disposed through septic tanks. For the sake of the input-output model this amount was considered to flow from the "Cache La Poudre Rural Domestic Users" directly to the "Aquifer."

A total mass balance of the "Cache La Poudre Rural Domestic Users" is shown in Appendix F (Figure F-12). The overall picture of the municipal and domestic return flows in the study area is depicted in Table 5-7.

5.3 Industrial Sector

A fast growing industry sustains a strong economic viability within the Cache Le Poudre River basin study area. The trend is expected to

Table 5-6. Sewage Treatment Plants Discharging their Effluent into Cache La Poudre River or its Tributaries.

Sewage Treatment Plants (9)	Served Community	Type of Treatment	Served Population	Design Capacity	1970 Treated Volumes (acre-feet)	Destination of flows (6)
Greeley Sewage Treatment Facilities	City of Greeley and Monfort (Meat Industry)	Trickling Filters Activated Sludges (1)	38,902 (1970)	7 mgd (2)	8,190 (1)	Cache La Poudre River (miles 21-00)
Fort Collins Sewage Treatment Plant No. 1	City of Fort Collins Cache La Poudre Rural Domestic Users and Minor Industries	Trickling Filters Activated Sludges (1)	44,037 (1970)	5 mgd (1)	4,698 (1)	Cache La Poudre River (miles 47-21)
Fort Collins Sewage Treatment Plant No. 2	City of Fort Collins, Cache La Poudre Rural Domestic Users and Minor Industries	Activated Sludges (1)		4.8 mgd (1970)(1) 20.8 mgd (1977)(1)	3,617 (1)	Cache La Poudre River (Miles 47-21) and Fossil Creek Reservoir Inlet
Boxelder Sanitation District Sewage Treatment Plant	Cache La Poudre Rural Domestic Users	Lagoon, Polishing Pond, Filtering Dyke (2)	250 (1971) (3)	1.1 cfs (2)	38 (7)	Cache La Poudre River (Miles 47-21), Aquifer and Atmosphere
South Fort Collins Sanitation District Sewage Treatment Plant	Cache La Poudre Rural Domestic Users	Aerated Lagoon, Polishing Pond (2)	500 (1971) (3)	1.5 cfs (4)	112 (7)	Fossil Creek Res., Aquifer and Atmosphere
Wellington Sewage Treatment Plant	Cache La Poudre Rural Domestic Users	Aerated Lagoon Polishing Pond (2)	700 (1971) (3)	0.1 cfs (2)	110 (7)	Boxelder Creek, Aquifer and Atmosphere
Windsor Sewage Treatment Plant	Cache La Poudre Rural Domestic Users and Eastman Kodak	Aerated Lagoon Polishing Pond (2)	2,000 (1974) (2)		340 (7) (8)	Cache La Poudre River (Miles 47-21), Aquifer and Atmosphere
Eaton Sewage Treatment Plant	Cache La Poudre Rural Domestic Users	Oxidation Ditch (2)	1,390 (1974) (2)	0.3 cfs (2)	224 (7)	Eaton Draw, Aquifer and Atmosphere

(1) Janonis, 1977.
(2) Toups, 1974.
(3) Larimer County Comprehensive Sewer Study, 1971
(4) Information supplied by Mr. Keith Liden, Planning Division, Larimer County.
(5) This is the Fort Collins population (43,337 inh.) and the population served by Mountain View Sanitation District (750 inh.)
(6) Information regarding the volumes flowed to each destination are contained in the individual water balances of each plant (Appendice
(7) Estimated on the basis of a pro capita use of 200 gal/day. Only 50% of the domestic water is assumed to go to the sewage treatment plant.
(8) 22 extra acre-feet are added. This is the amount discharged by Eastman Kodak (Patterson, 1977).
(9) Other small sewage treatment facilities exist in the study area. The destination of their effluents is the aquifer (Land Disposal). These flows are considered to be discharged from the Cache La Poudre Rural Domestic Users directly to the aquifer for the purposes of the input-output modeling.

Table 5-7. Cache La Poudre Basin Area Municipal and Other Domestic Return Flows in 1970.

Domestic Users	Total Supply (Ac.-ft) (1)	Consumptive Use (Ac.-ft) (2)	Total Return Flows (Ac.-ft) (3)	Sewage Treatment Plants (4)	Final Destination of Return Flows
City of Fort Collins	10,104	4,436	5,668	Fort Collins Sewage Treatment Plant No. 1	Cache La Poudre River (Miles 47-21)
				Fort Collins Sewage Treatment Plant No. 2	Cache La Poudre River (Miles 47-21 and Fossil Creek Reservoir
City of Greeley	12,031	5,633	6,398	Greeley Sewage Treatment Facilities	Cache La Poudre River (Miles 21-00)
Cache La Poudre Rural Domestic Users	7,964	2,389	5,575	Septic Tanks	Aquifer, Crow Creek Basin and other South Platte Sub-basins
				Fort Collins Sewage Treatment Plant No. 1	Cache La Poudre River (miles 47-21)
				Fort Collins Sewage Treatment Plant No. 2	Cache La Poudre River (Miles 47-21) and Fossil Creek Reservoir
				Boxelder Sanitation District Sewage Treatment Plant	Cache La Poudre River (Miles 47-21) Aquifer and Atmosphere
				South Fort Collins Sanitation District Sewage Treatment Plant	Fossil Creek Reservoir, Aquifer and Atmosphere
				Wellington Sewage Treatment Plant	Boxelder Creek, Aquifer and Atmosphere
				Windsor Sewage Treatment Plant	Cache La Poudre River (Miles 47-21) Aquifer and Atmosphere
				Eaton Sewage Treatment Plant	Eaton Draw, Aquifer and Atmosphere
Grand Totals	30,099	12,458	17,641		

(1) These amounts are the total supplies from the various sources. See the water balances of the correspondent user for full explanation (Appendix F)

(2) See the water balance of the correspondent users for explanations (Appendix F).

(3) These amounts are the total return flows to the various destinations. See the water balances of the correspondent users for full explanation (Appendix F).

(4) The amounts to each treatment plant are showed in the water balances for the correspondent communities (see Appendix F).

continue. Although industrial water uses are not so great in magnitude as irrigation, such water use is important and critical as a "factor of production" in various industries in the basin.

5.3.1 Industrial activities in the study area. A variety of industrial activities exist in the Cache La Poudre basin study area. These range from agriculture related industries such as the beet sugar industry and meat packing, to mining, and manufacturing, and fish hatching.

Some of the plants have composite sources of water supply; these may be combinations of treated municipal water with self-supplied groundwater, treated municipal with self-supplied surface water or treated municipal with self-supplied ground and self-supplied surface water; this water is used for industrial processes and for sanitary appliances.

Sugar beet industry - The sugar beet industry is one of the agriculture related industry activities in the study area. This industry is a heavy seasonal user of water. The input-output interaction of the sugar beet industry has the pecularity of considerable water inputs occurring together with the sugar beets entering the industry facilities. These amounts of water needed to be introduced in the input-output balance in order to fully explain the industry return flows. For this reason a particular element has been introduced among the "entries" into the system. It is referred as "Other Origins" and plays its role as an origin of the sugar beet water to industry. This is merely an accounting device.

Two major factories, located in the study area and both owned by the "Great Western" sugar beet company, were in operation in 1970. The factory at Eaton (referred in the input-output model as "Eaton G. W. Sugar Beet Factory") was located in Weld County at the Town of Eaton. This plant was closed during the 1976 campaign without intention to reopen. Thus it will have no future role in the Cache La Poudre water system. The Eaton sugar beet factory was a "straight-house" operation with a continuous diffuser and complete drying facilities. Molasses was shipped to the Loveland plant for further sugar recovery by the "Steffen" process. The factory had a standard rate of processing of 2,000 tons of beets per day with a maximum slice rate of 2,400 tons of beets per day during the 1970 campaign (McGinnis, R. A., 1971). The factory received the majority of its water supply from company wells. Well water was delivered to a spray pond. The pond also received condenser water from the plant and some flow from Eaton Draw. The spray pond served to cool and recondition the condenser waters before their reuse in the factory. Mixed waters were then transferred to the main water supply tank within the factory. Water for domestic needs was received from the city of Eaton.

The Great Western Sugar Company factory of Greeley, Colorado, is located in Weld County along the Cache La Poudre River in east Greeley. The Greeley sugar beet factory has a "straight-house" operation having a continuous diffuser and complete pulp drying facility. Molasses from the process is generally shipped either to the Longmont or the Loveland factory for further sugar recovery. The factory has a standard rate of processing of 2,000 tons of sugar beets per day with a maximum slice rate of 2,400 tons of beets per day (McGinnis, R. A., 1971). The principal source of plant water supply has been the Cache La Poudre River. River waters were diverted into a small pond and have been used primarily for the flume water loop. Supplemental water has been obtained from the City of Greeley and a company well. This water was directed to diffuser makeup, washing of raw materials and domestic plant uses. The Greeley facility was introduced in the input-output model as "Greeley G. W. Sugar Beet Factory."

Meat packing industry - Another rural related industry is meat packing. A major plant, "Monfort of Colorado," is located within the basin, at Greeley. It is the major industrial water consumptive user in the study area. The Monfort meat packing plant is located several miles north of the City of Greeley. Monfort's two cattle feedlots were located in the rural areas away from Greeley. The Gilcrest feedlot was seven miles southwest of the City of Greeley, and the Kuner lot was twelve miles east of the city. In 1974, Kuner replaced the original Monfort feedlot, which was situated adjacent to the plant (Monfort of Colorado, 1975). The packing plant had been in Greeley since 1960. The packing plant processed sheep and cattle during the past decade. The company employed about 2,000 people in 1975 (Monfort of Colorado, 1975). In 1970, the water supply was from the City of Greeley and several on-site company wells.

Mining industry - The major mining activity in the area is sand and gravel excavation. This type of industry does not actually incur high values of consumptive use, but affects the water system by transferring groundwater to the surface, due to the dewatering operations. Only the biggest facility, the "Greeley Sand & Gravel Co." has been introduced as an individual component of the water system.

The Greeley Sand and Gravel Company has been in operation since 1954. It produces pit run sand and gravel for production of concrete and asphalt as well as for base coarse material for roads. The pit operation is one of 39 pits at Greeley as noted by Schwochow and others in 1974 (Schwochow, S. D., et al., 1974). The pit location near the Cache La Poudre River takes advantage of deposits of clean gravels and medium to coarse-grained sands with thicknesses ranging up to 50 feet near Greeley (Schwochow, S. D., et al., 1974). The Greeley Sand and Gravel facility produced 204,000 tons of aggregate in 1970 based upon a 255 day operation at 800 tons per day (U.S. Army, May 1971).

Fish hatcheries - Two hatchery complexes are located in the basin; at Bellvue and at Rustic. The consumptive use of the fish hatcheries is negligible, since the water diverted is completely returned. The fish hatcheries have several functions: (i) to compensate for a decrease in fish losses due to construction of man-made barriers which have disturbed natural spawning areas and/or diversion of stream flows for water uses; (ii) recovery and maintenance of fish stocks which may have been over-exploited in the past; (iii) abatement of fish losses due to pollution or natural alterations in the stream; (iv) introduction of a species more suitable to an altered environment. Few hatcheries are ideally suited for a yield of trout brood stock as well as rearing of other related species due to possible temperature optimums and time variations of diverted water flow. During the selection of a once-through-flow hatchery site, the primary requisite is a uniform, ample supply of clear, good quality water, within the optimum temperature range and free of disease organisms (Bell, February 1973). Although the water supply must be adequate to serve as a year-round sustained functional use, the hatchery and pond system have very little consumptive use. The water may be recirculated when reconditioned within an economic compensation of increased fish production under conditions of limiting amounts of water and incidence of fish diseases (U.S. Bureau of Commercial Fisheries, 1969). However, the present day hatcheries or rearing ponds do not reuse water due to an availability of fresh clean water; the system requires a replacement water supply of 5 to 10 percent. The problem of a gradual buildup of metabolic wastes is the major reason for a reluctance to reuse hatchery water. In spite of these considerations, a great deal of water reuse occurs in the Cache La Poudre Bellvue-Watson Complex.

The Bellvue-Watson Units are located near the town of Bellvue several miles from Fort Collins. This is a duplex unit where the Bellvue Unit is a hatchery and the Watson Unit is a rearing unit. The Bellvue Unit utilizes 900 gpm of water from nearby wells and returns the water to the Watson Unit for an intended reuse. The inflow of water to the Watson Unit is augmented with 1,800 gpm of surface water; an intended conjunctive use of ground and surface waters. The total water discharge from the Watson Unit averages 2,700 gpm to the Cache La Poudre River. The Bellvue-Watson complex was introduced in the Cache La Poudre input-output model as two separate units in order to show the reuse pattern: "Bellvue Fish Hatchery" and "Watson Fish Hatchery."

Another facility which was considered as an individual element of the Cache La Poudre water system is the "Rustic Fish Hatchery." It is located above Rustic on the Cache La Poudre River. This rearing unit accepts the transfer of "fingerling" trout from the downstream hatchery and eventually produce a substantial stock of yearling trout. Diversion of water is from the Cache La Poudre River at a steady flow of 2,700 gpm. The flow passes through the rearing ponds and is returned to the river.

Manufacturing - The major manufacturing establishment in the study area is the Eastman Kodak factory. Eastman Kodak is located in the town of Windsor, about 11 miles northwest of Greeley. Janonis (1977) reported that the Eastman Kodak received its water supply from the "Greeley Distribution System" in 1970. "Eastman-Kodak" is the only manufacturing industry which was given individuality in the Cache La Poudre input-output model.

Power industry - Janonis (1977) reported the only relevant power facility operating in the Cache La Poudre basin to be the "Fort Collins Power Plant." This plant ceased operation in 1973, but is reported anyway as an individual system component. The power plant was located in Fort Collins along the Cache La Poudre River. Up to 1965 city water was used for boiler makeup and river water was used for cooling. In 1965 a flood destroyed the river water pumping facility, so since that time, to 1973, the power plant used city water for all purposes.

Many other smaller but relevant industries existed in the study area in 1970; however, these minor industries were not given individual reference as elements of the Cache La Poudre water system. Among these industries the Woodward Governor Inc., the Teledyne Aqua Inc., and the Ideal Cement could be mentioned. These were all lumped together in a single element as "Minor Industries." Some of the material herein reported about industrial activity in Cache La Poudre basin was derived from Patterson (1977).

5.3.2 Industrial water diversions and return flows. A major problem in delineation of industrial water disposition relates to the availability and accuracy of data on industrial water utilization, including annual water diversions, water lost by evaporation and groundwater seepage, and other use factors. To the authors' knowledge no report dealing with industrial water utilization discusses the accuracy and adequacy of the data. This includes reports by the U.S. Government Agencies, individual industry association and the Water in Industry surveys that have been prepared by the National Association of Manufacturers. The accuracy of water data varies widely from industry to industry, from plant to plant within any given industry, and in relation to the different factors involved — e.g., delivered water compared with reused water, the amount paid for water compared with in-plant costs of pumping water, and quality of boiler feedwater compared with quality of wastewater being discharged. Any systematic investigation of the available data will reveal obvious inconsistencies, large data gaps, and the crudeness of many estimates. The exchange values herein used for the input-output model are as reported by Patterson (1977) and by Janonis (1977) in the often mentioned "South Platte Study."

Patterson (1977) reported that the "Greeley G. W. Sugar Beet Factory" used 2,271 acre-feet in 1970. This amount was supplied by the "Greeley Distribution System" (276 acre-feet), by the "Aquifer" through company wells (296 acre-feet) and by direct diversion from the Cache La Poudre River (1,583 acre-feet). The difference, 116 acre-feet, was assumed to be sugar beet water. About 1,966 acre-feet of return water was discharged into Cache La Poudre. The losses were assumed split between evaporation (235 acre-feet) to the "Atmosphere" and infiltration (70 acre-feet) to the "Aquifer." The mass balance of "Greeley G. W. Sugar Beet Factory" is shown in Appendix G, Figure G-1.

The "Eaton G. W. Sugar Beet Factory" used 1,344 acre-feet of water in 1970. Of this total 147 acre-feet was supplied by the "Soldier Canyon Water Treatment Plant," 1,131 acre-feet was supplied by private wells, and 132 acre-feet were introduced as beet water. About 1,344 acre-feet was discharged to the Cache La Poudre River, 34 acre-feet was lost to evaporation, and 32 acre-feet infiltrated into the "Aquifer." The mass balance of "Eaton G. W. Sugar Beet Factory," from Patterson (1977), is shown in Appendix G, Figure G-2.

The information about the "Fort Collins Power Plant" water exchanges was derived from Janonis (1977). He reported that the plant used a total of 825 acre-feet in 1970. This amount was supplied by the "Fort Collins Distribution System." A return flow of 783 acre-feet was discharged into Cache La Poudre River (Miles 47-21). The rest, 41 acre-feet, was evaporated. The mass balance of the "Fort Collins Power Plant" is reported in Appendix G, Figure G-3.

Eastman Kodak (Janonis, 1977) received 32 acre-feet of city water from "Greeley Distribution System." This amount was 30 percent evaporated (10 acre-feet) and 70 percent discharged to the "Windsor Sewage Treatment Plant" (22 acre-feet). The mass balance of "Eastman Kodak" is shown in Appendix G, Figure G-4.

Monfort used a total of 3,765 acre-feet in 1970 (Patterson, 1977). About 617 acre-feet was supplied by the "Greeley Distribution System," and 3,148 acre-feet was supplied by the "Aquifer" through wells. About 1,792 acre-feet was returned to the "Greeley Sewer System," 855 acre-feet was lost to the "Atmosphere," and 1,120 discharged to the Cache La Poudre River. However, since 1973, Monfort has its own sewage treatment facility, which discharges to a small tributary of the South Platte River. The mass balance of the Monfort Plant is shown in Appendix G, Figure G-5.

The "Greeley Sand and Gravel Company" dewatering generated 1,454 acre-feet of water in 1970 (Patterson, 1977). About 1,336 acre-feet was discharged into the Cache La Poudre River, and 118 acre-feet evaporated from a pond. The mass balance of "Greeley Sand and Gravel Co." is shown in Appendix G, Figure G-6.

The Bellvue-Watson fish hatchery complex diverted a total of 4,356 acre-feet in 1970 (Patterson, 1977). About 1,452 acre-feet were withdrawn by the "Bellvue" unit from the "Aquifer." The flow from the Bellvue unit was then transferred to the "Watson" unit for "reuse." However, the "Watson" unit diverted an additional 2,904 acre-feet of water from the Cache La Poudre River. The total amount of 4,356 acre-feet (used and reused water) was then discharged to the river by the "Watson" unit. The mass balances of these two fish hatchery units are shown in Appendix G. Figures G-7 and G-8. Patterson (1977) reported also a total diversion and return flow to the Cache La Poudre River of 4,356 acre-feet, by the "Rustic Fish Hatchery," the mass balance for this facility is seen in Appendix G, Figure G-9.

Concerning the "Minor Industries," Janonis (1977) reported a delivery of 111 acre-feet from the "Fort Collins Distribution System." This amount was assumed to be returned to the "Fort Collins Sewer System" (Appendix G, Figure G-10).

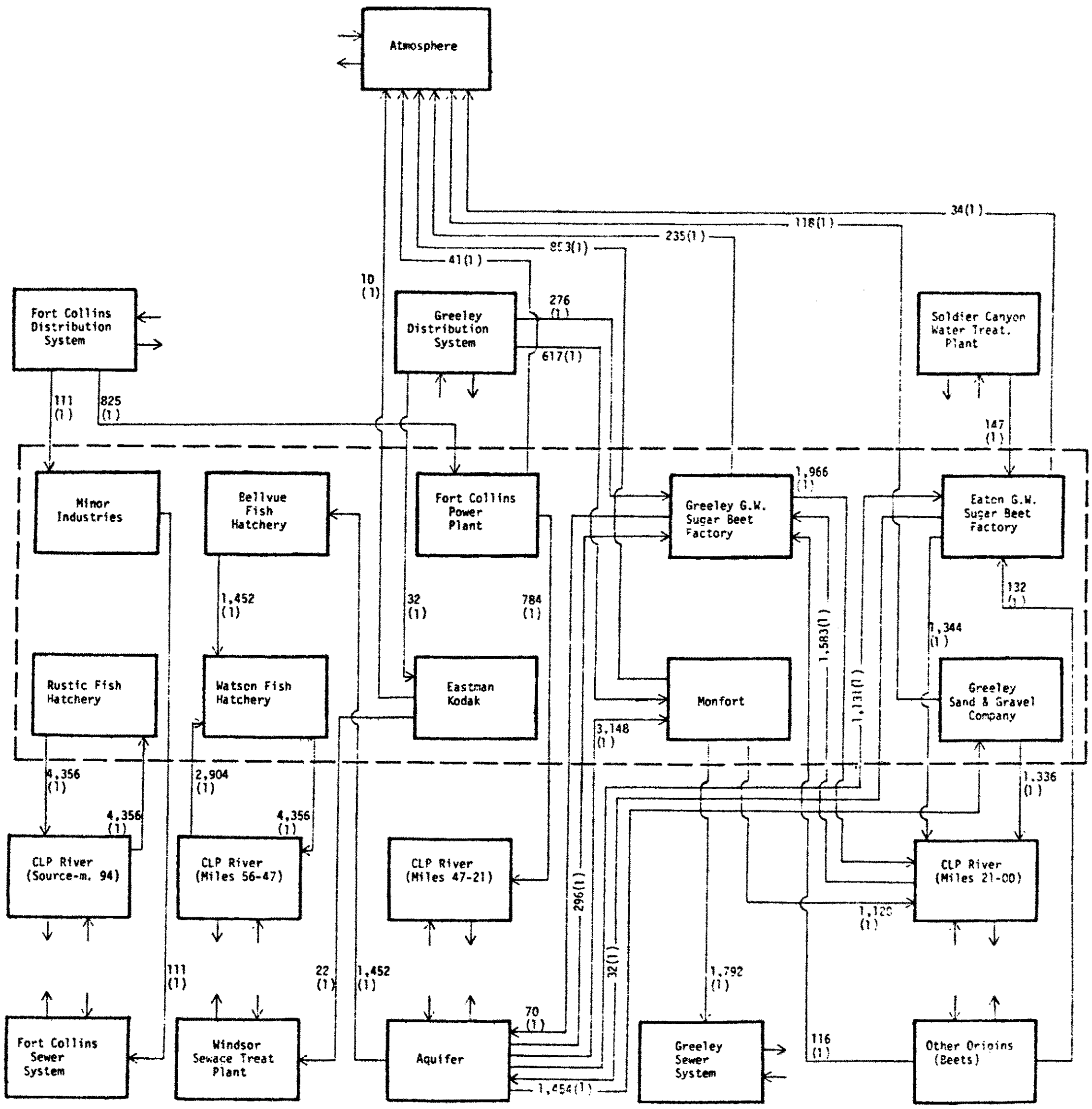
Still other industries were active in 1970, but their water exchanges were really minor in amount. These exchanges were either neglected or included among the water exchanges of the "City of Greeley."

The summary of all the industry related water exchanges in the system is given in Table 5-8 in tabular format. This same information is seen in graphical format in Figure 5-7. However, Figure 5-7 shows also the sources of water and the disposition of water taken in, providing a "picture" on the relationships between the industry sector components and the rest of the system.

Table 5-8. Industrial Diversions and Return Flows in 1970.

Industry	1970 Water Delivery (Acre-feet)				Losses (Acre-feet)		Returned Water (Ac-ft.)			Source of Information
	Aquifer	Surface Water	Municipal Water	Total Water	Evaporation	Seepage	Municipal Sewers	Rivers	Total	
Greeley G. W. Sugar Beet Factory	296	1,583	276	2,155	235	70	-	1,966	1,966	Patterson
Eaton G.W. Sugar Beet Factory	1,131	11	147	1,289	34	32	-	1,344	1,344	Patterson
Fort Collins Power Plant	-	-	825	825	41	-	-	784	784	Janonis
Eastman Kodak	-	-	32	-	10	-	22	-	22	Janonis
Monfort	3,148	-	617	3,765	853	-	1,792	1,120	2,912	Patterson
Greeley Sand & Gravel Co.	1,454	-	-	1,454	118	-	-	1,336	1,336	Patterson
Bellvue Fish Hatchery	1,452	-	-	1,452	-	-	-	-	1,452 (1)	Patterson
Watson Fish Hatchery	-	2,904	-	4,356(2)	-	-	-	-	-	Patterson
Rustic Fish Hatchery	-	4,356	-	4,356	-	-	-	4,356	4,356	Patterson
Minor Industries	-	-	111	111	-	-	111	-	111	Janonis

(1) This amount was delivered to Watson Fish Hatchery for reuse.
(2) 1,452 acre-feet of used water were delivered by the Bellvue Fish Hatchery.



(1) All of these amounts were explained and justified in paragraph 5.3.2.

Figure 5-7. 1970 Industry Related Water Exchanges Within the Cache La Poudre River Basin (acre-feet).

5.4 Agricultural Sector

Agriculture activity in the Cache La Poudre basin is spread along the alluvial valley of the river, and into the plains. It was estimated (by this study) that a total of 227,563 acres in the basin are irrigated. This estimate was derived from analysis of land use maps of the U.S. Soil Conservation Service. The outline of the irrigated areas within the basin was also reported on a satellite remote sensing photograph shown in Figure 5-8, where the irrigated areas were recognized easily due to their red color. This comparison provided good verification of the SCS maps; only very minor adjustments were made to the original estimates.

The irrigated land was considered as two distinct areas for the sake of the input-output model; they were designated as: "Upper Cache La Poudre Irrigated Areas" and "Lower Cache La Poudre Irrigated Areas." They are shown in Figure 5-9. The division between "upper" and "lower" is marked by canals, (which coincide roughly with elevation contours) which separate lands which might be served by gravity from the Fort Collins sewage treatment plants. The idea is to permit consideration of reusing Fort Colins wastewaters for irrigation purposes. The most upper ditches having the possibility of catching the Fort Collins return flows through the Cache La Poudre River are "Chaffe Ditch" and "Fossil Creek Reservoir Inlet" on the right bank of the river and "Timnath Reservoir Inlet," "Lake Canal" and "Greeley No. 2 Canal" on the left bank. Those five ditches were conisdered to represent the approximate boundaries between the two irrigated areas.

The "Upper" and "Lower" Cache La Poudre Irrigated Areas represent about 76 percent and 24 percent, respectively of the total irrigated area within the Cache La Poudre Water System, amounting to 172,948 acres and 54,615 acres. The major crops in these irrigated areas are alfalfa and corn, covering together some 62 percent of the total area. Also, a significant amount of land is used for production of hay, barley, sugar beets and beans. Minor crops are potatoes, sorghum, oats, winter wheat, and spring wheat. The distribution of crop types is summarized in Table 5-9.

5.4.1 Evaluation of irrigation water uses. Consumptive use is water that is lost to the atmosphere as a result of the various unit operations and unit processes associated with a given use. For irrigated agriculture it consists of plant transpiration, and evaporation from soil surfaces and water surfaces. Evapotranspiration is the amount of water vapor produced as a result of plant growth in an area due to both evaporation and transpiration. This term has almost the same meaning as agricultural consumptive use; the latter term may be more inclusive, however.

Potential evapotranspiration, PET, is the evapotranspiration that would take place on a fully vegetated surface provided that adequate water is available to satisfy all plant needs. If an insufficient amount of water is provided then the actual evapotranspiration, AET, will be less than the PET. The AET/PET ratio is affected then by soil texture and plant maturity. However, in this study, it is assumed in calculating consumptive use that the AET is equal to the PET.

Figure 5-8. Irrigated Areas in Cache La Poudre Basin (NASA Satellite Photo).

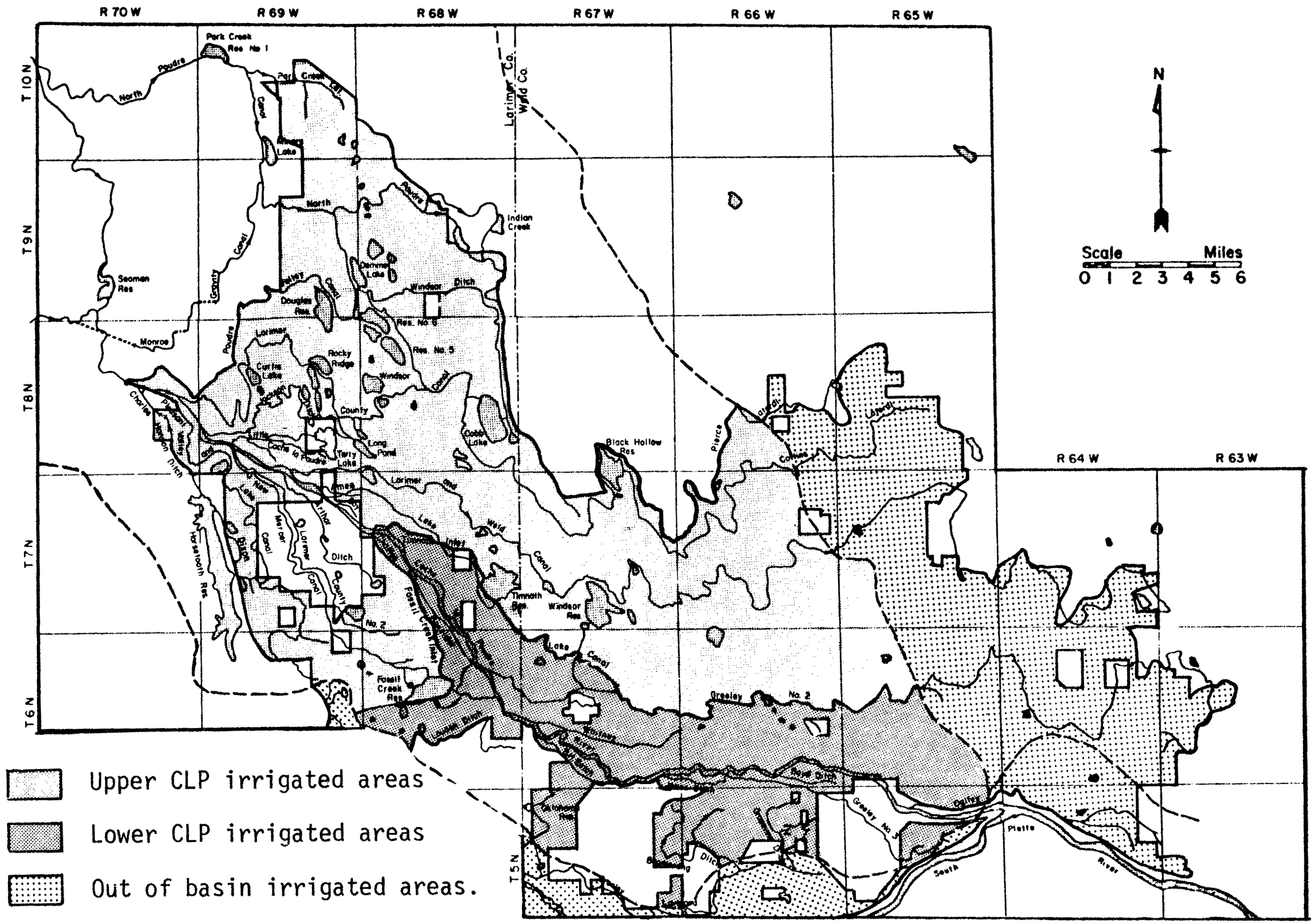


Figure 5-9. Irrigated Areas In Cache La Poudre Basin (From SCS Land Use Maps).

Table 5-9. Cache La Poudre Crop Irrigated Acreages (1).

Crop	County Irrigated Acreages		Total Irrigated Acreage	Percent of Total Irrigated Acreage
	Larimer	Weld		
Alfalfa	40,941	27,873	68,814	30.3
Corn	33,212	38,552	71,764	31.5
Winter Wheat	1,570	1,709	3,279	1.4
Spring Wheat	241	107	348	0.2
Barley	13,405	6,194	19,599	8.6
Oats	1,329	1,068	2,397	1.1
Sorghum	121	107	228	0.1
Sugar Beets	7,729	11,000	18,729	8.2
Potatoes	0	1,602	1,602	0.7
Beans	5,676	6,621	12,297	5.4
Hay	16,545	11,961	28,506	12.5
Total	120,769	106,794	227,563	100.0

(1) From Gerlek and Janonis (1977). Gerlek and Janonis derived these acreages from the 1970 Colorado Agricultural Statistics (Colorado Department of Agriculture) and from the Land Use Maps of Colorado Land Use Commission & U.S. Soil Conservation Service).

There are many empirical equations which have been developed to describe crop evapotranspiration. These equations range from the very simple to the very complex. Table 5-10 summarizes some of these equations according to their basic input data. Several of these equations have gained wide acceptance and are commonly used.

In this study, the Blaney-Criddle method was selected for the determination of PET because it was developed empirically from field data for the western U.S. and showed good correlation with the measurements of McGuinness and Bordne (1972). This method is widely accepted and relatively simple to use. It contains terms which account for plant type, plant growing season, mean monthly temperature, and seasonal and latitudinal variations in theoretical solar radiation. Furthermore, the Blaney-Criddle formula was used by Gerlek and Janonis (1977) for the "South Platte Study." Their work was the basis for this section; the results and derivations herein presented are then fully consistent with the "South Platte Study" values.

The Blaney-Criddle formula is given by the following equation:

$$U_c = PET = K\ F$$

where U_c is the consumptive use in inches per unit of area;

k is a weighted consumptive use coefficient,

F is the consumptive use factor = the sum of the monthly consumptive use factors for each month during the growing season,

$$F = \sum \frac{t\ p}{100}$$

t is the mean monthly air temperature, °F,

p is the percent of the annual daytime hours occurring during each month of the year. This value is given in Figure 5-10. This assumes a cloudless sky and therefore would give high answers during cloudy weather.

Crop consumptive use coefficients, K, are given by Blaney (1959), Criddle (1958), and Schulz (1973), for different types of vegetation. Table 5-11 summarizes their values of K for different plant types, growing seasons and geographical locations.

The consumptive use coefficients of Table 5-11 were used as a basis for establishing values of K for the Cache La Poudre basin irrigated areas. When a K was given for Colorado, this was used; otherwise the higher value was selected from the range given by Blaney and Criddle. Blaney (1959) states that the lower values of K are for coastal areas, while the higher values are for areas with an arid climate, such as the Cache La Poudre River Basin. The consumptive use coefficients selected for the study area along with the assumed irrigation growing seasons are shown in Table 5-12. These basic coefficients were then weighed by the percentages of land within the irrigated area for that crop as were given in Table 5-9. These weighted consumptive use coefficients are given in Table 5-13.

Table 5-10. Equations to Compute Crop Evapotranspiration (Adapted from Schulz, 1973 in Janonis and Gerlek, 1977).

Name of Equation	Data Required
Thornthwaite	Temperature
Lowry-Johnson	Temperature in growing season
Blaney-Criddle	Temperature, % Sunshine, Crop Coefficient
Jensen-Haise	Temperature, Solar Radiation
Turc	Temperature, Solar Radiation
Stephens-Stewart	Temperature, Solar Radiation
Makkink	Temperature, Solar Radiation
Grassi	Temperature, Solar Radiation, Crop Coefficient
Blaney-Morin	Temperature, % Sunshine, Relative Humidity, Crop Coefficient
Hamon	Temperature, Absolute Humidity, % Sunshine
Hargreaves	Temperature, Relative Humidity, % Sunshine
Papadakis	Temperature, Sat. Vapor Pressure at M.D. Temp. and at Min. Temp.
Penman	Temperature, Solar Radiation, Wind Humidity
Christiansen	Temperature, Radiation, Wind, Relative Humidity, % Sunshine, Elevation, Crop Coefficient
Van Bavel	Temperature, Solar Radiation, Wind, Humidity

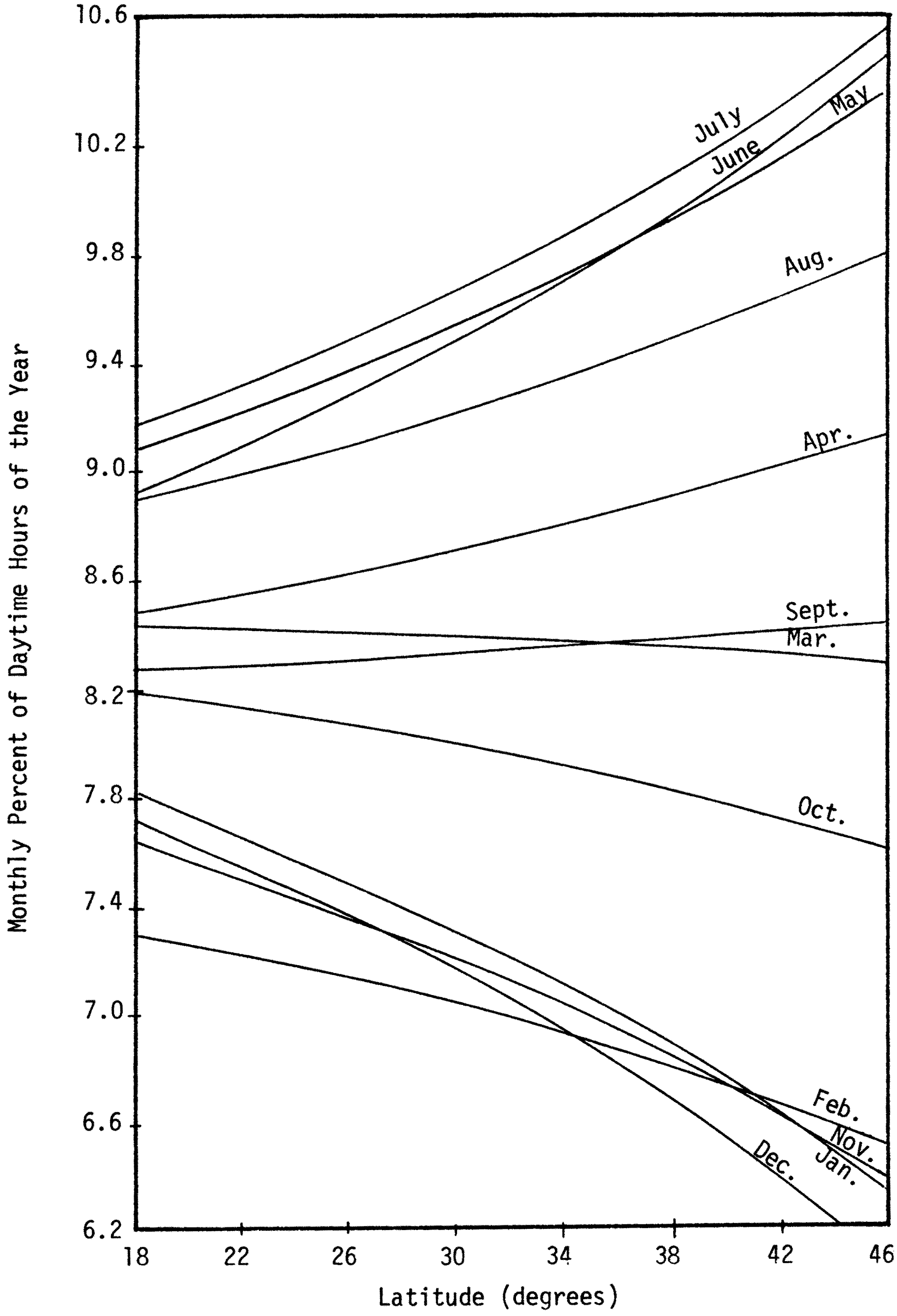


Figure 5-10. Percent of Annual Sunshine Hours Occurring During the Various Months (Adapted from Schulz, 1973 in Janonis and Gerlek, 1977).

Table 5-11. Consumptive Use Coefficients (Janonis and Gerlek, 1977).

Crop	Growing Season or Period	Consumptive Use Coefficient K		
		Schulz for Colorado	Blaney (1959) for West U.S. (1)	Criddle (1958) for West U.S.
Alfalfa	Between frosts	.85	.80 to .85	.85
Alfalfa	Pre frost-free Period	.70		
Beans	3 months		.60 to .70	.65
Corn	4 months		.75 to .85	.75
Cotton	7 months	.75	.65 to .75	.70
Citrus Orch.	7 months		.50 to .65	.60
Deciduous Orch.	Between frosts		.60 to .70	.65
Flax	7 to 8 months		.80	
Small Grains	3 months	.75	.75 to .85	
Grass & Hay	Between frosts	.75	.75	.75
Potatoes	3 to 3 1/2 months		.65 to .75	.70
Rice	3 to 5 months		1.0 to 1.2	1.00
Sorghum	4 to 5 months		.70	.70
Sugar Beets	5 1/2 to 6 months		.65 to .75	.70
Tomatoes	4 months		.70	
Small vegetables	3 months		.60	

(1) The lower values of K are for coastal areas, the higher values for areas with an arid climate.

Table 5-12. Blaney-Criddle Consumptive Use Coefficients for the Cache La Poudre Basin Irrigated Areas.

Crop	Irrigation Growing Season (1)	Monthly K Coefficient (2)
Alfalfa	May - Oct.	.85
Beans	May - Aug.	.70
Barley	May - July	.75
Corn	May - Aug.	.75
Hay	May - Oct.	.75
Oats	May - July	.75
Potatoes	May - Aug.	.75
Sorghum	May - Aug.	.70
Sugar Beets	May - Oct.	.75
Winter Wheat	April - June	.75
Spring Wheat	July - Sept.	.75

(1) Assumed valid for the entire South Platte River Basin.
(2) Based upon K values given in Table 5-11. When a K was given for Colorado, this was used; otherwise the higher value of K was selected from the range given by Blaney and Criddle.

Table 5-13. Weighted Consumptive Use Coefficients k To Be Used In the Blaney-Criddle Formula for the Computation of the Water Consumptive Use of Cache La Poudre Basin Irrigated Areas.

Month	Alfalfa k	Alfalfa Weighted k	Corn k	Corn Weighted k	Winter Wheat k	Winter Wheat Weighted k	Spring Wheat k	Spring Wheat Weighted k
Nov.	-	-	-	-	-	-	-	-
Dec.	-	-	-	-	-	-	-	-
Jan.	-	-	-	-	-	-	-	-
Feb.	-	-	-	-	-	-	-	-
March	-	-	-	-	-	-	-	-
April	-	-	-	-	.75	.011	-	-
May	.85	.258	.75	.236	.75	.011	-	-
June	.85	.258	.75	.236	.75	.011	-	-
July	.85	.258	.75	.236	-	-	.75	.002
Aug.	.85	.258	.75	.236	-	-	.75	.002
Sept.	.85	.258	-	-	-	-	.75	.002
Oct.	.85	.258	-	-	-	-	-	-

Month	Barley k	Barley Weighted k	Oats k	Oats Weighted k	Sorghum k	Sorghum Weighted k	Sugar Beets k	Sugar Beets Weighted k
Nov.	-	-	-	-	-	-	-	-
Dec.	-	-	-	-	-	-	-	-
Jan.	-	-	-	-	-	-	-	-
Feb.	-	-	-	-	-	-	-	-
March	-	-	-	-	-	-	-	-
April	-	-	-	-	-	-	-	-
May	.75	.065	.75	.008	.70	.001	.75	.062
June	.75	.065	.75	.008	.70	.001	.75	.062
July	.75	.065	.75	.008	.70	.001	.75	.062
Aug.	-	-	-	-	.70	.001	.75	.062
Sept.	-	-	-	-	-	-	.75	.062
Oct.	-	-	-	-	-	-	.75	.062

Month	Potatoes k	Potatoes Weighted k	Beans k	Beans Weighted k	Hay k	Hay Weighted k	Sum Weighted k
Nov.	-	-	-	-	-	-	0.0
Dec.	-	-	-	-	-	-	0.0
Jan.	-	-	-	-	-	-	0.0
Feb.	-	-	-	-	-	-	0.0
March	-	-	-	-	-	-	0.0
April	-	-	-	-	-	-	0.011
May	.75	.005	.70	.038	.75	.094	0.778
June	.75	.005	.70	.038	.75	.094	0.778
July	.75	.005	.70	.038	.75	.094	0.769
Aug.	.75	.005	.70	.038	.75	.094	0.696
Sept.	-	-	-	-	.75	.094	0.416
Oct.	-	-	-	-	.75	.094	0.414

(1) These weighted k were obtained as products of the monthly k coefficients of Table 5-12 times the percent of total irrigated acreage for each crop (Table 5-9) over 100.

The normal mean monthly temperatures in a representatative climatological station (Fort Collins) were used for the computation of the consumptive use factor F . It was preferred to use the normal values instead of the 1970 annual values in order to make the model usuable for planning purposes and for projections beyond the 1970. Normal and 1970 monthly mean temperatures are reported in Table 5-14. The departures between 1970 and normal values are also shown in the table. One realizes that there is not too much difference. Therefore, the computations using the normal values can be considered representative of a long horizon as well as of the 1970 situation.

Table 5-14. Average Monthly Temperatures, Monthly Normals and Departure from Normals in Fort Collins (Taken from "Climatological Data for Colorado" and "Climatography of the United States No. 81-4, Decennial Census of U.S. Climate").

Months	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Averages for 1970	30.1	37.6	33.3	42.5	58.7	64.7	71.2	71.6	58.3	45.1	39.2	30.6
Normals	26.6	29.7	36.2	46.4	55.4	64.9	71.0	69.2	60.7	49.8	36.7	30.4
Depart. from Normals	3.5	7.9	-2.9	-3.9	3.0	-0.2	2.4	2.4	-2.4	-4.7	2.5	0.2

The values of all the variables which were needed for using the Blaney-Criddle formula are summarized in Table 5-15 (columns 1, 2, 3 and 4). The consumptive use U_C as computed through the formulat (in inches) is reported in column 5 of the same table for each month. The total yearly consumptive use resulted in 23.43 inches. This is equivalent to 444,317 acre-feet consumptive use over the total 227,563 irrigated acres. The computations of the agriculture consumptive use were taken from Gerlek and Janonis (1977).

This total value was then distributed between "upper" and "lower" irrigated areas in proportion to the acreages of the two areas (i.e., 76% and 24%). Consumptive uses of 337,681 acre-feet and 106,636 acre-feet resulted respectively for the "upper" and "lower" areas. This implies a uniform temperature over the area and a uniform crop distribution. However, the values so calculated are not all inclusive with respect to the total "in farm" agriculture water sues, due to the inefficiencies of water application.

The efficiency of agricultural water use in Cache La Poudre Valley is typical of most western areas. Some irrigators using sprinkler irrigation, but the water that is used for sprinkling is primarily taken from water wells rather than irrigation ditches. The reason for this is that the water comes out of the wells under pressure from a pump and it is just as easy to continue to maintain this pressure and run it through sprinkler nozzles as to dump it into an open irrigation ditch. However, the majority of the farmers in Poudre Valley used flood irrigation techniques.

Table 5-15. Computation of 1970 Water Consumptive Use (U_c) for Cache La Poudre Irrigated Areas Using the Blaney-Criddle Formula (Derived from Janonis and Gerlek, 1977).

Month	Mean Mo. Air Temp. °F (1)	% Sunshine Lat = 40.5° (2)	$F = \frac{(1)x(2)}{100}$ (3)	Weighted k (4)	Monthly U_c = (3)x(4) (5)
Nov.	36.7	6.70	2.46	0.0	0.0
Dec.	30.4	6.48	1.97	0.0	0.0
Jan.	26.6	6.73	1.79	0.0	0.0
Feb.	29.7	6.70	1.99	0.0	0.0
March	36.2	8.32	3.01	0.0	0.0
April	46.4	8.96	4.20	0.011	0.05
May	55.4	10.05	5.57	0.778	4.34
June	64.9	10.10	6.55	0.778	5.10
July	71.0	10.25	7.28	0.769	5.60
Aug.	69.2	9.56	6.62	0.696	4.61
Sept.	60.7	8.49	5.15	0.416	2.14
Oct	49.8	7.74	3.85	0.414	1.59
				TOTAL	23.43

$$U_c = PET = kF$$

(1) The normal monthly temperatures were used as more valid for planning purposes. However, these values are very close to the monthly means.

(2) These are the percent of the annual daytime hours occurring during each month of the year (from Schulz, 1973, See Fig.5-10).

(3) F is the consumptive use factors.

(4) K is the weighted consumptive use coefficients, computed in Table

(5) U_c is the consumptive use in inches per unit area.

A literature search of irrigation efficiencies indicated that there is very little factual data. Almost all investigators use an approach involving irrigation efficiencies, but because of lack of factual data most had to assume their efficiency data.

Bagley (1965) gives irrigation efficiencies measured by the Utah Agricultural Experiment Station for ground water in Milford Valley, Utah as 48.5 percent in 1959, 49.8 percent in 1960, and 60.9 percent in 1961. This increasing efficiency trend appears to be due to stress from a diminishing ground water supply. Evans (1971) in his work on the Cache La Poudre Valley assumes a farm application efficiency of 50 percent for surface water and 60 percent for ground water. Anderson and Maass (1971) assume different efficiencies for different crop types for irrigated farmland near Deming, New Mexico. Alfalfa has an assumed field irrigation efficiency of 70 percent and farm irrigation efficiency of 60 percent. Beans, corn, cotton, grain, and sorghum had an assumed field irrigation efficiency of 65 percent and farm irrigation efficiency of 55 percent. Lurvey (1973) in his work on the consolidation and rehabilitation of canals in the Cache La Poudre Valley based his irrigation efficiencies on those assumed by Evans (1971).

Blaney and Criddle (1962) state that some irrigation authorities have estimated system efficiencies of less than 30 percent. They also state that farm irrigation efficiencies assumed to be reasonable for Montrose, Colorado would be 60 percent for alfalfa and orchards, 55 percent for corn, and 50 percent for hay. The Bureau of Reclamation in their Westwide Study (1975) shows an average system efficiency for Colorado of approximately 35 percent for 1970 (including of course conveyance efficiency). They also state that with improvements a possible farm efficiency of 65 percent could be achieved in Colorado. A farm irrigation efficiency of 60 percent was assumed for this study; it seemed to be a reasonable compromise among the reported surveys and the Cache La Poudre practice.

A portion of the crop water requirements are satisfied by natural precipitation. Gerlek and Janonis (1977) estimated that an area average of 9.07 inch of the total precipitation can be considered "effective" for the crop consumptive use requirements. This value was accepted for this study and implied computed amounts of 130,720 and 41,280 acre-feet of "effective precipitation" over the "upper" and "lower" Cache La Poudre irrigated areas. The irrigation water applied was 206,961 and 65,356 acre-feet, respectively, (by calculation above). Therefore, the total irrigation amounts diverted to the two irrigated areas (i.e., to the farms) by ditches from streams and wells, applying 60% efficiency values, was computed to be 344,935 acre-feet and 108,927 acre-feet respectively for the "upper" and "lower" portions.

5.4.2 Ditch and reservoir operation. About 52.9 percent of the total agricultural water deliveries in the Cache La Poudre irrigated areas was found to be supplied by surface water delivery structures; the rest was pumped from the aquifer. This percentage will be numerically justified in paragraph 5.4.3, but is mentioned here just for indicating the dimension of the surface water distribution and storage system whose 1970 farm deliveries amounted to 240,428 acre-feet (52.9 percent of 453,862 acre-feet, the total irrigation deliveries to farms).

The ditch and reservoir system in operation in the Cache La Poudre basin is a very complex one. The ditches and canals mostly divert their waters from the plains reaches of the river. A little water is diverted also from the mountain reaches and from the North Fork of the river. Part of this water was delivered directly to the irrigated areas, but the most of it is handled through an intricate system of off-stream reservoirs. The whole reservoir and ditch system allows a complex set of water exchanges among the irrigation companies for a more effective yield of their water rights. Eventually some water is put back in the river for downstream use. A picture of the extent and nature of the ditch and reservoir system for agriculture deliveries is shown in Figure 5-11.

The water sources for these ditches include the Cache La Poudre river native flows, transmountain diversions, the "Colorado-Big Thompson Delivery System," imports from the Big Thompson River, and municipal return flows.

The Water Commissioner for the District No. 3 of the State Engineer Office indicated (Mr. John Neutze, personal conversation, 1977) 25 major ditches reporting direct diversions from the Cache La Poudre River in 1970. These canals and their 1970 diversions as given by the Water Commissioner are reported in Table 5-16. Besies these, nine more canals exist in the system. Four of these (i.e., "Louden Ditch," "Oklahoma Ditch," "Boomerang Lateral" and "Grapevine Lateral") originate in the Big Thompson basin. The others ("Pierce Lateral," "Collins Lateral," "Charles Hansen Canal," "Dixon Feeder Canal" and "Taylor Gill Ditch") are fed by other major canals or by reservoirs.

Some of the system ditches export water to other river basins. These are "Larimer and Weld Canal," "Pierce Lateral," "Collins Lateral" and "Greeley No. 2 Canal" exporting a total of 52,011 acre-feet to "Crow Creek Basin," and Oglivy Ditch exporting 8,262 acre-feet to "Other South Platte Sub-basin." These exports were estimated on the basis of an areal distribution of the deliveries between "in basin" and "out of basin" served areas porportionally to the respective surfaces as grasped from the U.S. Soil Conservation Service land use maps and reported in Figure 5-11 (see also Appendix E, Figures E-4, E-13, E-21, E-27, and E-28). These exports are reported in Table 5-17.

Most of the ditches in the Cache La Poudre River basin were constructed with limited funds during periods of rapid growth. Those carrying water to the most productive areas and for the lowest cost were constructed first, with no plan for comprehensive or overall development. With additional growth, more ditches were added to serve lands at a slightly higher elevation. Frequently, lands in the same elevation as those already developed but farther from the point of diversion required increased canal capacities or new canals. The result is that three or four canals may exist where only one would suffice.

This piece meal development has required several times as much main canal and rights-of-way as needed, which results in more operation and maintenance costs, and more seepage and water logged lands

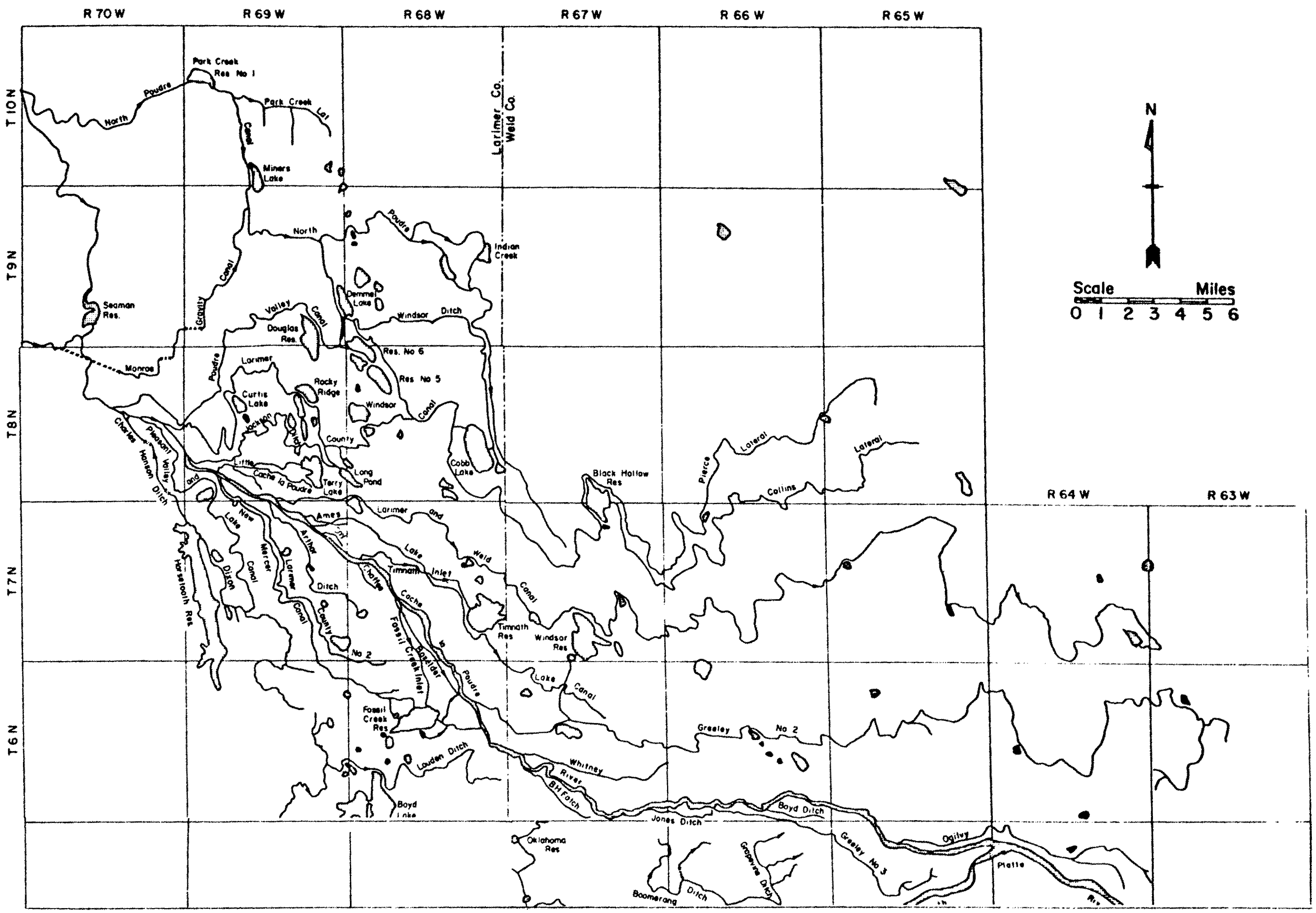


Figure 5-11. Irrigation Reservoir and Ditch System in the Cache La Poudre River Valley (Evans, 1971).

Table 5-16. Irrigation Ditch Diversions from Cache La Poudre River in 1970 (1).

Ditches	Location	Diverted Amounts (acre-feet)	Totals
North Poudre Ditch	North Fork of Cache La Poudre	24,750	24,750
Munroe Gravity Canal	Cache La Poudre Mile 94-Mile 61	38,108	38,108
Poudre Valley Canal	Cache La Poudre Mile 61-Mile 56	17,594	17,594
Pleasant Valley & Lake Canal	Cache La Poudre Mile 56-Mile 47	14,648	
Larimer County Canal		71,826	
Jackson Ditch		7,224	
Little Cache La Poudre Ditch		13,380	
New Mercer Canal		7,224	
Larimer County No. 2 Canal		8,966	
Arthur Ditch		5,172	
Larimer-Weld Canal		73,450	
			201,890
Josh Ames Ditch	Cache La Poudre Mile 47-Mile 21	808	
Lake Canal		11,650	
Coy Ditch		920	
Timnath Reservoir Inlet		8,442	
Chaffee Ditch		513	
Boxelder Ditch		5,150	
Fossil Creek Reservoir Inlet		12,988	
Greeley No. 2 Canal		36,212	
Whitney Ditch		10,842	
B. H. Eaton Ditch		4,644	
			92,169
Jones Ditch	Cache La Poudre Mile 21-Mile 00	3,252	
Greeley No. 3 Ditch		17,856	
Boyd Ditch		740	
Ogilvy Ditch		13,590	
			35,438
		Total Irrigation Ditch Diversions	409,949

(1) The diversions are groupped together according to the correspondent reaches of Cache La Poudre River where the water is diverted from.

Table 5-17. Water Exports from Cache La Poudre River Basin Through Irrigation Ditches in 1970.

Ditch	Total Deliveries (ac-ft)(1)	Exported Percent (2)	Exported Amount (ac-ft)	Out of Basin Estination
Larimer-Weld Canal	53,579	35	18,753	Crow Creek Basin
Pierce Lateral	3,018	57	1,720	
Collins Lateral	29,604	48	14,210	
Greeley No. 2 Canal	43,321	40	17,328	
Total Irrig. Exports to Crow Creek Basin			52,011	
Ogilvy Ditch	10,328	80	8,262	Other S. Platte Sub-basins
Total Irrig. Exp. to Other S. Platte Sub-bas.			8,262	
Total Irrigation Exports			60,273	

(1) See also the irrigation ditch mass-balances in Appendix E.
(2) Estimated from the distribution of the served area in and out of the Cache La Poudre basin.

than would occur if the development were more unified. A multiplicity of water rights and complicated exchanges makes administration difficult. Some canals are larger than their decreed capacity, as storage rights are also exercised through them; they were built larger to reduce the time required to fill reservoirs. Some other ditches are smaller than their decreed capacity as they were not enlarged for later decrees.

Most of the systems were built by cooperative or community effort with interested individuals contributing much of the necessary labor. The present form of ownership is usually a stock company with users as shareholders. Funds for the necessary maintenance or upkeep of the system are provided by assessments on a per-share basis. To keep these assessments low, maintenance has been kept to an absolute minimum in most cases. Usually only enough maintenance is performed to enable the distribution of water during the coming season.

As a result, the condition of the system is not good; many structures are inadequate; serious bank sloughing, deepening and general erosion are evident; numerous large trees use water and interfere with operations; also leaky stretches of ditches are ignored, resulting in seepage and water logging of adjacent lands.

The consequence of this situation is a high rate of seepage losses to the aquifer. The loss percentages were estimated on the basis of the length of the canals and of their conditions wherever information was easily available. These seepage losses are reported for all the ditches and canals in Table 5-18. The magnitude of these estimates is such that the total seepage losses averages around a 30% of the total diverted

Table 5-18. Estimated Seepage Losses from Ditches and Canals in the Cache La Poudre Basin Area in 1970 (1).

Structure	Estimated Length (miles)	1970 Diverted Amount (ac-ft)	Estimated Seepage Percent	Seepage Losses (ac-ft)
Munroe Gravity Canal	17.0	38,108	15	5,716
Charles Hansen Canal	7.0	67,561	0	0
North Poudre Ditch	14.5	24,750	30	7,425
Poudre Valley Canal	33.5	23,650	23	5,445
Pierce Lateral	23.0	3,875	21	857
Pleasant Valley & Lake Canal	17.5	14,648	20	2,930
Larimer County Canal	45.5	71,826	23	16,971
Jackson Ditch	16.0	7,224	18	1,300
Little Cache La Poudre Ditch	5.0	10,260	8	820
Taylor Gill Ditch	4.5	3,120	5	156
New Mercer Canal	2.0	7,224	25	1,806
Larimer County No. 2 Canal	15.5	8,966	24	2,152
Arthur Ditch	8.5	5,172	18	930
Larimer Weld Canal	74.5	73,450	52	37,537
Josh Ames Ditch	3.5	808	5	40
Lake Canal	22.0	11,650	22	2,563
Coy Ditch	2.0	920	5	46
Timnath Res. Inlet	13.0	8,442	15	1,266
Chaffee Ditch	2.0	513	5	26
Boxelder Ditch	10.0	5,150	14	721
Greeley No. 2 Canal	54.5	36,212	45	16,295
Whitney Ditch	8.0	10,842	10	1,084
Eaton Ditch	5.0	4,644	8	371
Jones Ditch	4.5	3,252	8	260
Greeley No. 3 Ditch	13.5	17,856	15	2,678
Ogilvy Ditch	20.5	13,590	24	3,262
Boyd Ditch	3.5	740	5	37
Collins Lateral	28.5	38,952	24	9,348
Fossil Creek Res. Inlet	6.0	14,881	10	1,488

(1) The aggregate seepage loss for all canals was estimated at about 30 percent. This amount was distributed among the individual structures on the basis of canal length, diverted flow and maintenance level.

amount through all the ditches and canals, as was suggested by the experience of Mr. John Neutze, Water Commissioner for Cache La Poudre.

The storage capacity of the Cache La Poudre basin is given by some high mountain reservoirs and by the many plains reservoirs. The plains reservoirs consist essentially of the depressions scattered throughout the plains drainage area of the Cache La Poudre basin, which are a result of natural phenomena. The depressions are five to 50 feet deep, and were caused by wind scour. Some of these depressions collected rain water and formed watering holes and "buffalo wallows." These same basins now provide facilities for storing water at a relatively low expense. The discovery was made at an early date that these natural depressions could have their holding capacity increased greatly by building an embankment across a saddle in a rum and joining it to higher ground. Nearly all of these "basin" reservoirs in the Cache La Poudre River basin were completed prior to 1920 (USBR, 1966).

The reservoirs in the Cache La Poudre basin are usually filled during period of high runoff caused by melted snows, generally April to June. However, some plains reservoirs also take water during the fall and winter when other users do not require these flows. About 31 major reservoirs and lakes were individually considered in the model of the Cache La Poudre Water System. They are listed, together with their 1970 operation, in Table 5-19. Most of these reservoirs are owned by irrigation companies, but some (Comanche Reservoir, Barnes Meadow Reservoir, and Seaman Reservoir) are owned by the City of Greeley and one (Horsetooth Reservoir) is owned by the U.S. Bureau of Reclamation. Horsetooth Reservoir has a particular role in the Cache La Poudre Water System: it stores the "Colorado-Big Thompson Project" water from the west slope, which is transported through the continental divide and conveyed through the Hansen Feeder Canal. Some of the information about inputs and outputs for these reservoirs and lakes was available from the Water Commissioner for Cache La Poudre, but some other was estimated through mass-balance or judgment. This is especially true with respect to the exchanges within the ditch system. Significant losses occur in reservoirs and lakes, due to atmospheric evaporation and seepage into the aquifer. The seepage into the aquifer, although known to occur in definite amounts, was very difficult to evaluate. It was neglected for most of the reservoirs (i.e., assumed equal to zero), unless it could be computed through mass balance.

The atmosphere evaporation was estimated on the basis of the suggestion of Mr. John Neutze, Water Commissioner for Cache La Poudre basin. He had proposed values of 2.6 feet for the mountains impoundments and 3.5 feet for the plains impoundments. The total evaporated values were estimated multiplying the evaporation (in feet) times the average water surface in the year. However, the water surfaces needed to be estimated too. The estimates were done by measuring the maximum surface areas from U.S. Geological Survey maps and adjusting "by eye" these values in order to take account of the area reductions wherever the stored value had been considerably low throughout the year. The adjusted water surfaces are reported in Table 5-19 together with the 1970 estimated evaporation losses.

Table 5-19. List of Major Reservoirs in Cache La Poudre River Basin and Summary of Their 1970 Operation.

Reservoir or Lake (1)	Ownership (2)	Water Surface (acres)(3)	Evaporation (feet) (4)	Evaporation (acre-feet) (5)	Capacity (acre-feet) (2)	Initial Storage (6)	Final Storage (6)	Volumes to storage (7)	Volumes from stor. (7)
Chambers Lake	Water Supply and Storage Company	192	2.6	499	8,824	1,169	1,357	188	
Comanche Res.	City of Greeley	64	2.6	166	2,629	319	0		319
Long Draw Res.	Water Supply and Storage Company	268	2.6	698	4,400	41	94	53	
Barnes Meadow Res.	City of Greeley	0	2.6	0	898	0	0	0	
Joe Wright Res.	North Poudre	0	2.6	0	800	0	0	0	
Black Hollow Res.	Water Supply and Storage Company	230	3.5	806	7,485	3,626	3,816	190	
Terry Lake	Larimer and Weld Res. Company	460	3.5	1,610	8,145	0	4,272	4,272	
Horsetooth Res.	U.S. Bureau of Reclamation	1,990	3.5	6,965	151,752	75,866	92,512	16,646	
Halligan Res.	North Poudre	150	2.6	390	6,428	1,543	0		1,543
Claymore Lake	Pleasant Valley and Lake Canal	64	3.5	224	883	767	336		431
Seaman Res.	City of Greeley	186	2.6	484	5,008	3,045	3,045	0	
Cobb Lake	Windsor Res. and Canal Company	384	3.5	1,344	22,300	16,330	17,520	1,190	
North Poudre Res. No. 5	North Poudre	480	3.5	1,680	8,413	4,364	3,840		524
North Poudre Res. No. 6	North Poudre	544	3.5	1,904	9,986	3,065	4,936	1,871	
Long Pond (8)	Water Supply and Storage Company	192	3.5	672	5,042	2,725	2,985	260	
Fossil Creek Res.	North Poudre	512	3.5	1,792	11,508	5,399	4,929		470
Timnath Res.	Cache La Poudre Res. Company	510	3.5	1,785	10,070	6,935	4,272		2,663
Reservoir No. 8 (9)	Windsor Res. and Canal Company	320	3.5	1,120	14,131	7,471	10,610	3,139	
Douglass Res.	Windsor Res. and Canal Company	448	3.5	1,568	8,834	5,710	6,276	566	
Windsor Res.	Windsor Res. and Canal Company	640	3.5	2,240	17,689	7,211	0		7,211
Curtis Lake	Water Supply and Storage Company	131	3.5	460	1,525	862	850		12
North Poudre Res. No. 2	North Poudre	205	3.5	718	3,910	2,131	2,401	270	
North Poudre Res. No. 3	North Poudre	180	3.5	630	3,441	597	1,470	873	
North Poudre Res. No. 4	North Poudre	70	3.5	245	1,674	442	243		199
North Poudre Res. No. 15	North Poudre	194	3.5	679	5,526	2,557	4,083	1,526	
Clarks Lake	North Poudre	126	3.5	441	871	465	690	225	
Indian Creek Res.	North Poudre	130	3.5	455	1,908	1,309	1,556	247	
Kluver Res.	Water Supply and Storage Company	68	3.5	238	1,503	853	802		51
Rocky Ridge Res.	Water Supply and Storage Company	195	3.5	682	4,492	3,203	2,773		470
WSSC (10) No. 3	Water Supply and Storage Company	100	3.5	350	4,750	3,552	2,703		849
WSSC (10) No. 4	Water Supply and Storage Company	85	3.5	298	1,012	407	462	55	
TOTALS				31,143	335,837	161,964	178,793	31,317	14,488

(1) The major reservoirs of the Cache La Poudre Basin are listed. The choice was made on the basis of the capacity and of the relevance of the reservoir or the lake with respect to the operation of the Cache La Poudre Water System. Some of these reservoirs were lumped together for input-output model. These are: Indian Creek Res. and Clarks Lake, North Poudre Res. Nos. 2,3,4, and 15 (identified as "Other" North Poudre Reservoirs) and Rocky Ridge Res., Kluver Res. WSSC No. 3 and WSSC No. 4 (identified as "Other" Water Supply and Storage Co. Reservoirs).

(2) Information derived from Skogerboe, V., Radosevich, G., and Vlachos, E., Consolidation of Irrigation Systems, Environmental Resources Center, Colorado State University, Fort Collins, 1973.

(3) These average values for 1970 were estimated from storage records.

(4) These values were estimated by the Water Commissioner for Water District No. 3 (Colorado State Engineer, Division 1)Values of 3.5 and 2.6 feet were given for the plainsand mountain reservoirs respectively.

(5) Values obtained as products of column 3 times column 4.

(6) Values obtained from the records of the Water Commissioner for Water District No. 3 (Colorado State ENgineer Division 1) for the water year 1970. The initial storage is at Nov. 1, 1969. The final storage is at Oct. 1, 1970. The storage changes during Oct. 1970 were not easily available, are not reported herein and were neglected in the computation of the storage carryover.

(7) When the final storage exceeds the initial, the difference is considered to be put in storage for carryover to next years and is reported in the column "Volumes to Storage". When the final storage is less than the initial, the difference is considered as coming from the previous year storage for carryover and is reported in the column "Volumes from storage".

(8) Includes also Richard's Lake.

(9) Includes also the Annex to Reservoir No. 8.

(10) Water Supply and Storage Company.

Some information about the water releases from reservoirs to ditches and canals or about the incoming water was available through measurements recorded by the Water Commissioner for the Cache La Poudre basin. Other information was estimated or computed by the mass balance procedure.

In order to achieve a full balance for the 1970 operation of the water system it was also necessary to take care of the values impounded for later year carryover or released from previous storage. Whenever the final storage in an impoundment structure was less than the initial, release from reservoir storage was implied. A fictitious system entry element, referred as "reservoir storage" was introduced to behave as an "origin" for these water releases. Similarly, a fictitious exit element, referred as "reservoir storage" too, was created as a destination for the volumes which were actually leaving the 1970 circulation within the system since they were being put in storage.

Storage information was available from the Water Commissioner for the Cache La Poudre basin. The values were referred to the 1970 water year. The initial storage was considered at November 1, 1969. The final storage was considered at November 1, 1970. However the information at the period end was easily available only at October 1, 1970. Then the storage changes during October 1970 were neglected. Initial and final storage volumes are reported in Table 5-19. When the final storage exceeded the initial the difference was reported in the column "Volumes to Storage" and considered forwarded to the "Reservoir Storage" exit element. When the final storage was less than the initial, the difference was reported in the column "Volumes from Storage" and was considered as originated from the "Reservoir Storage" entry element.

Very individual assumptions were sometimes needed for mass balancing some ditches, canals, lakes or reservoirs. These are reported in the individual mass balance sketches in Appendix E for ditches and canals and Appendix D for reservoirs and lakes. These appendices actually reprsent the assemblage of all the input-output information for the related elements, as collected, estimated or computed.

5.4.3 Water balance of the irrigated areas. According to the estimates and computations of paragraph 5.4.1 total values of 337,681 acre-feet and 106,636 acre-feet were consumptively used by the crops in the "upper" and "lower" Cache La Poudre Irrigated Areas. 130,720 acre-feet and 41,280 acre-feet were supplied by the "effective" precipitation, according to the estimate of 9.07 inches (Gerlek and Janonis, 1977) over respective areas of 172,948 and 54,615 acres. The portions of the crop consumptive use provided by irrigations were then 206,961 acre-feet and 65,356 acre-feet. Applying a farm irrigation efficiency of 60%, as explained in paragraph 5.4.1 irrigation amounts of 344,935 adn 108,927 acre-feet resulted for the two Cache La Poudre Irrigated Areas. The additional water supplied because of the irrigation inefficiencies was then 137,974 acre-feet (344,935 - 206,961) to the "upper" areas and 43,571 acre-feet (108,927 - 65,356) to the "lower" areas. These amounts were assumed to be lost to atmosphere through evaporation (20%) and to the aquifer through seepage (80%). The amounts lost to atmosphere were then 27,595 acre-feet and 8,714 acre-feet from the two irrigated areas. The seeped volumes were 110,379 and 34,857 acre-feet.

Amounts of 150,310 and 90,118 acre-feet of irrigation water were delivered to the two irrigated areas by the ditch and reservoir systems. These values are the sums of all the irrigation deliveries from ditches and reservoirs as reported in the mass balance sketches of Appendices D and E. The rest of the irrigation water up to the totals of 344,935 and 108,927 acre-feet was assumed to be supplied by the "Aquifer" through wells. This computed groundwater pumpage amounts to 194,625 and 18,809 acre-feet in the two irrigated areas.

As illustrated in paragraph 5.1.1, total precipitation of 220,239 acre-feet and 65,340 acre-feet occurred over the two irrigated areas. Of these amounts, only 130,720 acre-feet and 41,280 acre-feet were considered "effective" for crop consumptive use. The remaining amounts (89,519 and 24,061 acre-feet) were soon evaporated (assume 50%) or infiltrated into the "Aquifer" (50%).

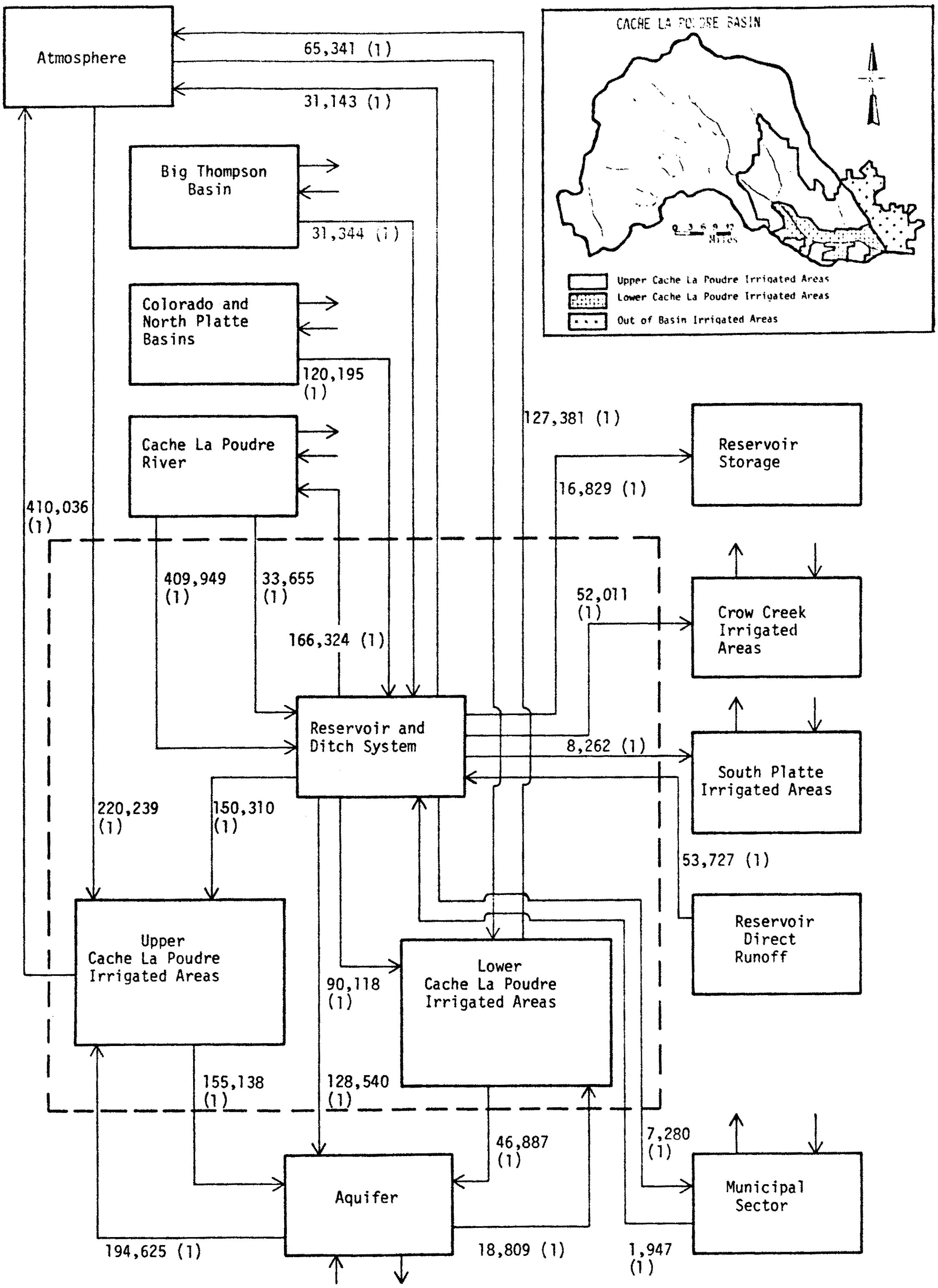
In summary, the "Upper Cache La Poudre Irrigated Areas" received a total amount of 565,174 acre-feet; 220,239 acre-feet were precipitation from the "Atmosphere" and 344,935 acre-feet were irrigation deliveries. Of this amount, 410,036 acre-feet were returned to the "Atmosphere": 337,681 acre-feet as crop consumptive use, 27,595 acre-feet as evaporation losses from the irrigation facilities and 44,760 acre-feet as evaporated precipitation. An amount of about 155,138 acre-feet seeped into the "Aquifer": 110,370 acre-feet as infiltration losses due to the irrigation practices and 44,760 acre-feet as infiltrated precipitation. This mass-balance is illustrated in Appendix H, Figure H-4.

The "Lower Cache La Poudre Irrigated Areas" received a total amount of 130,696 acre-feet; 65,341 acre-feet were precipitation from the "Atmosphere" and 108,927 acre-feet were irrigation deliveries. Of these amounts, 127,381 acre-feet were returned to the "Atmosphere": 106,636 acre-feet as crop consumptive use, 8,714 acre-feet as evaporation losses from the irrigation facilities and 12,031 acre-feet as evaporated precipitation. About 46,887 acre-feet seeped into the "Aquifer": 34,857 acre-feet as infiltration losses due to the irrigation practices and 12,030 acre-feet as infiltrated precipitation. This mass balance is illustrated in Appendix H, Figure H-3.

An inclusive pictorial representation of the water exchanges related to agriculture water use in "Upper" and "Lower Cache La Poudre Irrigated Areas" is given in Figure 5-12. Some of the "blocks" of the Figure 5-12 line diagram are actually an aggregation of elements of the Cache La Poudre Water System. The water exchanges among these "aggregated blocks" were computed through the appropriate summations of the water exchanges among the "elementary" system components.

5.5 River Flows in Cache La Poudre River and Its Tributaries

The surface drainage system of the Cache La Poudre River basin is represented in the input-output model by the six reaches of the main stem of the river and by the tributaries: Eaton Draw, Boxelder Creek



(1) These values are aggregated summations of the water exchanges between the related blocks.

Figure 5-12. 1970 Water Exchanges Related to Cache La Poudre Basin Irrigation (Acre-Feet).

and North Fork of Cache La Poudre. The reasons for this choice were explained in paragraph 4.1.2. The smallest tributaries are not given individuality as drainage elements in the input-output model; their runoffs were considered as flowing directly from the raw lands to the river, to its major tributaries, to lakes, or to reservoirs.

The procedure for the mass balance of the representative drainage elements is now presented in the following sections, i.e., in paragraphs 5.5.1, 5.5.2 and 5.5.3. A brief description of the general natural hydrologic characteristics of the Cache La Poudre River basin is first given in order to provide basic orientation for the computations which follow.

Little Beaver Creek is a minor tributary of the Cache La Poudre River in the mountain portion of the basin. This tributary has no particularly interesting role in the water exchanges within the system, but is suitable for showing the natural hydrologic regime in the mountain areas, since its flows are not affected by any discharge, diversion or regulation.

The 1970 monthly flows of Little Beaver Creek, as recorded at the USGS gaging station No. 06748530, are reported in Figure 5-13. It is soon realized that the majority of the flow occurs during the May-July period, concurrently with the snow melting phenomenon. Then, during the winter season, the flows remain very low at a uniform level.

Snow melt in winter time is very unlikely to occur. Under these circumstances the natural winter flows can be suspected to originate from aquifer discharges to the river channel. One could also suspect that these aquifer contributions have an annual cycle of discharge. However, if these fluctuations exist, they are presumably small, due to the attenuation effect provided by aquifer storage.

In order to allow an evaluation of the aquifer contributions to the river system the hypothesis was assumed that the aquifer contribution is constant throughout the year. The monthly value of this contribution can be set equal to the minimum monthly flow. In other words, the aquifer provides a constant "base flow" to the mountain streams in the basin. In Figure 5-13, referring to the Little Beaver Creek discharge diagram, the base flow is 71 acre-feet/month. This base flow is represented in the figure by the dotted line. Then, the area under the dotted line represents the annual discharge which is originated from the aquifer contribution. The area between the dotted line and the discharge diagram is consequently the annual discharge originating from surface runoff. These assumptions were applied to the task of computing the aquifer contributions to the mountain streams in the Cache La Poudre River basin.

5.5.1 Tributaries of the Cache La Poudre River.

<u>North Fork of Cache La Poudre River</u> - This sub-basin was divided in two portions: above and below the "North Poudre Ditch" diversion point. This type of disaggregation was suggested by the possibility of easily estimating the stream flow at this point. The

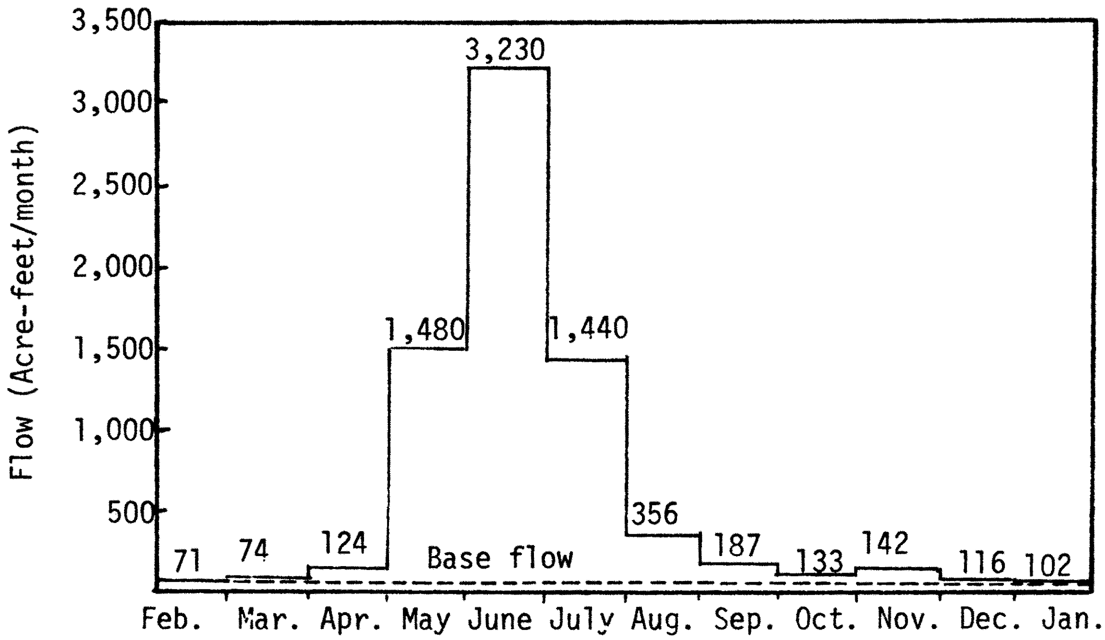


Figure 5-13. Monthly Flows of Little Beaver Creek (Recorded at USGS Gaging Station No. 06748530). The Base Flow is 71 Acre-Feet/Month.

North Poudre Ditch is known to have diverted 24,750 acre-feet in 1970 leaving negligible downstream residual flow (Mr. John Neutze, Water Commissioner for Cache La Poudre). The actual stream flow was then estimated as equal to this amount. The North Fork of the Cache La Poudre sub-basin and its two portions are illustrated in Figures 5-14 and 5-15.

The discharges from various origins in the upper portion of the sub-basin were computed first. The "base-flow separation" method, described above, was used. As mentioned, a diagram of the monthly distribution of the stream flows is the basis for applying the method. The discharge diagram at the North Poudre Ditch diversion point was not readily available, and so it had to be constructed artificially. The natural virgin flow was first computed. This was done by "removing" the man-made effects. These effects derive from the flow augmentation due to the "Wilson Supply Ditch" imports (2,910 acre-feet in 1,970) and from the Halligan Reservoir carry over regulation (390 acre-feet withdrew from the storage and discharged downstream in 1970). The natural virgin flow resulted in 20,687 acre-feet (24,750 - 390 = 20,687). This annual natural virgin flow was then distributed among the various months using the same distribution of the little Beaver Creek flow. The flow distribution of this creek was considered in fact representative for the all mountain areas of the Cache La Poudre basin. The minimum monthly flow (207 acre-feet) was assumed as the constant aquifer contribution then amounting to an annual value of 2,484 acre-feet (270 x 12). The surface runoff to this portion of the basin was then 18,203 acre-feet, computed as difference between the natural virgin streamflow (20,687 acre-feet) and the aquifer contribution (2,484 acre-feet). All these computations are also shown more completely in Figure 5-14.

A similar procedure was used for the identification of the amounts originating from aquifer and surface runoff to the lower portion of the "North Fork of Cache La Poudre" sub-basin. In this case the natural virgin flow at the North Poudre Ditch diversion point, proportionally to the basin areas. The basin area of the lower portion of the North Fork of Cache La Poudre is 112,640 acres. The basin area above the North Poudre Ditch diversion point is 222,080 acres. Then, the natural virgin flow at the lower section of the lower portion of the sub-basin was 20,687 acre-feet x 112,640 acres/222,080 acres = 10,492 acre-feet. This amount was considered to be distributed among the various months as the flows of Little Beaver Creek. A base flow of 105 acre-feet/month was found, which produced a total annual aquifer contribution of 1,260 acre-feet (105 x 12). Finally, the surface runoff was equal to the natural native flow (10,492 acre-feet) minus the aquifer contribution (1,260 acre-feet) and amounted to 9,232 acre-feet. This natural virgin flow coincided with the actual flow at the lower section of the stream, since no artificial effect occurred in the lower portion of the sub-basin. This flow was discharged to the "Seaman Reservoir," located immediately above the confluence of the North Fork with the main stem of the Cache La Poudre River. The computations for the lower portion of the North Fork of the Cache La Poudre are illustrated in Figure 5-15.

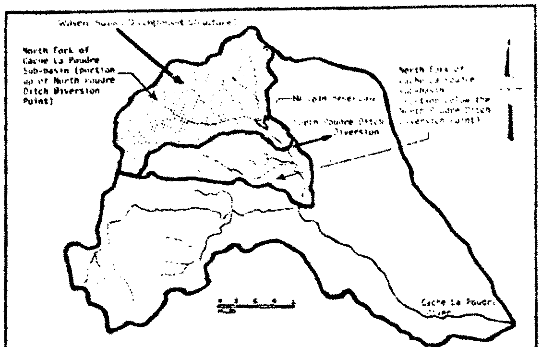
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Little Beaver Creek Flows near Rustic	Monthly Flow (ac-ft)	133	142	116	102	71	74	124	1,480	3,230	1,440	356	187	7,460
(USGS 06748530 Gaging Station)(1)	% of Annual Flow	1.7	1.9	1.5	1.3	1.0	1.0	1.6	19.8	43.2	19.3	4.7	2.5	100
Virgin Flow at North Poudre Ditch Diversion Point (acre-ft)(2)		352	393	310	269	207	207	331	4,121	8,987	4,018	975	517	20,687
Groundwater Runoff to River (acre-feet)(3)		207	207	207	207	207	207	207	207	207	207	207	207	2,484
Mountain Land Runoff to River (acre-feet)(4)		145	186	103	62	0	0	124	3,914	8,780	3,811	768	310	18,203

(1) Little Beaver Creek is one of the sub-tributaries of Cache La Poudre River and was considered to be representative of the virgin flow time distribution over the entire Mountain Portion of Cache La Poudre basin. It's flows are not affected by reservoir regulation, diversions, discharges or any other man-made influence.

(2) 2[illegible] ac. feet were diverted in 1970 by the North Poudre Ditch. This value is considered to be equal to the actual 1970 flow at the diversion point since only little water is left downstream. The 1970 virgin flow was computed subtracting the Wilson Supply Ditch import (2,910 acre-feet) and the withdrawal from Halligan Res. (390 ac-ft). The result (20,687 ac-ft) was then distributed among the various months according to the same monthly percentages of Little Beaver Creek.

(3) A "base flow", equal to the minimum monthly flow in the year (i.e. 207 ac. ft) was assumed to be contributed by the aquifer to the river.

(4) The surface runoff contributed by the Mountain lands to the river is equal to the virgin runoff minus the aquifer contribution.



Sub-basins of North Fork of Cache La Poudre River

Figure 5-14. Surface and Groundwater Runoffs to North Fork of Cache La Poudre River Above North Poudre Ditch Diversion Point in 1970 Water Year.

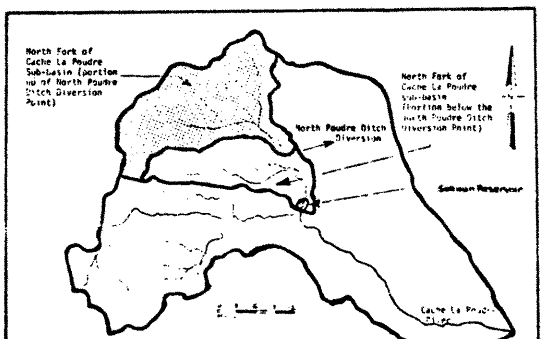
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Total
Little Beaver Creek Flows near Rustic	Monthly Flow (ac-ft)	133	142	116	102	71	74	124	1,480	3,230	1,440	356	187	7,460
(USGS 06748530 Gaging Station)(1)	% of Annual Flow	1.7	1.9	1.5	1.3	1.0	1.0	1.6	19.8	43.2	19.3	4.7	2.5	100
Virgin Flow at Seaman Reservoir (acre-feet)(2)		178	199	157	136	105	105	168	2,077	4,587	2,025	493	262	10,492
Groundwater Runoff to River (acre-feet)(3)		105	105	105	105	105	105	105	105	105	105	105	105	1,260
Mountain Land Runoff to River (acre-feet)(4)		73	94	52	31	0	0	63	1,972	4,482	1,920	388	157	9,232

(1) Little Beaver Creek is one of the sub-tributaries of Cache La Poudre River and was considered to be representative of the virgin flow time distribution over the entire mountain portion of Cache La Poudre basin. It's flows are not affected by reservoir regulation diversions, discharges or any other man-made influence.

(2) The virgin flow at the North Poudre Ditch Diversion Point was computed to be 20,687 acre-feet (see figure 5-14). The basin area between Seaman Reservoir and the North Poudre Ditch diversion point is 112,640 acres. The basin area above the North Poudre Ditch Diversion point is 222,080 acres. Assuming the river virgin flows to be proportional to the basin areas, the annual virgin flow at Seaman Reservoir results: 20,687 acre-feet x 112,640 acres/222,080 acres = 10,492 acre-feet. This amount was considered to be distributed among the various months according to the same monthly percentages of Little Beaver Creek.

(3) A base flow equal to the minimum monthly flow in the year (i.e. 105 ac-ft) was assumed to be contributed each month by the aquifer to the river.

(4) The surface runoff contributed by the Mountain Lands to the river is equal to the virgin runoff minus the aquifer contribution.



Sub-basins of North Fork of Cache La Poudre River

Figure 5-15. Surface and Groundwater Runoffs to North Fork of Cache La Poudre River Below the North Poudre Ditch Diversion Point in 1970 Water Year.

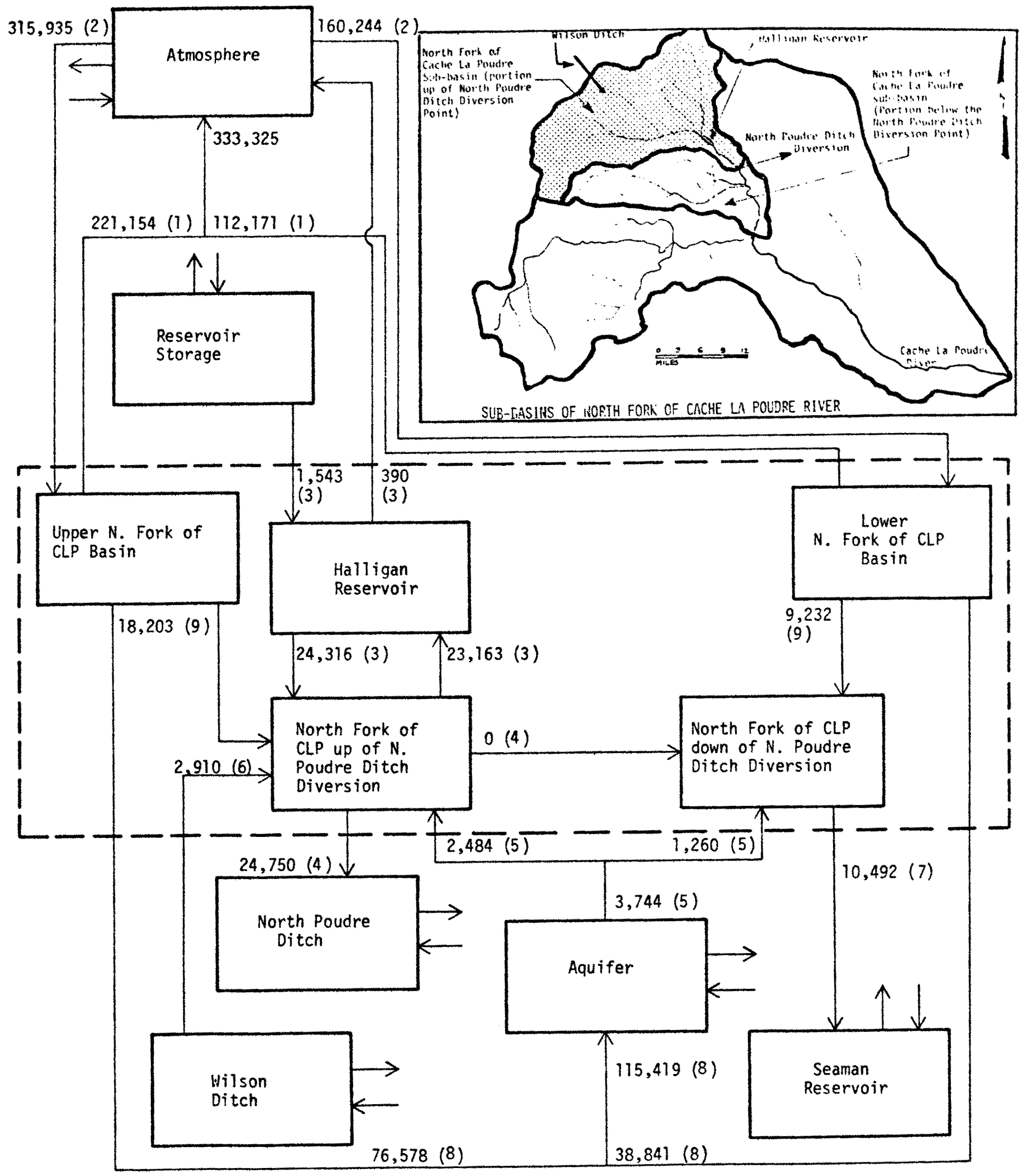
The computed values for the water exchanges related to the whole "North Fork of Cache La Poudre" tributaries were then aggregated as is shown in Appendix C, Figure C-7. A detailed breakdown of these water exchanges is presented in Figure 5-16.

Boxelder Creek and Eaton Draw - The two tributaries of the Cache La Poudre River, Boxelder Creek and Eaton Draw, are located in that part of the Cache La Poudre basin which was often referred to as "plains." The natural streamflows of these tributaries are very low. This is due to the fact that lower precipitations occur in this part of the basin, and most of this precipitation either evaporates soon or infiltrates into the "Aquifer" (see also paragraph 5.1.1). The little natural runoff which could occur to the Boxelder Creek (since it is actually located in the western portion of the plains, close to the mountain area) is captured by the network of irrigation reservoirs which are located in that area.

The previous considerations lead to neglect the land runoff and the natural stream flows of these tributaries. However, their role in the input-output model of the Cache La Poudre Water System is as conveyance elements from two small sewage treatment plants: "Boxelder Sanitation district Sewage Treatment Plant" and "Eaton Sewage Treatment Plant." The actual flows of these two tributaries were assumed equal to these municipal discharges: 77 acre-feet for "Boxelder Creek" and 157 acre-feet for "Eaton Draw." These values were computed in paragraph 5.2.3. It was assumed that no exchange with the aquifer occurred in these tributaries. Boxelder Creek discharges its contribution to Cache La Poudre River in the reach between miles 47 and 21; Eaton Draw in the reach between mile 21 and the South Platte confluence. The mass balances of Boxelder Creek and Eaton Draw are shown in Appendix C, Figures C-8 and C-9.

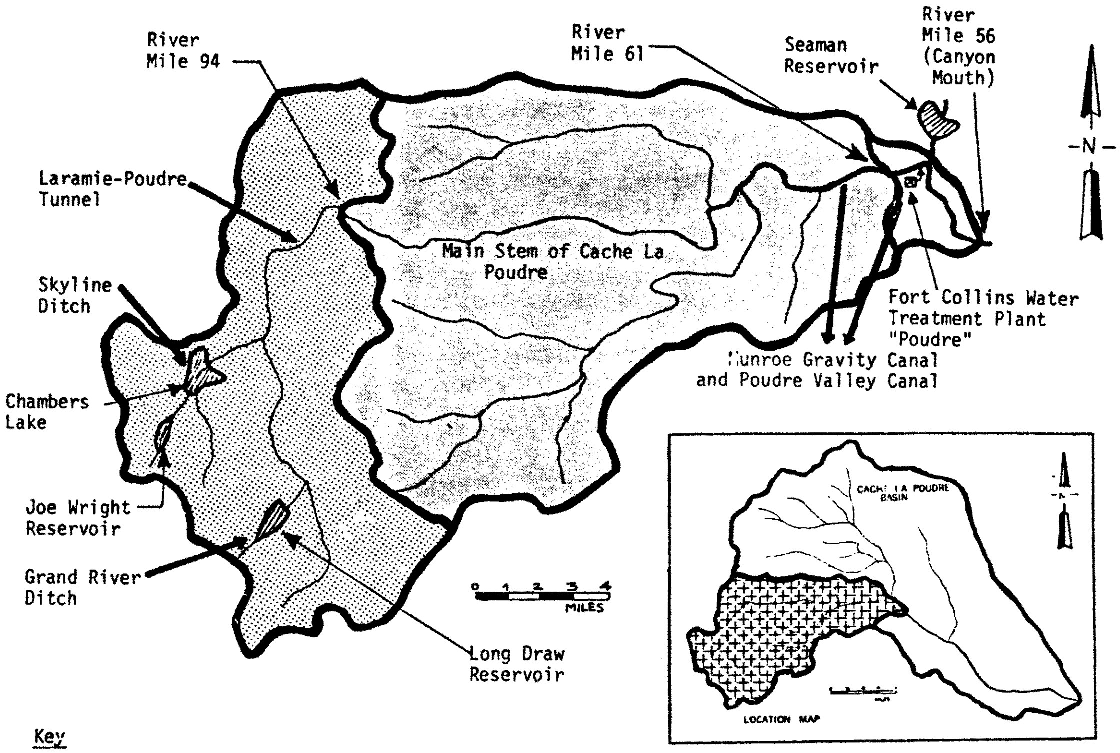
5.5.2 Mountain reaches of Cache La Poudre River. The basin land area contributing surface runoff to the mountain reaches of Cache La Poudre River is shown in Figure 5-17. The river in the mountains was divided into three reaches: Source-Mile 94; Mile 94-Mile 61; Mile 61-Mile 56. This permitted a discernment of the character of the stream as it changed in the downstream direction.

The 1970 water discharges originating from the "aquifer" and the basin runoff were computed using the "base-flow separation" method, as follows. The natural virgin flow at mile 56 (Canyon Mouth) was first calculated. Then, the natural virgin flows at miles 61 and 94 were computed as proportional to the corresponding upper basin areas. The basin contributing areas were estimated to amount to 474 sq. mi., 468 sq. mi. and 186 sq. mi. at river mileages 56 (Canyon Mouth), 61 and 94. The actual flow at mile 56, which is the lower section of the mountain portion of the river, was measured at the USGS gaging station No. 06752000. It amounted to 262,800 acre-feet in the 1970 water year. The amount of natural virgin flow was derived by subtracting from this value the man-made flow additions (transmountain imports, reservoir storage releases, municipal discharges) and adding the man-made diversions (municipal diversions, irrigation diversions,



(1) Evaporation values estimated as 70% of the precipitation.
(2) Precipitation of 17.14 in; over respective areas of 222,080 and 112,640 acres for upper and lower sub-basins.
(3) See Appendix D, Figure D-10.
(4) Provided by the Water Commissioner for Cache La Poudre.
(5) Estimated as "base flow" discharge.
(6) USGS, Water Resources Data for Colorado in 1970.
(7) See Appendix D, Figure D-12.
(8) Computed through mass balance of the basin areas.
(9) Computed as explained in paragraph 5.5.1.

Figure 5-16. Source and Destinations of River Flows in North Fork of Cache La Poudre in 1970 (Acre-Feet).



Key

Basin of the main stem of Cache La Poudre River between the source and mile 94.
Basin of the main stem of Cache La Poudre River between miles 94 and 61.
Basin of the main stem of Cache La Poudre River between miles 61 and 56.

Actual flow at River Mile 56 (Canyon Mouth) = 262,800 Acre-feet (USGS records)

Discharges to River

Source	Amount (Acre-feet)
Grand River Ditch	12,830
Skyline Ditch	1,550
Laramie-Poudre Tunnel	14,990
Seaman Reservoir	10,008
Ft. Collins "Poudre" Wat.Tr.Pl.Backwash	784
Comanche Reservoir (1)	319
Joe Wright Reservoir (1)	0
Barnes Meadow Reservoir (1)	0
Total discharges (Mountain reaches)	40,481 (8)

Diversions from River

Destination	Amount (Acre-feet)
Munroe Gravity Canal	38,108
Poudre Valley Canal	17,594
Fort Collins "Poudre" Water Tr. Plant	9,701
Chambers Lake (2)	188
Long Draw Reservoir (2)	53
Total Diversions (Mountain reaches)(3)	65,644 (8)

Virgin flow at Canyon Mouth (Mile 56) = Actual flow - Discharges + Diversions =
= 262,800 - 40,481 + 65,644 = 287,960 Acre-feet.

Virgin flows at Various River Mileages

River Mileage	Basin Area (Sq. Miles)	Virgin Flow (Acre-ft) (4)	Monthly Base Flow (Ac-ft) (5)
Mile 56	474	287,960	2,880
Mile 61	468	284,310	2,840
Mile 94	186	113,000	1,130

Computations of Aquifer Discharges to the Mountain Reaches of Cache La Poudre River in 1970.

Reach	Upstream Aquifer Generated Flow Portions (6) (Acre-feet)	Downstream Aquifer Generated Flow Portions (6) (Acre-feet)	Aquifer Discharge which was collected along the reach (7) (Acre-feet)
Source-Mile 94	0	1,130	13,560
Miles 94-61	1,130	2,840	20,520
Miles 61-56	2,840	2,880	480

Computation of 1970 flow at River Mile 94 (Ac-ft)	
113,000 +	(Virgin flow at Mile 94)
12,830 +	(Grand River Ditch Imports)
1,550 +	(Skyline Ditch Imports)
14,990 -	(Laramie Poudre Tunnel Imports)
188 -	(To Chambers Lake Storage)
53 =	(To Long Draw Reservoir Storage)
142,129 Acre-feet	(1970 computed flow at Mile 94)

Computation of 1970 flow at River Mile 61 (Ac-ft)	
284,310 +	(Virgin flow at Mile 61)
12,830 +	(Grand River Ditch Imports)
1,550 +	(Skyline Ditch Imports)
14,990	(Laramie-Poudre Tunnel Imports)
188 -	(To Chambers Lake Storage)
53 +	(To Long Draw Reservoir Storage)
319 -	(from Comanche Reservoir Storage)
38,108 =	(Diverted by Munroe Gravity Canal)
275,650 Acre-feet	(1970 computed flow at Mile 61)

(1) These Reservoirs released in 1970 some quantity of water which was stored since the previous years.
(2) Some volumes of water were stored in 1970 in these reservoirs for carryover to next years.
(3) The reservoir evaporation is another subtraction from the river flows, but was neglected in this analysis.
(4) The virgin flows were computed from the virgin flow at Canyon Mouth (Mile 56), proportionally to the basin areas.
(5) The base flow (i.e. the minimum monthly flow) is assumed to be originated from the aquifer. This minimum flow was estimated as 1.0% of the year virgin flow. 1.0% is the portion of the year flow which occurs in little Beaver Creek, a mountain tributary of Cache La Poudre River whose flows are not affected by any man-made influence. The flow distribution of Little Beaver Creek along the year was assumed to be representative for the whole mountain portion of Cache La Poudre Basin.
(6) These values were obtained multiplying the monthly base flow at the mileages limiting the reaches times 12 (months in the year)
(7) These values were obtained as difference between the aquifer generated flow portions at the end and at the beginning of each river reach.
(8) The amounts flowing through the reservoirs are not considered as discharges or diversions since cancel out for thesake of these computations.

Figure 5-17. River Flows and Aquifer Contributions in Mountain Reaches of Cache La Poudre.

amounts put in storage for next year carryover). The evaporation losses from reservoirs were neglected in this stage of the analysis.

All discharges and diversions above the "Canyon Mouth" are listed in Figure 5-17. The total discharges were 40,481 acre-feet; the total diversions 65,644 acre-feet. The "Rustic Fish Hatchery" diversion did not affect the natural flow since they are compensated by an equal discharge amount (see Appendix G, Figure G-9). Then the natural virgin flow at the Canyon Mouth resulted 287,960 acre-feet (262,800 - 40,481 + 65,644 = 287,960).

The natural virgin flows at river miles 61 and 94 were calculated as 284,310 acre-feet and 113,000 acre-feet respectively as determined in proportion to the contributing basin areas. The monthly base flows were estimated as a 1% of these values. This percentage is the portion of the annual flow which occurred in Little Beaver Creek in the month of minimum flow. The monthly base flows (i.e., aquifer originated flows) at river miles 56, 61 and 94 resulted in 2,880 acre-feet, 2,840 acre-feet and 1,130 acre-feet, respectively. This means that 1,130 acre-feet of aquifer contribution to the stream flow were generated monthly between the source and river mile 94, that 1,710 acre-feet (2,840 - 1,130 = 1,710) were generated between miles 94 and 61 and 40 acre-feet (2,880 - 2,840 = 40) were generated between miles 61 and 56. This is equivalent to total annual aquifer contributions of 13,560 acre-feet; 20,520 acre-feet and 480 acre-feet to the river reaches source-mile 94, mile 94-mile 61 and mile 61-mile 56. These values were obtained by simply multiplying the monthly aquifer discharges to the reaches times 12.

The actual flows at river miles 61 and 94 were finally computed from the natural flows by "re-introducing" all the upstream man-made effects as shown in the two final tables of Figure 5-17. These values resulted 275,650 acre-feet and 142,129 acre-feet, respectively.

The mass-balances of all the inputs and outputs for the three mountain reaches of the main stem of the Cache La Poudre River are reported in Appendix C, Figure C-1 to C-3. The basin surface runoffs from the "Mountain Lands" were computed from the mass-balances. These runoffs amounted to 78,100 acre-feet, 142,053 acre-feet and 3,173 acre-feet for the three reaches, in the upstream-downstream order.

5.5.3 Plains reaches of Cache La Poudre River. The three plains reaches of the Cache La Poudre River, below the mouth of the Poudre Canyon (Mile 56-Mile 47, Mile 47-Mile 21 and Mile 21-Mile 00) have low surface runoff from the surrounding lands. This runoff was completely neglected in the input-output model, since it was considered not significant.

The plains reaches of the Cache La Poudre River are those where the majority of diversions and return flows occur. The diversions are summarized in Table 5-20 for all reaches of the river, mountains and plains both. The return flows are listed in Table 5-21.

Because of the high groundwater level in the banks along the river, due to the extensive irrigation activity, large amounts of water return to the river through the aquifer, as was explained already in paragraph 3.1.3.

Table 5-20. Total Diversions from Cache La Poudre River in 1970.

Stream/ River Mileage	Diversion Structures(2)	Diverted Amounts (Acre-feet)	Totals(1)
North Fork of Cache La Poudre	Irrigation Ditches	24,750	
			24,750
Cache La Poudre Source-Mile 94	Irrigation Ditches	0	
	"Rustic" Fish Hatchery	4,356	
			4,356
Cache La Poudre Miles 94-61	Irrigation Ditches	38,108	
			38,108
Cache La Poudre Miles 61-56	Irrigation Ditches	17,594	
	Ft. Collins Wat.Tr.Pl.(Poudre)	9,701	
			27,295
Cache La Poudre Miles 56-47	Irrigation Ditches	201,890	
	Greeley "Bellvue" Wat.Tr.Pl.	11,217	
	"Watson" Fish Hatchery	2,904	
			216,011
Cache La Poudre Miles 47-21	Irrigation Ditches	92,169	
			92,169
Cache La Poudre Miles 21-00	Irrigation Ditches	35,438	
	Greeley G.W. Sugar B. Fact.	1,583	
			37,021
		Total Diversions	439,710

(1) The volumes flowing to the mountain reservoirs are not included in these totals.
(2) Detailed breakdown of the irrigation ditch diversions was given in table 5-16.

Table 5-21. Discharges to Plains Reaches of Cache La Poudre River in 1970 (1).

River Reach	Discharger	Amount (ac-ft) (2)	Totals (Ac-ft) (Excluding Aquifer)	Totals (Ac-ft) (Including Aquifer)
Cache La P. Miles 56-47	Charles Hansen Canal	67,228		
	Claymore Lake	460		
	Greeley "Bellvue" Wat.T.Pl.	672		
	Watson Fish Hatchery	4,356		
	Aquifer (3)	16,568	72,716	88,374
Cache La Poudre Miles 47-21	Fossil Creek Reservoir	15,125		
	Long Pond	52		
	Ft.Collins Sew. Tr.Pl.No.1	4,698		
	Ft.Collins Sew. Tr.Pl.No.2	1,724		
	Windsor Sew. Tr. Plant	257		
	Boxelder S.D.Sew.Tr.Pl.	26		
	Fort Collins Power Plant	784		
	Aquifer (3)	45,235	22,743	67,978
Cache La Poudre Miles 21-00	Greeley No. 3 Ditch	4,600		
	Greeley Sew.Tr.Facilities	8,190		
	Monfort (Meat ind.)	1,120		
	Greeley Sand & Gravel Co.	1,336		
	Eaton G.W.Sugar B. Fact.	1,344		
	Greeley G.W. Sugar B. Fac.	1,966		
	Eaton Draw	157		
	Aquifer (3)	36,536	18,713	55,249
Total Discharges to Plains Reaches			114,172	211,601

(1) The plain portion of Cache La Poudre river is that one from the Poudre Canyon Mouth to the South Platte confluence. This river portion was subdivided in three reaches: from mile 56 to mile 47, from mile 47 to mile 21 and from mile 21 to the South Platte Confluence.

(2) Explanation of these values are given in the correspondent specific sections of this report.

(3) The aquifer contributions to the plain reaches of the river were computed from the mass balance of the plain reaches. The only other input is the flow from the mountain portion of the river (262,800 ac. ft., USGS, gaging station No. 06752000). The land surface runoff was neglected. The outputs are the flow to South Platte river (129,200 ac.ft., USGS, gaging station No. 06752500) and the river diversions (216,011 + 92,169 + 37,021 = 345,201 ac. ft., see table 5-20). The mass balance of the plain reaches of the Cache La Poudre river gives a total aquifer contribution equal to 97,429 ac. ft. This flow was then distributed among the three reaches proportionally to the reach lengths.

The flows in the plains reaches of Cache La Poudre river were measured at the USGS gaging stations. These are located at canyon mouth (gaging station 06752000) and lower immediately above the confluence with the South Platte River (gaging station 06752500). In the 1970 water year the discharges reported for these two stations were 262,800 acre-feet and 129,200 acre-feet, respectively (USGS "Water Resources Data for Colorado, 1970").

The total aquifer contribution to the three plains reaches of the river was computed from a mass balance of inputs and outputs for these reaches. The inputs (beside the aquifer) are: the flow from the upstream reach (miles 61-56) amounting to 262,800 acre-feet (USGS) and the discharges to the river as computed in Table 5-21 (211,601 acre-feet). The outputs are the outflow to the South Platte River amounting to 129,200 acre-feet (USGS) and the diversions as derived from Table 5-20 (216,011 acre-feet + 92,169 acre-feet + 37,021 acre-feet = 345,201 acre-feet).

The mass balance of the three plains reaches of the Cache La Poudre river yielded a total aquifer contribution of 97,429 acre-feet. This total aquifer discharge was assumed to occur uniformly along the river length. Then the total value was distributed among the three reaches proportionally to the reach lengths. Aquifer discharges of 16,568 acre-feet, 45,235 acre-feet and 36,536 acre-feet were computed for the three plains reaches in the upstream-downstream order.

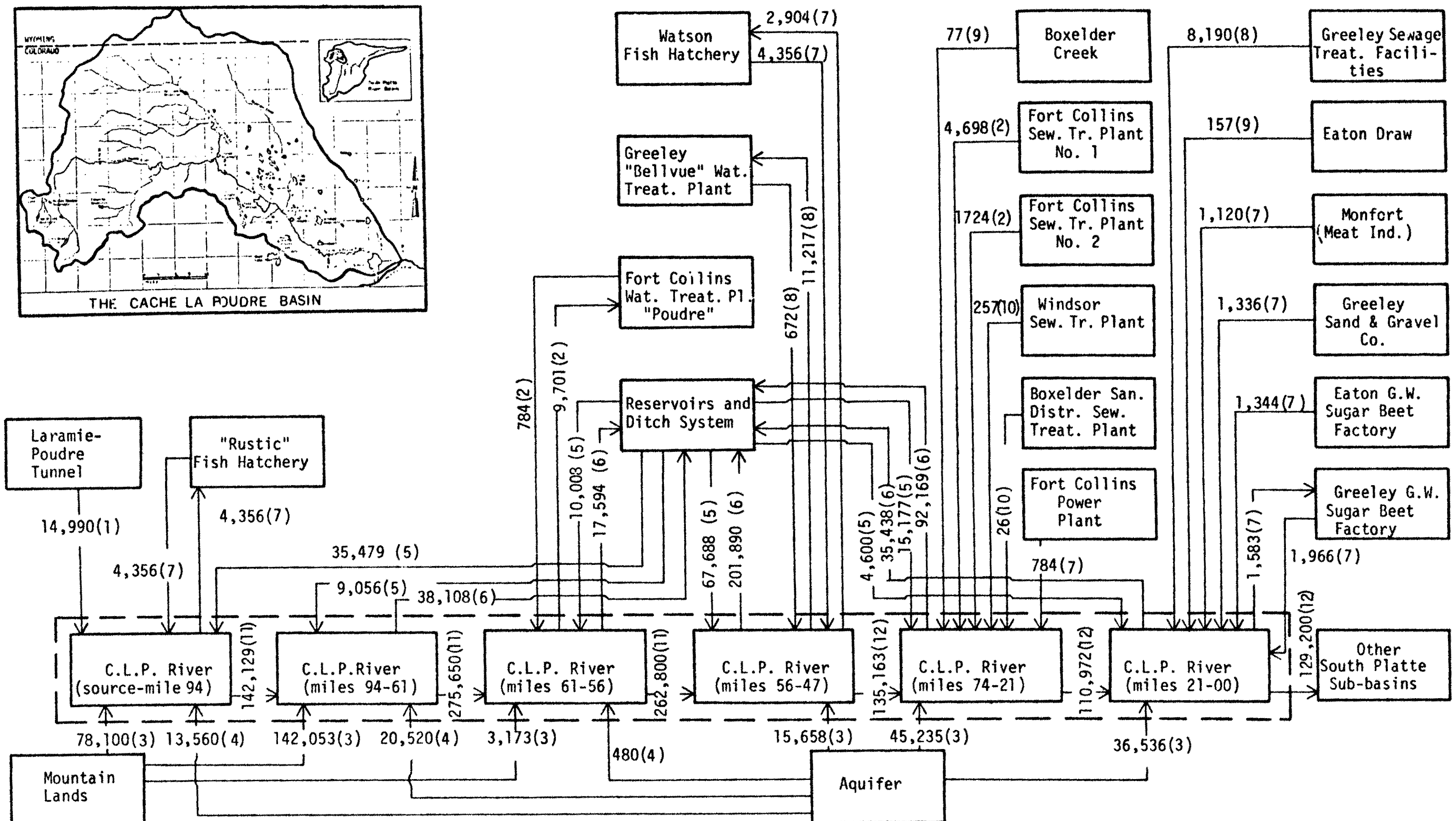
The mass balance sketches for the plains reaches of Cache La Poudre are presented in Appendix C, Figures C-4 to C-6. A line diagram representation of the water exchanges affecting the whole main stem of the Cache La Poudre River is presented in Figure 5-18. All the municipal, industrial and agriculture interactions are shown also.

5.6 The Cache La Poudre Aquifer

Ground water is an important source of water in the lower Cache La Poudre River basin. During periods of low precipitation and short surface-water supply, supplemental irrigation water from ground water sources provides the needed moisture to sustain crops in this predominantly agricultural area.

Alluvial deposits overlying rocks of the Late Cretaceous age constitute the principal aquifers in the area. The yield from the alluvium ranges from a few gallons to 2,000 gallons per minute. Because of the availability of surface water, ground water is used principally as a supplemental irrigation supply. During periods of low surface-water supply, heavy pumping of wells substantially lowers the water table in parts of the area, but the ground water reservoir is replenished again by normal precipitation patterns (Hershey and Schneider, 1964), as well as by the irrigation. The location of the principal aquifers in the study area is shown in Figure 5-19. Principal sources of recharge to the aquifers are seepage from ditches and storage reservoirs, downward percolation of applied surface water and precipitation.

There is a dearth of information about groundwater in the Cache La Poudre Valley from which to base any estimate of safe yield, data



(1) See paragraph 5.1.2.
(2) See paragraph 5.2.1.
(3) Computed through mass balance of the river reaches.
(4) This is the "base flow" of the natural virgin discharge.
(5) This is the sum of the "exchanges" from all ditches, reservoirs and lakes to this river reach.
(6) This is the sum of the exchanges from this river reach to all ditches, reservoirs and lakes.
(7) See paragraph 5.3.2.
(8) See paragraph 5.2.2.
(9) See paragraph 5.5.1.
(10) See paragraph 5.2.3.
(11) See paragraph 5.5.2
(12) See paragraph 5.5.3.

Figure 5-18. Water Exchanges Related to the Main Stem of Cache La Poudre River in 1970 (Acre-Feet).

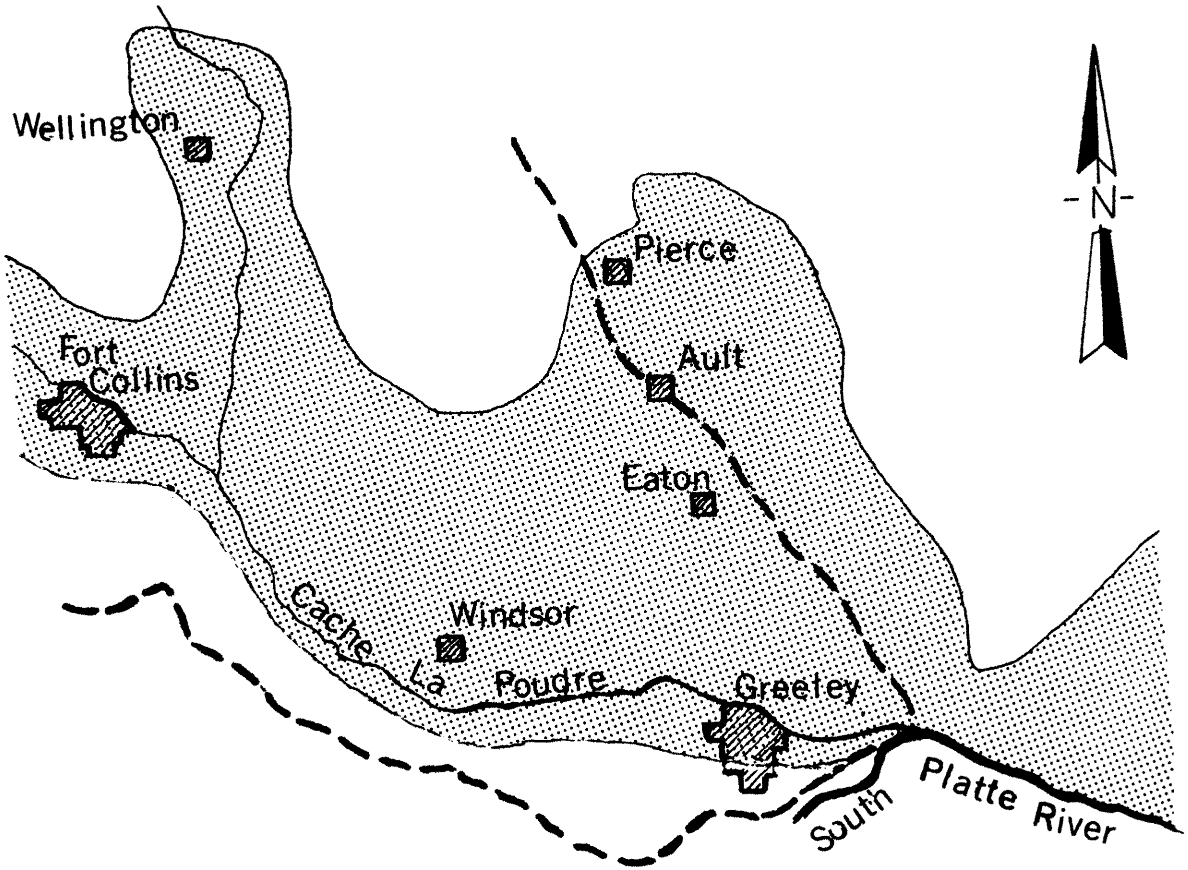


Figure 5-19. Location of the Main Aquifers in the Study Area (Adapted from Evans, 1971).

on water quality, or annual recharge and outflows of the sub-surface waters. Also there is very little information on pumping yields, groundwater levels, or pumping tests. Also lacking is information about geologic factors and natural recharge from deep percolation of irrigation waters. Thus it is difficult to evaluate the present and potential role of groundwater in the system.

Because of this lack of information about groundwater it is preferred to avoid a detailed study of the groundwater exchanges including space distribution of recharge and withdrawals. All the aquifer formations under the Cache La Poudre basin boundaries were lumped together into a single element of the Cache La Poudre water system referred as "Aquifer."

Most of the data referring to water exchanges with the aquifer were estimated or computed based upon assumptions needed in the process of water balancing for the agriculture sector, the municipal sector, the industrial sector, the river system and the raw lands. The aquifer related water exchanges were used mostly as the "slack variables" to balance the system. Thus, the evaluations of the aquifer related water exchanges are necessarily affected by this "error concentration" which derives directly or indirectly from possible errors in other exchange evaluations, inaccuracies or imprecisions. Some water was transmitted through groundwater exchanges out of the study area to external aquifer formations. No areal identification was given to these external aquifers. These were just lumped together as an exit element referred as "Out of Basin Aquifers."

5.6.1 Inputs to the aquifer. Four major sources of recharge were found for the Cache La Poudre "Aquifer": deep percolation due to precipitation and irrigation, infiltration from septic tanks and from small municipal or industrial wastewater treatment plants and seepage from ditches and reservoirs.

The surface infiltration from the land occurred through both raw lands and irrigated areas. The infiltration from the raw lands was calculated to be 100,459 acre-feet. The majority of this amount was from the "Mountain Lands" (96,917 acre-feet); the remaining portion was from the "Unirrigated Plains" (3,542 acre-feet). These amounts were computed through the respective mass balances of these lands. A total amount of 202,025 acre-feet infiltrated into the aquifer from the irrigated areas: 155,138 acre-feet from the "Upper Cache La Poudre Irrigated Areas" and 46,887 acre-feet from the "Lower Cache La Poudre Irrigated Areas" (see paragraph 5.4.3). The total amount seeped from the four types of land was computed as 302,484 acre-feet. Of this amount, the natural recharge was 157,248 acre-feet. This value was obtained as sum of the total infiltration from the raw lands (100,459 acre-feet) and of a portion of the infiltration from the irrigated areas: 56,789 acre-feet (44,759 acre-feet from the "Upper" irrigated areas and 12,030 acre-feet from the "Lower" irrigated areas). These values are the only infiltrations which derive from the atmosphere precipitation and which are not lost to atmosphere through crop consumptive use or evaporation (see paragraph 5.4.3).

The municipal and domestic discharge to the "Aquifer" derive from the smallest sewage treatment plants in the study area (Boxelder Sanitation District, South Fort Collins Sanitation District, Wellington, Windsor and Eaton) discharging respectively 8 acre-feet, 16 acre-feet, 22 acre-feet, 70 acre-feet and 45 acre-feet) and from the septic tanks serving that portion of the Cache La Poudre basin rural population which is not connected to sewage treatment plants (3,757 acre-feet). These values were all derived in paragraph 5.2.3. The total amount discharged to the "Aquifer" by the "Municipal Sector" was 3,918 acre-feet. Very little amounts were discharged by the industry. This amounted to a total of 102 acre-feet; 70-acre-feet was discharged by the "Greeley G. W. Sugar Beet Factory" and 32 acre-feet was discharged by the "Eaton G. W. Sugar Beet Factory" (see paragraph 5.3.2)

The total seepage from the ditch and reservoir system was computed as 128,540 acre-feet. Of these, 126,035 acre-feet was seepage from the ditches (see Table 5-18). About 2,505 acre-feet was seepage from the reservoirs; the seepage from Longs Pond was 1,718 acre-feet, and the seepage from Timnath Reservoir was 787 acre-feet. The seepage from all the other lakes and reservoirs was neglected in the input-output model as explained in paragraph 5.4.2.

A potential inflow to the "Aquifer" could relate to groundwater flows entering the aquifer beneath the surface boundaries of the Cache La Poudre basin. These inflows were most probably equal to zero. The total inflows to the aquifer, as computed, amounted to 435,044 acre-feet.

5.6.2 Outputs from the aquifer. Four general type of outputs were found for the Cache La Poudre "Aquifer": withdrawals for municipal, industrial or irrigation use, outflows to the river system, infiltration into sewer systems and groundwater flows out of the basin boundary.

The groundwater pumpage for domestic supply amounted to 3,901 acre-feet. This value is the sum of the pumpage through the wells of the Northern Colorado Water Association and of all the pumpage through private wells supplying that portion of the Cache La Poudre basin rural population which is not served by water distribution systems. The value of 3,901 acre-feet was derived in paragraph 5.2.3.

The industrial groundwater pumpage amounted to 7,481 acre-feet. This water was used by the "Greeley G. W. Sugar Beet Factory" (296 acre-feet), the "Eaton G. W. Sugar Beet Factory" (1,131 acre-feet), the "Monfort" (3,148 acre-feet), and the "Bellvue Fish Hatchery" (1,452 acre-feet) or pumped for dewatering the pits by the "Greeley Sand and Gravel Co." (1,454 acre-feet).

A total amount of 213,434 acre-feet was supplied to satisfy irrigation demands amounting to 194,625 acre-feet in the "Upper Cache La Poudre Irrigated Areas" and 18,809 acre-feet in the "Lower Cache La Poudre Irrigated Areas." These amounts were computed assuming that the crop consumptive use water which was not supplied by any other source was provided by groundwater pumping (the computations were presented in paragraph 5.4.3).

The outflows to the river system were computed to amount to 135,733 acre-feet. This value is the sum of the amounts contributed to the six reaches of the main stem of the Cache La Poudre river and to the North Fork of Cache La Poudre, as computed in paragraphs 5.5.1, 5.5.2, and 5.5.3. A large portion of this amount was actually return flow from the irrigated areas, whose occurrence is due to the raise of the groundwater level in the agricultural areas consequent to the irrigation practice.

An amount of 2,418 acre-feet was assumed to infiltrate into the "Fort Collins Sewer System." This value was computed on the basis of the estimates and suggestions of Mr. Chuck Inghram (City of Fort Collins), as illustrated in paragraph 5.2.1.

The outflows herein listed until this point amount to a total of 362,967 acre-feet. The groundwater outflows are not included in this number. An evaluation of these outflows is given in paragraph 5.6.3, as derivable from the mass balance of all "Aquifer" inputs and outputs.

5.6.3 Mass balance of the aquifer. Besides the aquifer inputs and outputs which are listed in paragraphs 5.6.1 and 5.6.2, two (at least potential) inputs and outputs exist too: releases from groundwater storage held over from the previous year and storage for next year carryover. An annual global depletion of the groundwater levels would imply the introduction of equivalent amounts of water into the active system exchanges. Contrary-wise, an increase in groundwater levels would eliminate the correspondent volume from the system free circulation. These inputs and outputs could have been introduced as exchanges with the "Groundwater Storage" if it had occurred. However, groundwater levels in the Cache La Poudre basin have not changed significantly over many years. Therefore, both input and output from and to "Groundwater Storage" have been assumed to be zero.

The water balance among all the inputs (435,044 acre-feet) and all the outputs besides the groundwater outflows (362,967 acre-feet) yields that an amount of 72,077 acre-feet should have left the "Aquifer" through underground exchanges. It is reasonable that this discharge flowed to the lower South Platte aquifer formations beneath the surface boundary of the Cache La Poudre basin. In the input-output model this output was introduced as flowing to the exit element referred as "Out of Basin Aquifers."

VI THE CACHE LA POUDRE INPUT-OUTPUT MODEL

The essential challenge of this work was to adopt the input-output water balance methodology to the local-regional scale, i.e., the Cache La Poudre River basin. The work builds upon the input-output model developed for the whole South Platte River basin, providing a "zoom" enlargement of one of the sub-basins, i.e., the Cache La Poudre. The purpose was to provide a system representation suitable for "tactical" level, water oriented planning, vis a vis the "strategic" level planning purpose of the South Platte basin-wide model. The model provides a way to plan for future needs in terms of the context of an already complex and mature agro-urban water system.

6.1 The Model

The input-output water balance model representation of the Cache La Poudre River basin is shown in Figure 6-1 and in Plate 1 (the latter is merely a more readable enlargement of the former). The model consists of a matrix showing transfers of water, in acre-feet per year, for the water year 1970, between the various components of the water resource system. A given row of the matrix shows the distribution of the total *output* of water from that row to the various components which receive the water as inputs, shown in columns. By the same token the distribution of total water input to a given system component is shown in the respective column. Thus, the whole *system* is tied together in an integrated fashion to the matrix representation. The matrix was constructed on an eight foot by eight foot board; for practical use the characters used were large enough to be legible by photographic reproduction.

The 123 x 123 matrix shown has some 600 numerical entries of empirical data. Each item of data is documented in the 123 component mass balance diagrams of the Appendices and in Chapter V.

All of this, i.e., the overall matrix, the empiricism of a real case, and the documentation, comprises a *demonstration* for the construction of an input-output model at the local-regional level for the purpose of tactical level planning. The Cache La Poudre River basin model can provide guidance for other cases just by the fact of its existence. The rationale of the model and the delineation of the construction process are given also, in order to provide the necessary insight needed for generalized application of the input-output concept in tactical level planning.

In order to provide an easier overall grasp of the vast amount of information contained in the Cache La Poudre input-output model an aggregated representation has been prepared, and is shown in Figure 6-2. The various system components belong to "sectors" and so all of the data in the matrix of Figure 6-1 have been aggregated into sectors, as shown in Figure 6-2. While the aggregated model does not have sufficient resolution for any degree of tactical level planning, it does provide a way to grasp the overall "water metabolism" of the Cache La Poudre system and is useful for that purpose only.

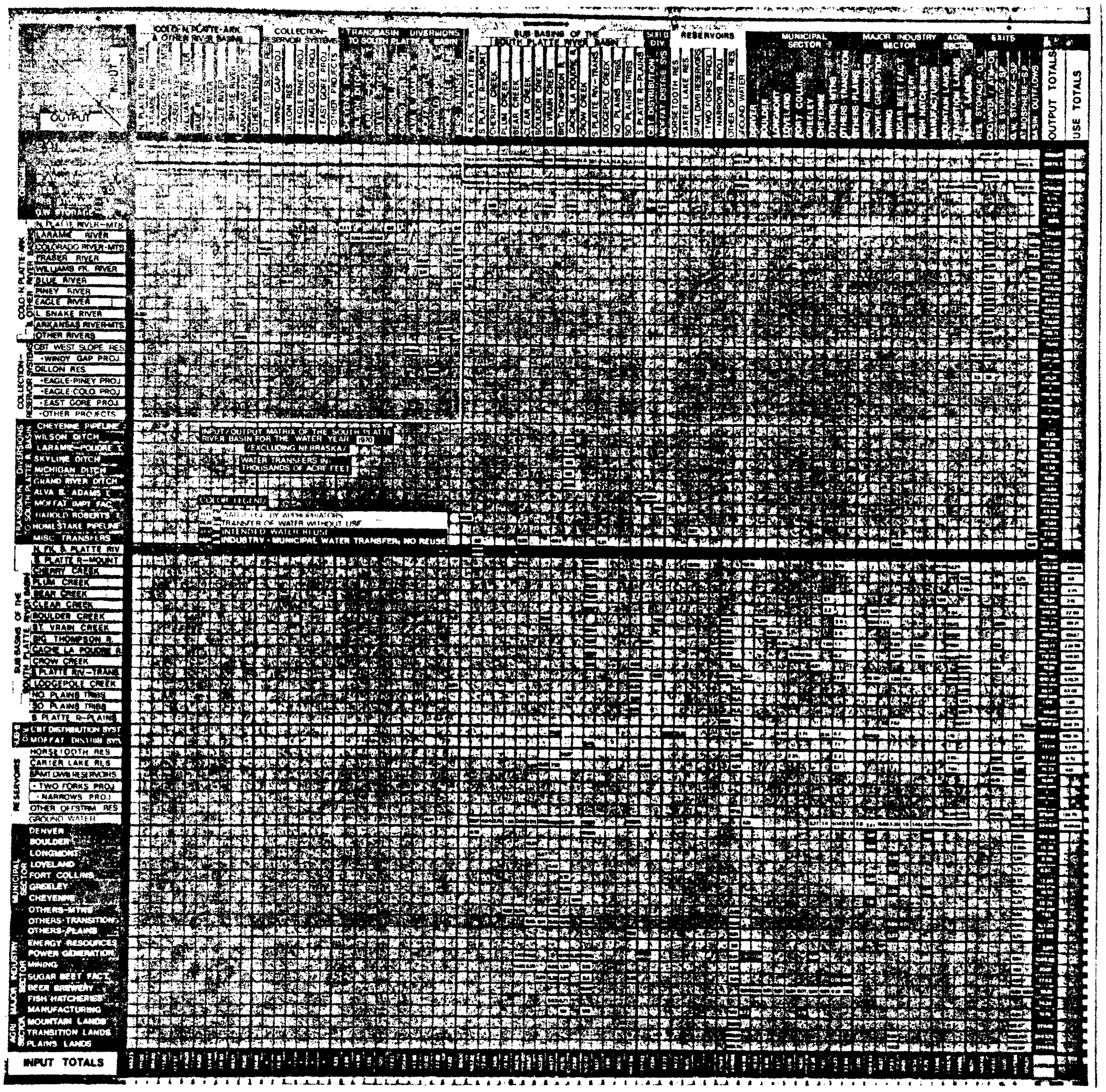


Figure 6-1 The Input-Output Model of Water Exchanges in the Cache La Poudre River Basin Water System in 1970. (For a Larger Photograph See Plate 1 in the Folder.)

ORIGINS \ DESTINATIONS	TRANSBASIN DIVERSIONS	CACHE LA POUDRE REACHES AND TRIBUTARIES	RESERVOIRS AND LAKES	DITCHES AND CANALS	MUNICIPAL SECTOR	INDUSTRIAL SECTOR	AGRICULTURE SECTOR AND OTHER LANDS	EXITS	OUTPUT TOTALS	USE TOTALS
ENTRIES	236,880	0	14,488	31,344	1,740	248	1,652,621	0	1,937,321	
TRANSBASIN DIVERSIONS	0	17,900	120,195	0	0	0	0	98,785	236,880	
CACHE LA POUDRE REACHES AND TRIBUTARIES	0	926,948	33,655	409,949	20,918	8,843	0	1[illegible]4,537	1,529,513	8,843
RESERVOIRS AND LAKES (1)	0	230,229	9,785	206,965	6,319	7,481	220,699	134,537	816,015	232,081
DITCHES AND CANALS	0	71,828	277,607	45,443	7,280	0	233,163	60,273	695,594	233,163
MUNICIPAL SECTOR	0	16,585	3,972	1,893	80,849	20,008	0	13,724	119,031	28,206
INDUSTRIAL SECTOR	0	15,262	102	0	1,925	1,452	0	1,291	20,032	1,452
AGRICULTURE SECTOR AND OTHER LANDS	0	250,761	356,211	0	0	0	0	1,499,511	2,106,483	
INPUT TOTALS	236,880	1,529,513	816,015	695,594	119,031	20,032	2,106,483	1,937,321	7,460,869	503,745

(1) Aquifer is included among reservoirs.

Figure 6-2. Aggregated Matrix Representation of the Input-Output Model of Cache La Poudre Basin Water System (1970).

A line diagram representation is another convenient format which provides an even greater intuitive "feel" for the system. Figure 6-3 is such a line diagram but aggregated differently than the matrix of Figure 6-2, in order to bring out some of the resolution missed by Figure 6-2.

From this one can see how different formats, i.e., aggregated matrices, line diagrams, component mass balance diagrams (i.e., the 123 component diagrams shown in the Appendices), all complement one another to serve different functions and to show different aspects of the total system. One can realize also that a line diagram equivalent of the whole system, disaggregated to the degree shown in Figure 6-1, would be unbelievably complex. At the same time, the merits of the input-output format in both simplifying the system and in dealing with a large amount of numerical data become evident.

6.2 Uses of the Model

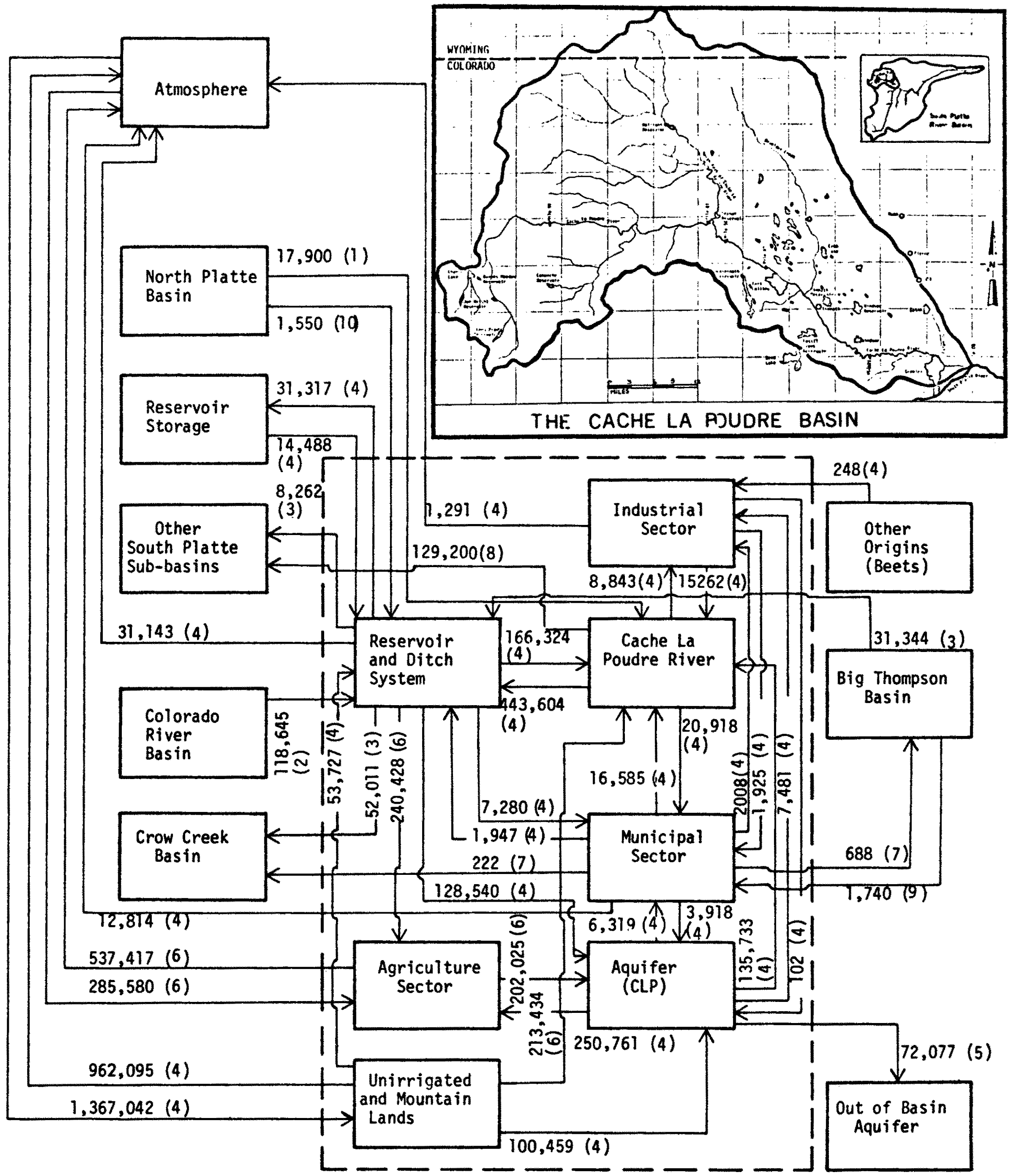
The input-output Cache La Poudre water balance model can be used for a variety of purposes. For example one can ascertain the feasibility of various detailed exchanges contemplated between different appropriators. On the other hand, the overall uses of water can be aggregated in any manner desired. Consider for example the overall extent of basin-wide reuse. A "reuse factor" may be defined as the ratio of total uses of water divided by the sum of the virgin flows plus imported water. The 1970 total basin wide use is seen to be 503,745 acre-feet, which is the sum of the figures in the "use" column on the far right hand side of the matrix. The virgin flow amounts to the sum: 122,915 (mountain lands to the Cache La Poudre River) + 31,440 (mountain lands to lakes) + 34,560 (aquifer to the Cache La Poudre River above mile 56) + 114,484 (Inports-High Mountains) + 28,839 (Imports-Plains) = 332,238 acre-feet. Thus the reuse factor is: 503,745/332,238, or 1.52. From this, it is seen that the water within the basin is used intensively.

On the other hand, consider a more "tactical" application. A sample question may be posed in this way: Is there any possibility that the "Fort Collins Distribution System" could supply more water to the "City of Fort Collins?"

The 1970 water use of the City of Fort Collins amounted to 10,104 acre-feet. This figure can be grasped from the matrix model representation looking at the "Fort Collins" column in the municipal sector. This water is used by a census population of 43,337 inhabitants. The per capita use results in about 208 gallons/day.

The 1990 Fort Collins population is estimated to be about 75,000 inhabitants (Janonis, 1977). Assuming that the per-capita demand at that time could still be 208 gallons/day, an annual water use of 17,500 acre-feet would result. Then about 7,400 additional acre-feet of water respect the 1970 situation should be supplied.

Looking at the model (either the matrix or Figure F-11) one realizes that the total supply is channeled through the "Fort Collins Distribution System." In turn, from the column of the "Fort Collins Distribution System" one realizes that the water is delivered from the "Fort Collins Water Treatment Plant - Poudre" and the "Fort Collins



(1) Imports through Wilson Ditch and Laramie-Poudre Tunnel.
(2) Imports through Grand River Ditch and Colorado-Big Thompson Delivery System.
(3) Through irrigation ditches.
(4) Aggregated value of the exchanges between the related blocks.
(5) Computed through mass balance of the aquifer.
(6) See paragraph 5.4.3.
(7) See paragraph 5.2.3.
(8) Cache La Poudre discharge into South Platte River.
(9) See paragraph 5.2.2.
(10) Imports through Skyline Ditch.

Figure 6-3. Aggregated Scheme of the 1970 Water Exchanges in Cache La Poudre Water System (Acre-Feet).

Water Treatment Plant - Horsetooth" (the same conclusion comes from Figure F-10). The "Fort Collins Distribution System" could supply more water to "City of Fort Collins" by increasing the input to the "Fort Collins Distribution System" (through the water treatment plants) or by decreasing some other output. The matrix row of "Fort Collins Distribution System" shows that water is supplied also to "Cache La Poudre Rural Domestic Users" to "Minor Industries" and to "Fort Collins Power Plant." Let's see if some amount of supply can be transferred from these users to the "City of Fort Collins." Assume we are not willing to modify the domestic supply to "Cache La Poudre Rural Domestic Users." Assume also that we do not modify the supply to the "Minor Industries." The remaining possibility is to modify the supply of "Fort Collins Power Plant" (this power plant is not in operation any more). Assuming that the transfer of the right to use this water is possible, 825 of the 7,400 acre-feet of additional supply could be derived from this source. The practical, legal, and political constraints relative to such decision may be critical, and are ignored for the purposes of this illustration.

Assuming to transfer the 825 acre-feet from the "Fort Collins Power Plant" to the "City of Fort Collins," still 6,575 acre-feet of additional supply are needed. There is no way to procure this water other than increasing the supply through one or both the water treatment plants. Let's examine the "Fort Collins Water Treatment Plant - Horsetooth." The correspondent matrix column (or eventually Figure F-8) shows that this plant is supplied through the "Dixon Feeder Canal." If one looks at the row which corresponds to the Horsetooth Treatment Plant, he will find (see also Figure F-8) that 276 acre-feet were lost from this plant to the atmosphere. Preventing this evaporation loss could provide more water for delivery to the "Fort Collins Distribution System." However, the Horsetooth Water Treatment Plant is already a quite modern and advanced design facility. Then one could assume that the elimination of this loss would not be easy (actually this is only an assumption which should be checked). However, forget this possibility and go to see if the supply through the "Dixon Feeder Canal" can be increased. The water to "Dixon Feeder Canal" is supplied by the "Horsetooth Reservoir." However the matrix (or Figure E-30) shows that 1,143 acre-feet are supplied to irrigation from the "Dixon Feeder Canal." Likely, this irrigation occurred in areas which are subject to the urban encroachment of Fort Collins. Then assume that this amount can be transferred to the City of "Fort Collins." The residual amount to be searched would be 6,575 - 1,143 = 5,432 acre-feet.

This residual amount could be supplied by the "Horsetooth Reservoir," for example. In this case using additional shares of the Colorado-Big Thompson Project by the City of Fort Collins would be needed. Leave this as an opportunity and check in another direction, through the "Fort Collins Water Treatment Plant - Poudre." Look at the correspondent column in the matrix or at Figure F-7. Here one sees that the origin of this water is from the Cache La Poudre River reach between miles 61 and 56. Assuming that the water treatment plant can increase its potentiality according with the operation schedule (even an enlargement could be considered) an increased diversion from the river could solve the Fort Collins water supply problem.

This increase could be provided by some exchange with the agricultural sector. It can be seen from the matrix (or also from Figures C-5 and C-6) that river diversions through irrigation ditches occur from the reaches between miles 47 and 21 and between miles 21 and 00. Since these diversions occur below the Fort Collins site, the exchange could be feasible. The "Fort Collins Water Treatment Plant - Poudre" could divert the 5,432 additional acre-feet which are needed, provided that a correspondent amount could be returned in some way to the irrigation diverters.

Then see if the Fort Collins return flows are suitable for this use (it is actually a reuse). The City of Fort Collins (see the correspondent row in the matrix or Figure F-11) discharges its wastewater to the "Fort Collins Sewer System." The "Fort Collins Sewer System" discharges in turn to the "Fort Collins Sewage Treatment Plant No. 1" and "Fort Collins Sewage Treatment Plant No. 2." One can see that both these plants discharge directly or indirectly to the lower reaches of the river. Then the physical possibility of the exchange exists. However, the additional water which is diverted cannot be entirely returned, since a portion will be lost due to the consumptive use by the Fort Collins population. This consumptive use can be estimated as a 40% of the supply. Then only a 60% of the additional supply (5,432 x 0.60 = 3,260 acre-feet) could be available for being returned to the river for downstream irrigation diversions. The difference (5,432 - 3,260 = 2,172 acre-feet) should be put back in the stream anyway, unless a decrease in ditch diversions is expected or additional natural flow is available. Looking for the other possible inputs to "Fort Collins Sewer System" in the correspondent column of the matrix or in Figure F-13, one discovers that a discharge from the Cache La Poudre Rural Domestic Users occurred too. This discharge is destined to increase respect the 1970 stiuation because of new sewers being connected with the Fort Collins system (e.g., the Laporte Sanitation District). This extra discharge will probably cover the needed amount of 2,172 acre-feet and will allow to make the exchange possible.

Actually, the increase of the river diversions by the "Fort Collins Water Treatment Plant - Poudre" could also derive from procurement of additional storage in the high mountains, which is the case relative to planned construction of the Joe Wright Reservoir. This new reservoir should impound some additional imports through the "Michigan Ditch" (Janonis, 1977).

This speculation of the future development of the Fort Collins supplies was a theoretical exercise. The sole purpose was to show how the input-output analysis may be used in a wide ranging manner to speculate about the various development possibilities. Once the basic model is formulated, it has a wide range of applications, limited only by the imagination of the user. Not the least is the graps of an overall water system provided for virtually any person willing to take the time to learn the concept of the model. This in itself could be useful in maintaining a factual atmosphere during politically oriented discussions.

REFERENCES

1. Alleman, Darryl. (Director of the Water and Sewer Department, Greeley, Colorado) a personal interview with B. Janonis, July 14, 1975.

2. Alleman, Darryl. (Director of the Water and Sewer Department, Greeley, Colorado) personal communication with B. Janonis, October 29, 1976.

3. Anderson, Raymond L. "Data on Selected Irrigation Companies, Water Districts 1,2,3,4,5, and 6 - South Platte Basin, Colorado," (Review Draft) USDA-ERS, December, 1961.

4. Anderson, Raymond L. "Urbanization of Rural Lands in the Northern Colorado Front Range," USDA-ERS, 1970.

5. Anderson, Raymond L. and Maass, Arthur, "A Simulation of Irrigation Systems," Technical Bulletin 1431, USDA-ERS, 1974.

6. Babcock, H. M., and L. J. Bjorkland. Groundwater Geology of Parts of Laramie and Albany Counties, Wyoming and Weld, Colorado, USGS-WSP, 1367, 1956.

7. Bagley, Jay M. "Effects of Competition on Efficiency of Water Use," Proceedings, ASCE, Journal of the Irrigation and Drainage Division, March, 1965.

8. Barkley, J. R. "Northern Colorado Water Conservancy District - What is it? Why was it Created? What Has it Done and What is it Doing for Northern Colorado?" May, 1974.

9. Beet Sugar Development Foundation. State of Art, Sugar Beet Processing Waste Treatment, Prepared for the Environmental Protection Agency, Water Pollution Control Research Series, July, 1971.

10. Bell, M. C. Fisheries Handbook of Engineering Requirements and Biological Criteria, Fisheries-Engineering Research Program, Corps of Engineers, North Pacific Division, Portland, Oregon, February 1973.

11. Berry, Joseph W. "The Climate of Colorado," Climates of the States, Vol. 2, Water Information Center, April, 1968.

12. Biggs, Michael W. Irrigation System Consolidation, Unpublished M.S. Thesis, Colorado State University, Fort Collins, Colorado 1968.

13. Bishop, A. Bruce, and Hendricks, David W. "Water Reuse Systems Analysis," Journal of the Sanitary Engineering Division, ASCE, Vol. 97, No. SA1, Proc. Paper 7898, February 1971, pp. 41-57.

14. Bittinger, M. W. Groundwater in Colorado: Colorado's Groundwater Problems. Colorado State University Experiment Station Bulletin, 504-S (1959), p. 28.

15. Bittinger, M. W. Hydrological Data: Cache La Poudre River Basin. Fort Collins, Colorado: Bittinger and Associates, 1969.

16. Bittinger and Associates (Consulting Engineers) "Consumptive Use of Water - City of Fort Collins," Ref: 566, September, 1975.

17. Black and Veatch (Consulting Engineers) "Preliminary Design Investigation - Alternatives for Wastewater Treatment - City of Fort Collins Wastewater Treatment Plant No. 1," 1974.

18. Black and Veatch (Consulting Engineers), "Report on Water Demands and Wastewater Loadings and Revenue Requirements and Rates for the Water and Sewer Utilities - Fort Collins, Colorado," 1974.

19. Bittinger and Associates. "Schematics of the Ditch and Reservoir Systems of Irrigation Districts Nos. 6, 5, 4, 3, and 2," prepared for Northern Colorado Water Users Association, Fort Collins, Colorado, 1968a.

20. Blaney, Harry F. and Criddle, Wayne D. "A Method of Estimating Water Requirements in Irrigated Areas from Climatological Data," USDA-SCS, December, 1947.

21. Blaney, Harry F. "Monthly Consumptive Use Requirements for Irrigated Crops," Proceedings, ASCE, Journal of the Irrigation and Drainage Division, March, 1959.

22. Blaney, Harry F., and Criddle, Wayne D. "Determination of Consumptive Use and Irrigation Water Requirements," Technical Bulletin 1275, USDA-ARS, 1962.

23. Blaney, Harry F., and Criddle, Wayne D. Determining Water Requirements for Settling Water Disputes. Natural Resources Journal, University of New Mexico School of Law, 4(1):129-41 (May, 1964), p. 129.

24. Bluestein, Mark and Hendricks, David W. Tetra Tech., Inc. (Consulting Engineers) "Draft Final Report, Study Areas II and VI, Water Quality Analysis and Environmental Assessments, South Platte River," May, 1975.

25. Boyd, David. History of Greeley and the Union Colony of Colorado. Greeley, Colorado: The Greeley Tribune Press, 1890.

26. Boyd, David. "Irrigation Near Greeley, Colorado," of Water Supply and Irrigation, U.S. Geological Survey Report No. 9, Washington D.C., 1897.

27. Brenton, R. W. (Program Manager, Environmental Affairs, The Great Western Sugar Company) A personal conversation with D. W. Hendricks, November, 1976.

28. Brookman, John A. Colorado Ground Water Levels, Spring 1969. Civil Engineering Section, Colorado State University Experiment Station, Fort Collins, Colorado, 1969.

29. Burbank, W. S., Lovering, T. S., Goddard, E. N., and Eckel, E. B. Geological Map of Colorado, USGS, 2 sheets (repro. 1959).

30. Cannell, Glen H. Irrigation Efficiency as it Influences Water Requirements of Crops. American Society of Agricultural Engineering, Special Publication. SP-SW-0162, St. Joseph, Michigan, 1962.

31. Carpenter, L. G. Seepage and Return Waters, Colorado Agricultural Experiment Station Bulletin 180. Fort Collins, Colorado (1911).

32. Chow, Ven Te (ed.). Handbook of Applied Hydrology, New York: McGraw-Hill, Inc., 1964.

33. Code, W. E. Use of Groundwater for Irrigation in the South Platte Valley of Colorado. Colorado Agricultural Experiment Station Bulletin 483, 43 pp., 17 Figs. (1943).

34. Colorado Department of Agriculture. "Colorado Agriculture Statistics-1970 Final," July 1972.

35. Colorado Division Number 1 Water Commissioners. "Annual Report, Nov. 1, 1969 - Oct. 31, 1970," 1970.

36. Colorado Division of Planning. "Colorado Population Projections-1970 to 2000," April, 1976.

37. Colorado Division of Planning. "County Population Projections - 1970 to 2000," Winter, 1976.

38. Colorado State Health Department. August 1965. "Industrial Waste Inventory," Reviewed by Bernard R. Sacks, Industrial Waste Engineer, In letter to Kenneth Monfort, President of Monfort of Colorado.

39. Colorado State University Experiment Station. Civil Engineering Section, "Colorado Ground Water Trends," CER72-73JAB32, 1973.

40. Comstock, C. W. Sixteenth Biennial Report of the State Engineer's Office to the Governor of Colorado for the year 1911 - 1912. Denver: Smith-Brooks Printing Company, 1912.

41. Criddle, Wayne D. "Consumptive Use and Irrigation Water Requirements of Milford Valley, Utah," USDA-ARS, April, 1958.

42. Criddle, Wayne D. "Methods of Computing Consumptive Use of Water," Proceedings, ASCE, Journal of the Irrigation and Drainage Division, January, 1958.

43. Davis, D. (Manager of Soldier Canyon Water Treatment Plant), telephone conversation, 1977.

44. De Haan, Roger W. "An Input-Output Analysis of the Total Water System in a River Basin," M.S. Thesis, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado, 1976.

45. De Haan, Roger W. and Hendricks, David W. "Input-Output Modeling in Water Resources System Planning," Environmental Engineering Technical Report, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado, November, 1975.

46. Deredec, Alain. "A Systematic Approach to the Water Supply of a Large Urban Area," M.S. Thesis, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado, 1972.

47. Dillie, J. M. A Brief History of Northern Conservancy District and Colorado-Big Thompson Project. Loveland, Colorado: NCWCD, 1958.

48. Engineering Consultants, Inc. Toups Corporation (Consulting Engineers) "Comprehensive Water Quality Management Plan, South Platte River Basin," Prepared for the Colorado Department of Public Health, Denver, Colorado, July, 1974.

49. Evans, Robert. "Hydrologic Budget of the Poudre Valley," M.S. Thesis, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado, 1971.

50. Fellows, A. L. Water Resources of the State of Colorado. Water Supply and Irrigation Paper No. 74, USGS Department of the Interior, Washington, D.C., 1902.

51. Fortunato, Martinez F. "Analysis of Total Water Use by Selected Cities and Industries," M.S. Thesis, Department of Civil Engineering, University of Colorado, Boulder, Colorado, August, 1965.

52. Geragaty, Miller, van der Leeden and Troise. "Water Atlas of the United States," Water Information Center, Port Washington, N.Y., 1973.

53. Gerlek, Steve. "Water Supply Analysis, South Platte Basin, 1970-2020," Vol. 2 of Water Supply Management Analysis and Alternative Development for the South Platte River Basin, 7 Vols., U.S. Army Corps of Engineers, Omaha, Nebraska, April, 1977.

54. Glover, R. E., The Pumped Well. Colorado State University Experiment Station Bulletin, 100. Fort Collins, Colorado (1968).

55. Goldbach, Joseph C., "Guide to Input-Output Modeling and Users Manual for IOPLOT," Vol. 7 of Water Supply Management Analysis and Alternative Development for the South Platte River Basin, 7 Vols., U.S. Army Corps of Engineers, Omaha, Nebraska, April 1977.

56. Gray, S. Lee. The Effect of the Northern Colorado Water Conservancy District on Water Transfer. Unpublished M.A. Thesis, Department of Economics, Colorado State University, July, 1965.

57. Hendricks, David W., Janonis, Brian A., Gerlek, Steve, Goldbach, Joseph C., and Patterson, James L. "Water Supply-Demand Analysis South Platte Basin, 1970-2020," Vol. 1 of Water Supply Management Analysis and Alternative Development for the South Platte River Basin, 7 Volumes, U.S. Army Corps of Engineers, Omaha, Nebraska, 1977.

58. Hendricks, David W., Janonis, Brian A., Gerlek, Steve, Goldbach, Joseph C., and Patterson, James L. "Water Supply-Demand Analysis, South Platte Basin, 1970-2020," Volume 1, Water Supply Management and Alternative Development for the South Platte River Basin, U.S. Army Engineer District, Omaha Corps of Engineers, Omaha, Nebraska, 1977.
    Volume 2, "Water Supply Analysis, South Platte Basin, 1970-2020," by Steve Gerlek.
    Volume 3, "Municipal Water Demands, South Platte Basin, 1970-2020," by Brian A. Janonis.
    Volume 4, "Industrial Water Demands, South Platte Basin, 1970-2020," by James L. Patterson.
    Volume 5, "Energy Water Demands, South Platte Basin, 1970-2020," by James L. Patterson.
    Volume 6, "Agricultural Water Demands, South Platte Basin, 1970-2020," by Brian A. Janonis and Steve Gerlek.
    Volume 7, "A Guide to Input-Output Modeling and Users Manual for IOPLOT," by Joseph C. Goldbach.

59. Hershey, L. A. and Schneider, P. A. "Ground Water Investigations in the Lower Cache La Poudre River Basin, Colorado," U.S. Geological Survey, Water Supply Paper 1669-X, 1964.

60. Inghram, C. (City of Fort Collins) Personal conversations, 1977.

61. Janonis, Brian A. and Gerlek, Steve. "Agricultural Water Demands, South Platte Basin, 1970-2020," Volume 6 of Water Supply Management Analysis and Alternative Development for the South Platte River Basin, 7 volumes, U.S. Army Corps of Engineers, Omaha, Nebraska, 1977.

62. Jensen, Marvin E. "Evaluating Irrigation Efficiency," Proceedings ASCE, Journal of the Irrigation and Drainage Division, March, 1967.

63. Johnson, H. G. (President, Water Supply and Storage Company, Fort Collins, Colorado), personal conversation with Gerlek, S., October 19, 1976.

64. J. T. Banner and Associates. (Consulting Engineers) "Report on Existing Sanitary Sewerage Facilities and Proposed Improvements for the City of Fort Collins, Colorado," November, 1964.

65. J. T. Banner and Associates. (Consulting Engineers) "Report on Existing Water Supply Facilities and Proposed Improvements for the City of Fort Collins, Colorado," November, 1964.

66. Kenner, J. (Northern Colorado Water Association) telephone conversation, 1977.

67. Larimer County. Colorado County Information Service, Colorado State University, 1973.

68. Lau, Daniel H. "A Preliminary Comparison of the Economics of Two Water Supply Alternatives for the City of Fort Collins," M.S. Thesis, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado, 1975.

69. Leontief, W. W. Input-Output Economics, Scientific American, October, 1951, Vol. 185, No. 4, pp. 15-21.

70. Loentief, W. W. The Structure of the U.S. Economy, Scientific American, Vol. 212, No. 4, April, 1965, pp. 25-35.

71. Liquin, Charles. (Public Works Director, Fort Collins, Colorado), personal conversations with Gerlek, S., 1976.

72. Liquin, Charles. (Public Works Director, Fort Collins, Colorado), a personal conversation with Janonis, B., October 8, 1976.

73. Liquin, Charles. (Public Works Director, Fort Collins, Colorado), a personal conversation with Janonis, B., March 8, 1977.

74. Lurvey, Charles F. "Consolidation and Rehabilitation of Canals in Poudre Valley," Environmental Resources Center, CSU, Fort Collins, Colorado, 1973.

75. McCain, Jerald F. and Jarrett, Robert D. "Manual for Estimating Flood Characteristics of Natural-Flow Streams in Colorado," prepared in cooperation with the U.S. Geological Survey, Colorado Water Conservation Board, Denver, Colorado, 1976.

76. McComas, M. R. Environmental Control of Inorganic Water Quality near Severance, Colorado, Masters Thesis, Colorado State University, Fort Collins, Colorado, July, 1966.

77. McConaghy, J. A. and Colburn, G. W. Records of Wells in Colorado. Basic Data, USGS-Colorado Conservation Board, Release No. 17, Denver, Colorado, 1964.

78. M & I, Inc. (Consulting Engineers) "Phase I of the Comprehensive Sewer Study for Larimer County," September, 1971.

79. McGinnis, R. A. Beet-Sugar Technology, Second Edition, Fort Collins, Colorado, Beet Sugar Development Foundation, 1971.

80. McGuinness, J. L. and Bordne, Erich F. "A Comparison of Lysimeter-Derived Potential Evapotranspiration with Computed Values," Technical Bulletin 1452, USDA-ARS, 1972.

81. McKinnon, J. C. Poudre Valley Contribution to Colorado Irrigation Practice, A Hundred Years of Irrigation in Colorado. Denver: Colorado Conservation Board, 1952.

82. Meyers, Stuart J. "Evaporation from the Seventeen Western States," U.S. Geological Survey Professional Paper 272-D, U.S. Government Printing Office, Washington, D.C., 1962.

83. Monfort of Colorado. "The Monfort Story," Published by Monfort of Colorado, Greeley, Colorado, 1975.

84. Nettleton, E. S. The Reservoir System of the Cache La Poudre Valley, USDA Office of Experiment Stations Bulletin, No. 92, Washington, D.C., 1901.

85. Neutze, J. (Water Commissioner for Cache La Poudre, Colorado State Engineer Office) personal inverviews, 1977.

86. Northern Colorado Water Conservancy District. With Water Enough...A Better Land. Pamphlet, NCWCD, Loveland, Colorado, undated.

87. Northern Colorado Water Conservency District. Operating Records for the Colorado-Big Thompson Project, 1970.

88. Northern Colorado Water Conservancy District. "Thirty Third Annual Report 1969-1970."

89. Patterson, James L. "Energy Water Demands, South Platte Basin, 1970-2020," Vol. 5 of Water Supply Management Analysis and Alternative Development of the South Platte River Basin, 7 Vols., U.S. Army Corps of Engineers, Omaha, Nebraska, April, 1977b.

90. Patterson, James L. "Industrial Water Demands, South Platte Basin, 1970-2020," Vol. 4 of Water Supply Management Analysis and Alternative Development for the South Platte River Basin 7 Vols., U.S. Army Corps of Engineers, Omaha, Nebraska, January, 1977a.

91. Poudre Valley Rural Electric Association. Files and Maps on Irrigation Pumps, Fort Collins, Colorado.

92. Rader, Brian F. Happy Valley: The Politics of Rural-Domestic Water Agencies, Unpublished M. A. Thesis, Department of Political Science, Colorado State University, June 1966.

93. Radosevich, G. E., Hamburg, D. H. and Swick, Loren L. "Colorado Water Laws, A Compilation of Statutes, Regulations, Compacts and Selected Cases," Center for Economic Education, Department of Economics and Environmental Resources Center, Colorado State University, Fort Collins, Colorado, August, 1975.

94. Radosevich, G. E., Nobe, K. C., Allardice, D. and Kirkwood, C. "Evolution and Administration of Colorado Water Laws: 1876-1976," Water Resource Publications, Fort Collins, Colorado, 1976.

95. Rohwer, Carl. History of Irrigation by Pumping Wells in Colorado. USDA unpublished report, 1953.

96. Schneider, Paul A. and Hershey, Lloyd A. Lower Cache La Poudre River Basin, Colorado. Colorado Groundwater Basic Data Report No. 8, State of Colorado, Department of Natural Resources, 1961.

97. Schwochow, S. D., Shroba, R. R. and Wicklein, P. C. Sand, Gravel and Quarry Aggregate Resources Colorado Front Range Counties, Department of Natural Resources, Colorado Geological Survey, Special Publication 5-A, Denver, Colorado, June 1974.

98. Smith, George L. and Schulz, E. F. "Normal Monthly and Annual Precipitation for Eastern Colorado," Colorado Agricultural Experiment Station, Fort Collins, Colorado, 1962.

99. Stockton, C. W. Hydrology of Upper Boxelder Valley, Larimer County, Colorado, M. S. Thesis, Colorado State University, Fort Collins, Colorado, 1965.

100. Schulz, E. F. "Problems in Applied Hydrology," Water Resources Publications, Fort Collins, Colorado, 1973.

101. Skogerboe, G. V., Radosevich, G. E., and Vlachos, E. C., "Consolidation of Irrigation Systems, Phase 1, Environmental Resources Center, Colorado State University, Fort Collins, Colorado, 1973.

102. <u>The Colorado River Compact</u>, 1944.

103. <u>The South Platte River Compact</u>, May 8, 1926.

104. <u>The Upper Colorado River Basin Compact</u>, October 11, 1948.

105. Thompson, Marion. A History of the Development Irrigation in the Cache La Poudre Valley, Unpublished M. A. Thesis, Department of History and Political Science, Colorado State College, Greeley, Colorado, June 1927.

106. Toups Corporation. (Consulting Engineers), "Characteristics and Problems of the Water Supply System - Main Report and Appendix," Volume V, Annex D, prepared for the Corps of Engineers, Omaha District, March, 1975.

107. "Treaty Between the U.S.A. and Mexico Respecting Utilization of the Colorado and Tijuana Rivers and the Rio Grande," 50 Stat. 1219, T.S., No. 994.

108. Tuck, Clark A. "Discharge of the Fort Collins Sewage System," (unpublished report) November 16, 1971.

109. Ullman, T. (Water and Sewer Department, Greeley) a personal telephone conversation, 1977.

110. U.S. Army Corps of Engineers. May 1971, "Application for Permit to Discharge or Work in Navigable Waters and Their Tributaries," Engineering Form No. 4345, Office of Management and Budget Form No. 49-R 0408.

111. U.S. Army Corps of Engineers. "Water Resources Development; Colorado," Missouri River Division, Omaha, Nebraska, 1975.

112. U.S. Bureau of Commercial Fisheries. (Biological Laboratory), "Progress Report No. 154 for January through March 1969." Research on Fishway Problems Conducted at the Fisheries-Engineering Research Laboratory at Bonneville Dam under Contract No. DA 026-25142 with the U.S. Fish and Wildlife Service. Unpublished report by C. R. Weaver, Seattle, Washington, 1969.

113. U.S. Bureau of Reclamation. "Concluding Report, Cache La Poudre Unit, Colorado, Longs Peak Division, Missouri River Basin Project," Region 7, Denver, Colorado, 1966.

114. U.S. Bureau of Reclamation. "Report on the South Platte River Basin; Colorado, Wyoming and Nebraska," Denver, Colorado, June 1959.

115. U.S. Bureau of Reclamation. "The Story of the Colorado-Big Thompson Project," U.S. Government Printing Office, Washington, D.C., 1968.

116. U.S. Bureau of Reclamation. "Westwide Study Report on Critical Water Problems Facing the Eleven Western States," April, 1975.

117. U.S. Department of Commerce. Environmental Data Service, "Climatological Data for Colorado - 1970," Volume 75, Number 13, 1970.

118. U.S. Department of the Interior. "Final Environmental Statement on the Proposed Long Draw Enlargement Project," February 7, 1973.

119. U.S. Environmental Protection Agency. October 1971, Final Environmental Statement, Greeley, Colorado Waste Treatment Facility Project No. WPC Colo.-261, Prepared by Region VIII, Denver, Colorado, Reproduced by National Technical Information Services, Springfield, Virginia.

120. U.S. Environmental Protection Agency. "Technical Appendix on Industrial Waste - Source Evaluations, Water Quality Investigations in the South Platte River Basin, Colorado 1971-1972," National Field Investigations Center - Denver and Region VIII, Denver, Colorado, June 1972.

121. U.S. Environmental Protection Agency. Region VIII, "Summary on the Long-term Water Quality of the South Platte River Basin 1966-1972," Technical Investigations Branch, Surveillance and Analysis Division, August, 1974.

122. U.S. Geological Survey. "Miscellaneous Investigations Series, Lakes in the Boulder-Fort Collins-Greeley Area, Front Range Urban Corridor, Colorado," Washington, D.C., 1973c.

123. U.S. Geological Survey. "Water Resources Data for Colorado Water Year 1970," Part 1, Surface Water Records, U.S. Geological Survey, 1970.

124. Watershed Analysis of the North Fork of the Cache La Poudre River. Colorado State University, Fort Collins, Colorado, 1959.

125. Watrous, Ansel. History of Larimer County, Colorado, Fort Collins, 1911 (reprinted by Miller Manor Publications, 1972).

126. Weist, W. G., Jr. Hydrogeologic Data from Parts of Larimer, Logan, Morgan, Sedgwick, and Weld Counties, Colorado. Colorado Conservancy Board Basic Data Report No. 16, 1964.

127. Wentz, D. A. Environment of the Middle Segment of Cache La Poudre River, Colorado, Colorado Division of Wildlife, Department of Natural Resources, Denver, 1974.

128. White, Donald E. Inorganic Quality of Water as Related to Environment in the Lower Boxelder Creek Valley, Larimer County, Colorado. Unpublished M.S. Thesis, Colorado State University, Fort Collins, Colorado, 1964.

129. White, N. F., Sunada, D. K. and McCumas, M. Groundwater Quality Study of Severance Basin, Weld County, Colorado. Colorado State University Engineering Research Center Publication CER 66 NFW-DK55, Fort Collins, Colorado, 1966.

130. Wilkinson, W. G. (Division Engineer, State of Colorado Division No. 1), "Water Rights Tabulation," October 1973.

131. Wilkinson, W. G. (Division Engineer, State of Colorado Division No. 1) and C. J. Kuiper (Colorado State Engineer), "Revised Priority List for Division 1," July 10, 1974.

132. Wyoming vs. Colorado, 309, U.S. 572, (1940).

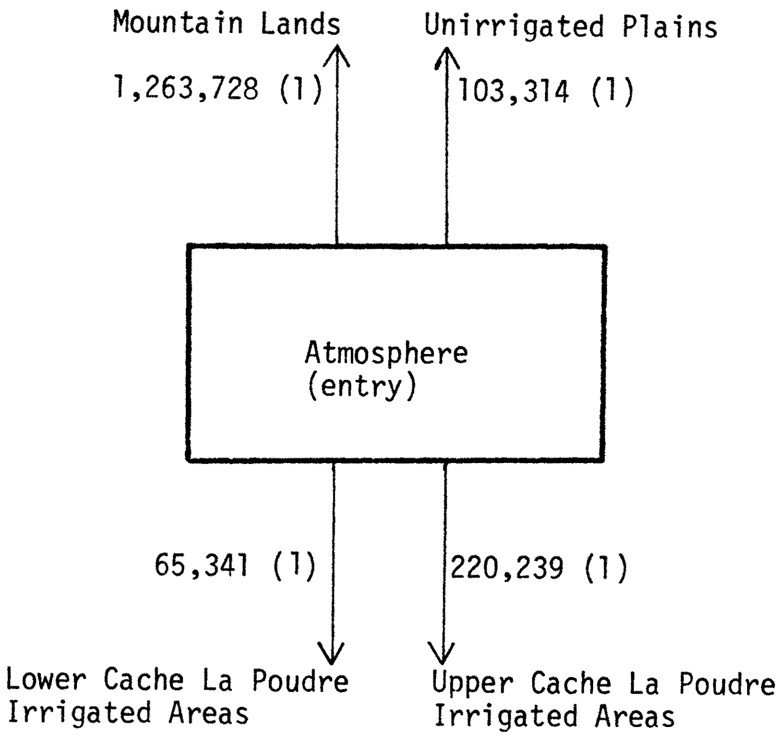
133. Wyoming vs. Colorado, 353, U.S. 953, (1957).

APPENDICES

The appendices depict the water mass-balance of all the selected key components of the case study water system. The figures included in the appendices are actually a form of input-output model representation of the system. Appendix A depicts the water entries into the system boundary. Appendices B to H depict the mass balances of the internal components of the system of either one of the three types: transport, treatment, use. Appendix I depicts the water exits to the exit components of the system. The nine appendices contain much of the support data and documentation used in the study.

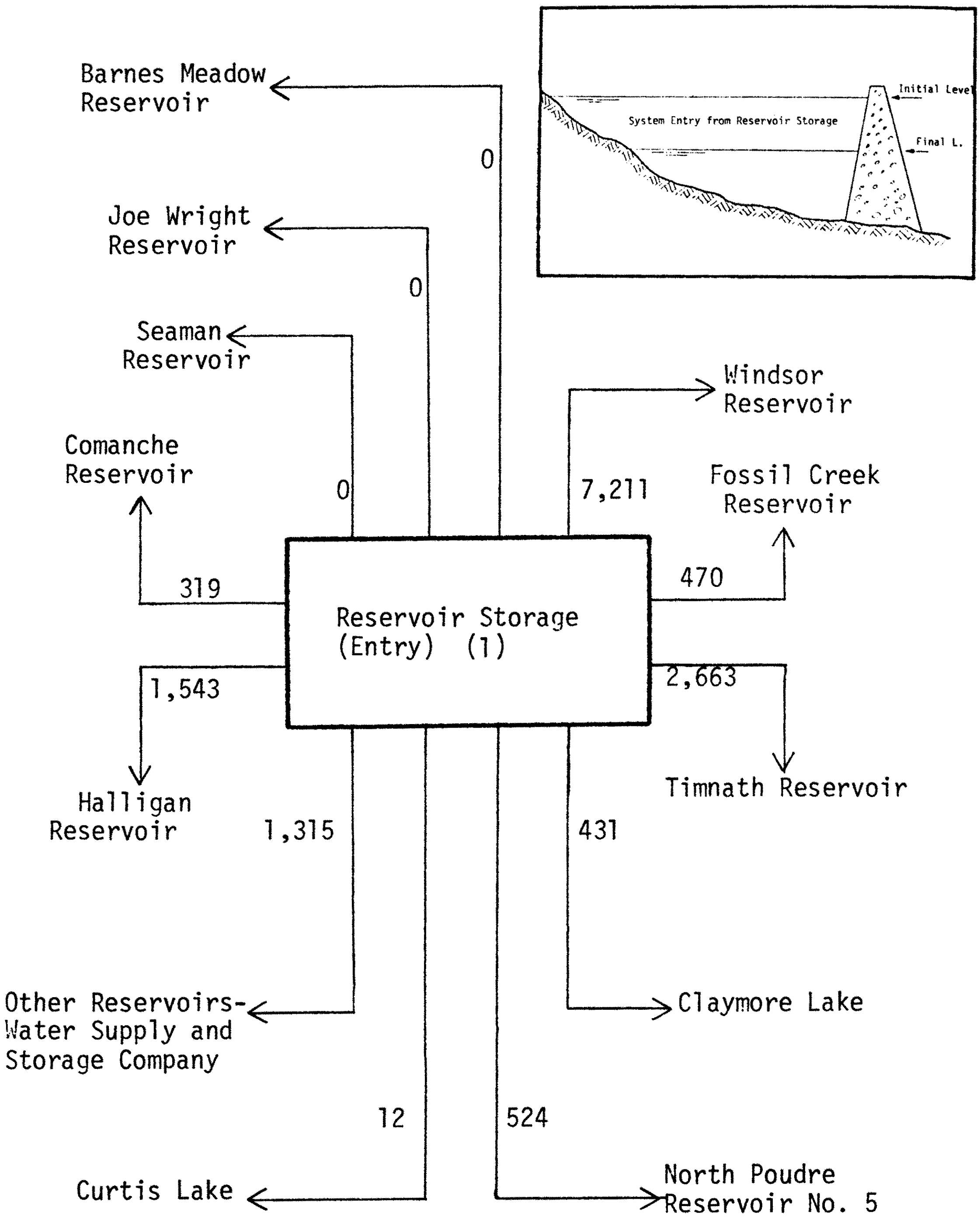
APPENDIX A

ORIGINS OF WATER IN THE CACHE LA POUDRE WATER SYSTEM



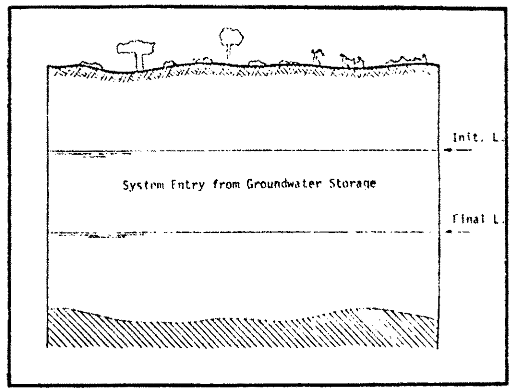
(1) These values represent the total 1970 precipitation volumes over the four land elements of Cache La Poudre Water System. The explanation of these numbers is given in paragraph 5.1.1 of the report and in Figure 5-1.

Figure A-1. Water Volumes Originated from "Atmosphere"



(1) These volumes originated from reservoir withdrawal and were computed as difference between the stored volumes at the beginning and end of the 1970 water year, wherever this difference resulted positive.

Figure A-2. Water Volumes Originated from "Reservoir Storage."



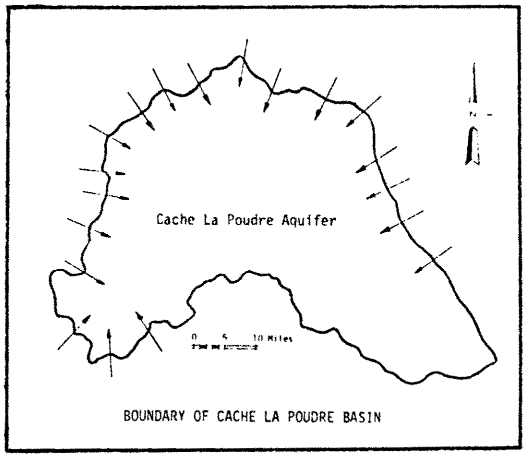
Groundwater Storage
(Entry)

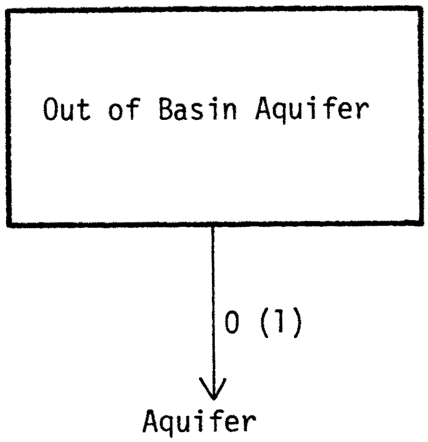
0(1)

Aquifer

(1) This origin element would take account for the water entries originating from groundwater mining. Because of the almost stable equilibrium of Cache La Poudre basin groundwaters this origin was considered inactive in 1970.

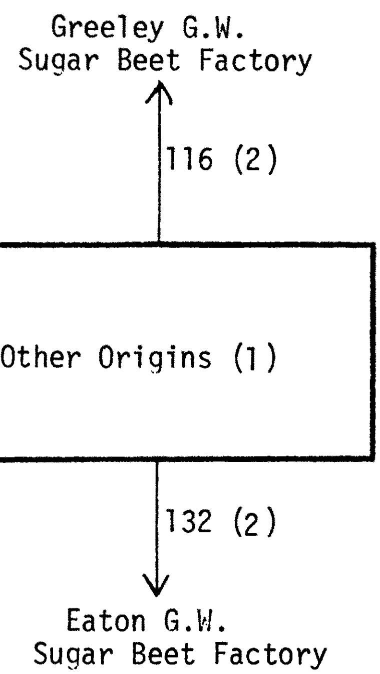
Figure A-3. Water Volumes Originated from "Groundwater Storage."





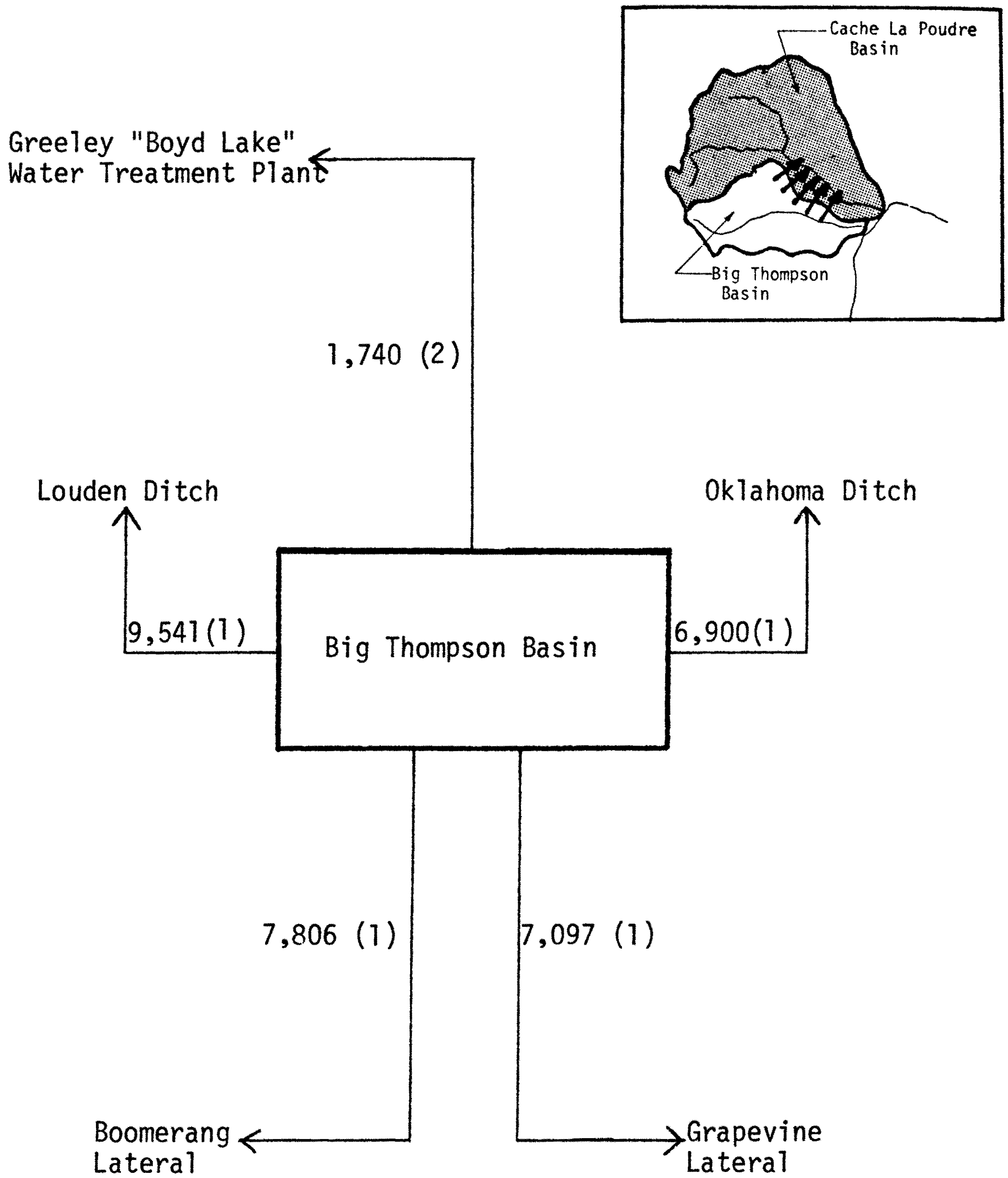
(1) This origin element was introduced for taking account of possible groundwater inflows beneath the surface boundary of the Cache La Poudre River basin. Since no evidence of such inflows was available, this entry element was considered inactive.

Figure A-4. Water Volumes Originated from "Out of Basin Aquifers."



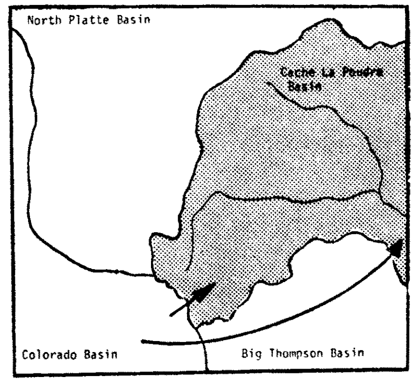
(1) This entry element was introduced in order to take account of the water volumes entering some industries as sugar beet water.
(2) These values were derived from the mass balance of Eaton and Greeley G.W. Sugar Beet Factories.

Figure A-5. Water Volumes Originated from "Other Origins."



(1) These volumes entered the Cache La Poudre Water System through irrigation ditches. The values were derived from Gerlek (1977).
(2) Janonis (1977).

Figure A-6. Water Volumes Originated in "Big Thompson River Basin."



Grand River Ditch

↑ 12,830 (1)

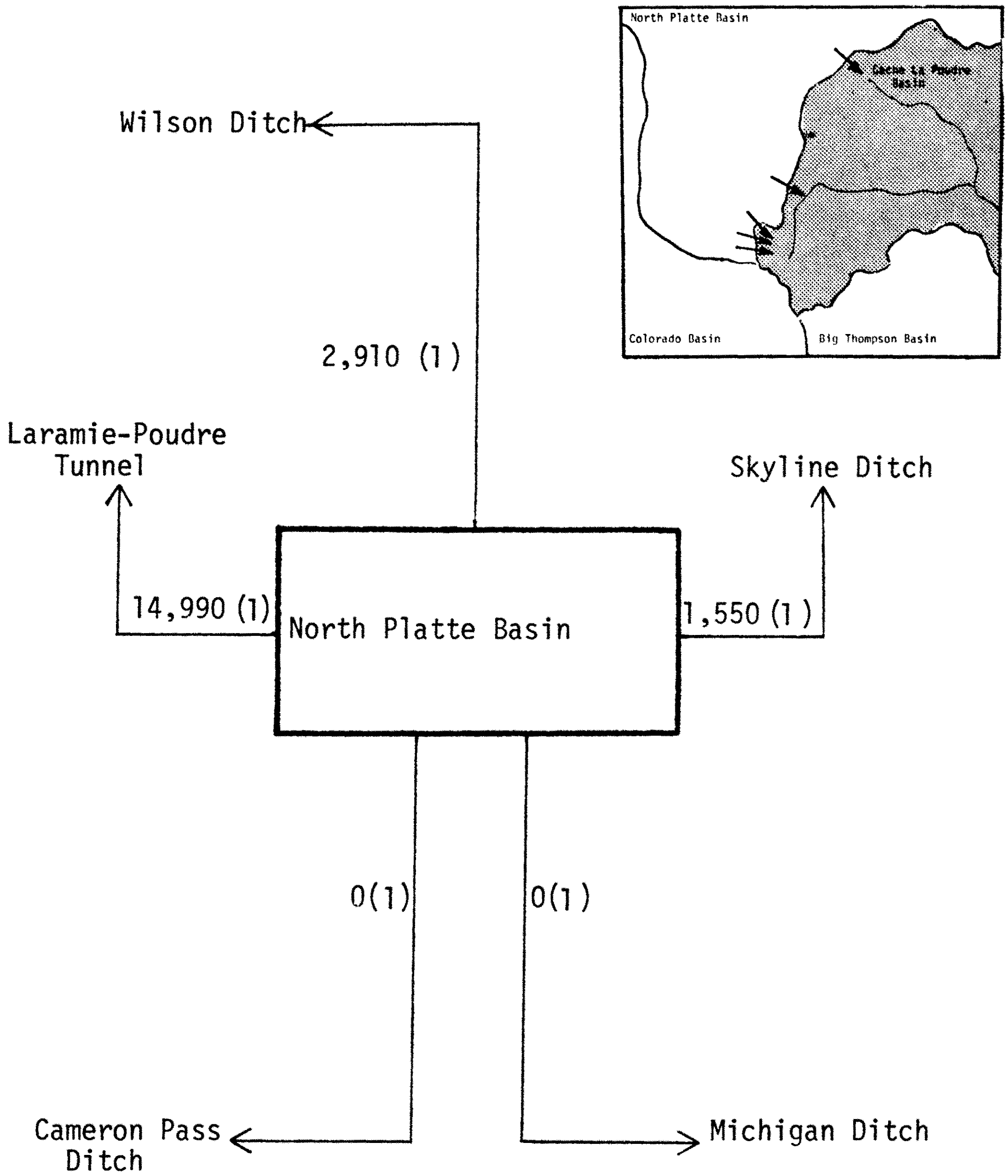
Colorado River Basin

↓ 204,600 (1)

Colorado-Big Thompson Delivery System

(1) Gerlek (1977).

Figure A-7. Water Volumes Originated from "Colorado River Basin."

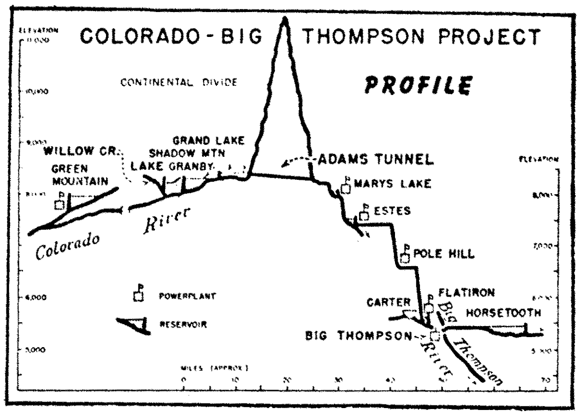


(1) These imported amounts were derived from the USGS, Water Resources Data for Colorado, 1970.

Figure A-8. Water Volumes Originated in "North Platte River Basin."

APPENDIX B

WATER BALANCES OF TRANSBASIN DIVERSIONS



Colorado River Basin

204,600 (1)

Colorado Big-Thompson Delivery System

98,785 (3)

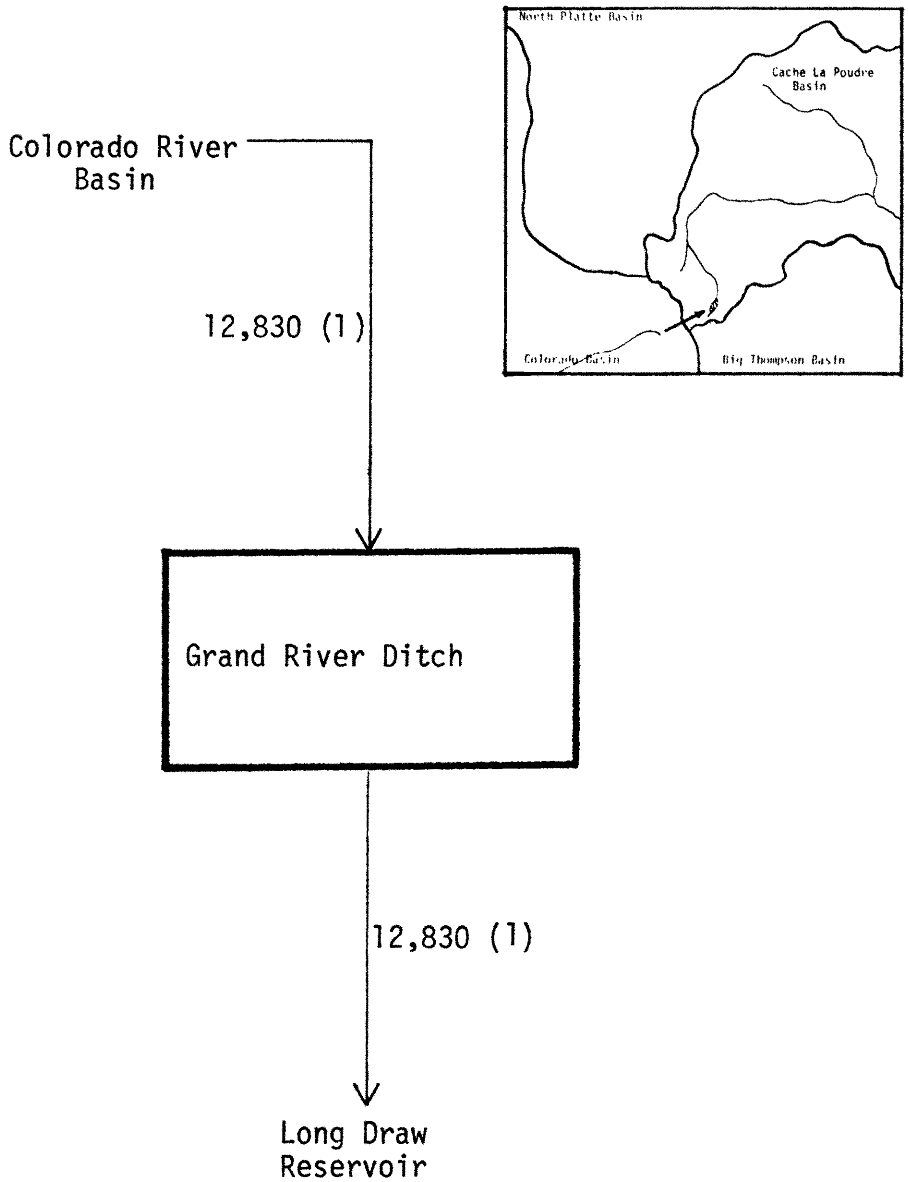
105,815 (2)

Other South Platte Sub-basins

Horsetooth Reservoir

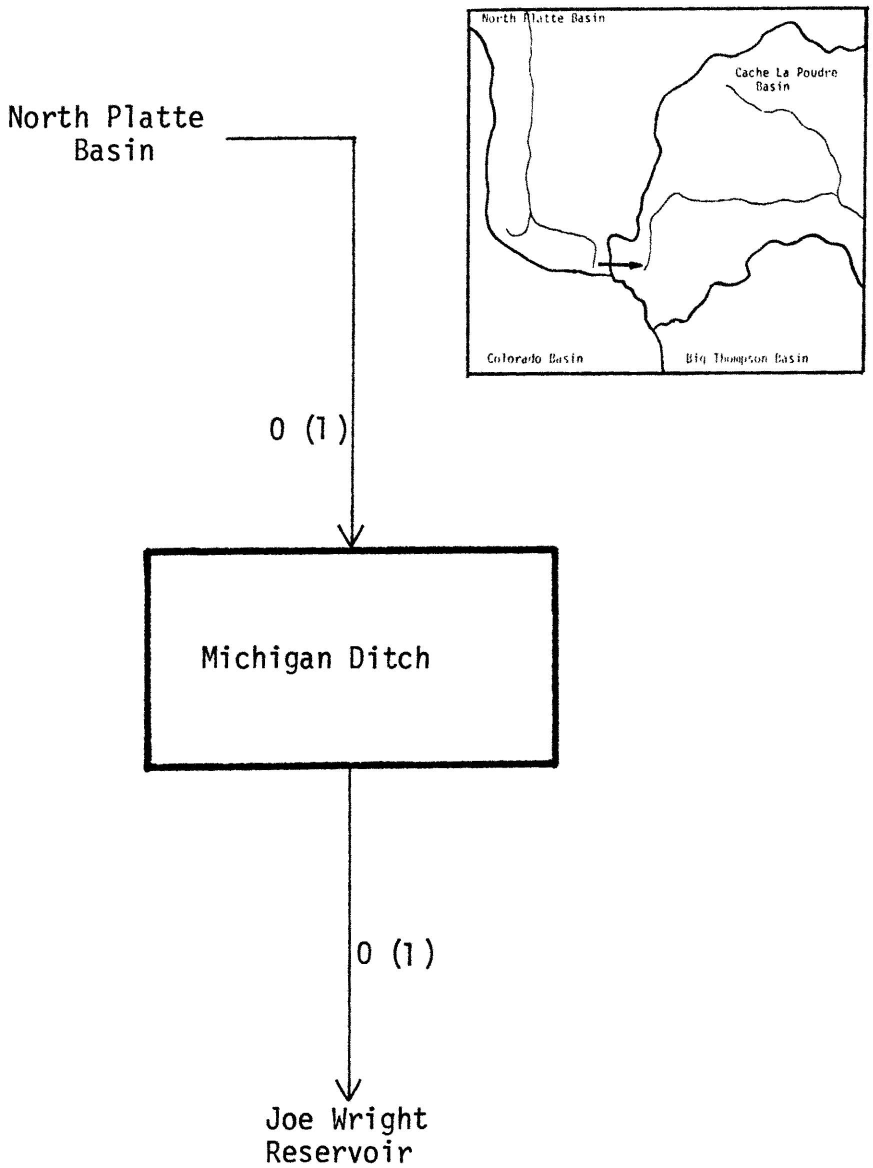
(1) These are the total diversions of Colorado River Waters through the "Colorado-Big Thompson Delivery System." The total amount was derived from Gerlek (1977).
(2) Derived through mass-balance of "Horsetooth Reservoir."
(3) Derived through mass-balance of "Colorado-Big Thompson Delivery System."

Figure B-1. Water Balance of "Colorado-Big Thompson Delivery System."



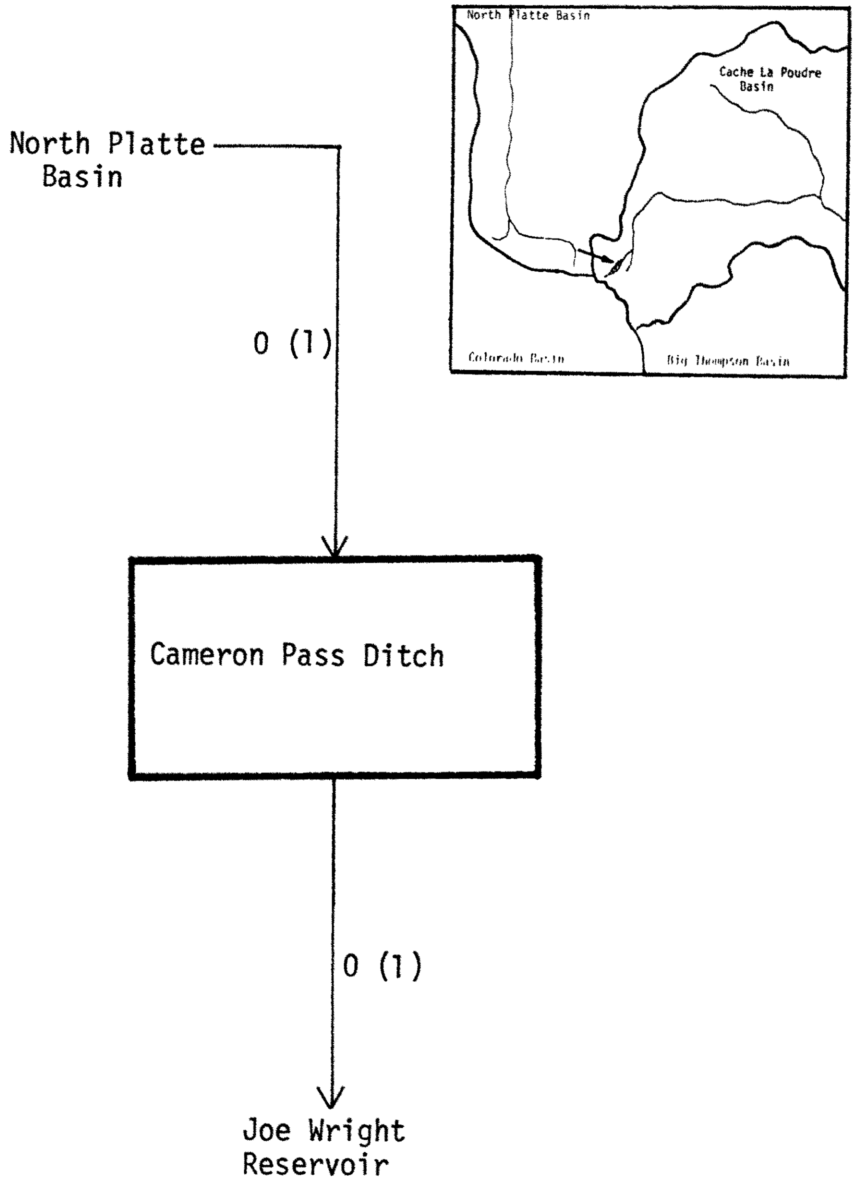
(1) These imported amounts were derived from Gerlek (1977).

Figure B-2. Water Balance of "Grand River Ditch."



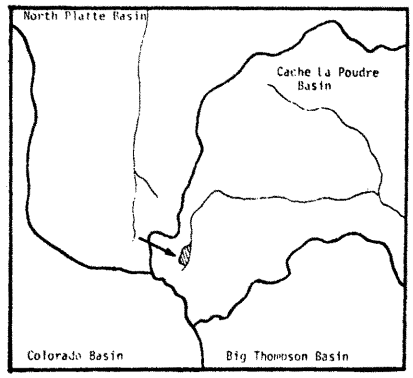
(1) Michigan Ditch was inactive in 1970 (USGS, Water Resources Data for Colorado, 1970).

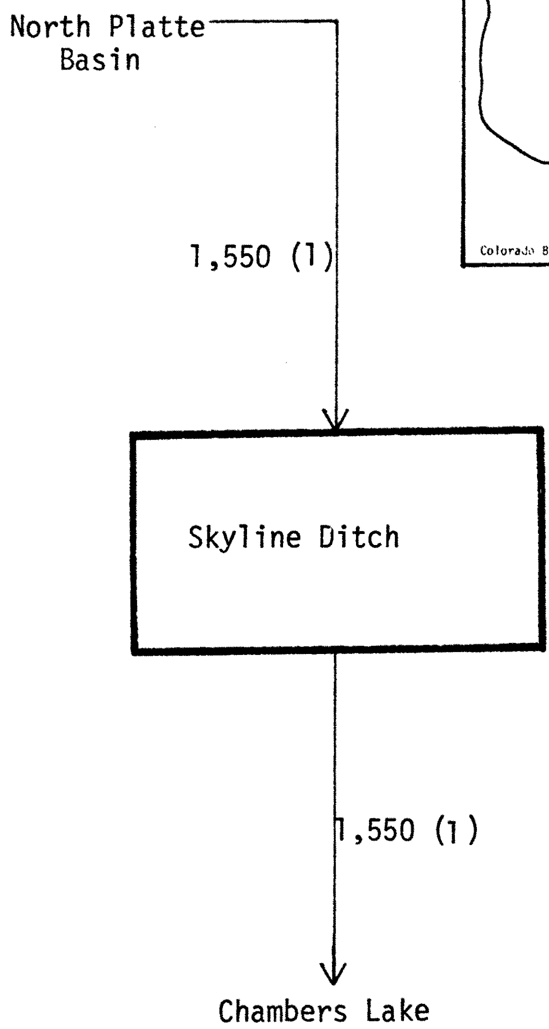
Figure B-3. Water Balance of "Michigan Ditch."



(1) Cameron Pass Ditch was inactive in 1970 (USGS Water Resource Data for Colorado, 1970).

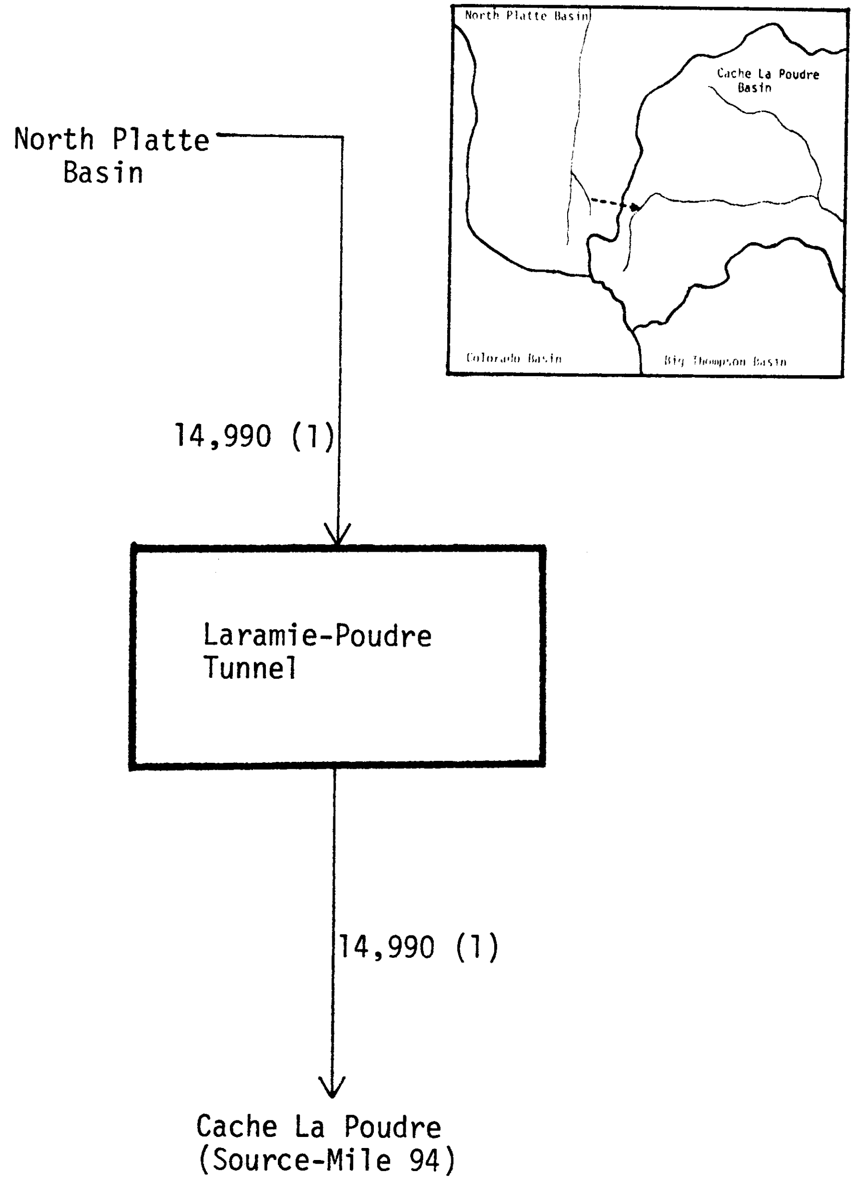
Figure B-4. Water Balance of "Cameron Pass Ditch."





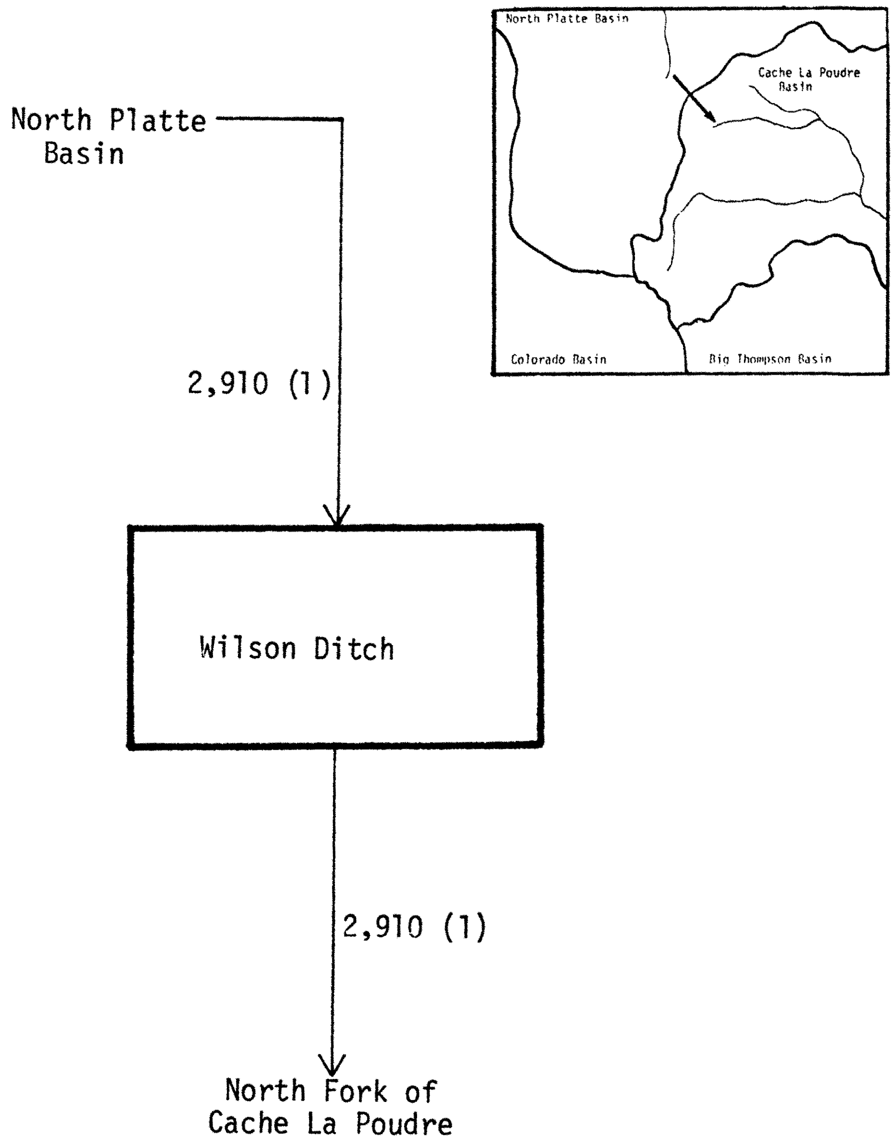
(1) USGS, Water Resource Data for Colorado, 1970.

Figure B-5. Water Balance of "Skyline Ditch."



(1) USGS, Water Resource Data for Colorado, 1970.

Figure B-6. Water Balance of "Laramie-Poudre Tunnel."

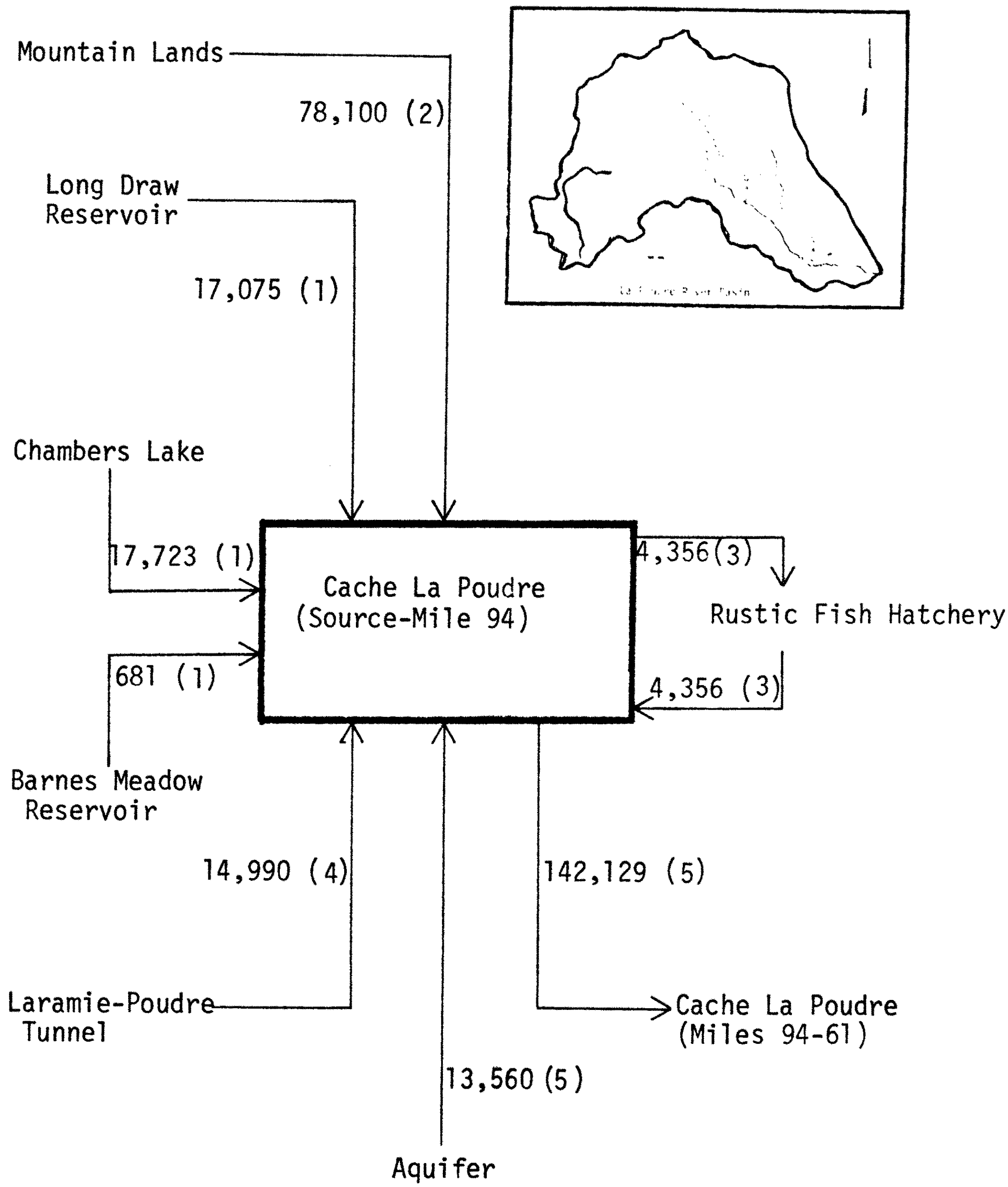


(1) USGS, Water Resource Data for Colorado, 1970.

Figure B-7. Water Balance of "Wilson Ditch."

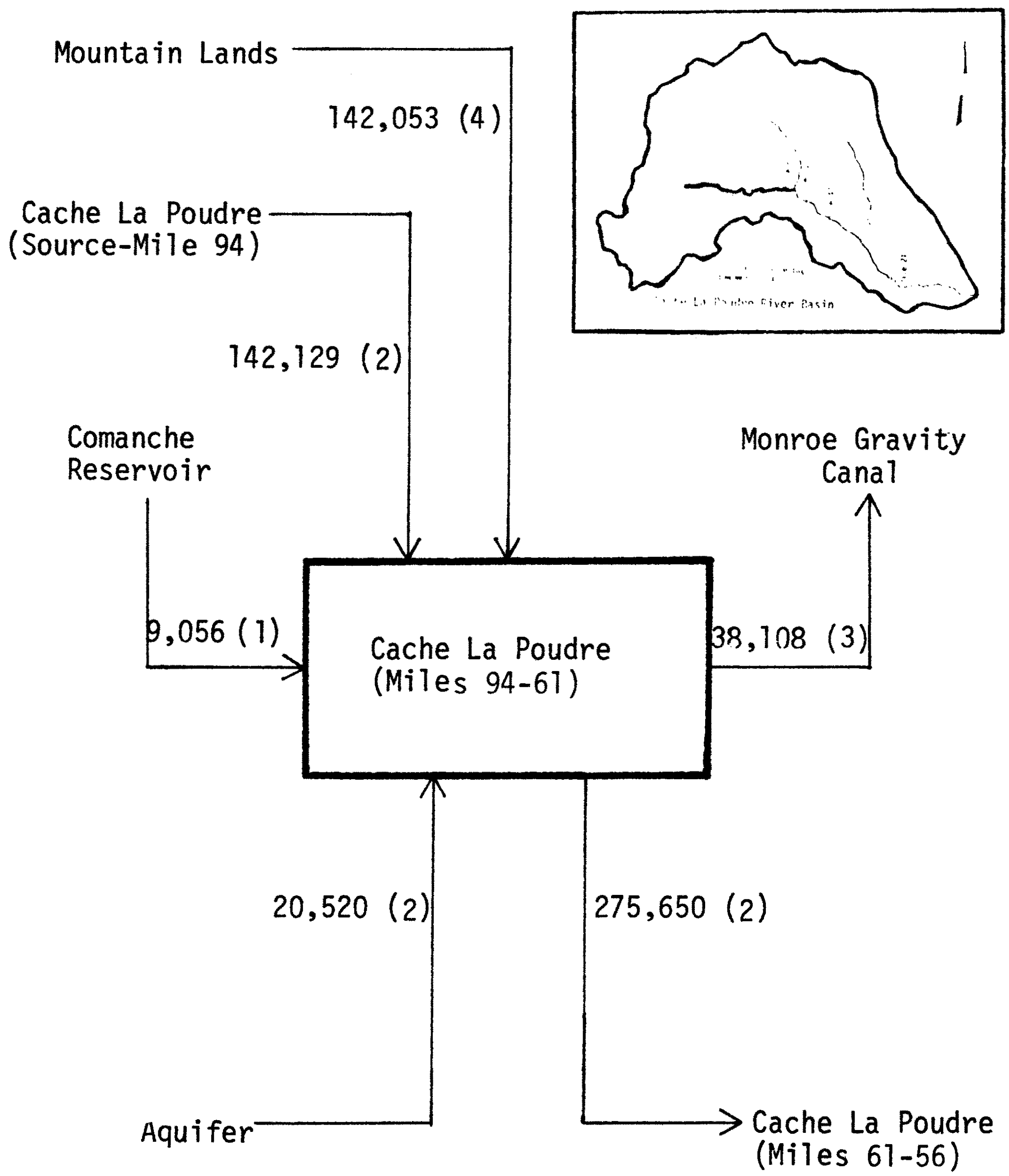
APPENDIX C

WATER BALANCES OF CACHE LA POUDRE REACHES AND TRIBUTARIES



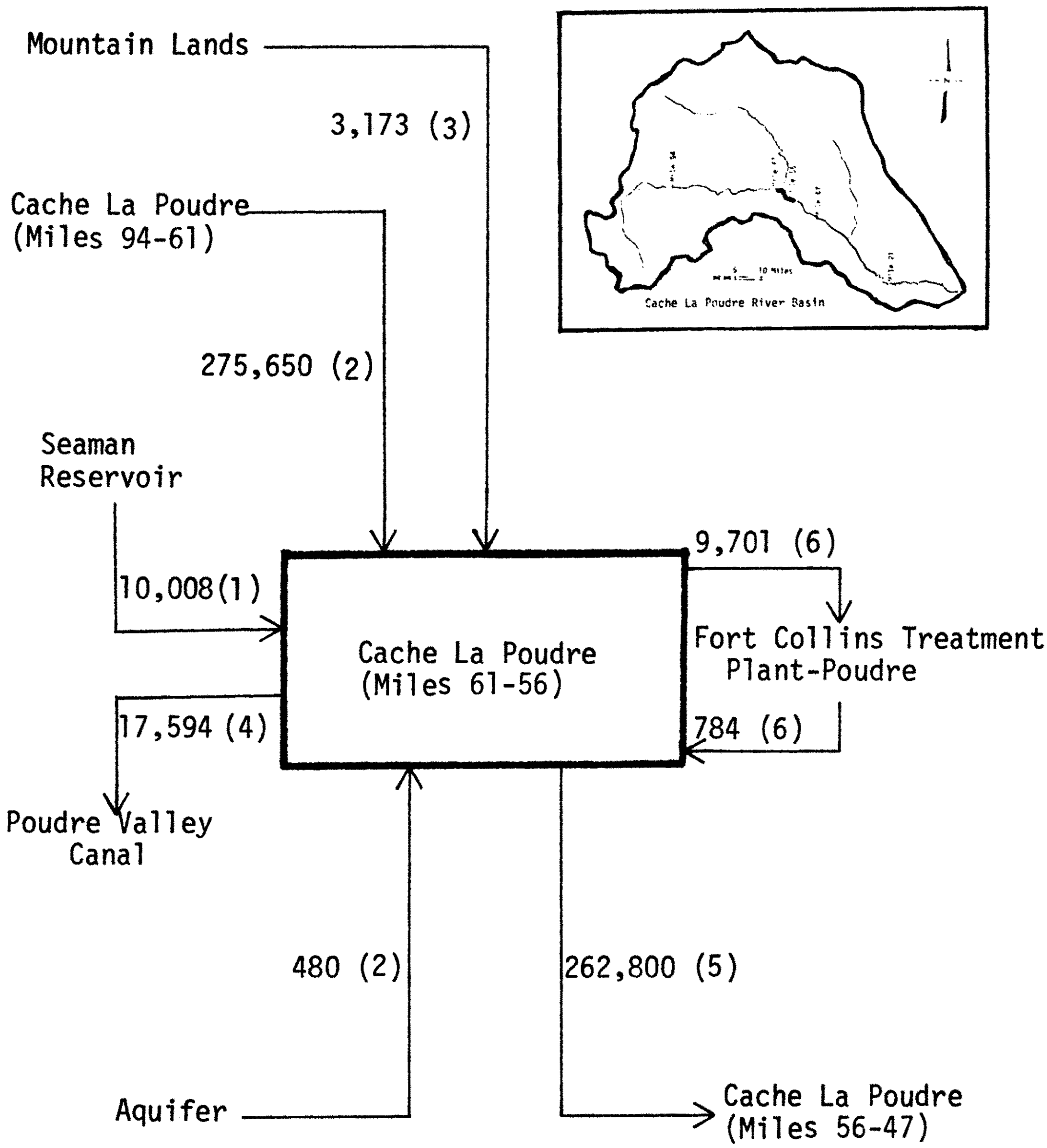
(1) See the water balance of the correspondent lake or reservoir.
(2) Computed through mass balance of the river reach.
(3) Patterson (1977).
(4) USGS, Water Resources Data for Colorado, 1970.
(5) This discharge was computed in paragraph 5.5.2.

Figure C-1. Water Balance of "Cache La Poudre, Source-Mile 94."



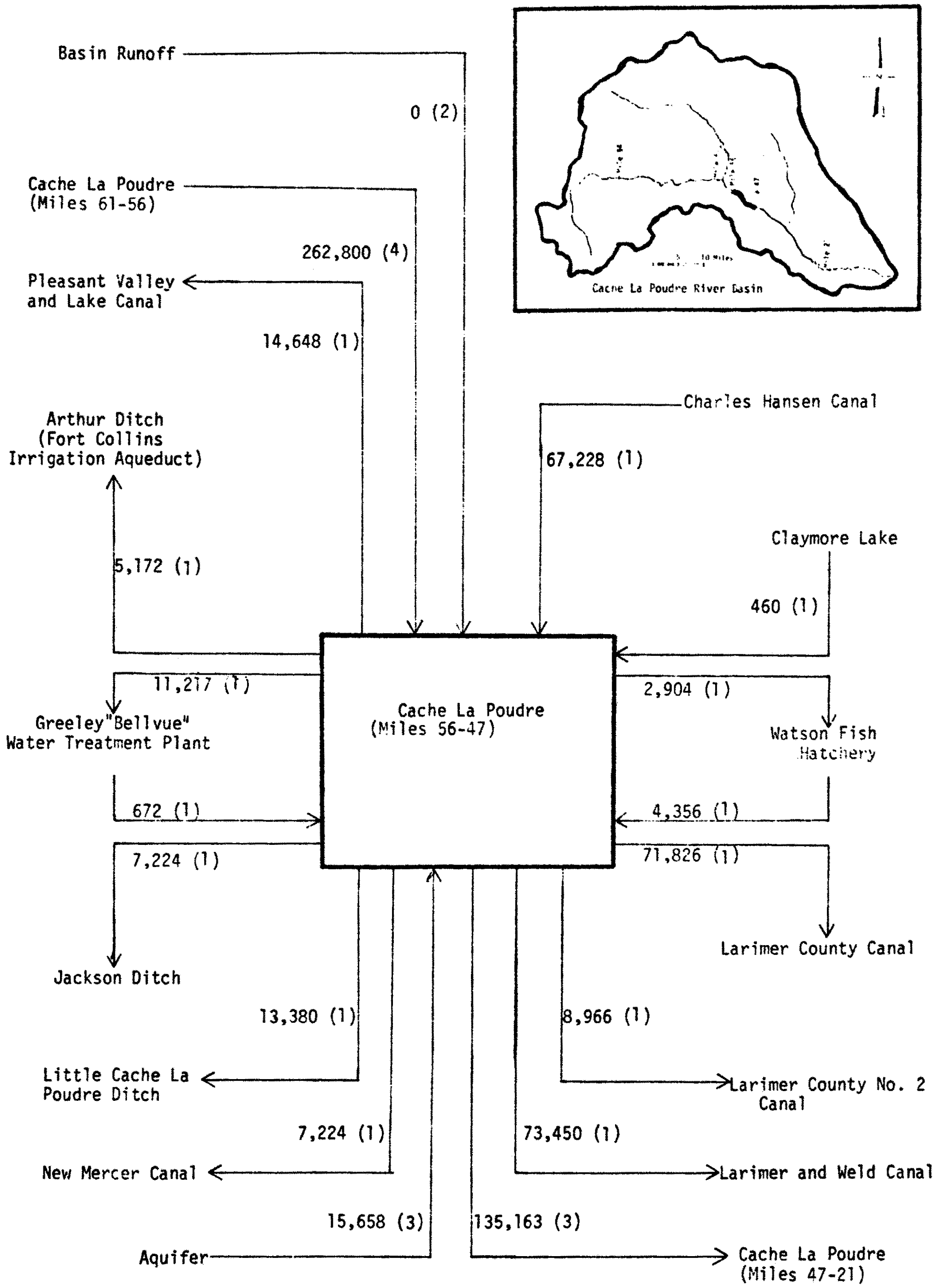
(1) See the water balance of Comanche Reservoir.
(2) This discharge was computed in paragraph 5.5.2.
(3) Records of Water Commissioner.
(4) Computed through mass balance of this river reach.

Figure C-2. Water Balance of "Cache La Poudre, Mile 94-Mile 61."



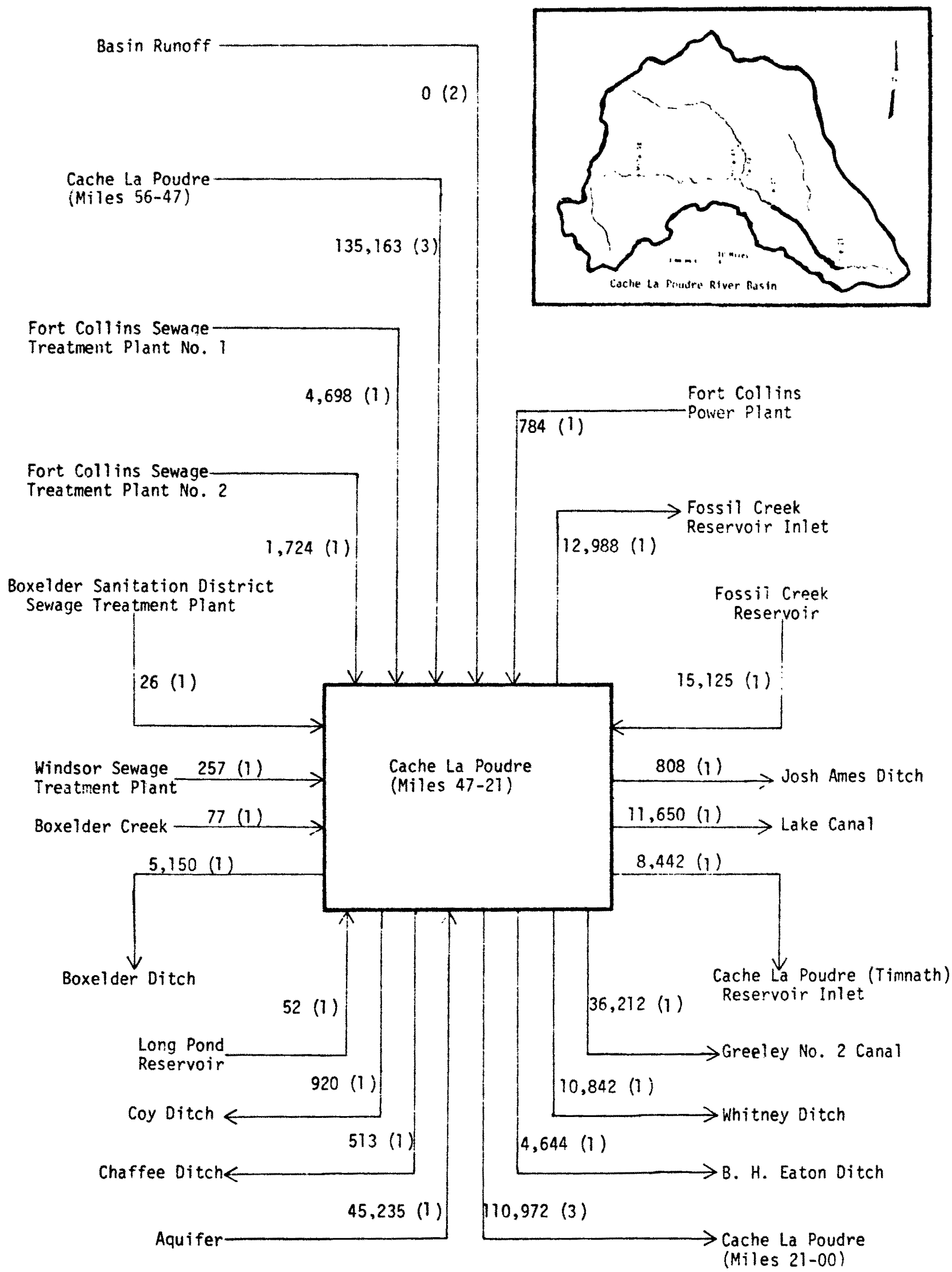
(1) See the water balance of Seaman Reservoir.
(2) This discharge was computed in paragraph 5.5.2.
(3) Computed through mass balance of this river reach.
(4) Records of Water Commissioner.
(5) USGS, Water Resources Data for Colorado, 1970.
(6) Janonis (1977).

Figure C-3. Water Balance of "Cache La Poudre, Mile 61-Mile 56."



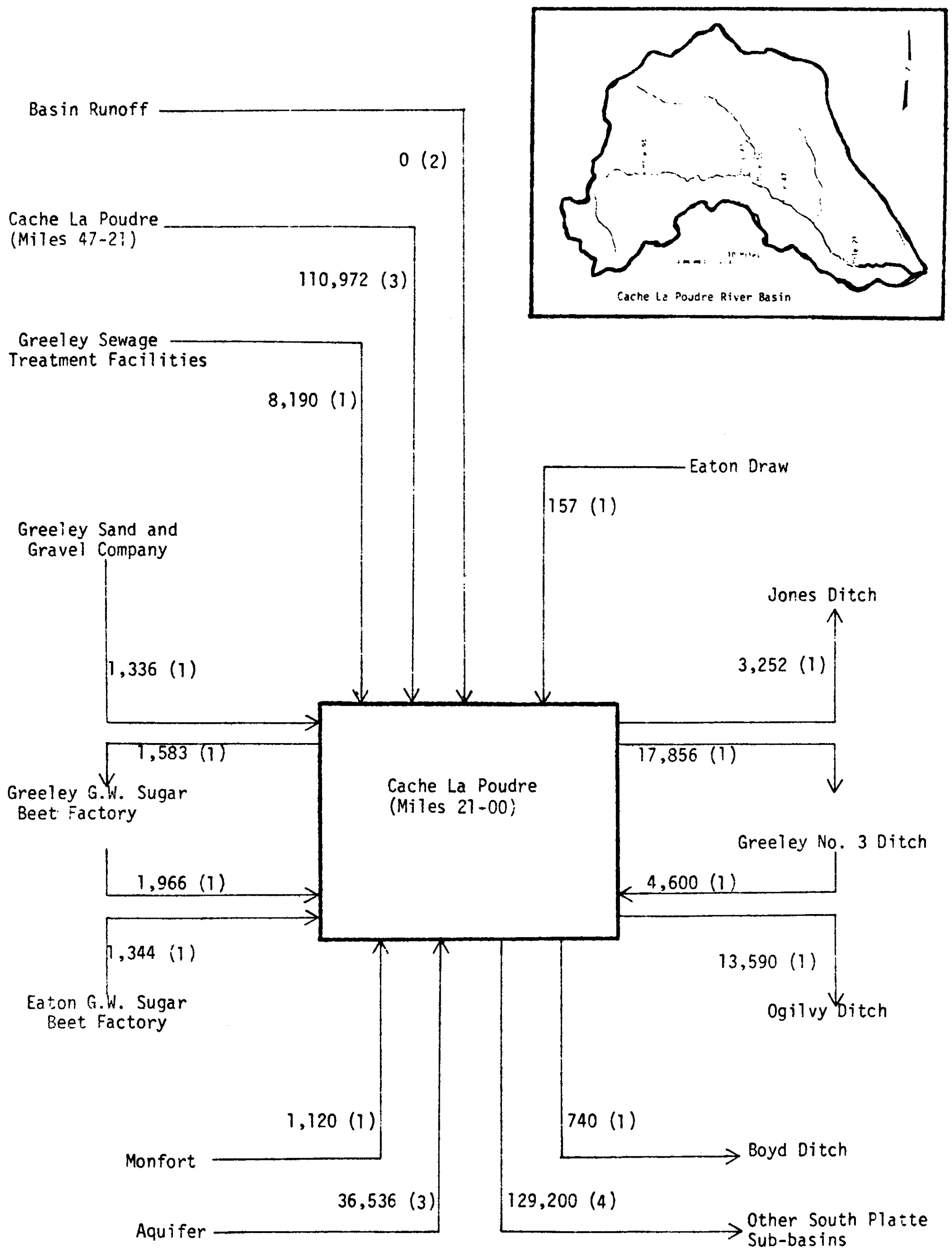
(1) See the water balance of the corresponding item.
(2) The basin runoff was considered negligible.
(3) This discharge was computed in paragraph 5.5.3.
(4) USGS, Water Resources Data for Colorado, 1970.

Figure C-4. Water Balance of "Cache La Poudre, Mile 56-Mile 47."



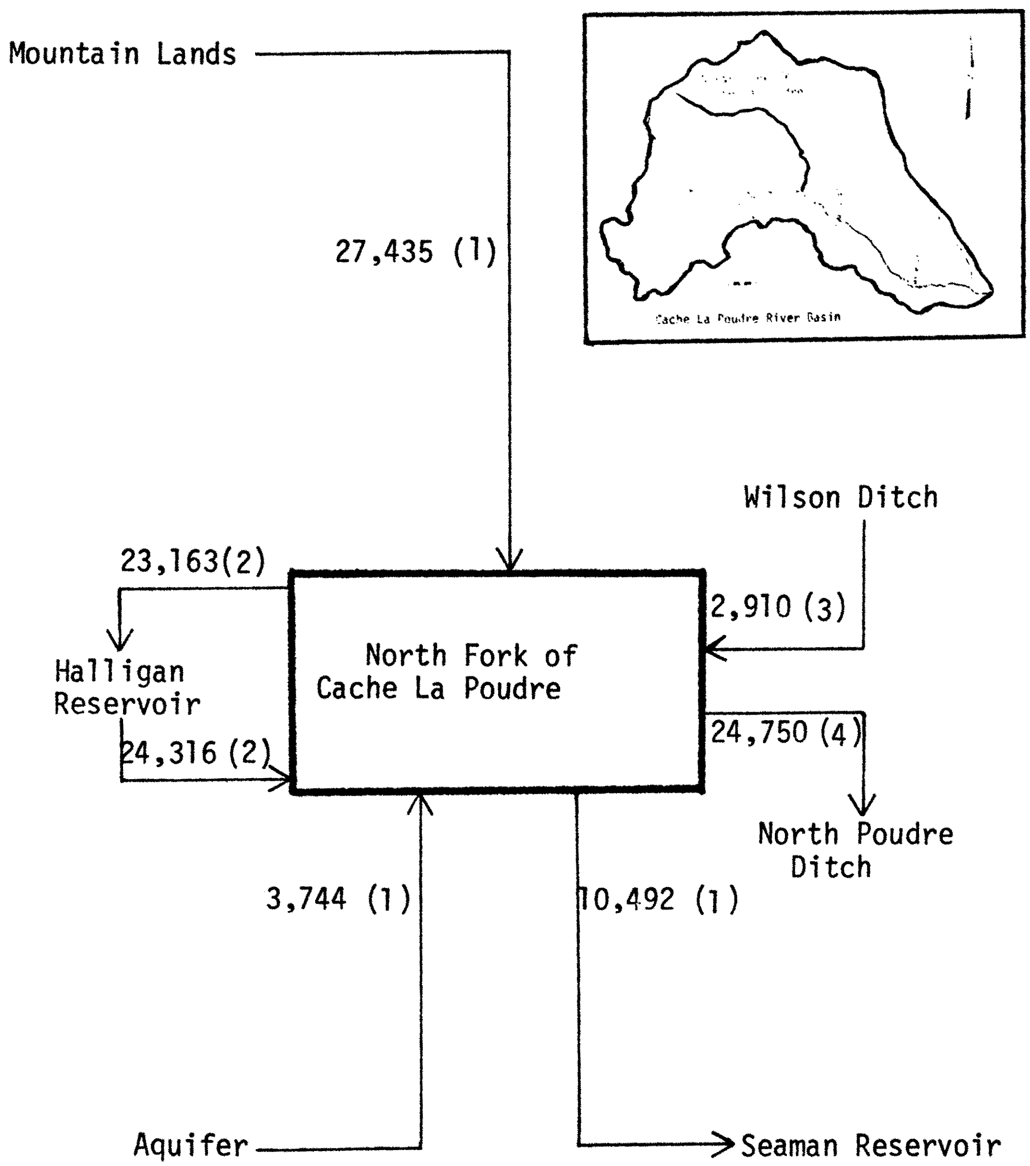
(1) See the water balance of the correspondent element.
(2) The basin runoff was considered negligible.
(3) This discharge was computed in paragraph 5.5.3.

Figure C-5. Water Balance of "Cache La Poudre, Mile 47-Mile 21."



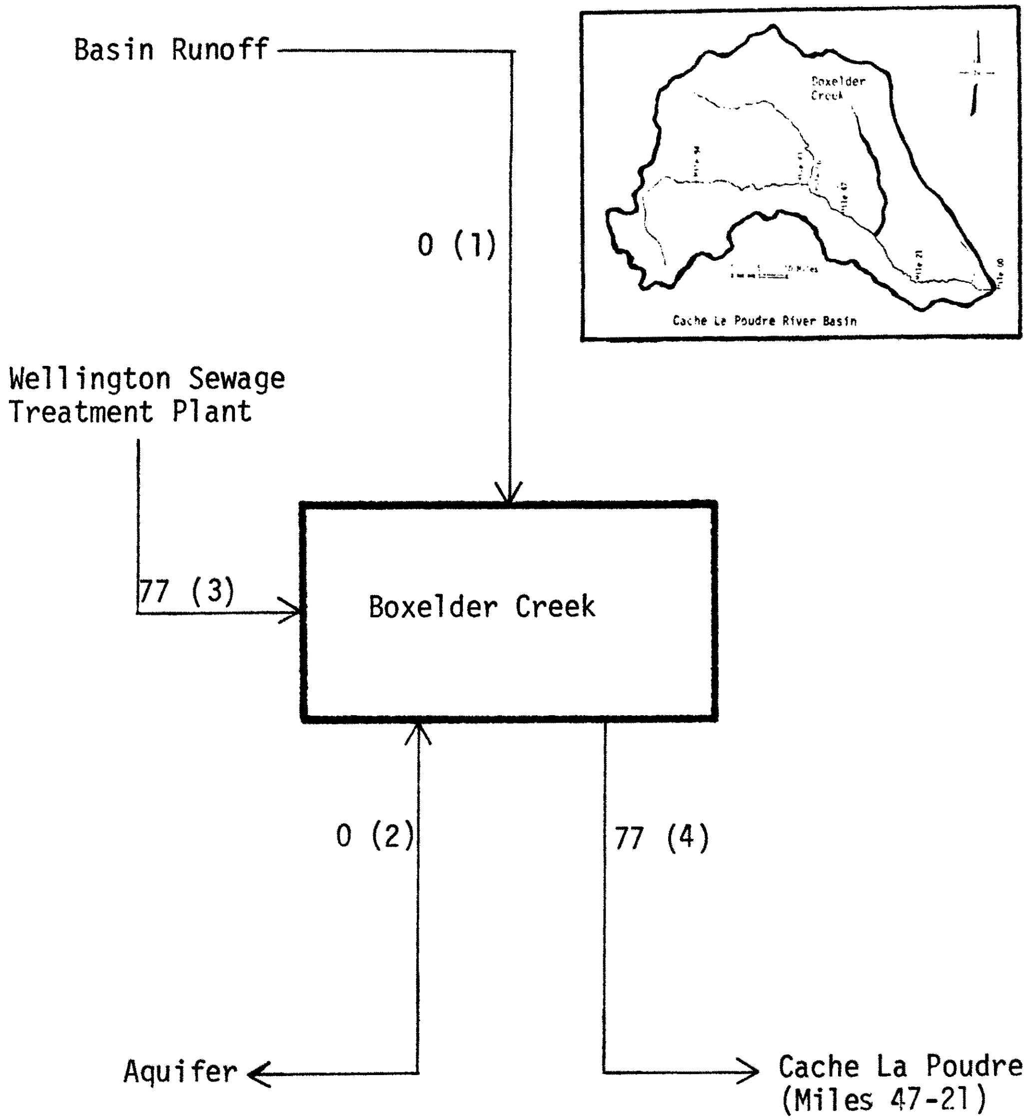
(1) See the water balance of the correspondent element.
(2) The basin runoff was considered negligible.
(3) This discharge was computed in paragraph 5.5.3.
(4) USGS, Water Resources Data for Colorado, 1970.

Figure C-6. Water Balance of "Cache La Poudre, Mile 21-Mile 00."



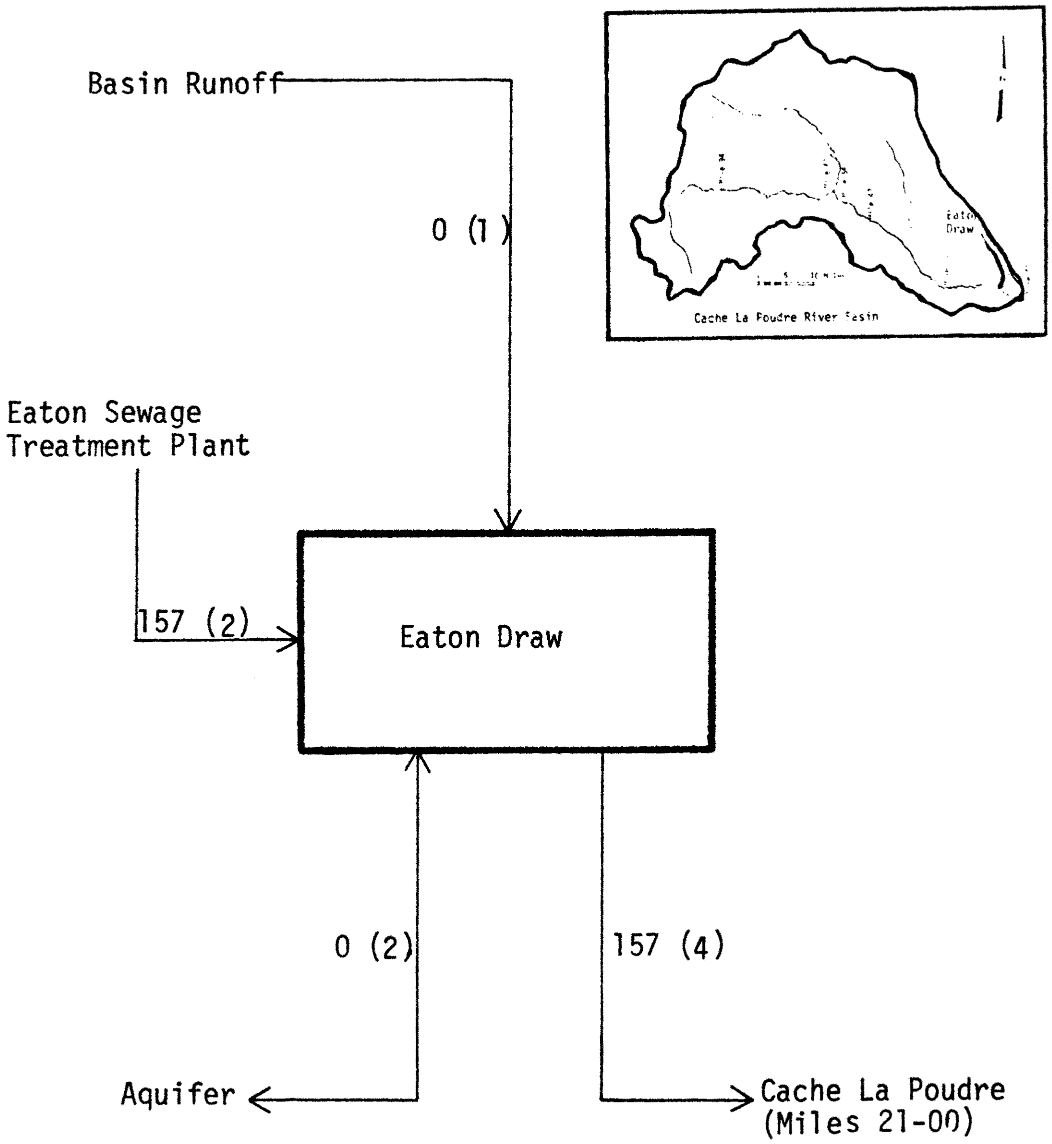
(1) This discharge was computed in paragraph 5.5.1.
(2) See the water balance of Halligan Reservoir.
(3) USGS, Water Resource Data for Colorado, 1970.
(4) Records of Water Commissioner.

Figure C-7. Water Balance of "North Fork of Cache La Poudre."



(1) The basin runoff was considered negligible.
(2) The aquifer related water exchanges were neglected.
(3) See the water balance of "Wellington Sewage Treatment Plant".
(4) Computed through mass balance of Boxelder Creek.

Figure C-8. Water Balance of "Boxelder Creek."

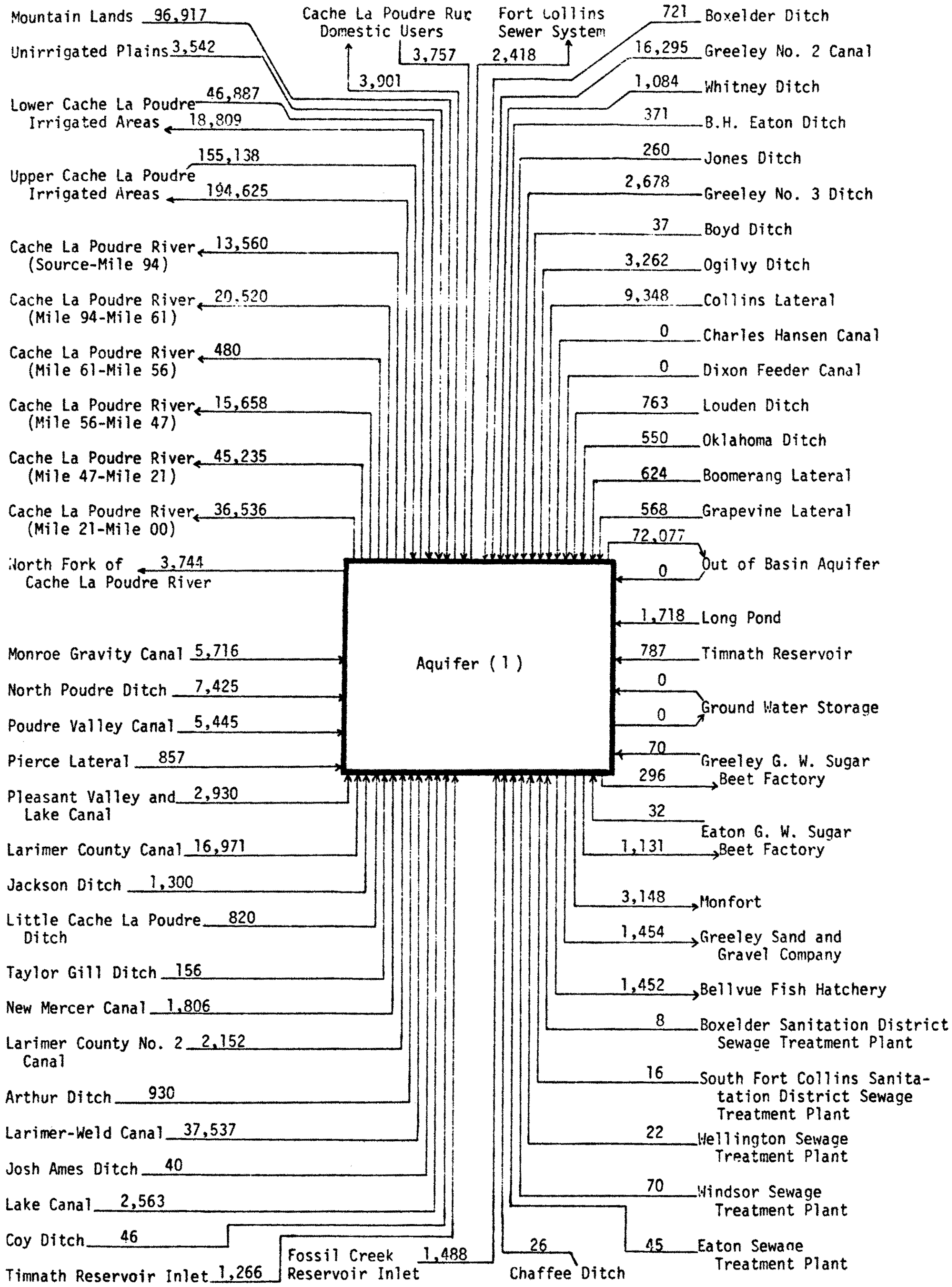


(1) The basin runoff was considered negligible.
(2) See the water balance of Eaton Sewage Treatment Plant.
(3) The aquifer related water exchanges were neglected.
(4) Computed through mass balance of Eaton Draw.

Figure C-9. Water Balance of "Eaton Draw."

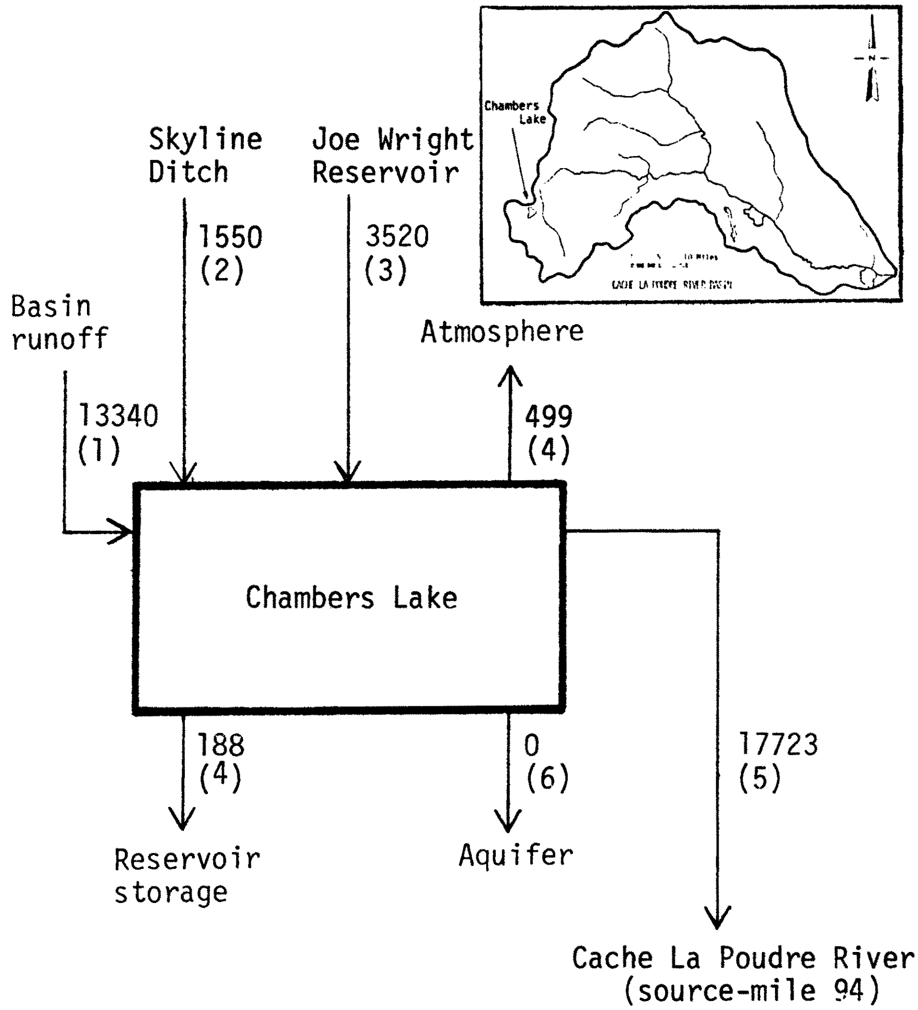
APPENDIX D

WATER BALANCES OF RESERVOIRS AND LAKES



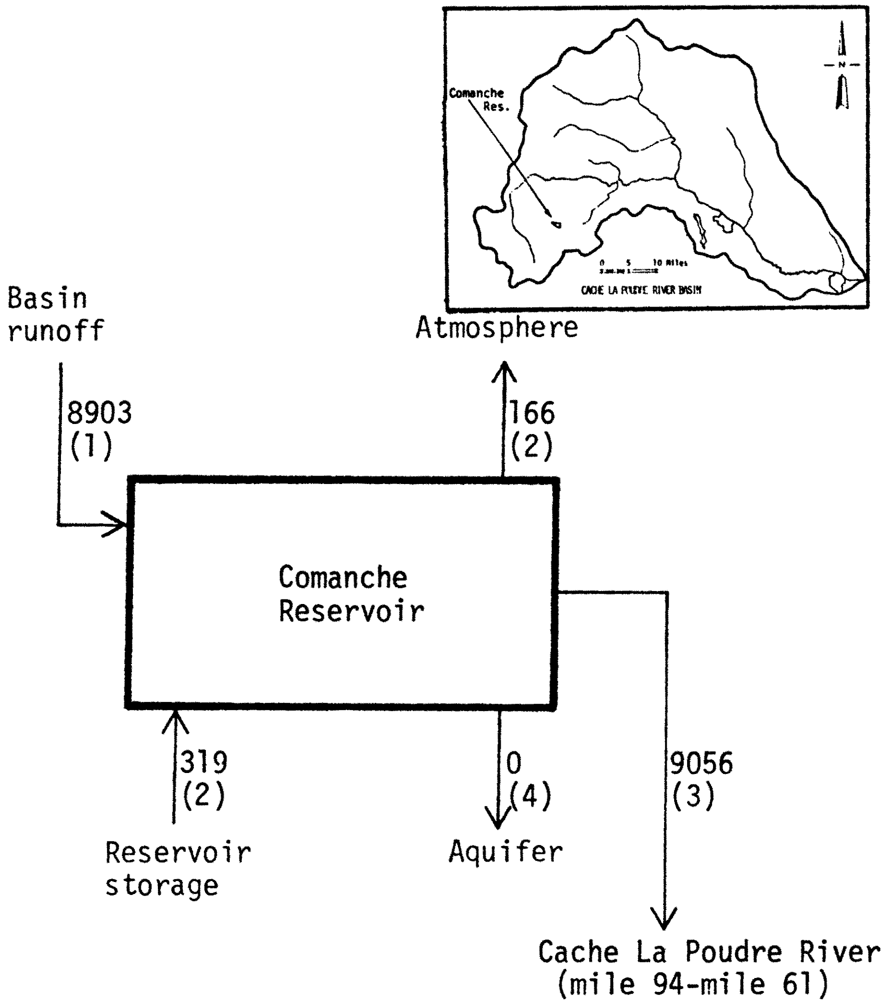
(1) The explanation of the exchange volumes is given in the water balance sketches of the correspondent element.

Figure D-1. Water Balance of the "Aquifer."



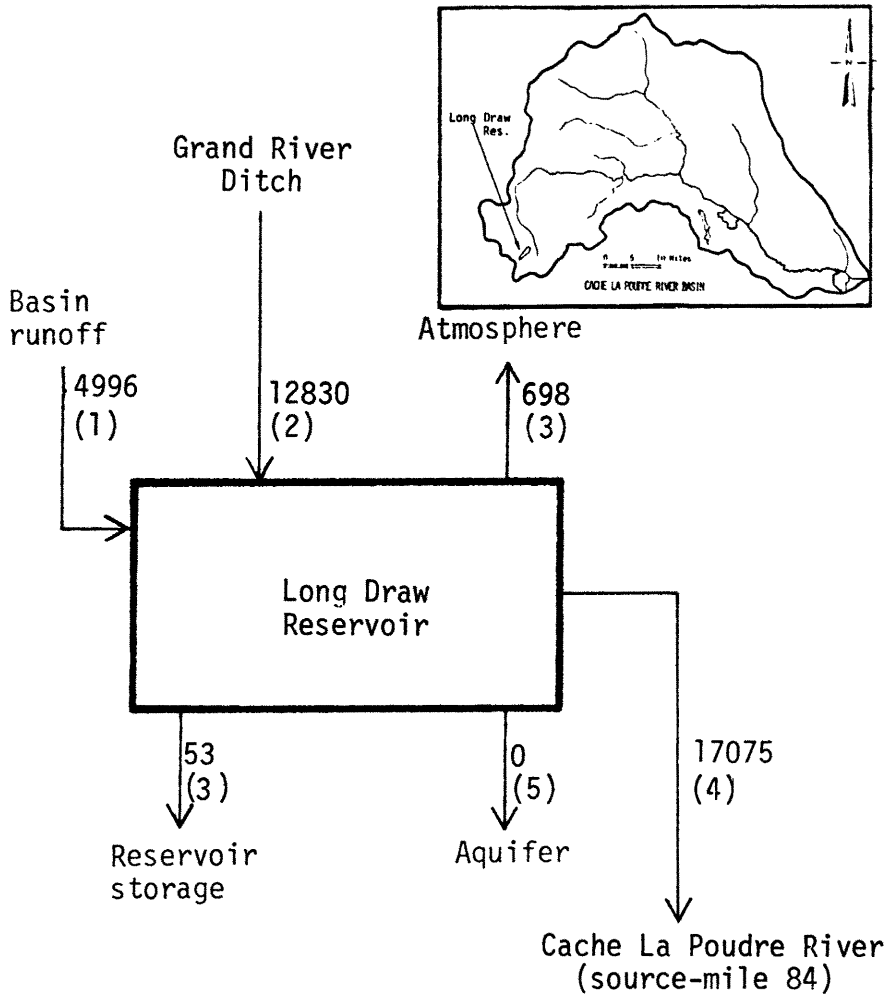
(1) Estimated from the virgin flow at Cache La Poudre River mile 94, proportionally to the basin areas. Chambers Lake direct drainage: 15,040 acres; total drainage area at mile 94: 127,360 acres; virgin flow at mile 94: 113,000 ac-ft (see paragraph 5.5.2). The flow from the lake direct drainage resulted 13,340 ac-ft (113,000 x 15,040/127,360 = 13,340).
(2) USGS, Water Resource Data for Colorado, 1970.
(3) Mass balance of Joe Wright Reservoir.
(4) Estimated (see paragraph 5.4.2 and Table 5-19).
(5) Mass balance of Chambers Lake.
(6) The seepage losses were neglected.

Figure D-2. Water Balance of "Chambers Lake."



(1) Estimated from the flow at USGS gaging station No. 06748600 proportionally to the basin areas. Comanche Res. direct drainage: 8,128 acres; total drainage area at the mentioned gaging station: 57,792 acres; recorded discharge at the gaging station: 63,300 acre-feet. The flow from the Commanche Res. drainage resulted 8,903 ac-ft (63,300 x 8,128/57,792 = 8,903).
(2) Estimated (see paragraph 5.4.2 and Table 5-19).
(3) Computed through mass balance of Comanche Reservoir.
(4) The seepage losses were neglected.

Figure D-3. Water Balance of "Comanche Reservoir."



(1) Estimated from the virgin flow at Cache La Poudre River mile 94, proportionally to the basin areas. Long Draw Res. direct drainage: 5,632 acres; total drainage area at mile 94; 127,360 acres; virgin flow at mile 94: 113,000 acre-feet (see paragraph 5.5.2). The flow from the reservoir drainage resulted 4,996 ac-ft (113,000 x 5,632/127,360 = 4,996).

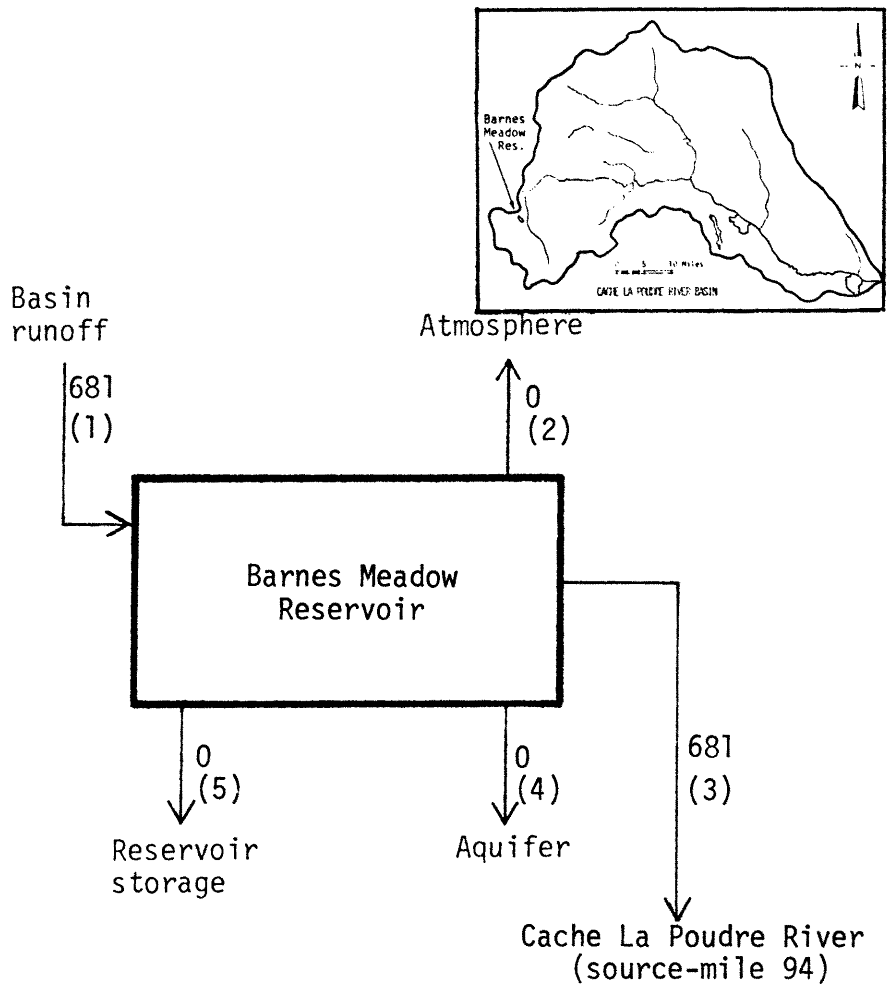
(2) Gerlek (1977).

(3) Estimated (see paragraph 5.4.2 and Table 5-19).

(4) Mass balance of Long Draw Reservoir.

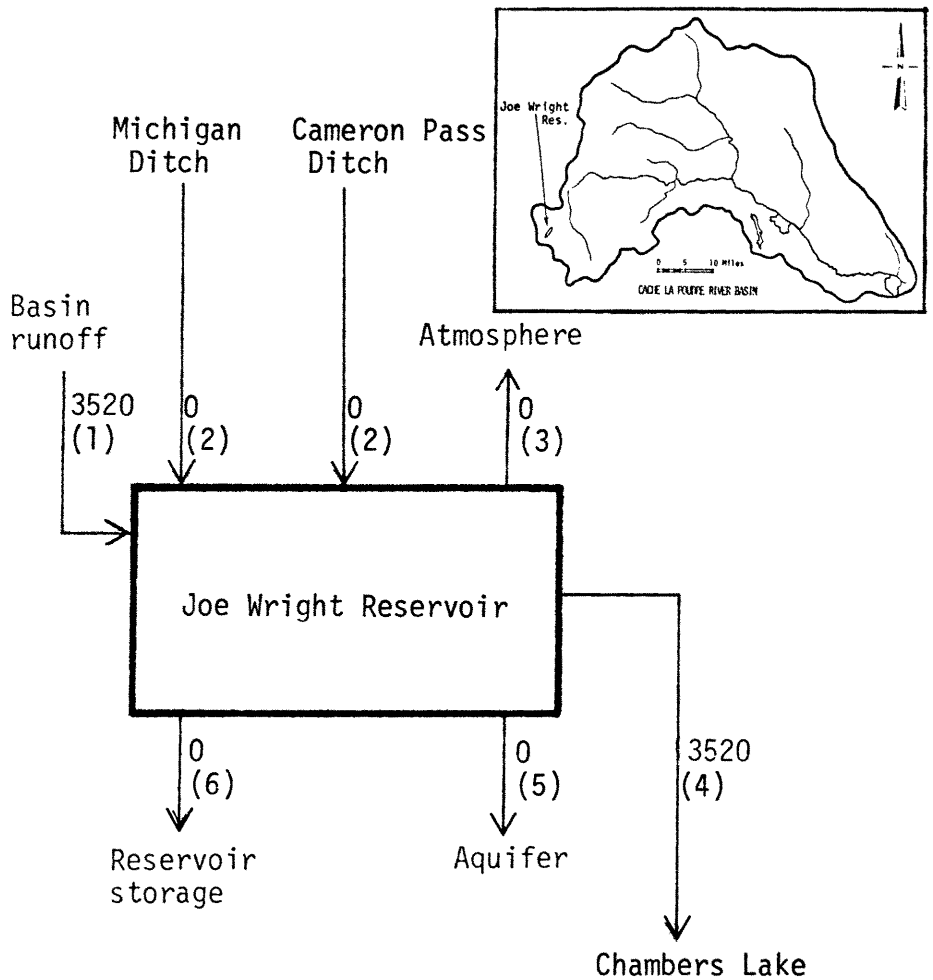
(5) The seepage losses were neglected.

Figure D-4. Water Balance of "Long Draw Reservoir."



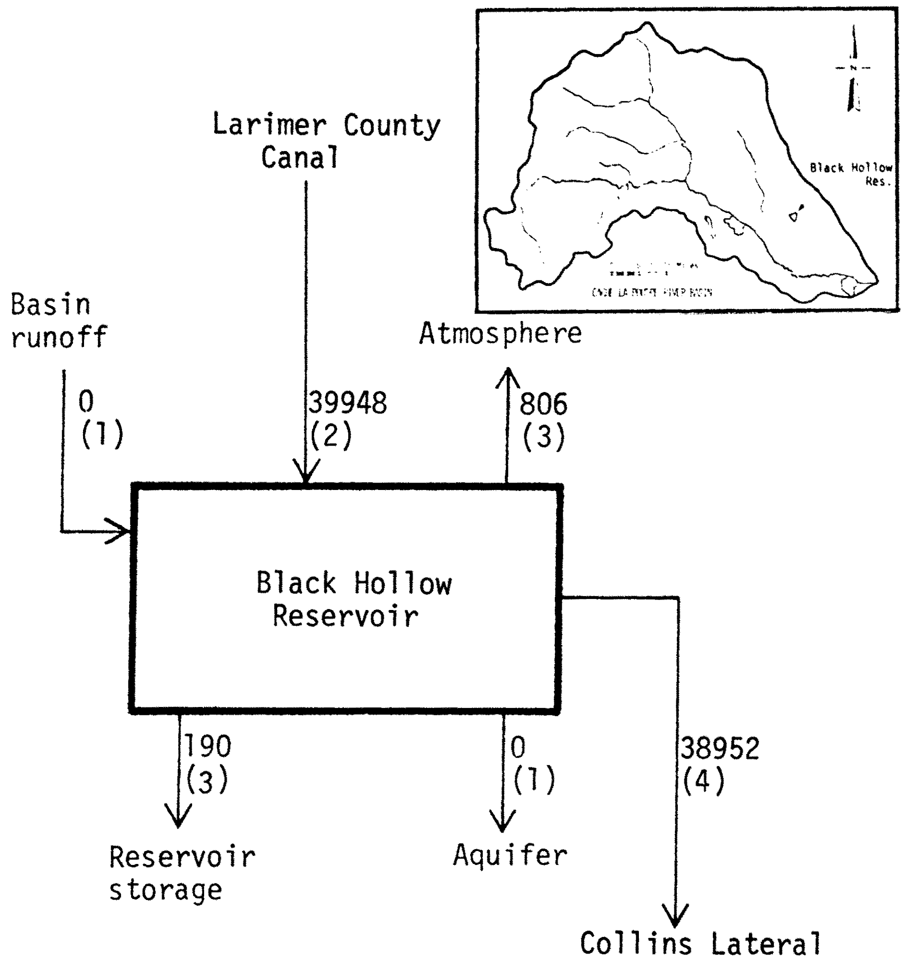
(1) Estimated from the virgin flow at Cache La Poudre River mile 94; proportionally to the basin areas. Barnes Meadow Res. drainage: 768 acres; total drainage area at mile 94: 127,360 acres; virgin flow at mile 94: 113,000 ac-ft (see paragraph 5.5.2). The discharge from the reservoir drainage resulted 681 ac-ft (113,000 x 768/127,360 = 681).
(2) Estimated (see paragraph 5.4.2 and Table 5-19).
(3) Mass balance of Barnes Meadow Reservoir.
(4) The seepage losses were neglected.
(5) The reservoir was invariably empty throughout the year.

Figure D-5. Water Balance of "Barnes Meadow Reservoir."



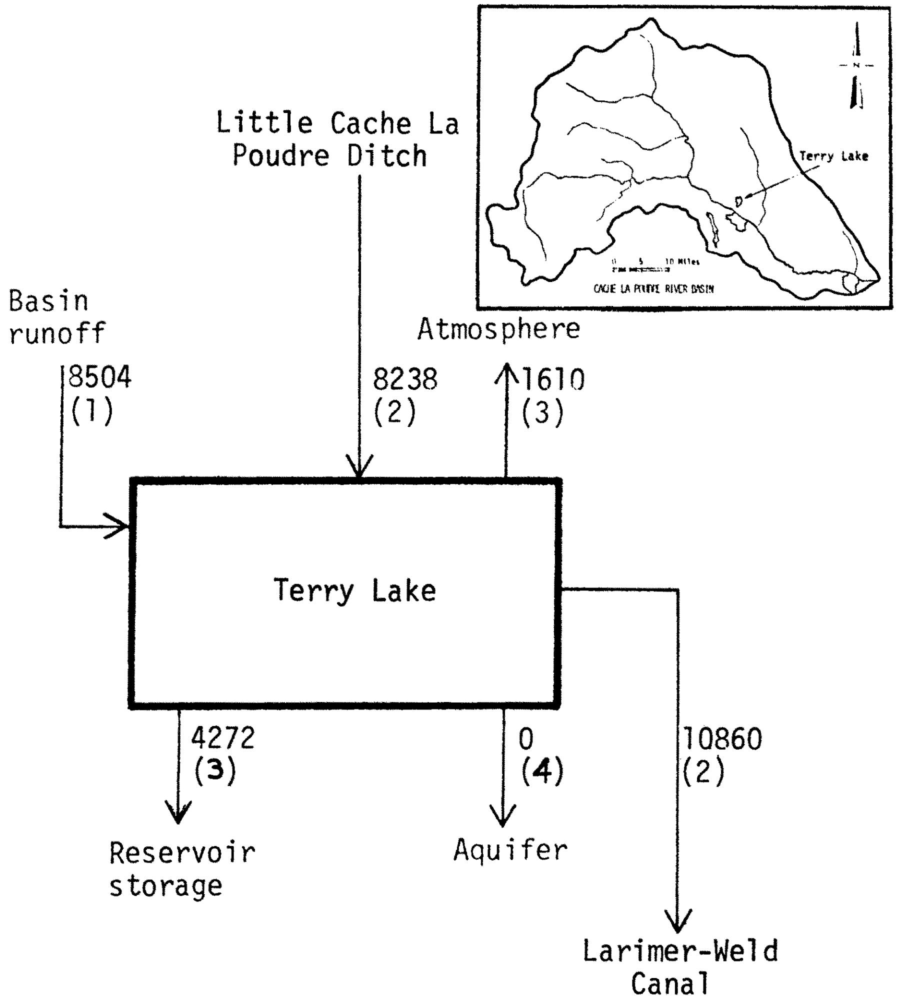
(1) Estimated from the virgin flow at Cache La Poudre River mile 94, proportionally to the basin areas. Joe Wright Res. direct drainage: 3,968 acres; total drainage area at mile 94: 127,360 acres; virgin flow at mile 94: 113,000 ac-ft (see paragraph 5.5.2). The flow from the reservoir direct drainage resulted 3,520 ac-ft (113,000 x 3,968/127,360 = 3,520).
(2) USGS, Water Resource Data for Colorado, 1970.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) Mass balance of Joe Wright Reservoir.
(5) The seepage losses were neglected.
(6) The reservoir was invariably empty throughout the year.

Figure D-6. Water Balance of "Joe Wright Reservoir."



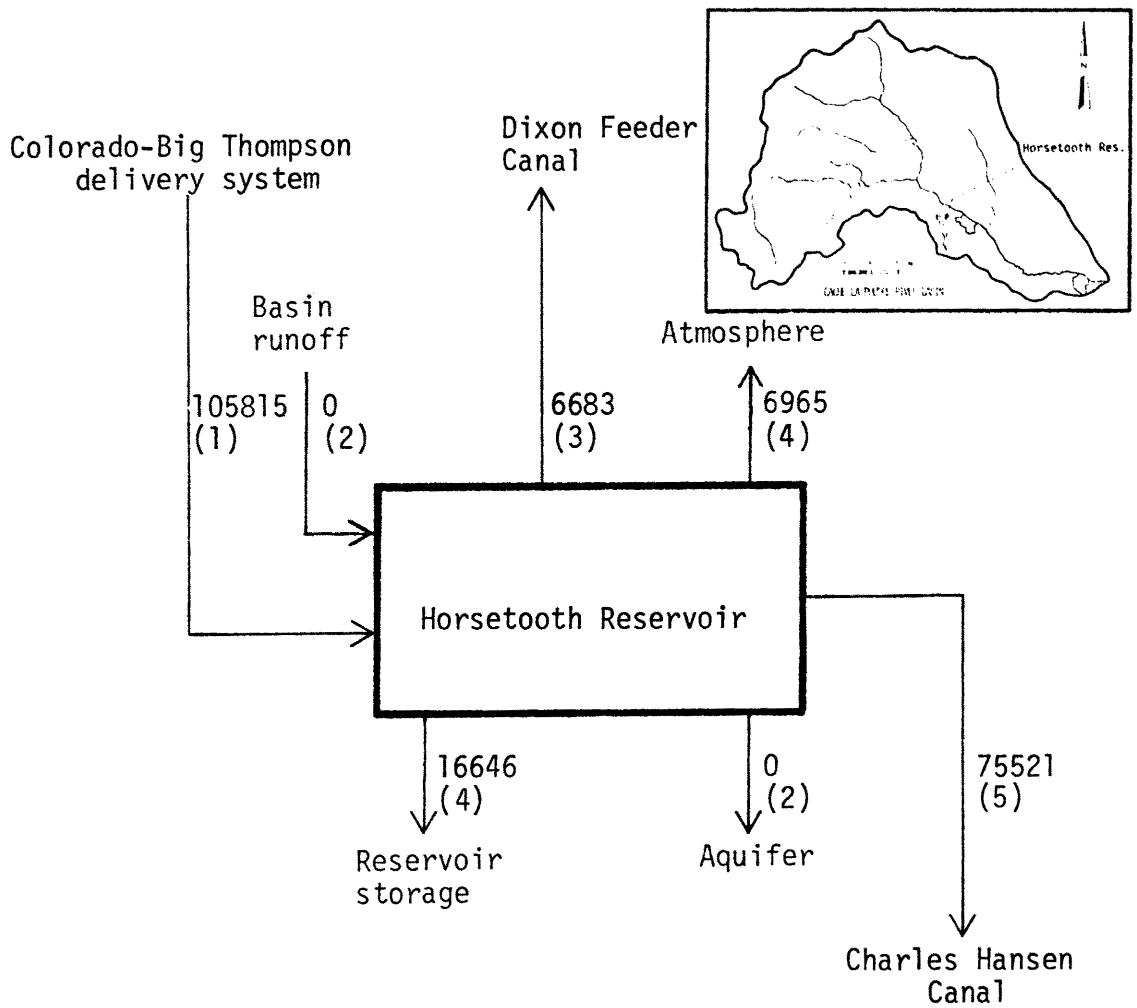
(1) The drainage runoff was neglected.
(2) Mass balance of Black Hollow Reservoir.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) Records of Water Commissioner (this is the 1976 value. No record was available for 1970).

Figure D-7. Water Balance of "Black Hollow Reservoir."



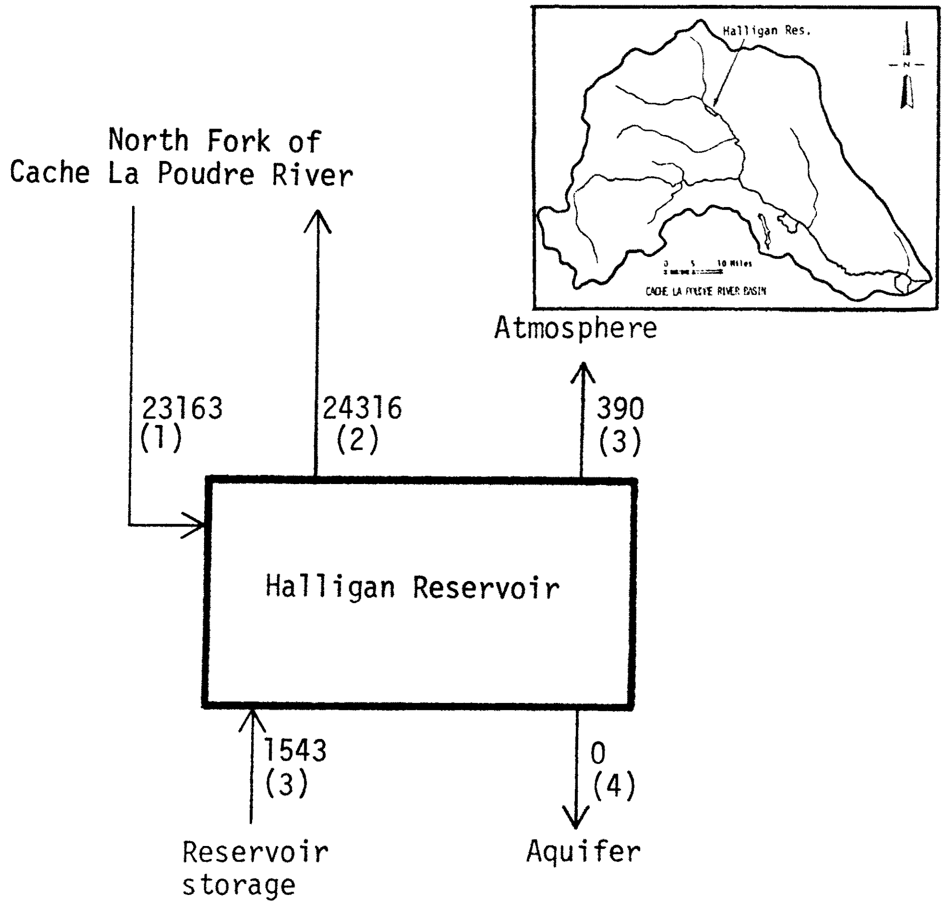
(1) This runoff from the "Unirrigated Plains" was computed through mass balance of Terry Lake.
(2) Records of Water Commissioner.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) The seepage losses were neglected.

Figure D-8. Water Balance of "Terry Lake."



(1) Computed through mass balance of Horsetooth Reservoir.
(2) Neglected. The mass balance is consequently affected.
(3) Northern Colorado Water Conservancy District, "Summary of Delivery Operations for 1970."
(4) Estimated (see paragraph 5.4.2 and Table 5-19).
(5) This value is the sum of the direct releases through Charles Hansen canal (2,237 ac-ft, North. Colo. Water Cons. District), of the releases through the Poudre river being conveyed through this canal (67,228 ac-ft., North Colo. Water Cons. District) and of the release to Poudre Valley Canal (6,056 ac-ft., 1970 Annual Report, Colorado State Engineer Off., Div. 1).

Figure D-9. Water Balance of "Horsetooth Reservoir."



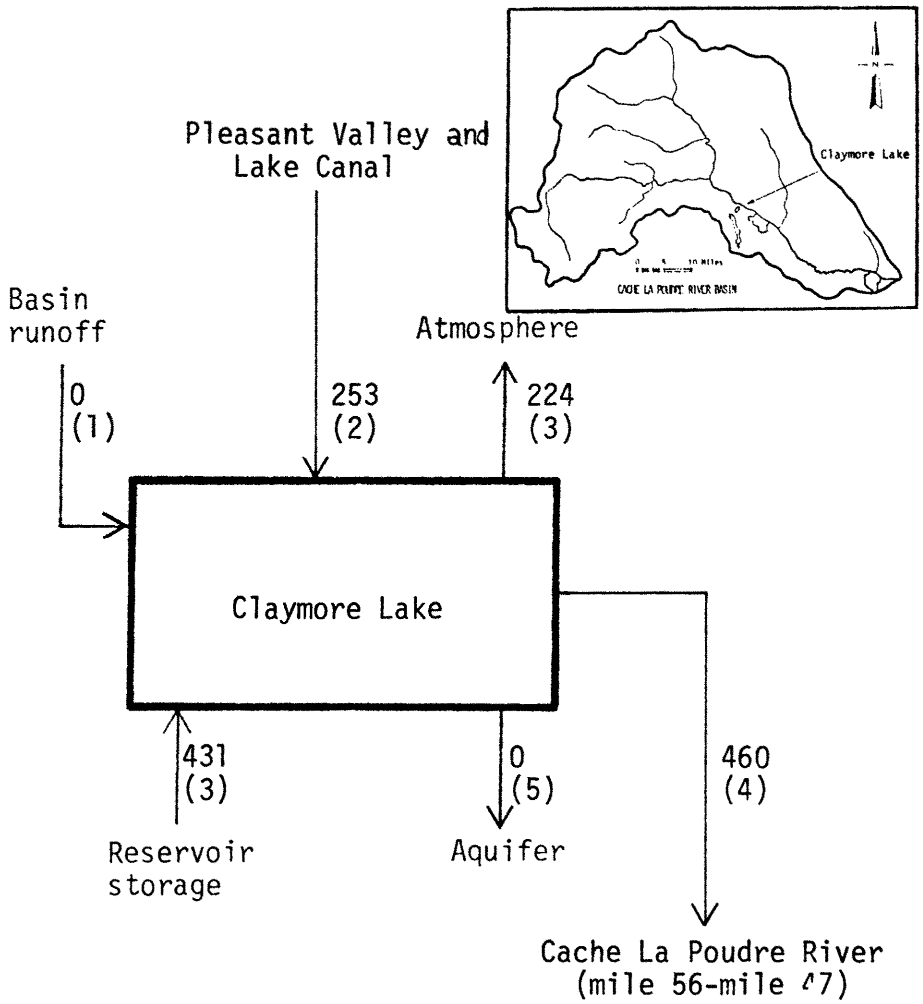
(1) Estimated from the virgin flow at North Poudre Ditch diversion point, proportionally to basin areas. Halligan Res. drainage: 217,600 acres; basin area at N. Poudre ditch div. point: 222,080 acres; computed virgin flow at N. Poudre ditch div. point: 20,687 ac-ft (see Figure 5-14). The direct flow from the Halligan drainage resulted 23,163 ac-ft (20,687 x 217,600/222,080 .2,910 ac-ft imported through the Wilson Ditch are added to this flow).

(2) Computed through mass balance of Halligan Res.

(3) Estimated (see paragraph 5.4.2 and Table 5-19).

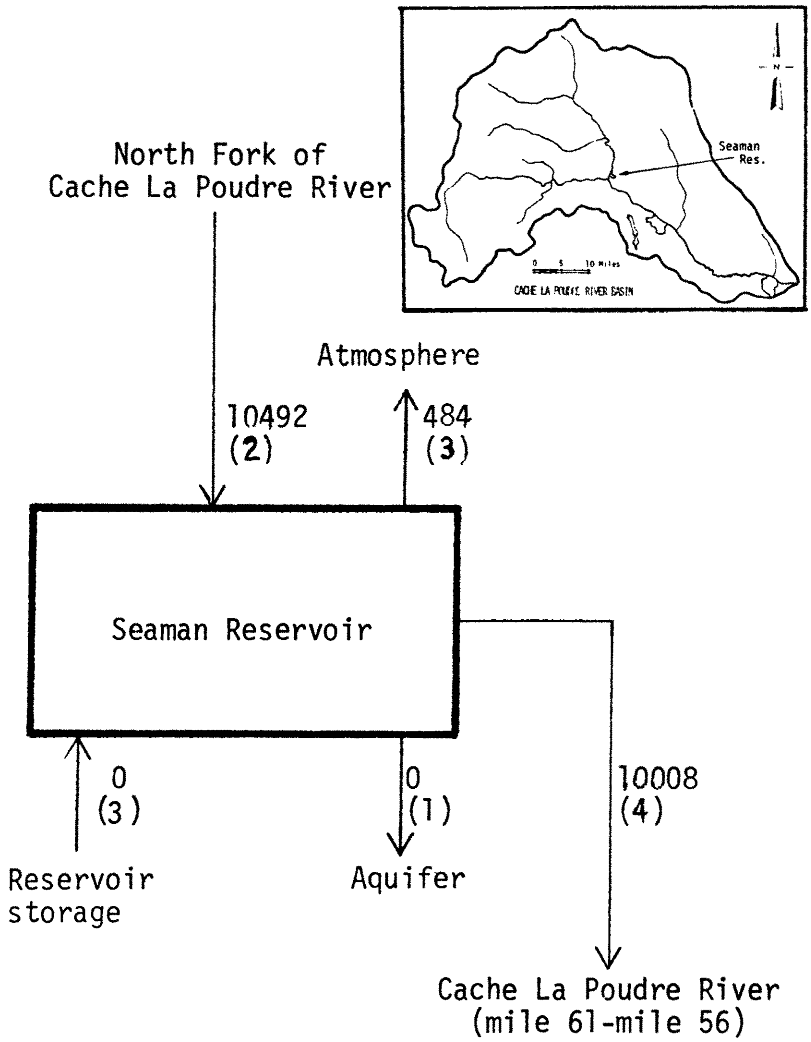
(4) The seepage losses were neglected.

Figure D-10. Water Balance of "Halligan Reservoir."



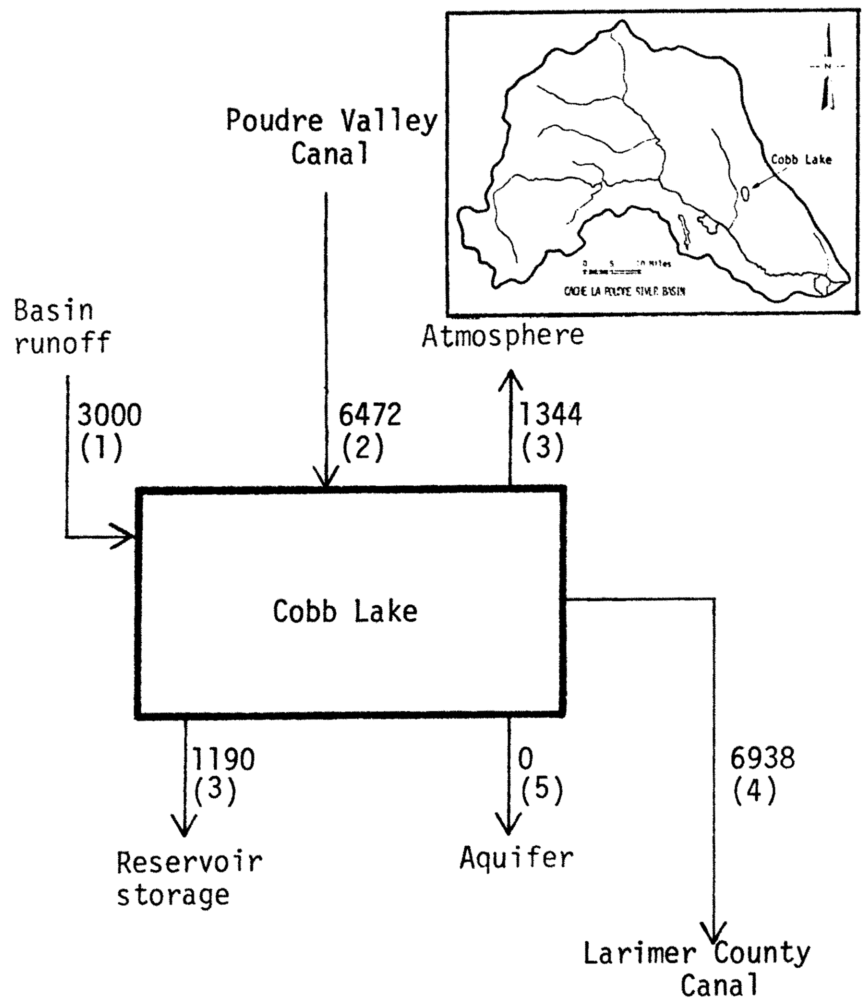
(1) The basin runoff was neglected.
(2) Computed through the mass balance of Claymore Lake.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) Records of Water Commissioner.
(5) The seepage losses were neglected.

Figure D-11. Water Balance of "Claymore Lake."



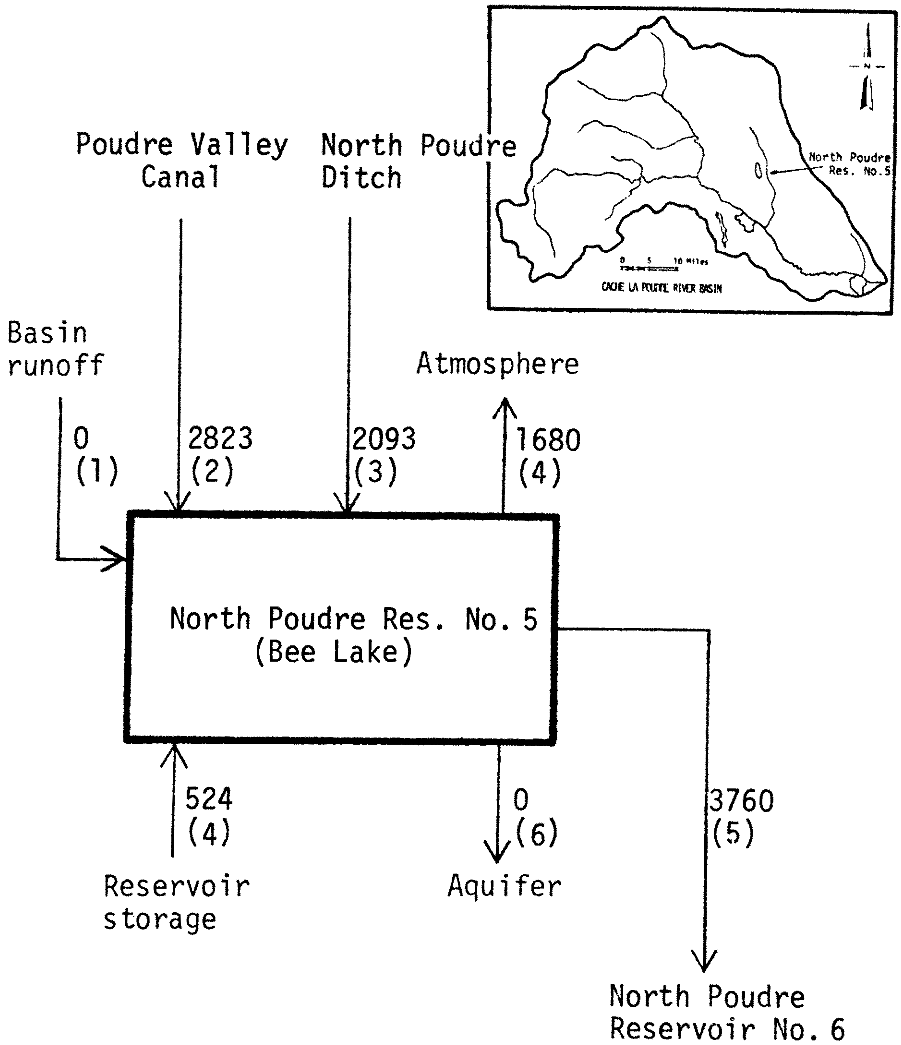
(1) The seepage losses were neglected.
(2) See Figure 5-15 and paragraph 5.5.1.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) Computed through mass balance of Seaman Reservoir.

Figure D-12. Water Balance of "Seaman Reservoir."



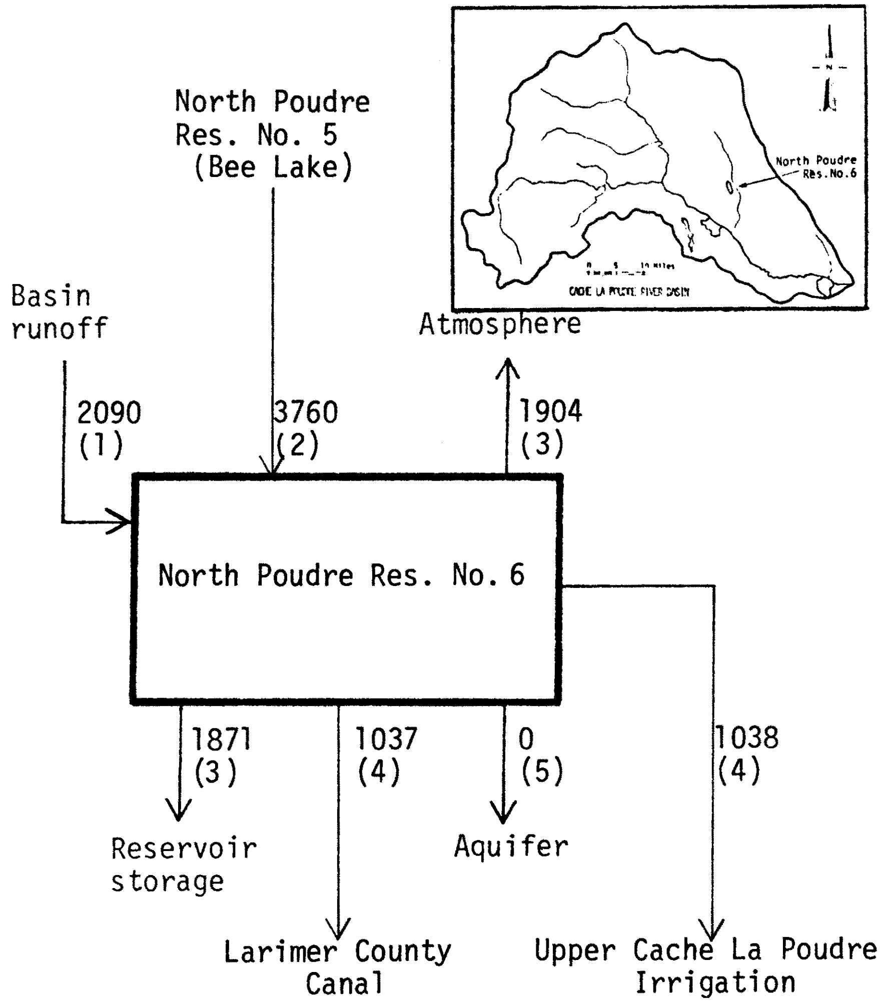
(1) This is an "eye" estimate of the surface runoff from the "Unirrigated Plains."
(2) Computed through mass balance of Cobb Lake.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) Records of Water Commissioner.
(5) The seepage losses were neglected.

Figure D-13. Water Balance of "Cobb Lake."



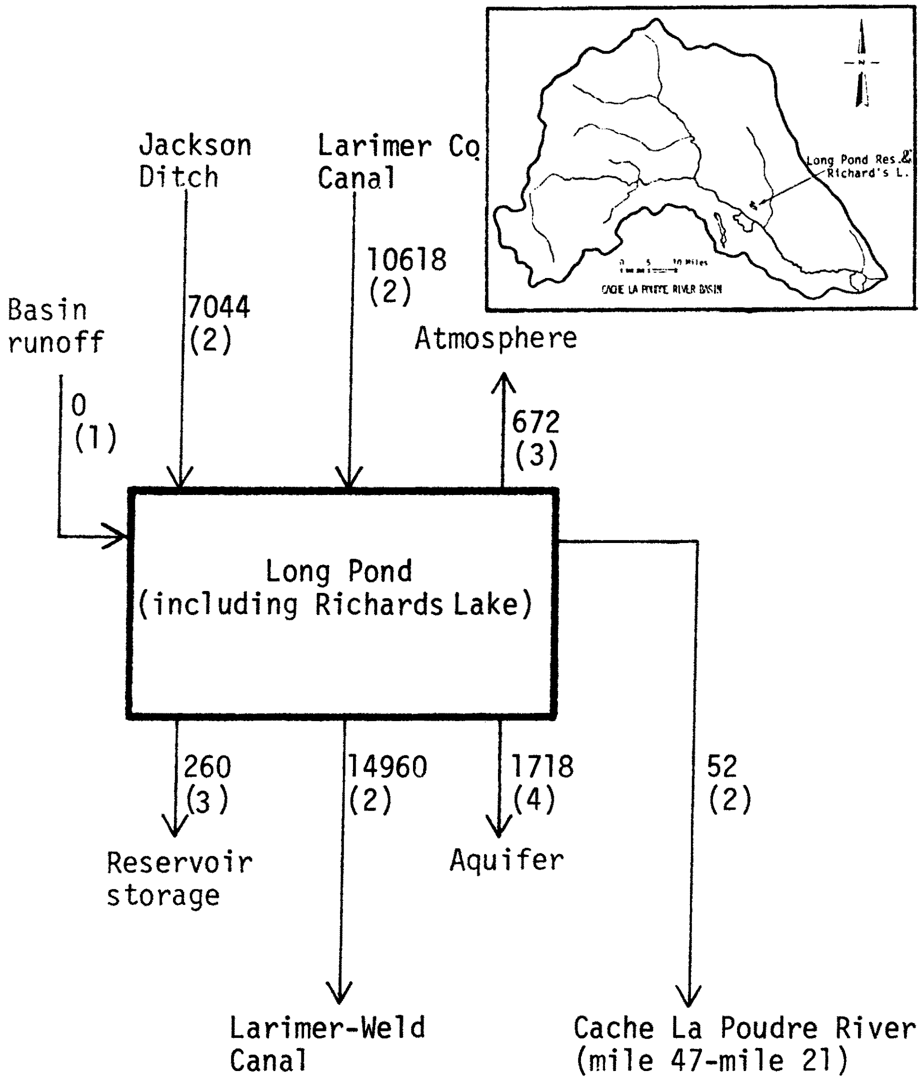
(1) The basin runoff was considered negligible.
(2) Computed through mass balance of Poudre Valley Canal.
(3) Computed through mass balance of North Poudre Res. No. 5.
(4) Estimated (see paragraph 5.4.2 and Table 5-19).
(5) Records of Water Commissioner.
(6) The seepage losses were neglected.

Figure D-14. Water Balance of "North Poudre Res. No. 5."



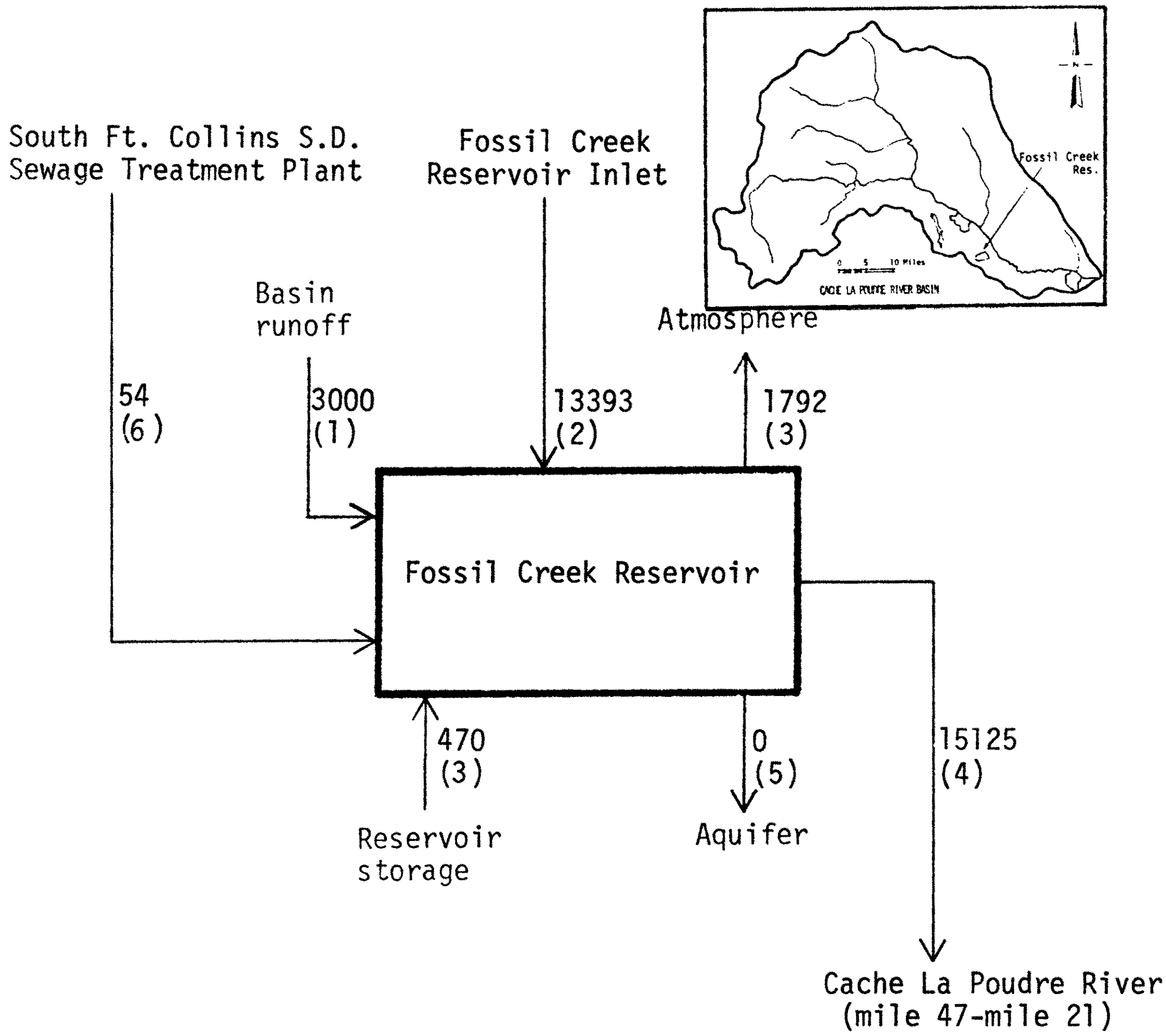
(1) This runoff from the Unirrigated Plains was computed through mass balance of North Poudre Res. No. 6.
(2) Records of Water Commissioner.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) Estimated. The records of Water Commissioner show a total release of 2,075 ac-ft to Larimer County Canal and Upper Cache La Poudre Irrigated Areas.
(5) The seepage losses were neglected.

Figure D-15. Water Balance of "North Poudre Res. No. 6."



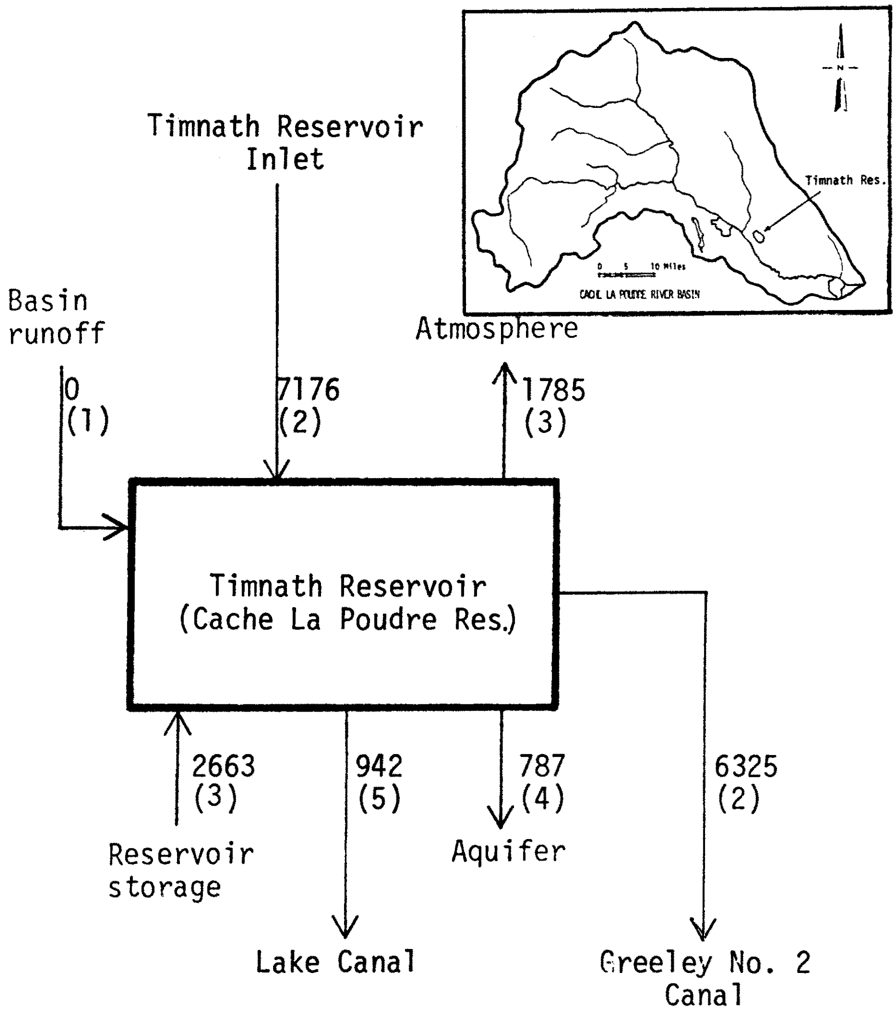
(1) The basin runoff was considered negligible.
(2) Records of Water Commissioner.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) The seepage losses were neglected.

Figure D-16. Water Balance of "Long Pond."



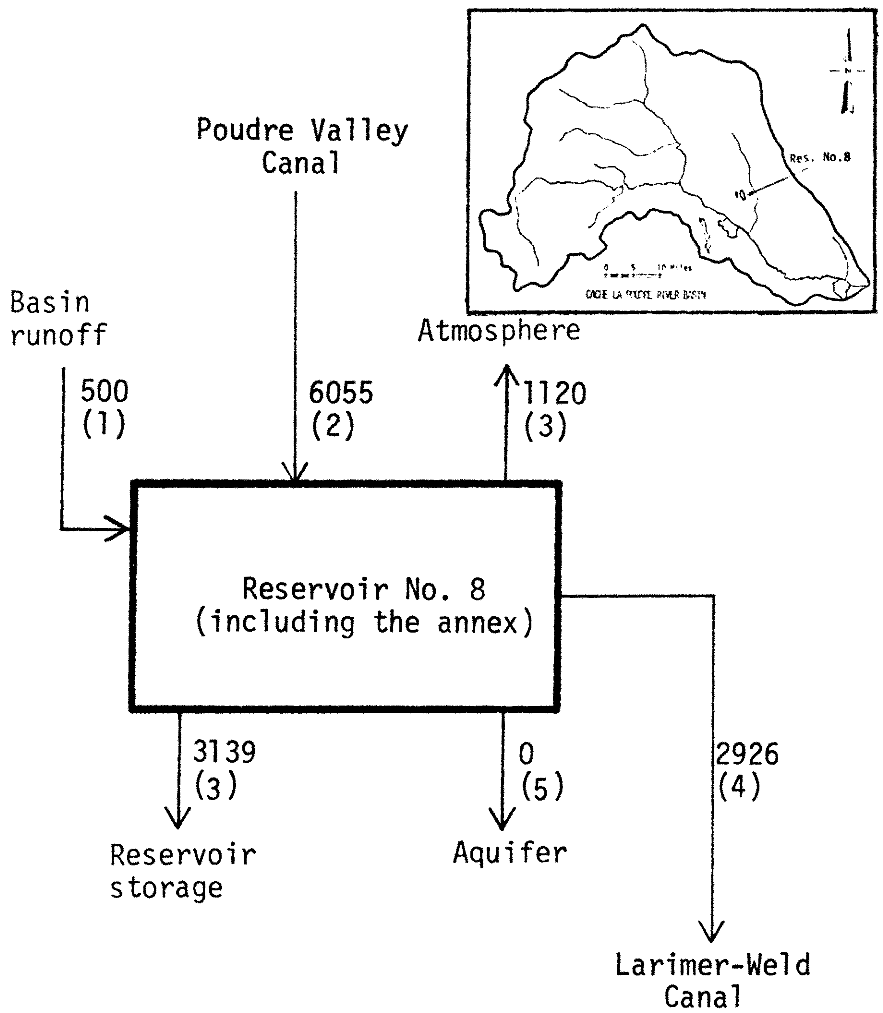
(1) Estimated by the Water Commissioner (Mr. J. Neutze).
(2) See Figure E-20.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) Computed through mass balance of Fossil Creek Reservoir.
(5) The seepage losses were neglected.
(6) See Figure F-17.

Figure D-17. Water Balance of "Fossil Creek Reservoir."



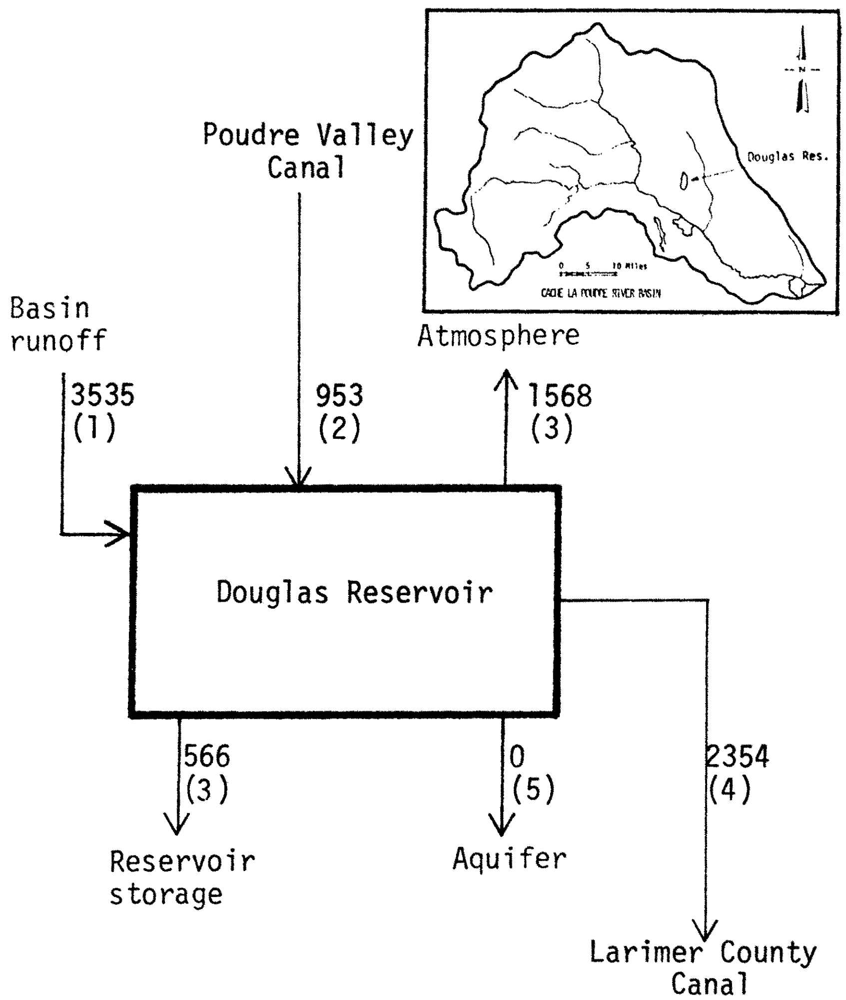
(1) The basin runoff was considered negligible.
(2) Records of Water Commissioner.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) Computed through mass balance of Timnath Reservoir.
(5) Record of Water Commissioner for 1976. No value was available for 1970.

Figure D-18. Water Balance of "Timnath Reservoir."



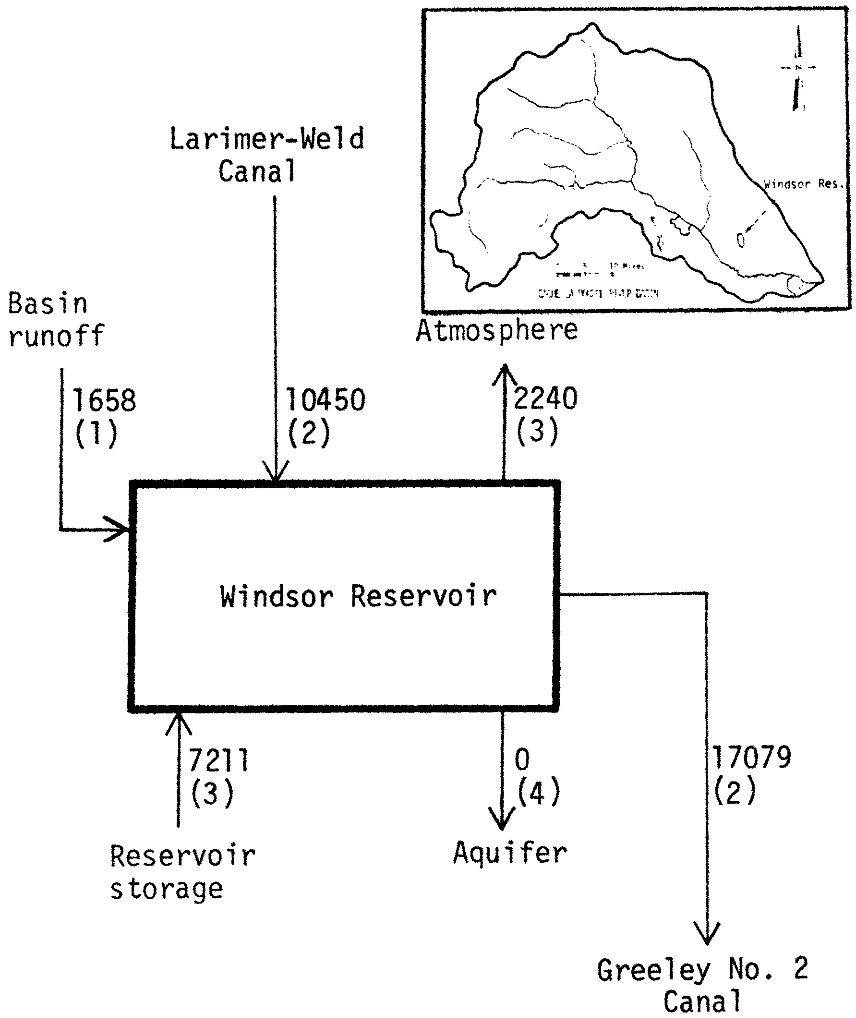
(1) This is an "eye" estimate of the surface runoff from the "Unirrigated Plains."
(2) Computed through mass balance of Reservoir No. 8.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) Records of Water Commissioner.
(5) The seepage losses were neglected.

Figure D-19. Water Balance of "Reservoir No. 8."



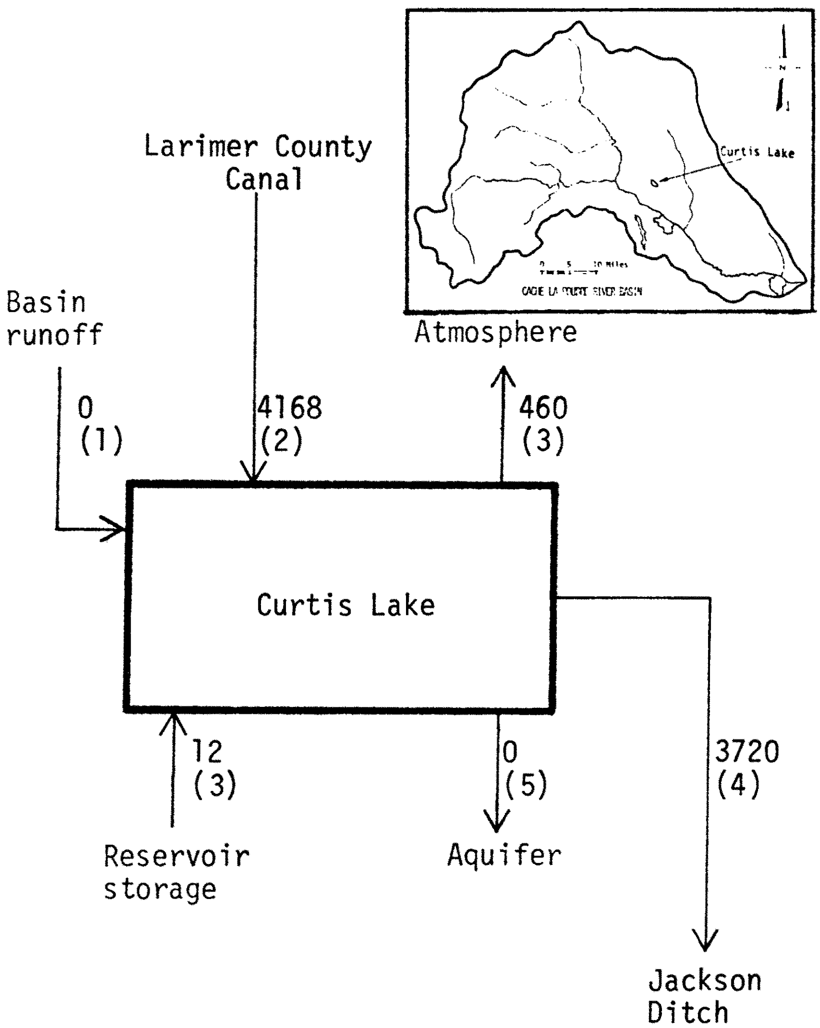
(1) This drainage runoff from the "Unirrigated Plains" was computed through mass balance of Douglas Reservoir.
(2) See Figure E-3.
(3) Estimated (see paragraph 5.4.2 and Figure 5-19).
(4) Records of Water Commissioner.
(5) The seepage losses were neglected.

Figure D-20. Water Balance of "Douglas Reservoir."



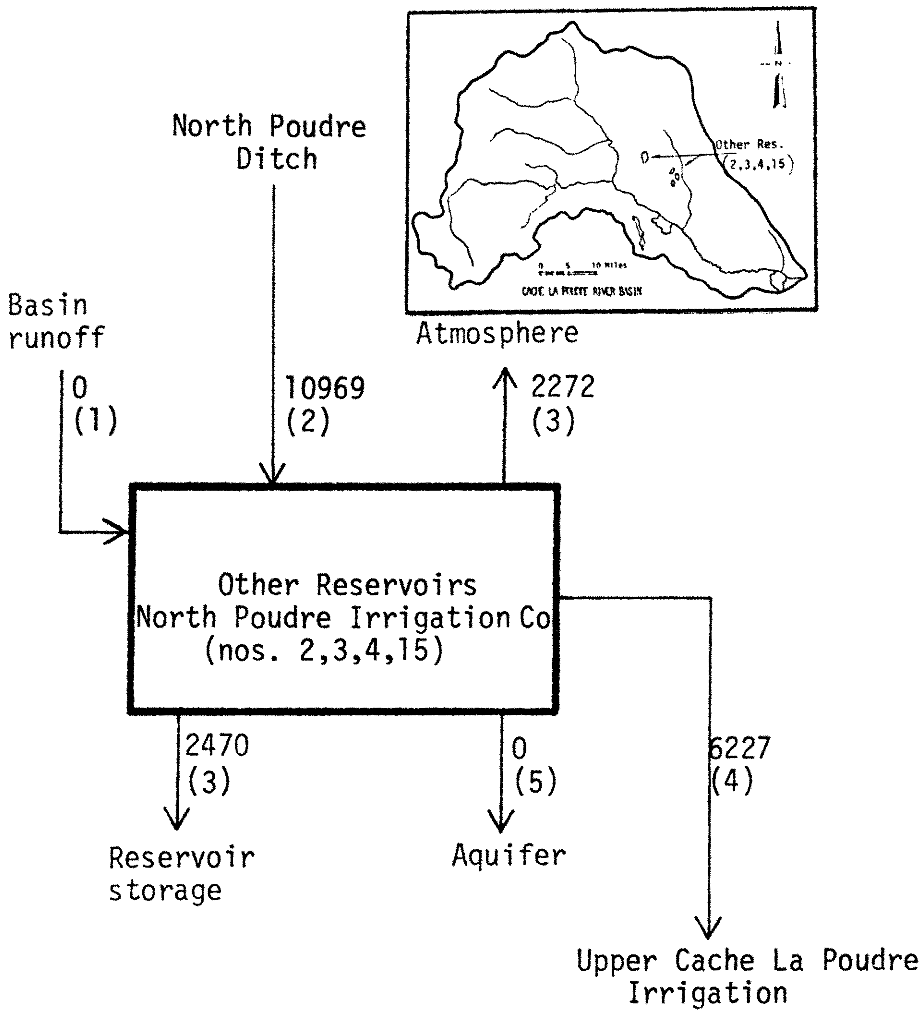
(1) This drainage runoff from the "Unirrigated Plains." was computed through mass balance of "Windsor Reservoir."
(2) Records of Water Commissioner.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) The seepage losses were neglected.

Figure D-21. Water Balance of "Windsor Reservoir."



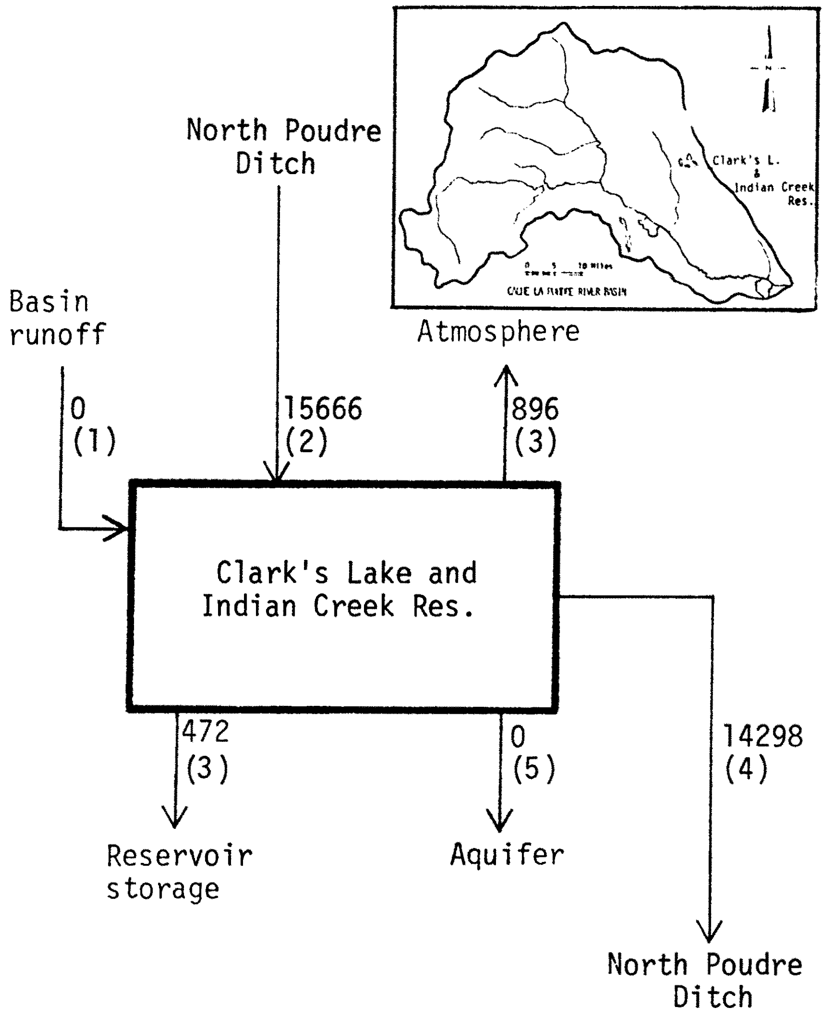
(1) The basin runoff was considered negligible.
(2) Computed through mass balance of Curtis Lake.
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) Computed through mass balance of Jackson Ditch.
(5) The seepage losses were neglected.

Figure D-22. Water Balance of "Curtis Lake."



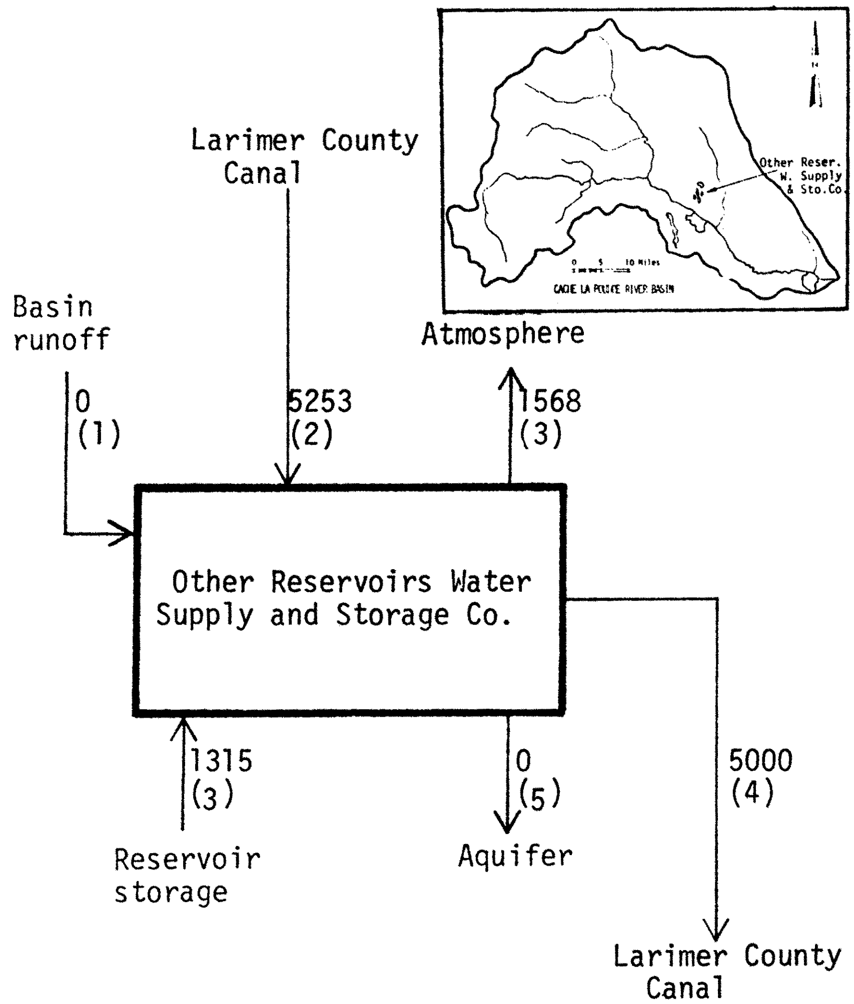
(1) The basin runoff was considered negligible.
(2) Computed through mass balance of "Other Reservoirs-North Poudre Irrigation Co."
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) "Eye" estimate.
(5) The seepage losses were neglected.

Figure D-23. Water Balance of "Other Reservoirs — North Poudre Irrigation Co."



(1) The basin runoff was considered negligible.
(2) Computed through mass balance of "Clark's Lake and Indian Creek Reservoir."
(3) Estimated (see paragraph 5.4.2 and Figure 5-19).
(4) See Figure E-2.
(5) The seepage losses were neglected.

Figure D-24. Water Balance of "Clark's Lake and Indian Creek Reservoir."

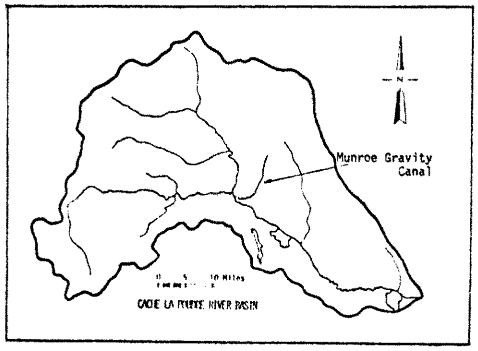


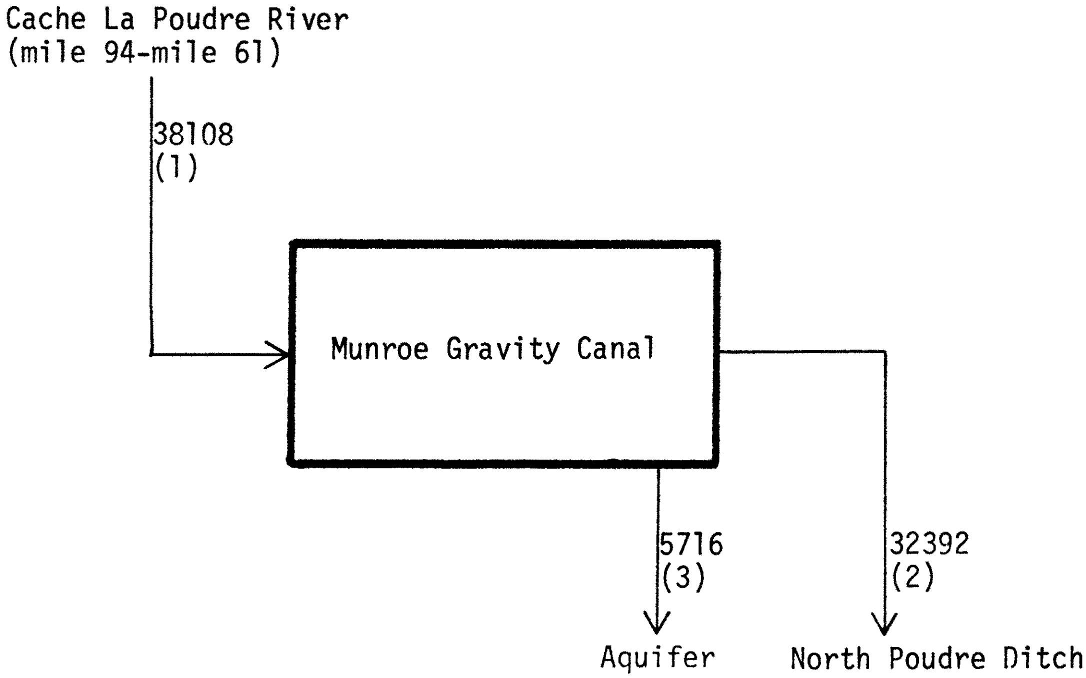
(1) The basin runoff was considered negligible.
(2) Computed through mass balance of "Other Reservoirs-Water Supply and Storage Co."
(3) Estimated (see paragraph 5.4.2 and Table 5-19).
(4) "Eye" estimate.
(5) The seepage losses were neglected.

Figure D-25. Water Balance of "Other Reservoirs — Water Supply and Storage Co."

APPENDIX E

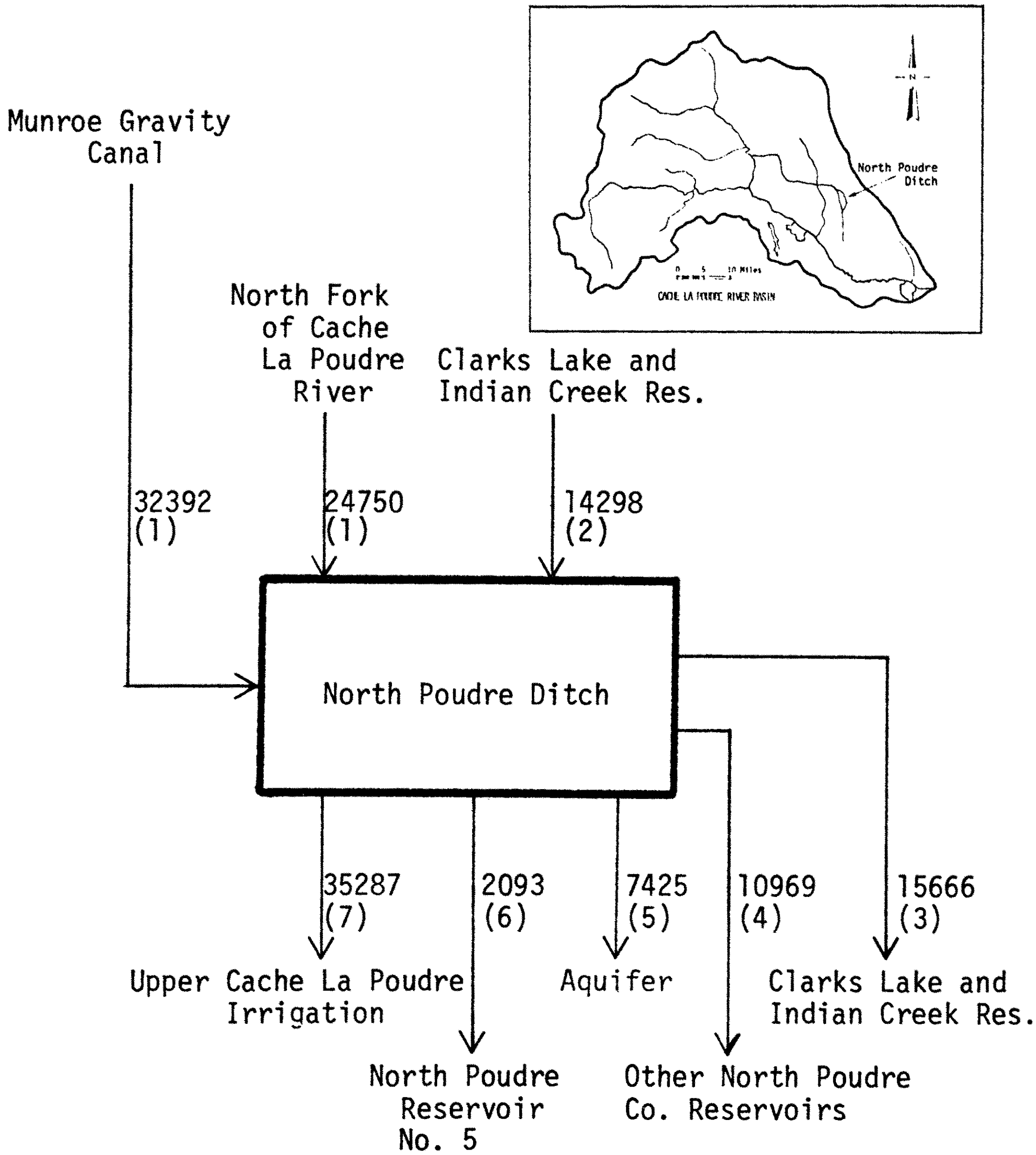
WATER BALANCES OF DITCHES AND CANALS





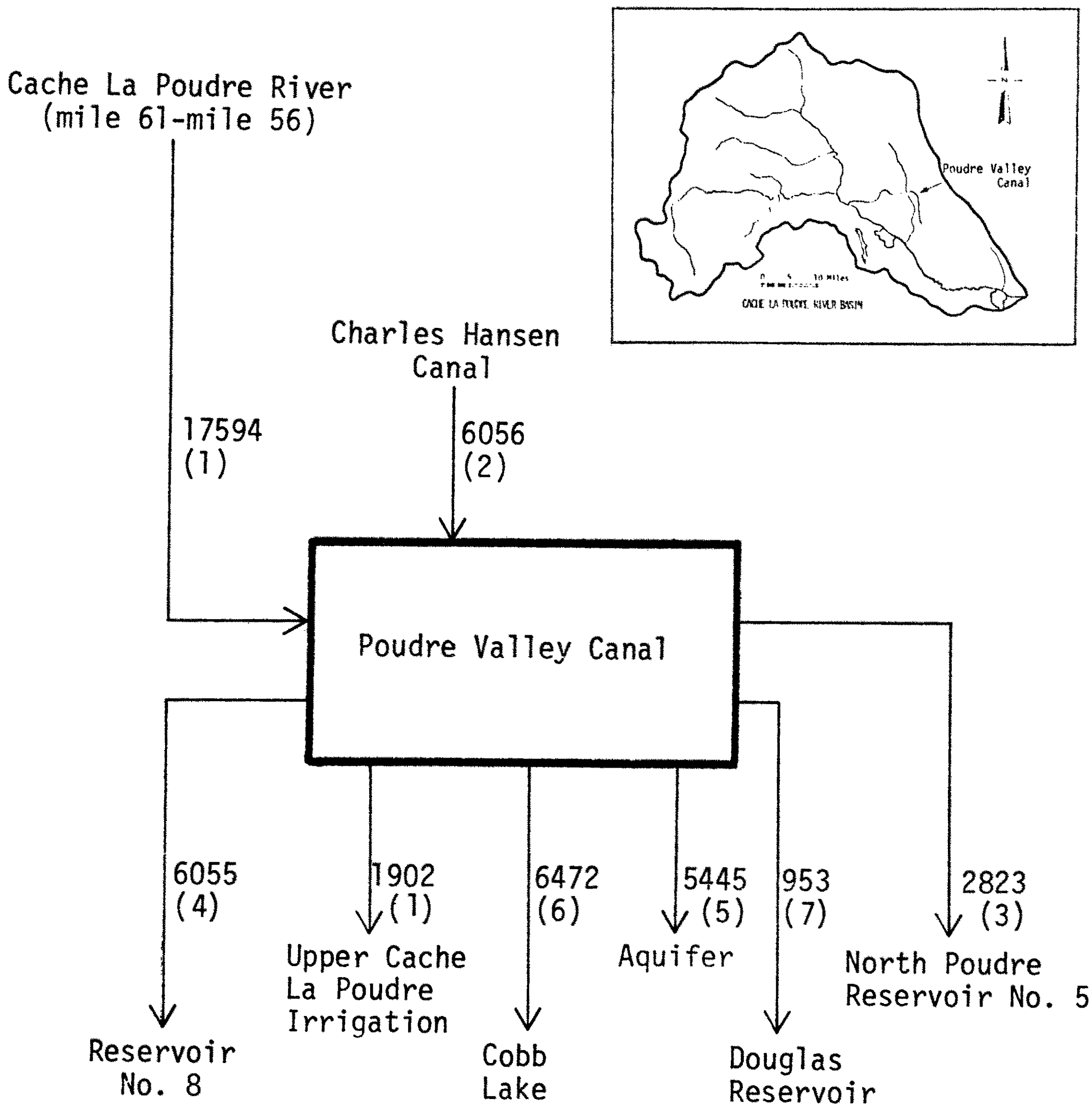
(1) Records of Water Commissioner.
(2) Derived through mass balance.
(3) Estimated as 15% of total diversions.

Figure E-1. Water Balance of "Munroe Gravity Canal."



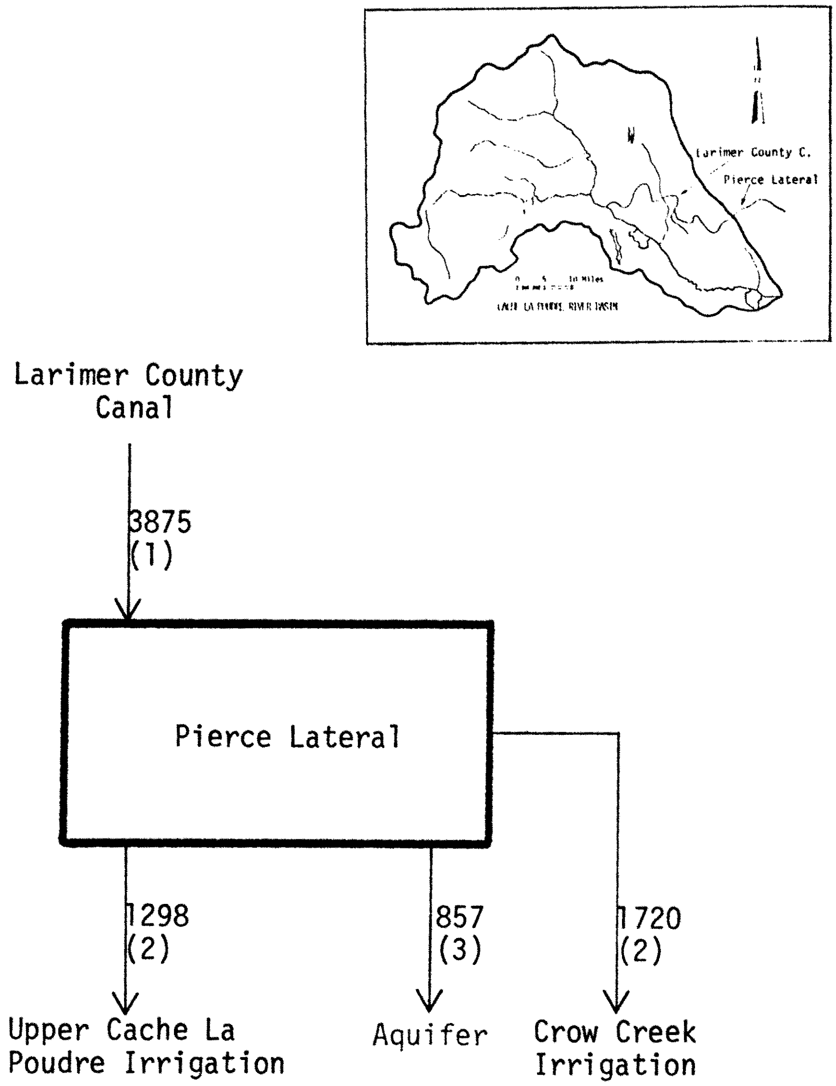
(1) Records of Water Commissioner.
(2) Mass balance of North Poudre Ditch.
(3) Mass balance of "Clarks Lake and Indian Creek Reservoir."
(4) Mass balance of "Other North Poudre Reservoirs."
(5) Estimated as 30% of river diversion.
(6) Mass balance of "North Poudre Reservoir No. 5."
(7) Estimated from areal coverage of "North Poudre Ditch" and "Other North Poudre Reservoirs."

Figure E-2. Water Balance of "North Poudre Ditch."



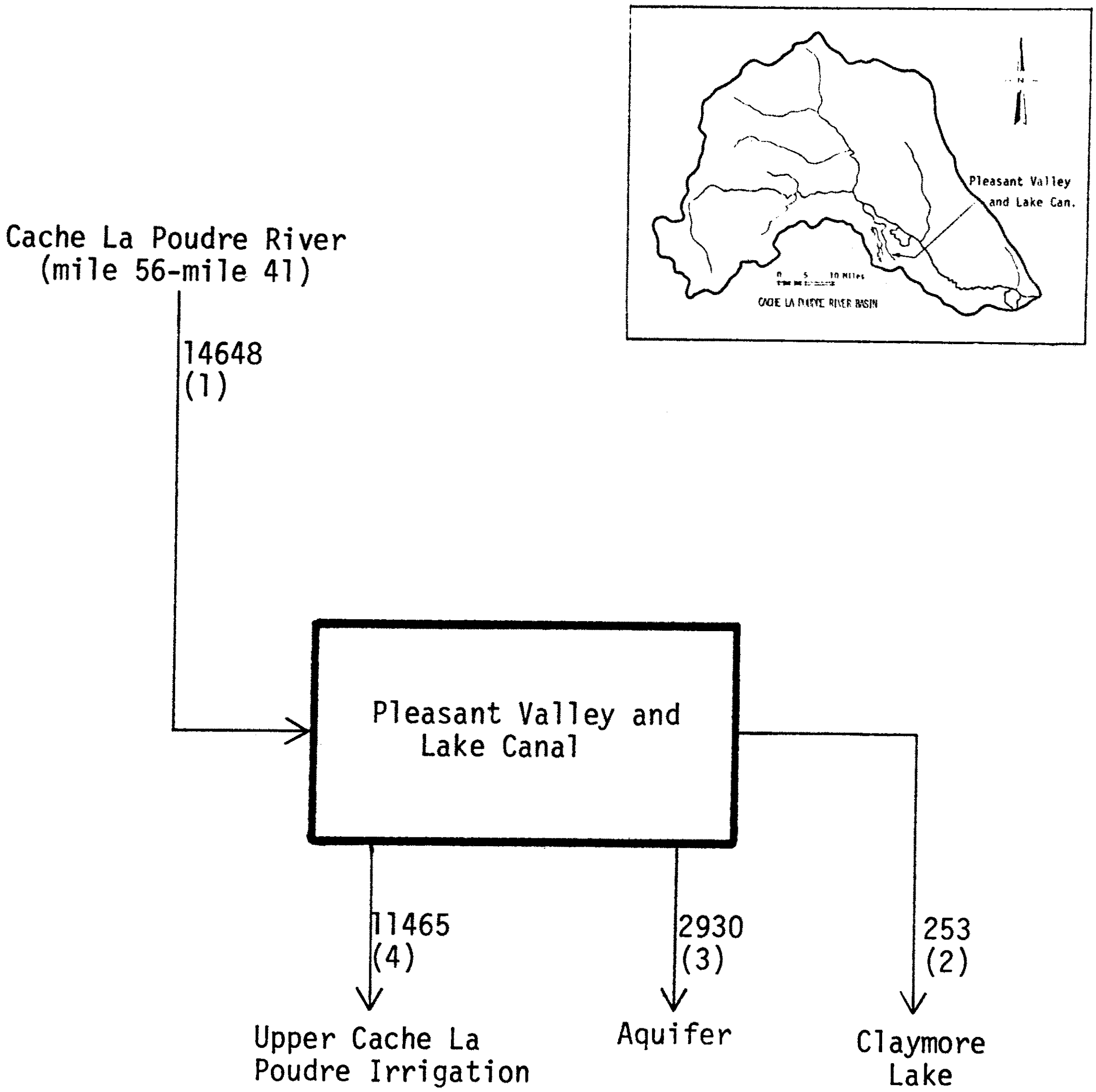
(1) Records of Water Commissioner.
(2) Colorado State Engineer, Division 1, 1970 annual report.
(3) Mass balance of "Poudre Valley Canal."
(4) Mass balance of "Reservoir No. 8."
(5) Estimated as 23% of total diversions.
(6) Mass balance of "Cobb Lake."
(7) Derived value. The Water Commissioner reported a total output of 13,480 ac-ft to Cobb Lake and Douglass and No. 8 Res.

Figure E-3. Water Balance of "Poudre Valley Canal."



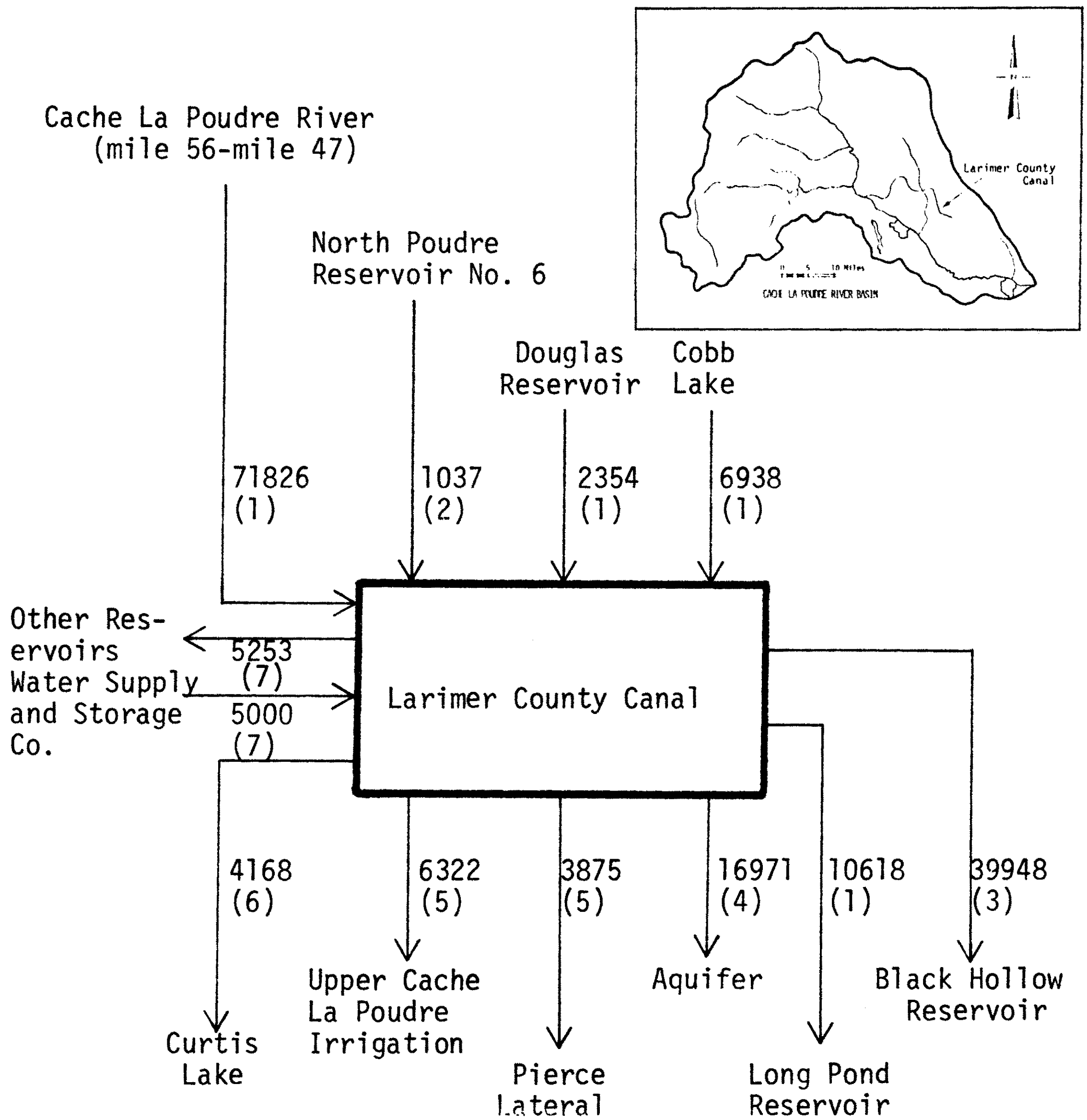
(1) Mass balance of "Larimer County Canal."
(2) The mass balance of Pierce Lateral produced a total irrigation delivery of 3,018 ac-ft. This value was split between Upper Cache La Poudre and Crow Creek irrigation in proportion to the distribution of served areas (See Table 5-17).
(3) Estimated as 21% of the diverted amount.

Figure E-4. Water Balance of "Pierce Lateral."



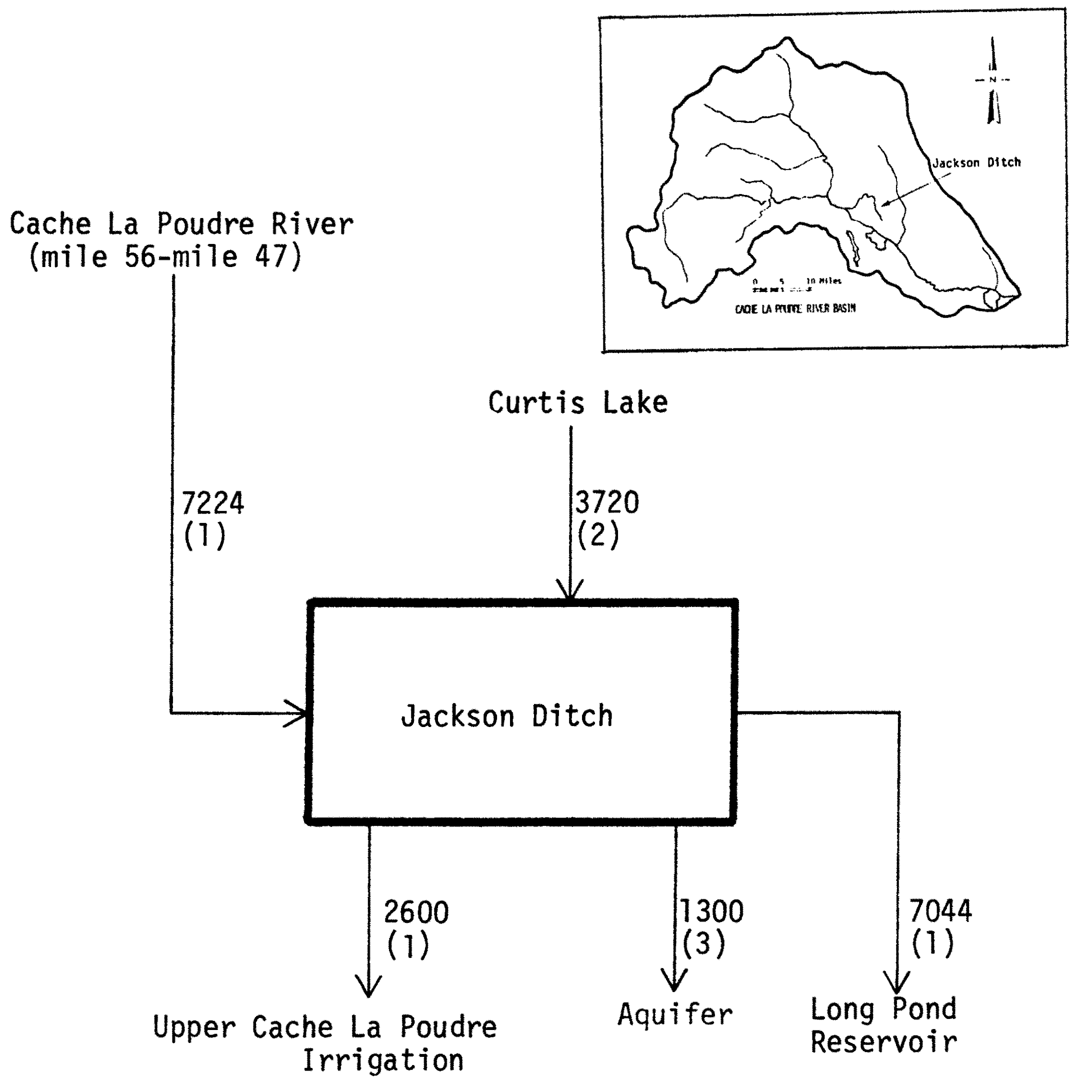
(1) Records of Water Commissioners.
(2) Mass balance of Claymore Lake.
(3) Estimated as 20% of total diverions.
(4) Computed through mass balance of Pleasant Valley and Lake Canal.

Figure E-5. Water Balance of "Pleasant Valley and Lake Canal."



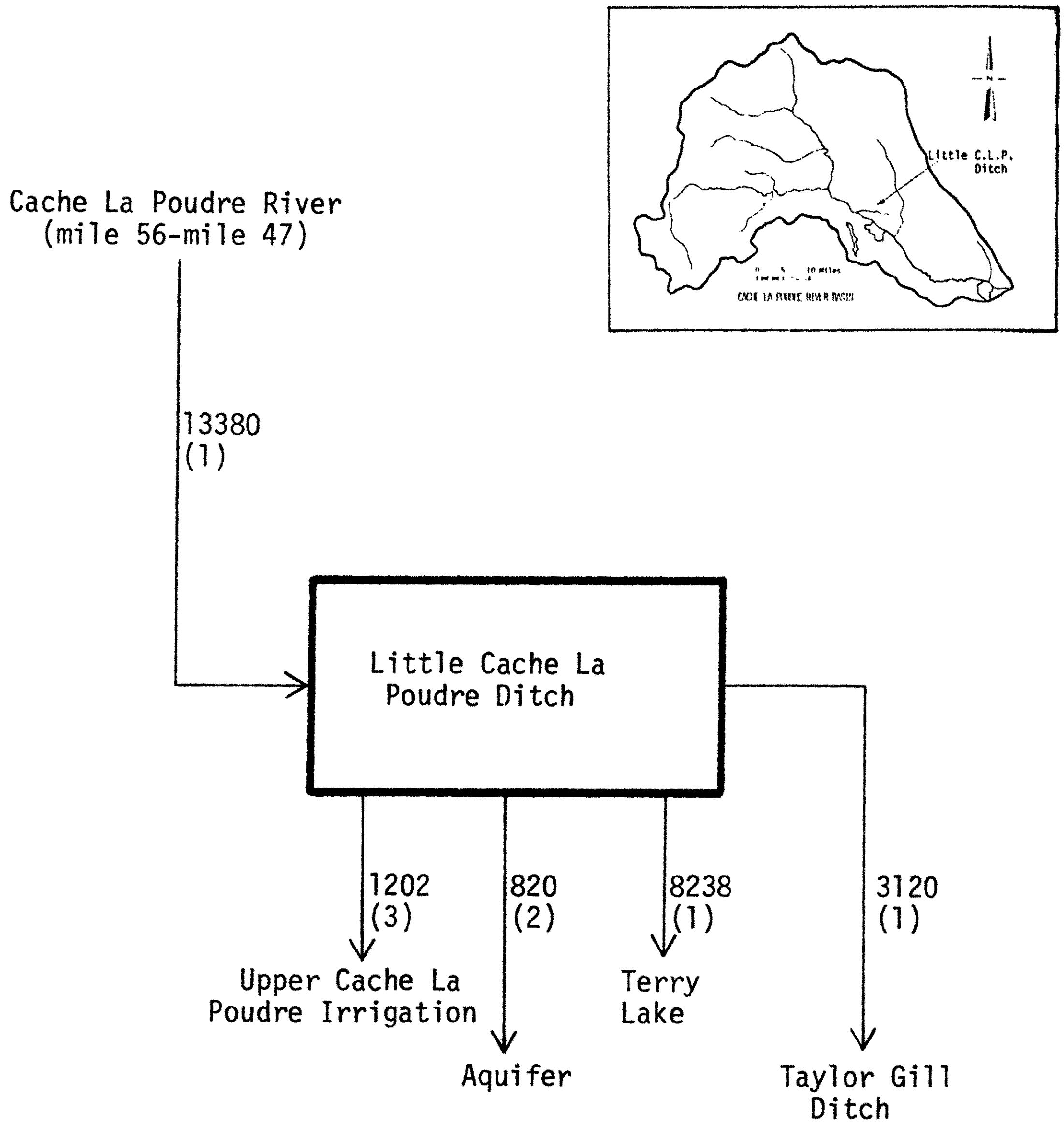
(1) Records of Water Commissioner.
(2) See North Poudre Res. No. 6.
(3) Mass balance of Black Hollow Reservoir.
(4) Estimated as 23% of river diversion.
(5) The mass balance indicates a total amount of 10,197 ac-ft being delivered to Upper CLP Irrig. and Pierce Lateral. The amount was split in proportion to the served areas.
(6) Mass balance of Curtis Lake.
(7) See "Other Res. Water Supply and Storage Co."

Figure E-6. Water Balance of "Larimer County Canal."



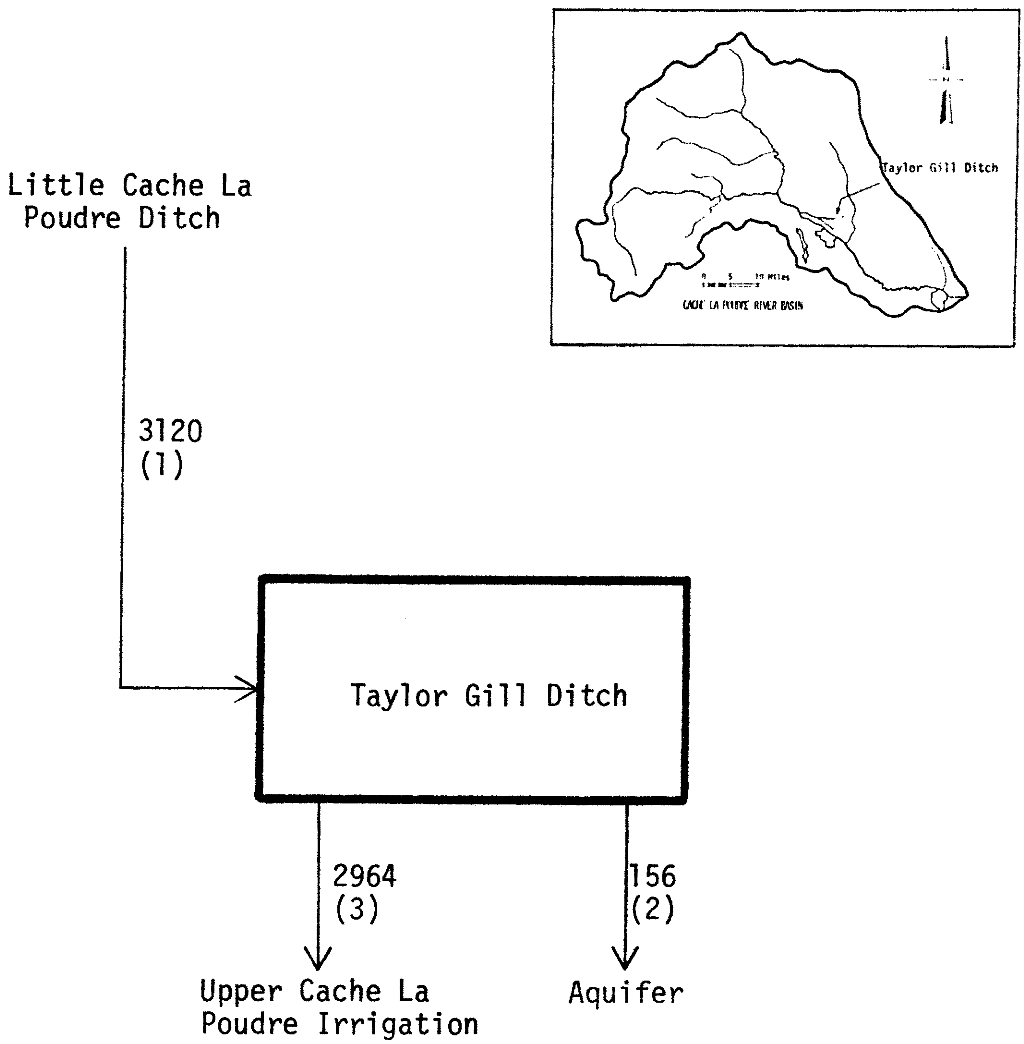
(1) Records of Water Commissioner.
(2) Mass balance of Jackson Ditch.
(3) Estimated as 18% of river diversion.

Figure E-7. Water Balance of "Jackson Ditch."



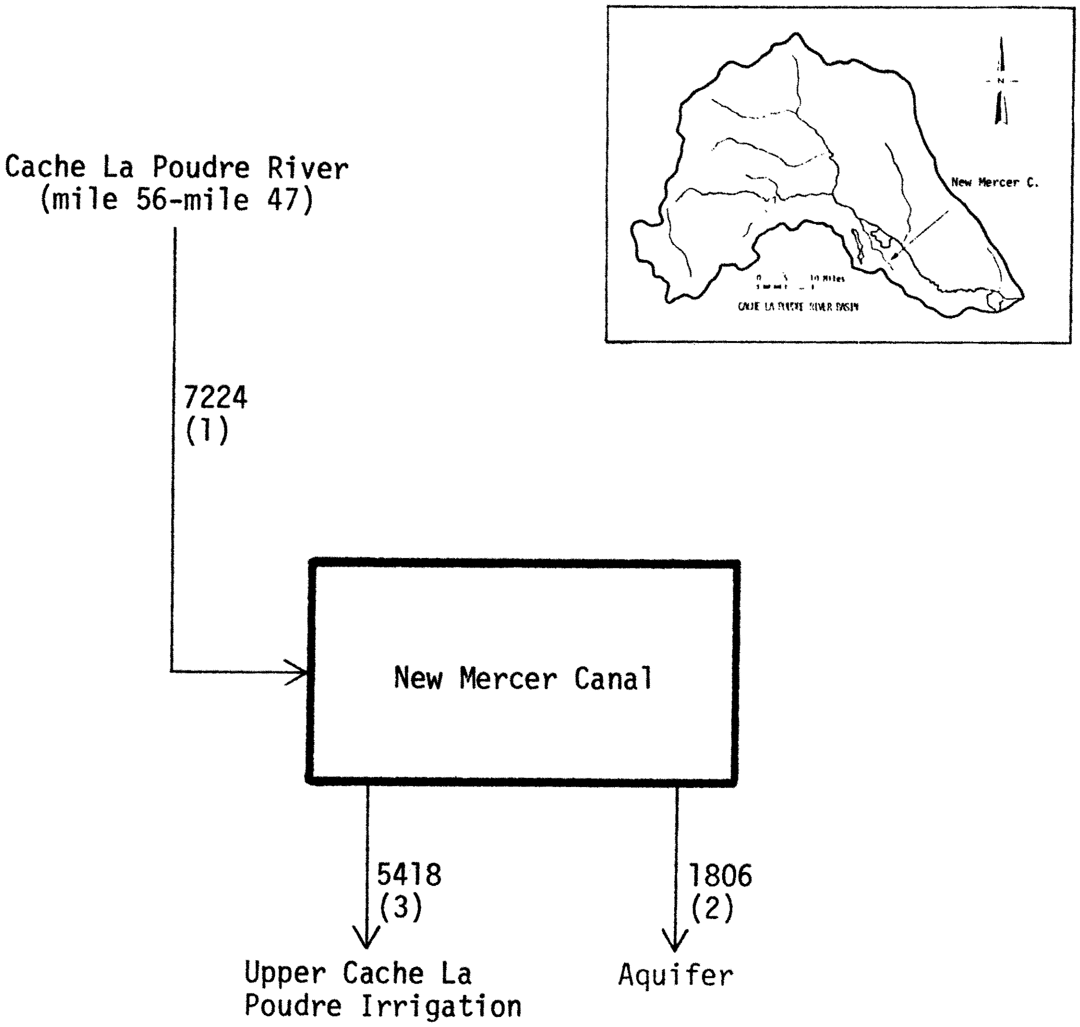
(1) Derived from records of Water Commissioner. 3,120 ac-ft of the total diversion were delivered to Taylor Gill Ditch.
(2) Estimated as 8% of the quantity not delivered to Taylor Gill Ditch.
(3) Derived through mass balance of Little Cache La Poudre Ditch.

Figure E-8. Water Balance of "Little Cache La Poudre Ditch."



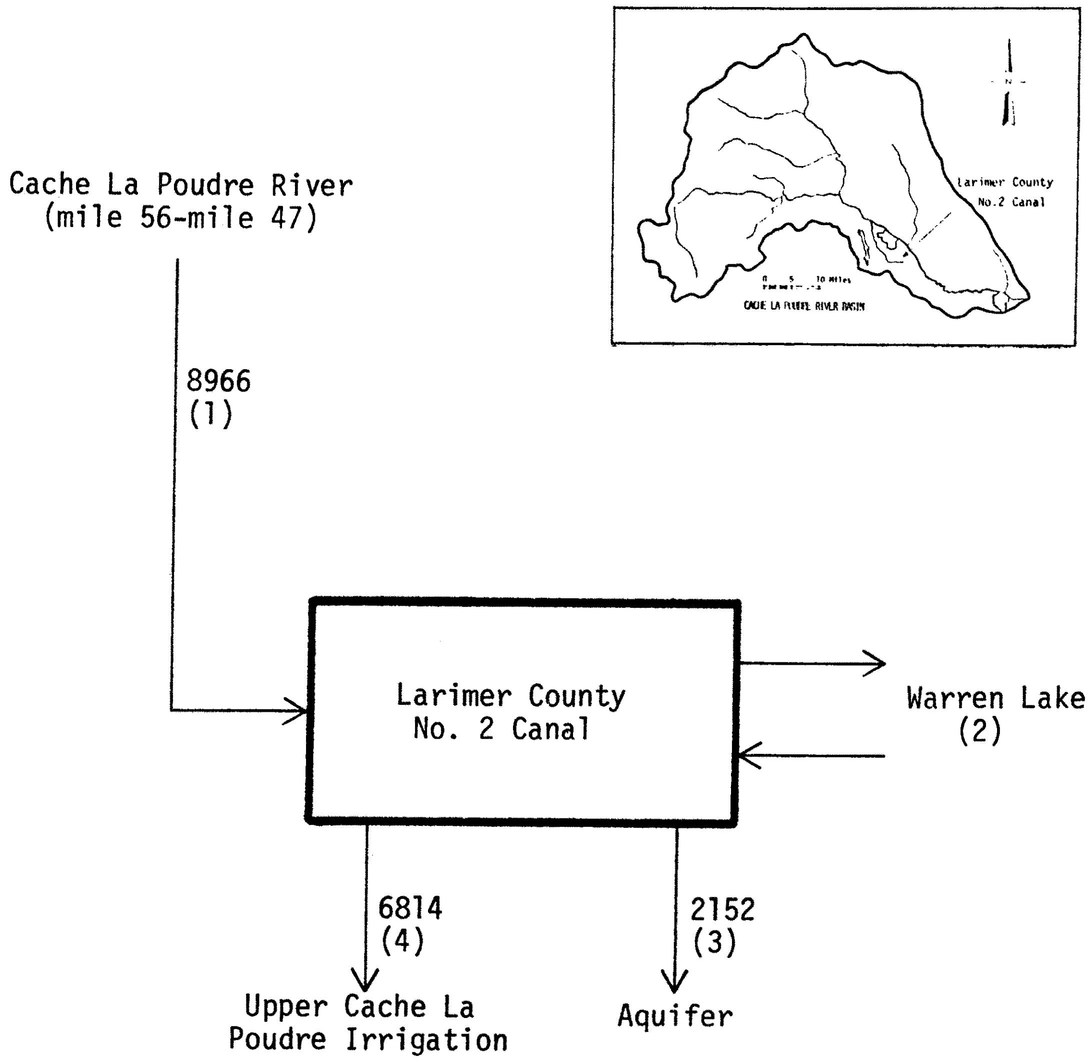
(1) Records of Water Commissioner.
(2) Estimated as 5% of the total diversion.
(3) Computed through mass balance of Taylor Gill Ditch.

Figure E-9. Water Balance of "Taylor Gill Ditch."



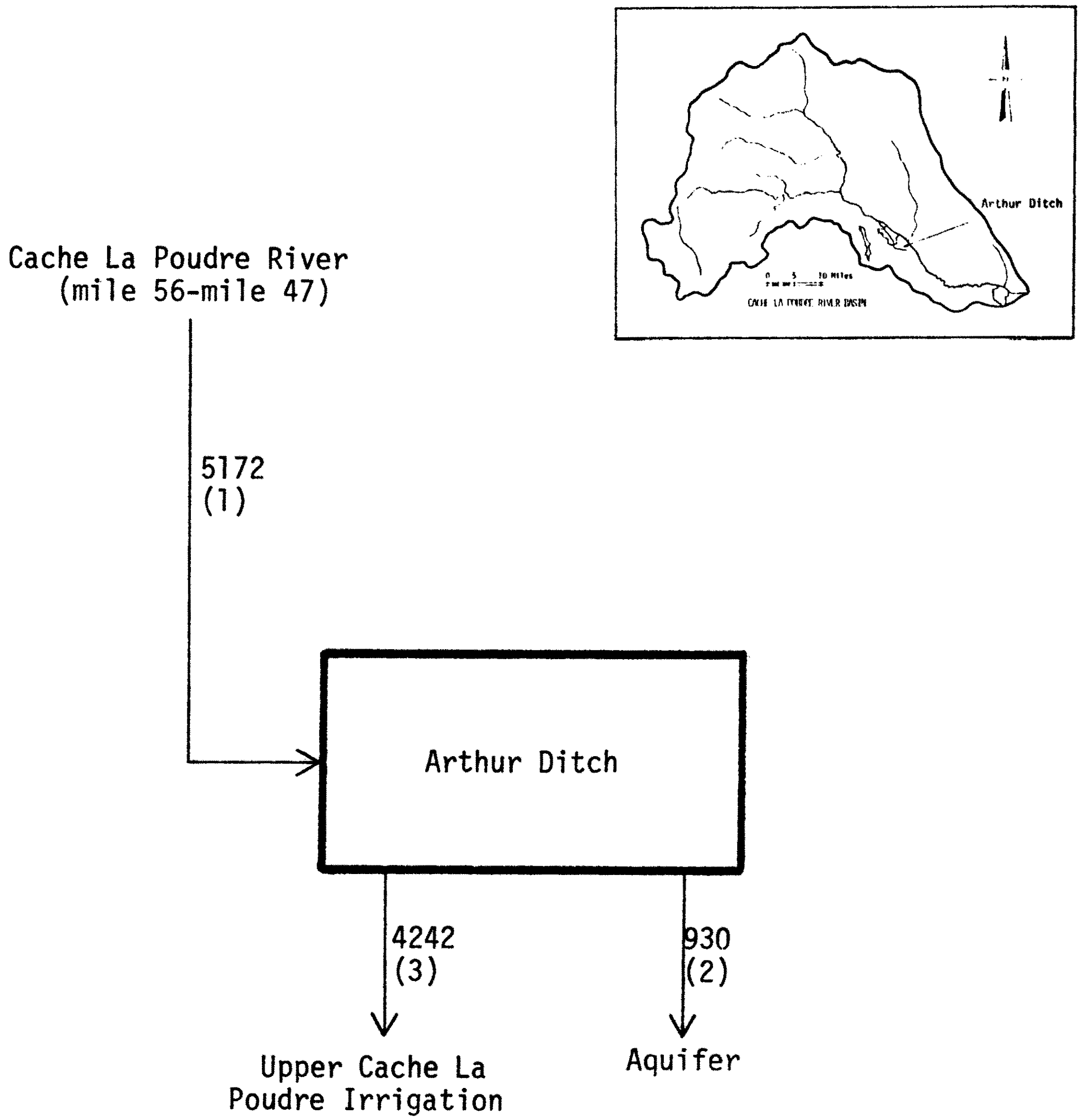
(1) Records of Water Commissioner.
(2) Estimated as 25% of the river diversion.
(3) Computed through mass balance of New Mercer Canal.

Figure E-10. Water Balance of "New Mercer Canal."



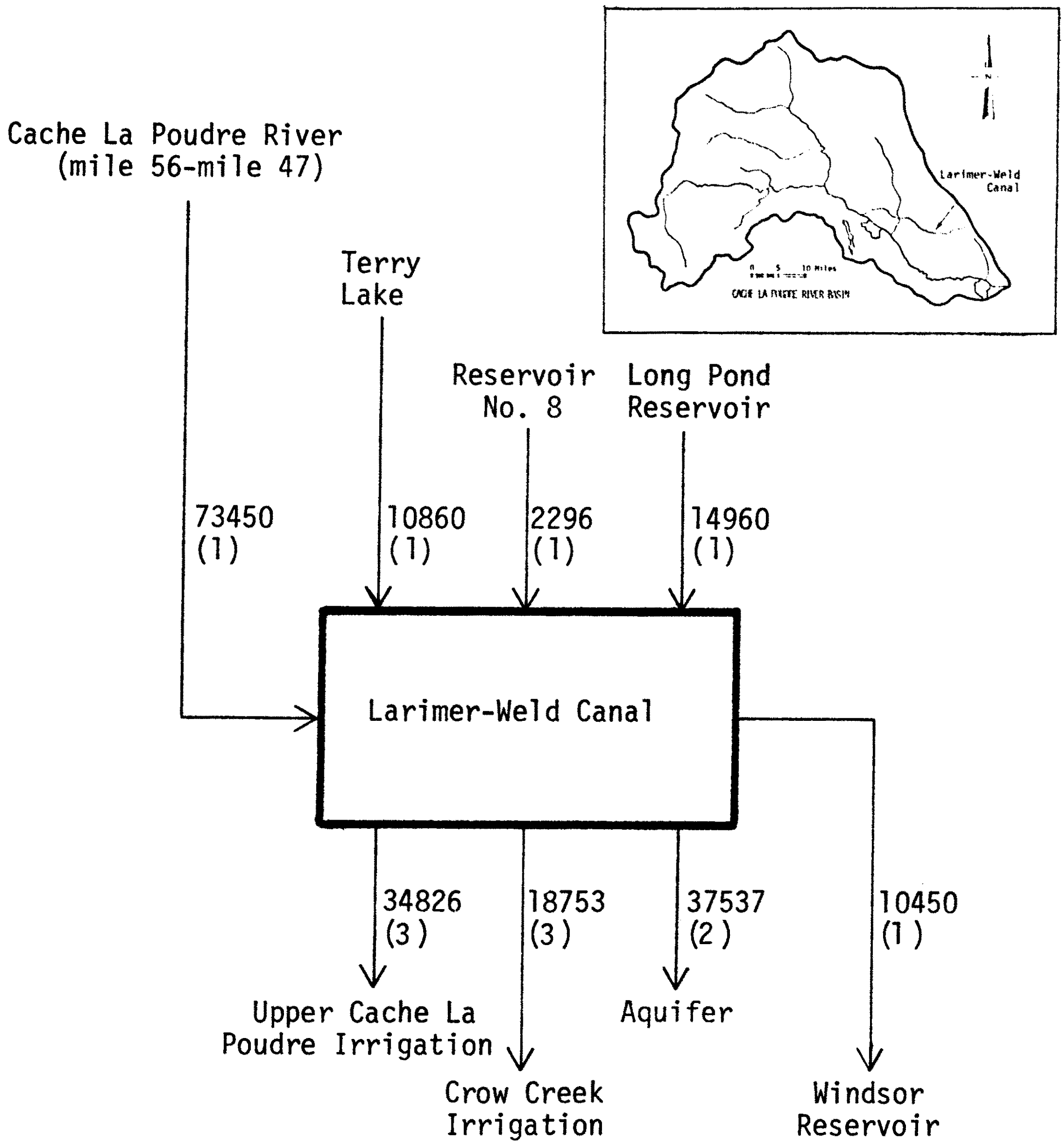
(1) Records of Water Commissioner.
(2) Warren Lake is an "equalizer," i.e., an impoundment structure for very short term flow regulation. Its losses were neglected. Therefore the inflow and outflow are equal, but their value is not known.
(3) Estimated as 24% of the river diversion.
(4) Computed through mass balance of Larimer County No. 2 Canal.

Figure E-11. Water Balance of "Larimer County No. 2 Canal."



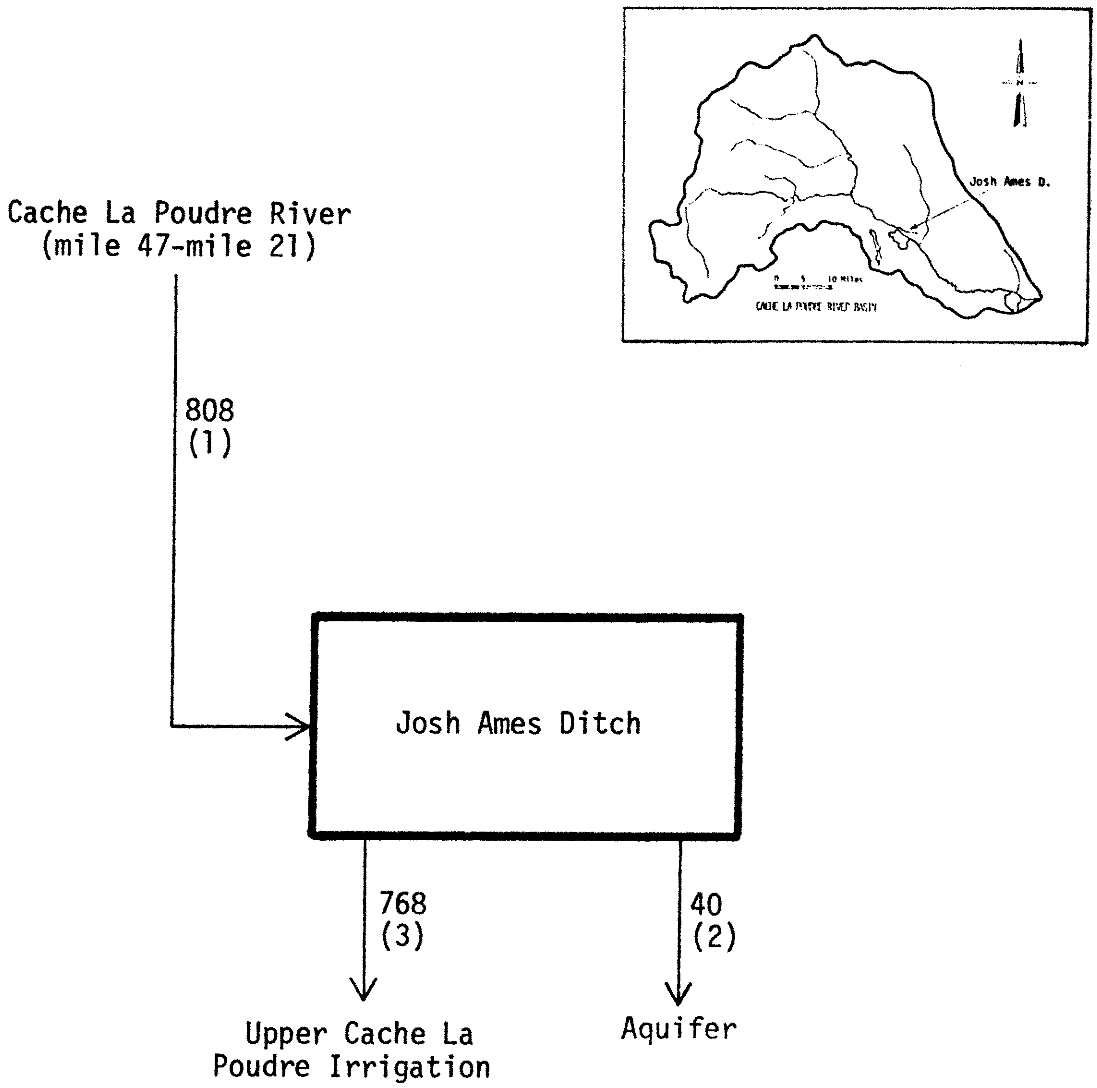
(1) Records of Water Commissioner.
(2) Estimated as 18% of the river diversion.
(3) Computed through mass balance of Arthur Ditch.

Figure E-12. Water Balance of "Arthur Ditch."



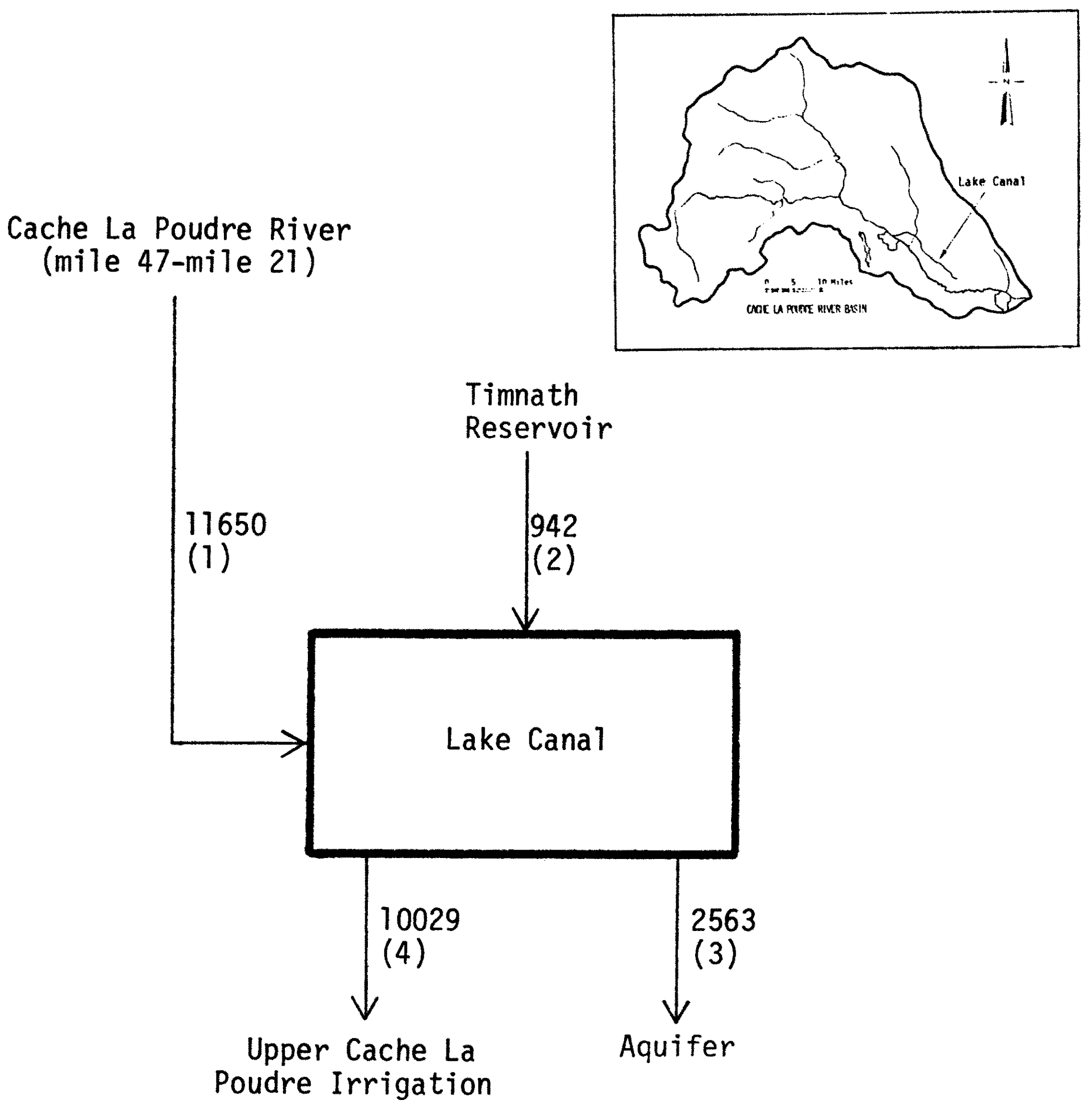
(1) Records of Water Commissioner.
(2) Estimated as 52% of the river diversion.
(3) The mass balance of Larimer-Weld Canal yields 53,579 ac-ft total direct deliveries to irrigation. This value was split between Upper Cache La Poudre and Crow Creek Irrigation proportionally to the served areas (65% and 35%).

Figure E-13. Water Balance of "Larimer-Weld Canal."



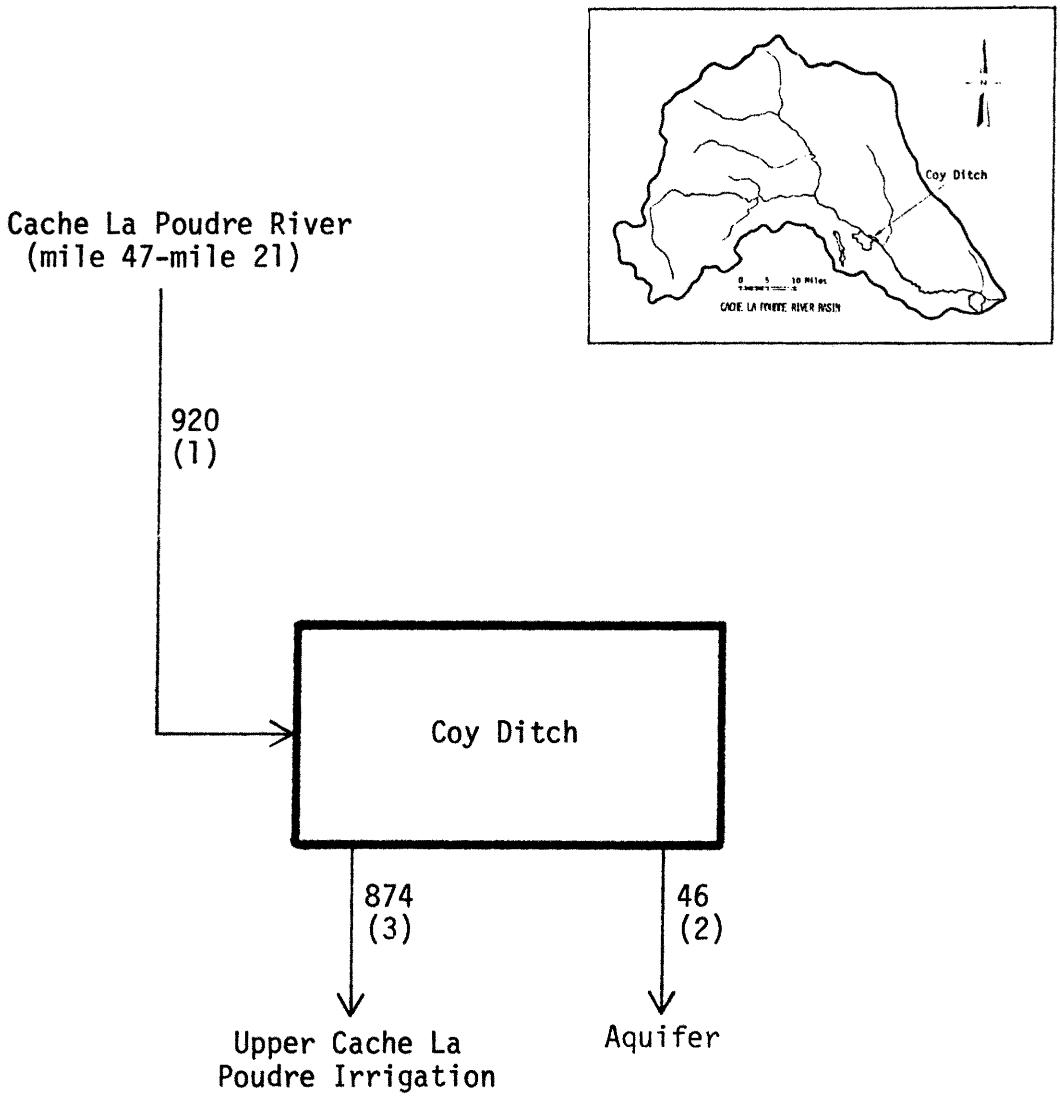
(1) Records of Water Commissioner.
(2) Estimated as 8% of the river diversion.
(3) Computed through mass balance of Josh Ames Ditch.

Figure E-14. Water Balance of "Josh Ames Ditch."



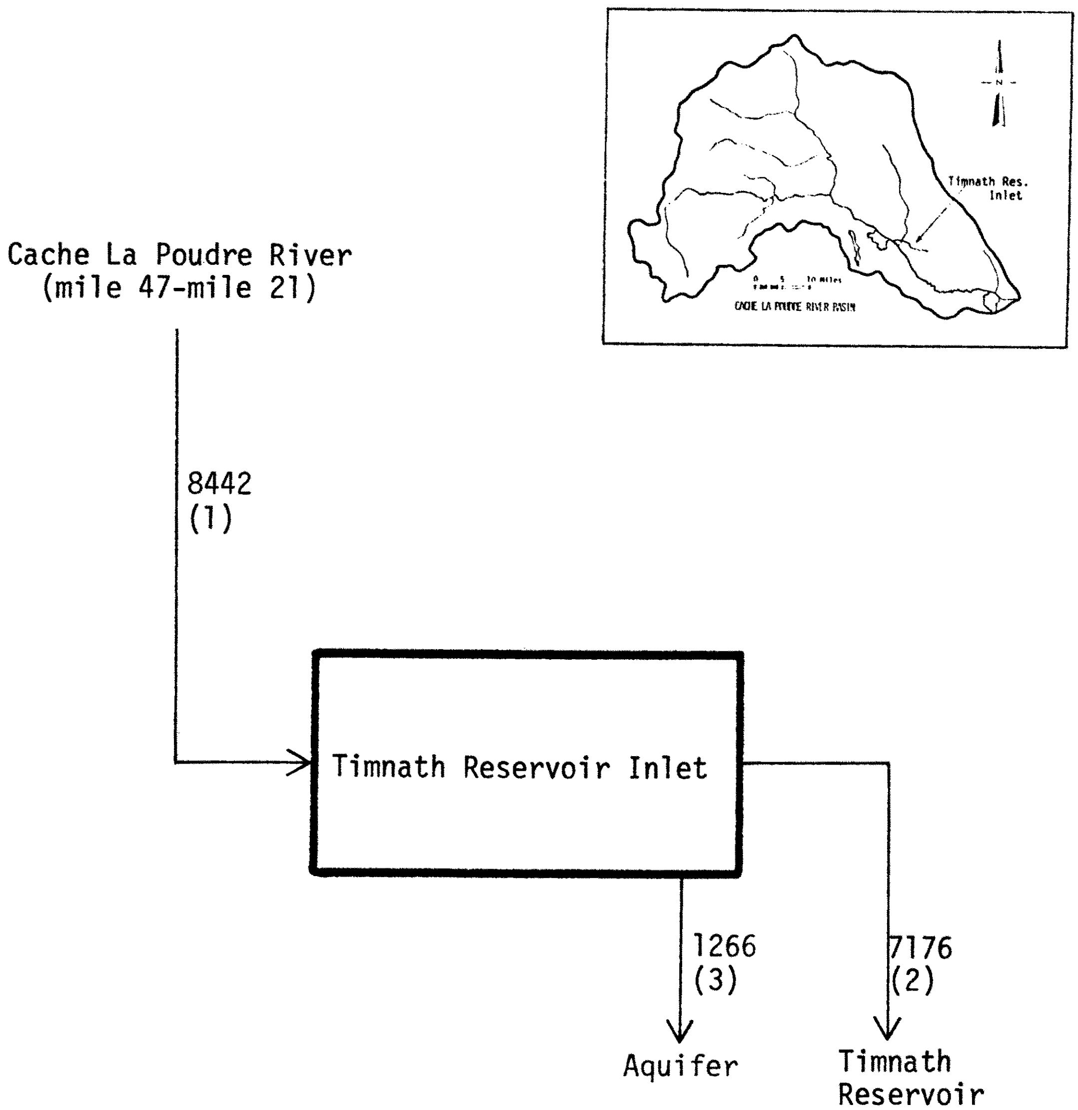
(1) Records of Water Commissioner.
(2) No value was available from the Water Commissioner for 1970. The 1976 record was used instead.
(3) Estimated as 22% of the river diversion.
(4) Computed through mass balance of Lake Canal.

Figure E-15. Water Balance of "Lake Canal."



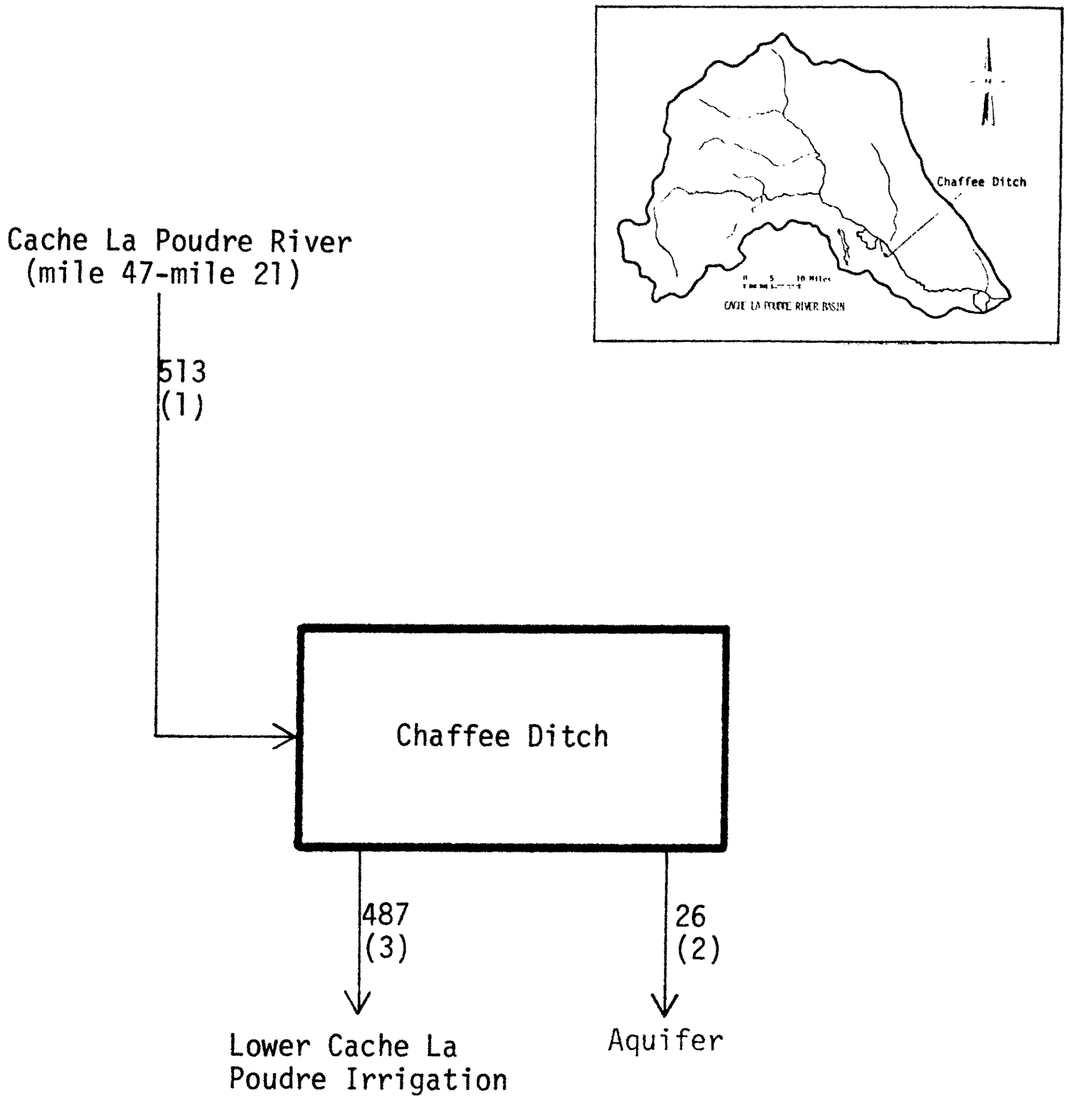
(1) Records of Water Commissioner.
(2) Estimated as 5% of the river diversion.
(3) Computed through mass balance of Coy Ditch.

Figure E-16. Water Balance of "Coy Ditch."



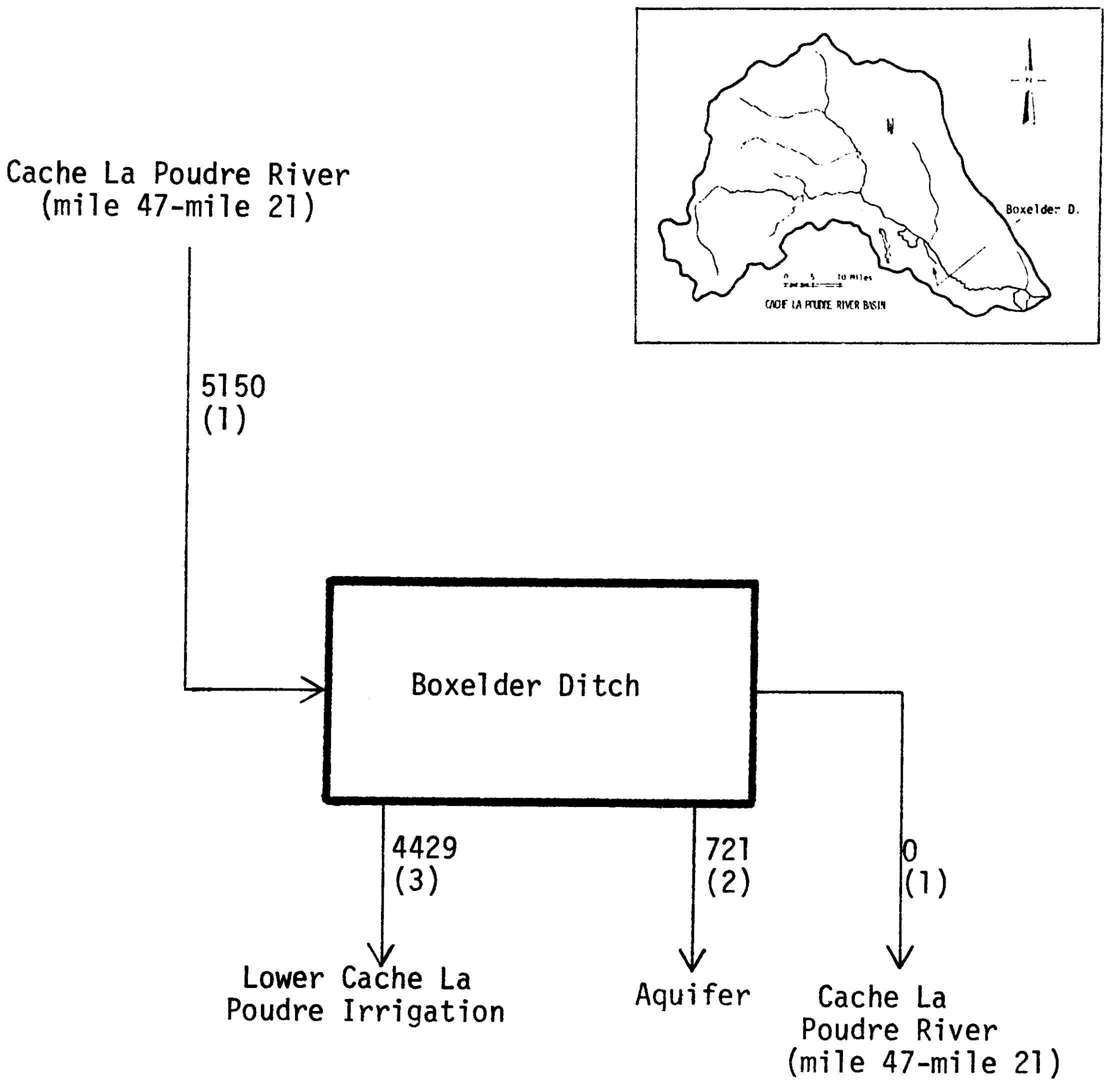
(1) Computed through mass balance of Timnath Res. Inlet.
(2) Records of Water Commissioner.
(3) Estimated as 15 % of the river diversion.

Figure E-17. Water Balance of "Timnath Reservoir Inlet."



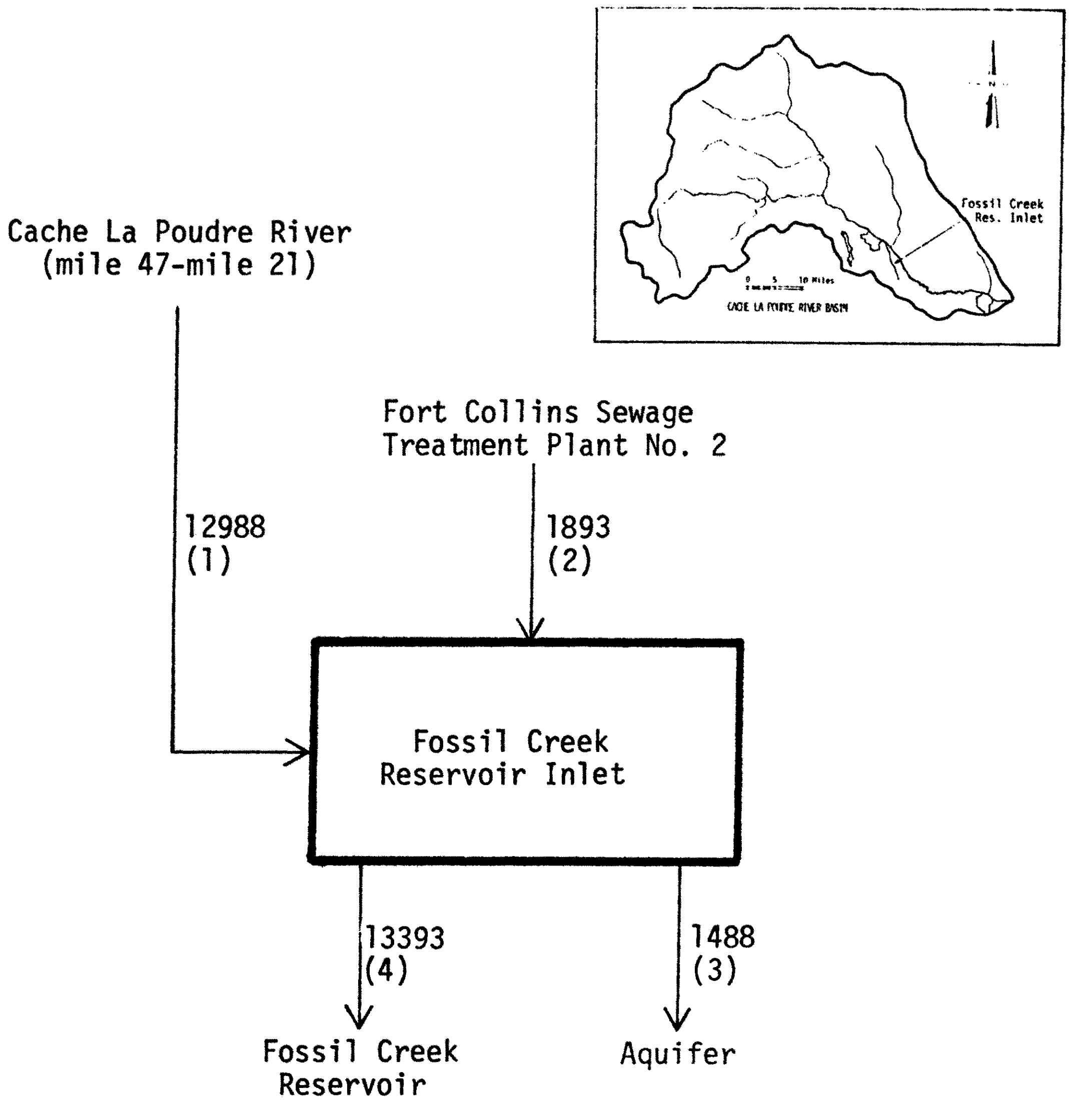
(1) Records of Water Commissioner.
(2) Estimated as 5% of the river diversion.
(3) Computed through mass balance of Chaffee Ditch.

Figure E-18. Water Balance of "Chaffee Ditch."



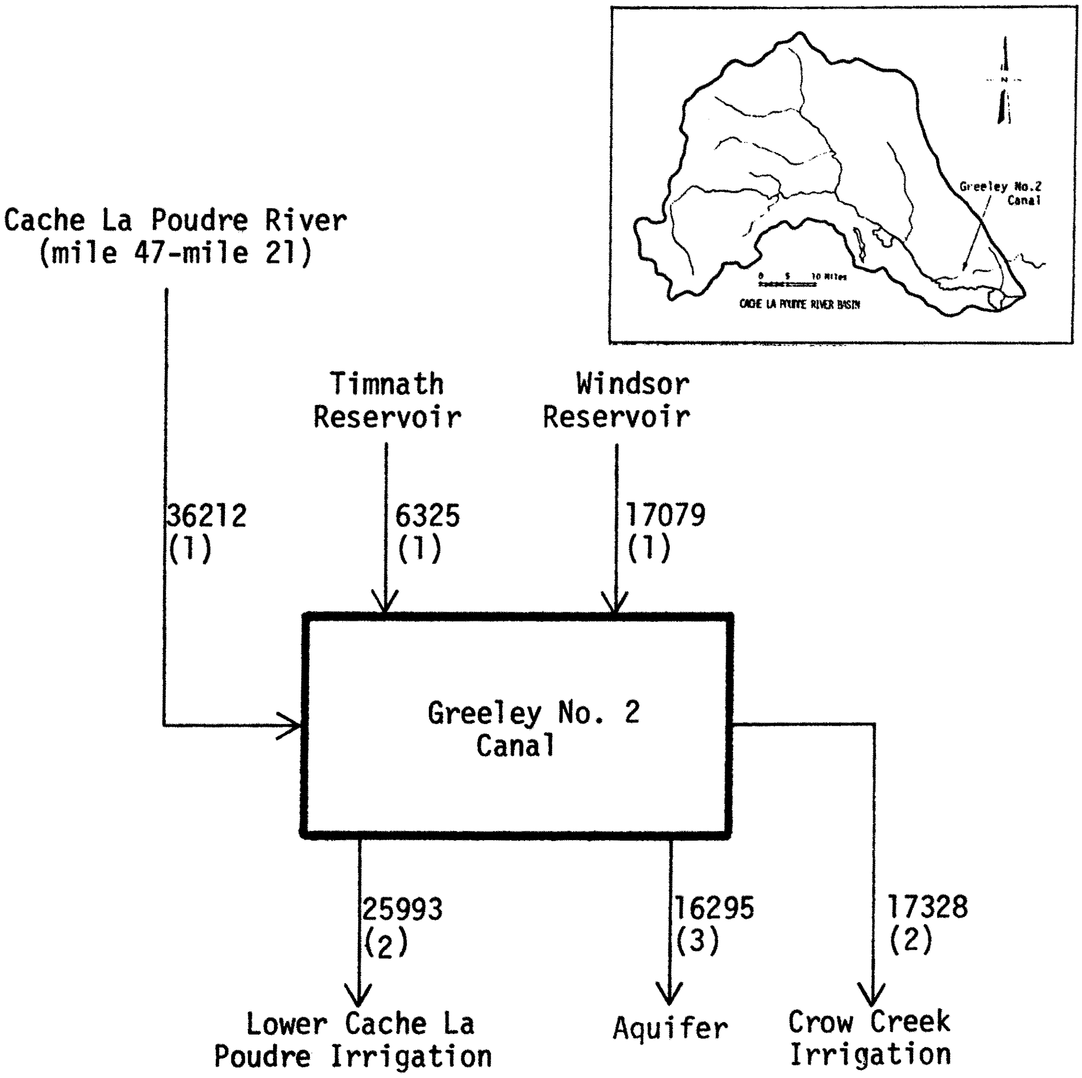
(1) Records of Water Commissioner.
(2) Estimated as 14% of the river diversion.
(3) Computed through mass balance of Boxelder Ditch.

Figure E-19. Water Balance of "Boxelder Ditch."



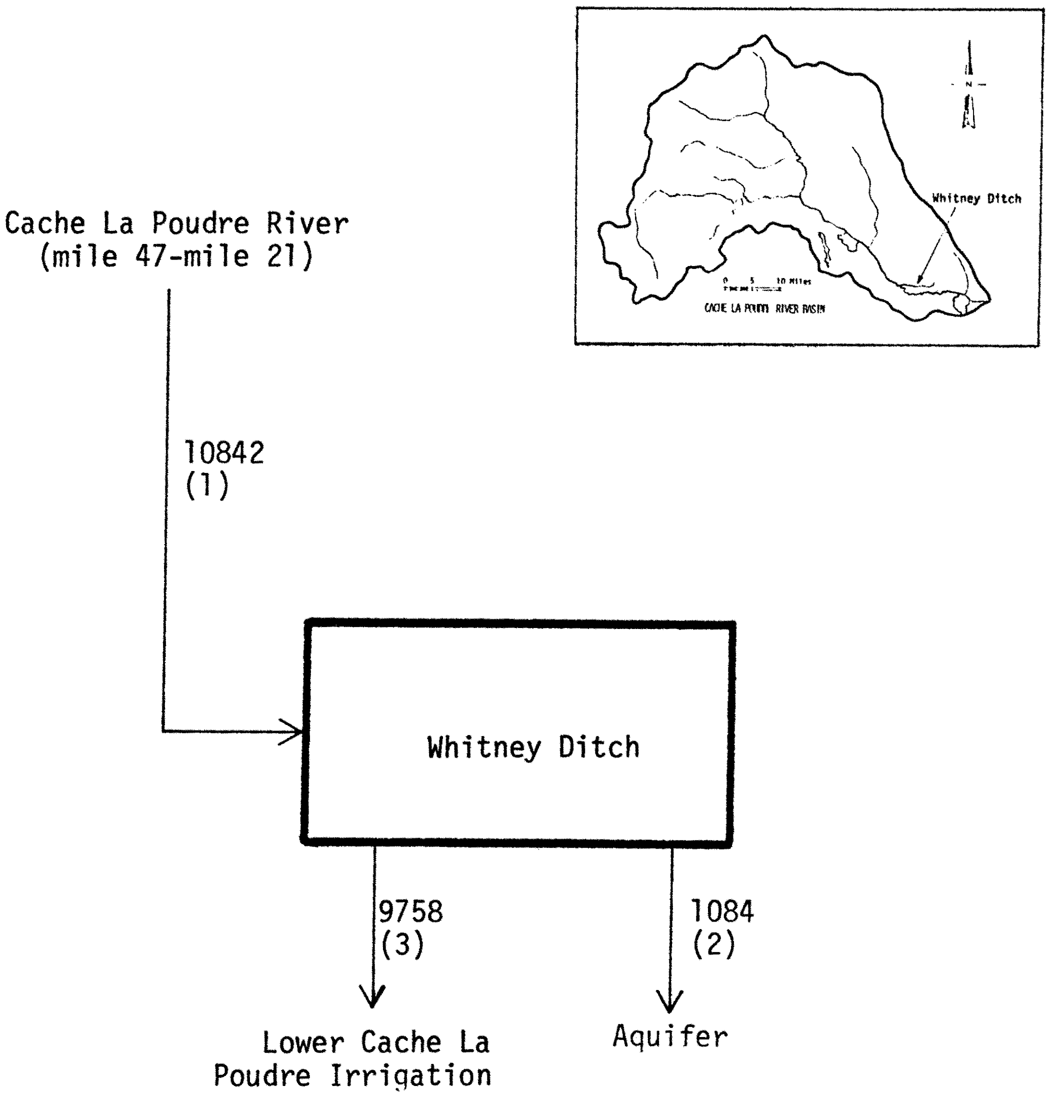
(1) Records of Water Commissioner.
(2) See Figure F-15 or paragraph 5.2.1.
(3) Estimated as 10% of the total inflow (12,900 + 1,893 ac-ft).
(4) Computed through mass balance of Fossil Creek Reservoir Inlet.

Figure E-20. Water Balance of "Fossil Creek Reservoir Inlet."



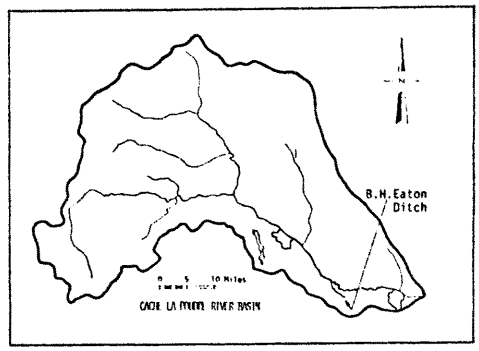
(1) Records of Water Commissioner.
(2) The mass balance of Greeley No. 2 Canal yields a total 43,321 ac-ft delivery to irrigation. This amount was split between Lower Cache La Poudre and Crow Creek irrigaton proportionally to the served areas (60% and 40%).
(3) Estimated as 45% of the river diversion.

Figure E-21. Water Balance of "Greeley No. 2 Canal."



(1) Records of Water Commissioner.
(2) Estimated as 10% of the river diversion.
(3) Computed through mass balance of Whitney Ditch.

Figure E-22. Water Balance of "Whitney Ditch."



Cache La Poudre River
(mile 47-mile 21)

4644
(1)

B.H. Eaton Ditch

4273
(3)

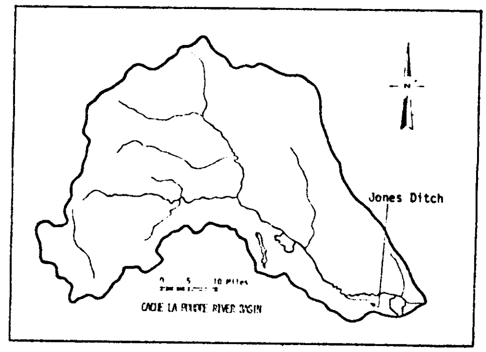
Lower Cache La
Poudre Irrigation

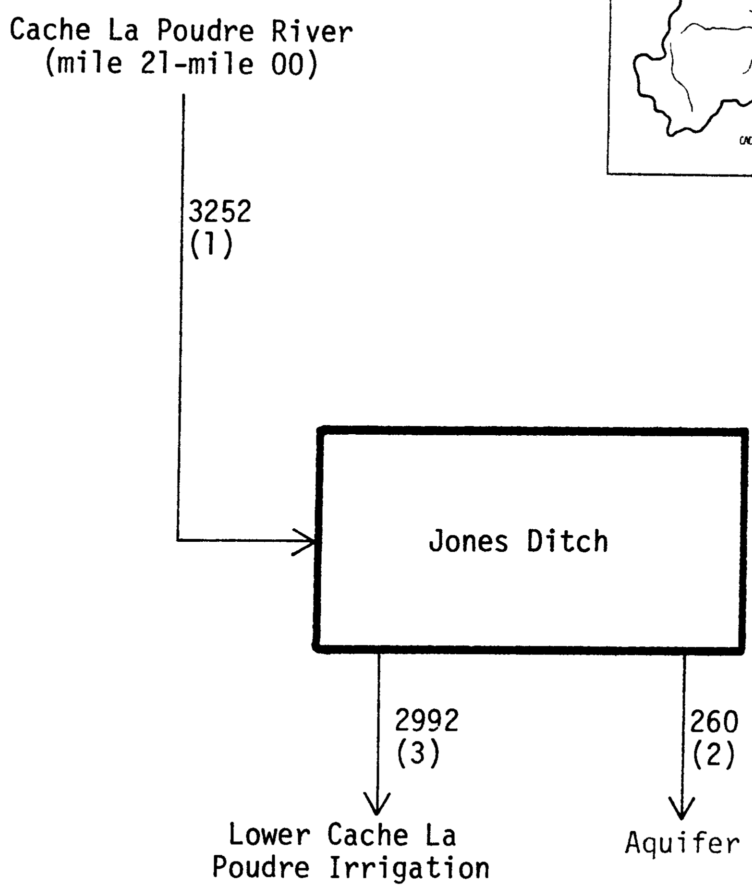
371
(2)

Aquifer

(1) Records of Water Commissioner.
(2) Estimated as 8% of the river diversion.
(3) Computed through mass balance of B.H. Eaton Ditch.

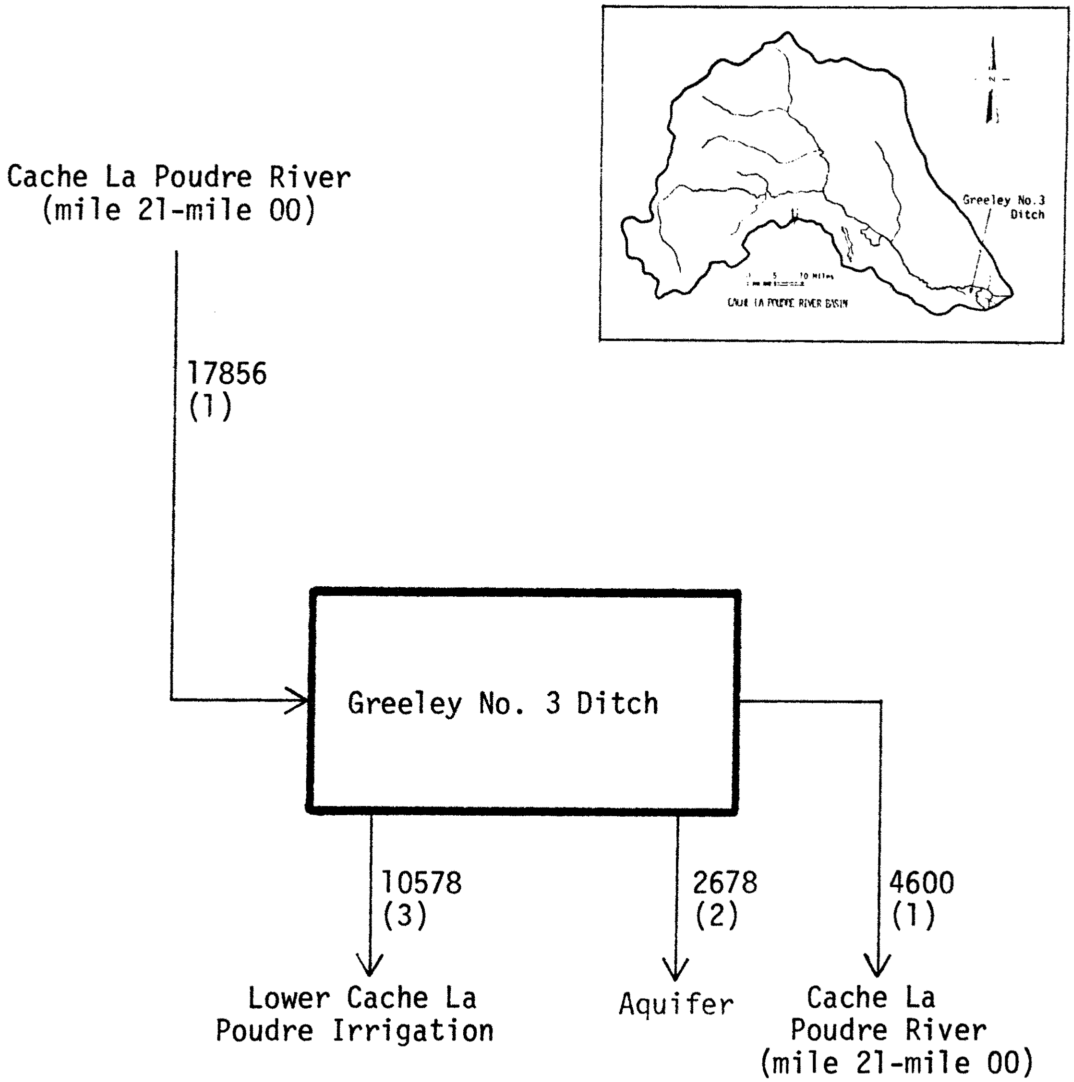
Figure E-23. Water Balance of "B. H. Eaton Ditch."





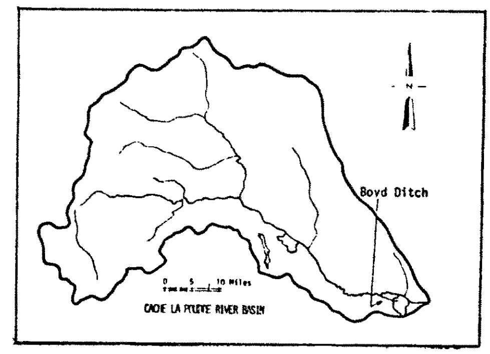
(1) Records of Water Commissioner.
(2) Estimated as 8% of the river diversion.
(3) Computed through mass balance of Jones Ditch.

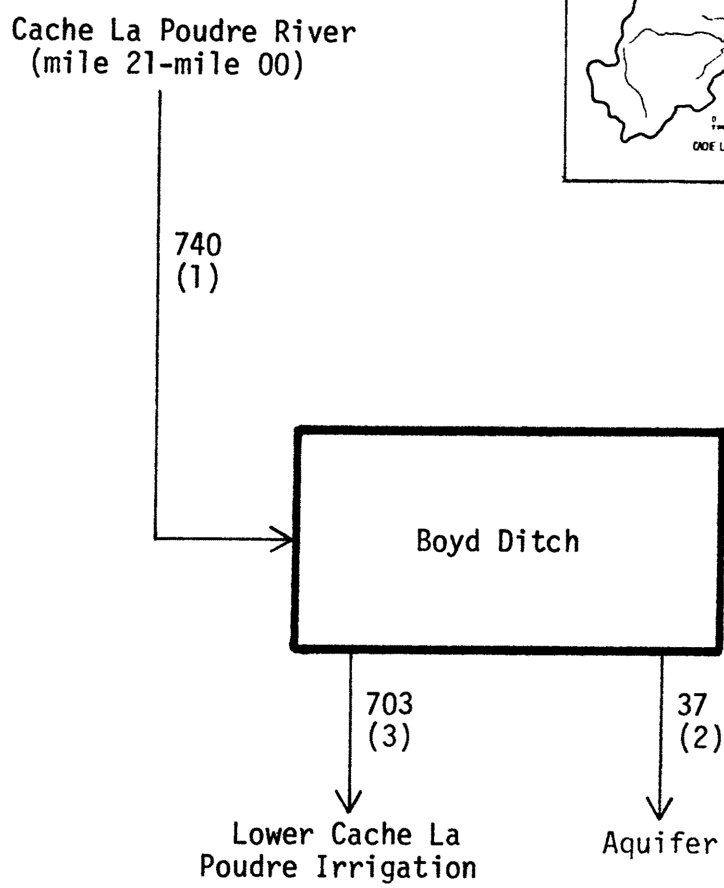
Figure E-24. Water Balance of "Jones Ditch."



(1) Records of Water Commissioner. 4,600 acre-feet werw discharged back into the river in order to eliminate the accumulation of trashes in the ditch.
(2) Estimated as 15 % of the river diversion.
(3) Computed through mass balance of Greeley No.3 ditch.

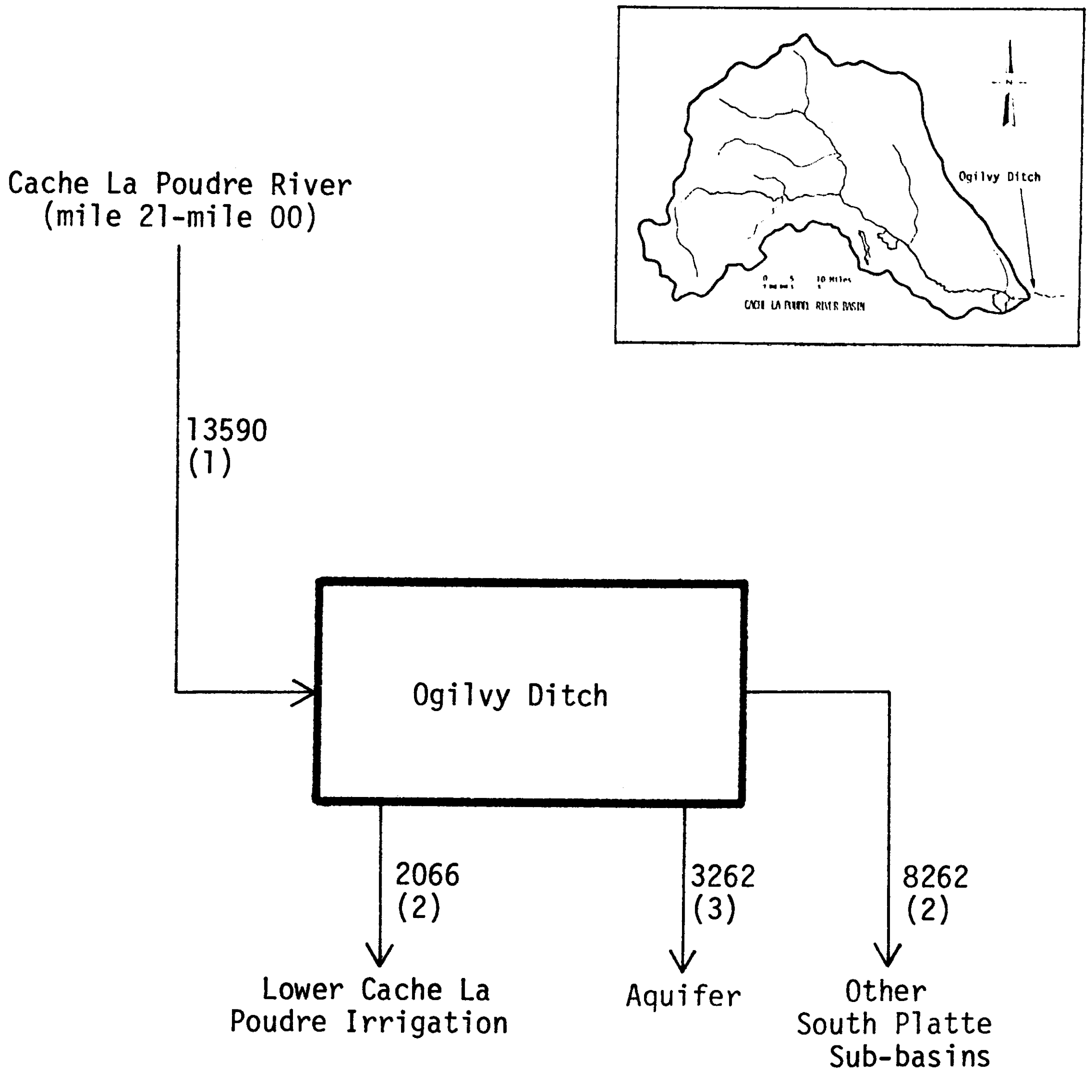
Figure E-25. Water Balance of "Greeley No. 3 Ditch."





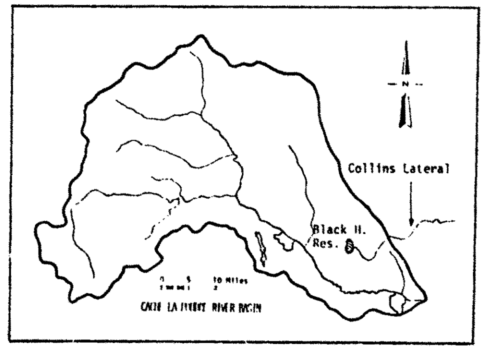
(1) Records of Water Commissioner.
(2) Estimated as 5% of the river diversion.
(3) Computed through mass balance of Boyd Ditch.

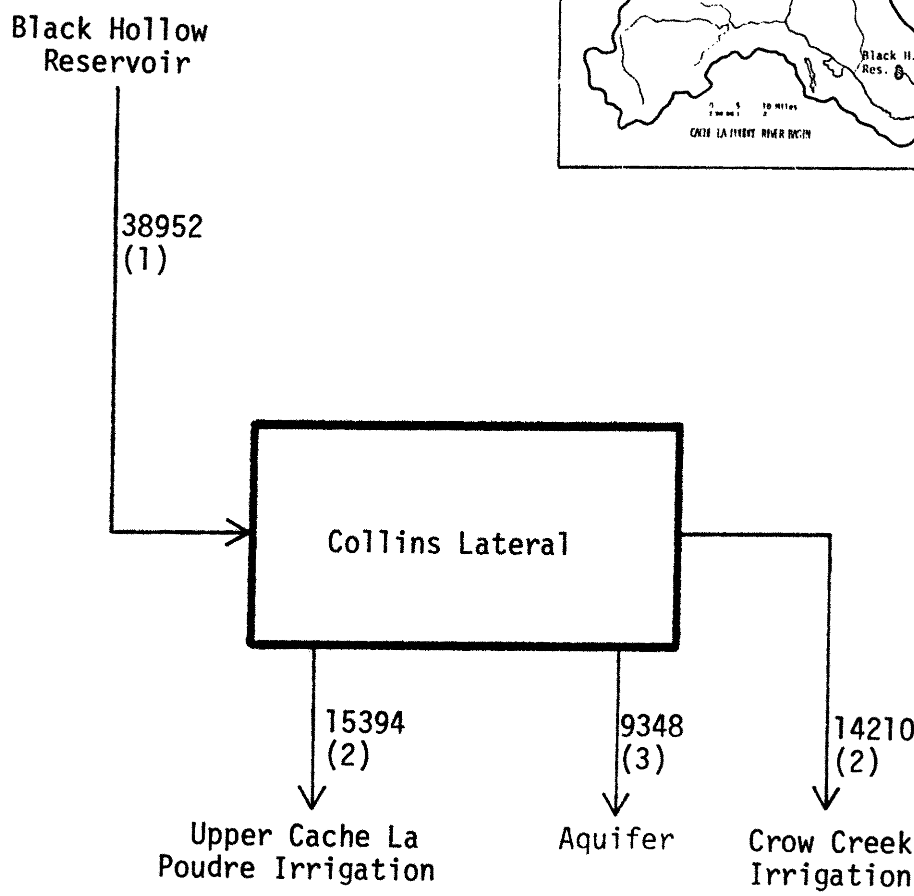
Figure E-26. Water Balance of "Boyd Ditch."



(1) Records of Water Commissioner.
(2) The mass balance of Ogilvy Ditch indicates that a total amount of 10,320 ac-ft was delivered to irrigation. This amount was split between "Lower Cache La Poudre Irrigation" and "Other South Platte Sub-basins" (irrigation in the direct South Platte drainage) proportionally to the served areas (20% and 80%).
(3) Estimated as 24% of the river diversion.

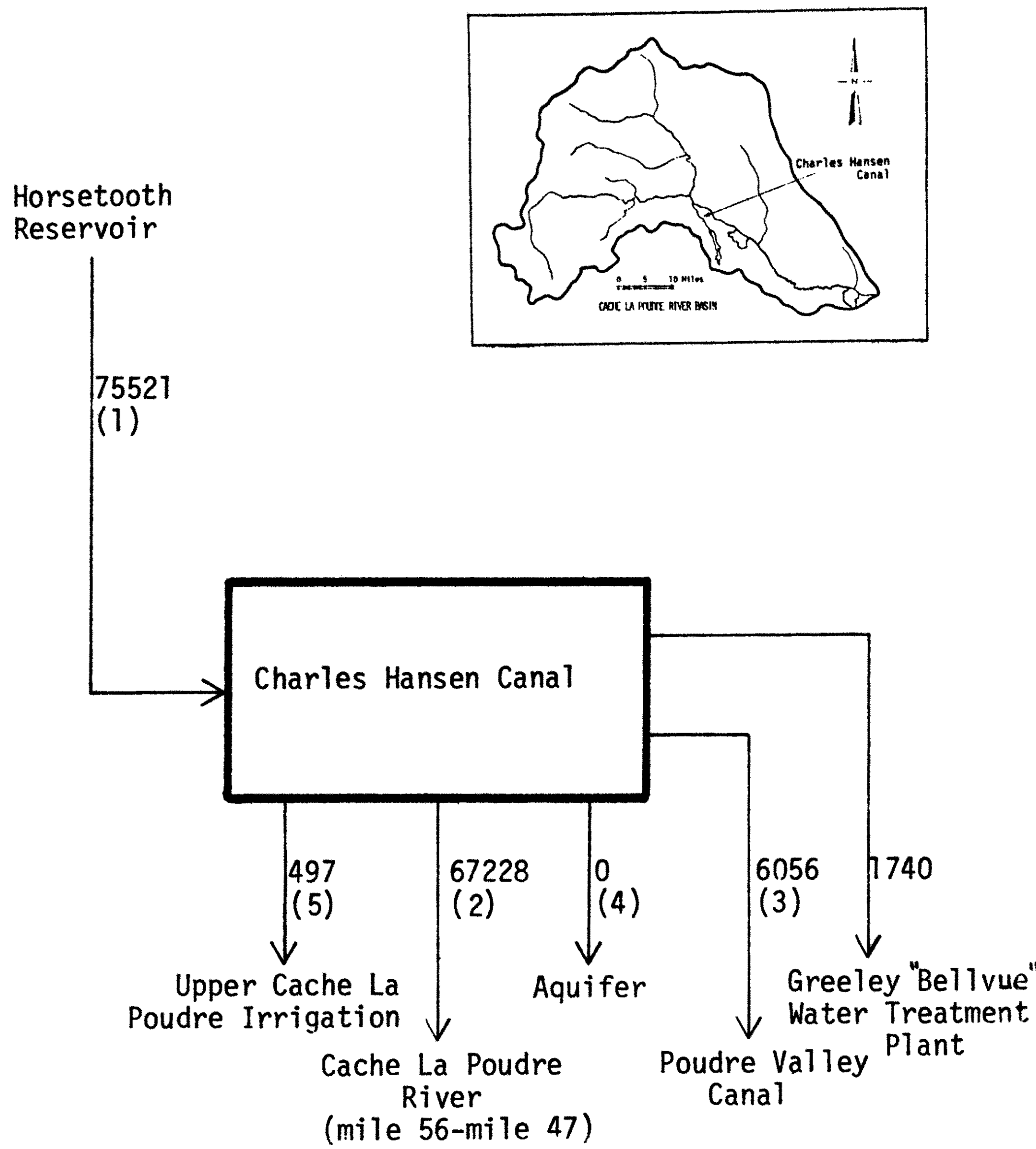
Figure E-27. Water Balance of "Ogilvy Ditch."





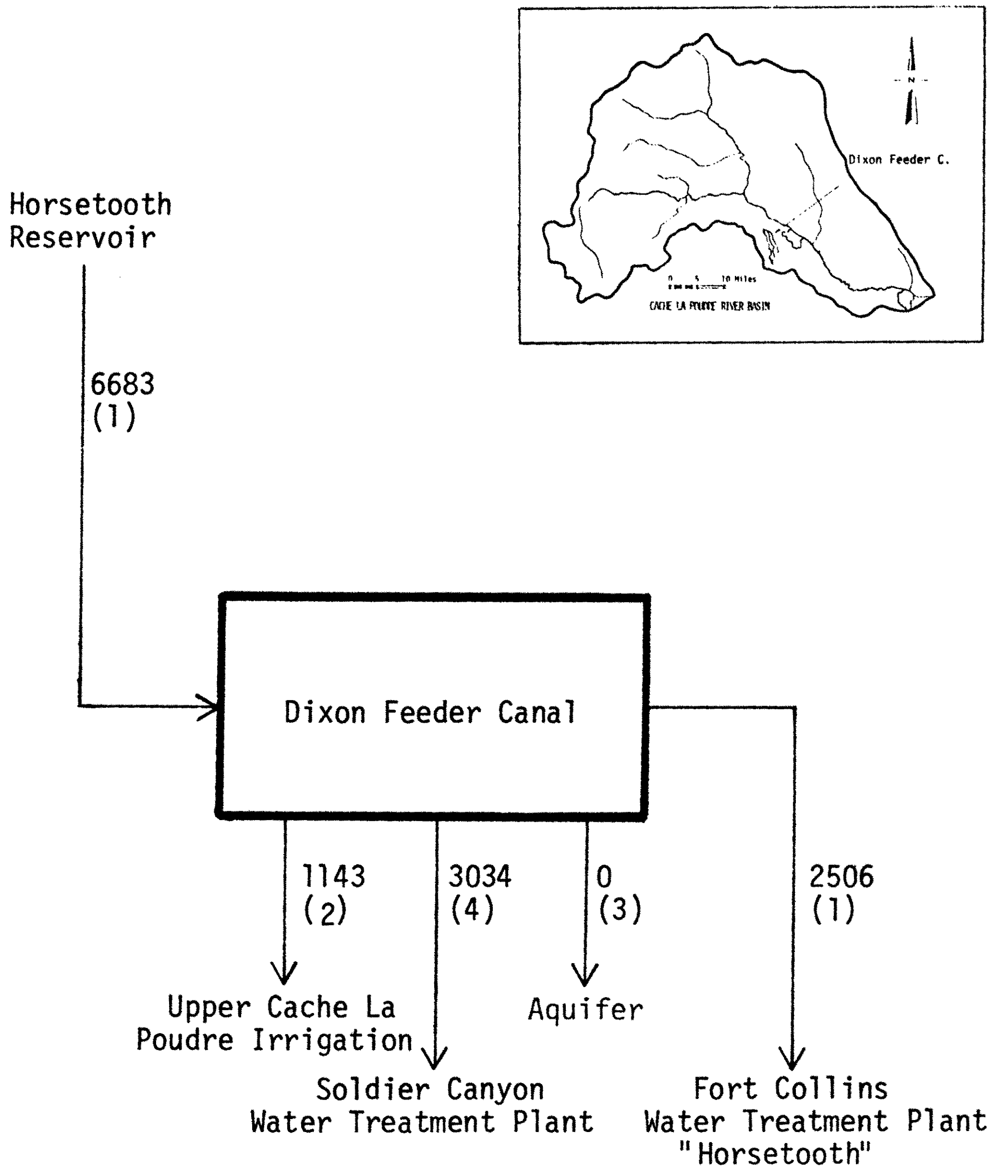
(1) Records of Water Commissioner. No record was available for 1970. The 1976 value was used instead.
(2) The mass balance of "Collins Lateral" indicated that a total amount of 29,604 ac-ft was delivered to agriculture. This amount was split between Upper Cache La Poudre and Crow Creek irrigation proportionally to the served areas (52% and 48%).
(3) Estimated as 24% of the inflows.

Figure E-28. Water Balance of "Collins Lateral."



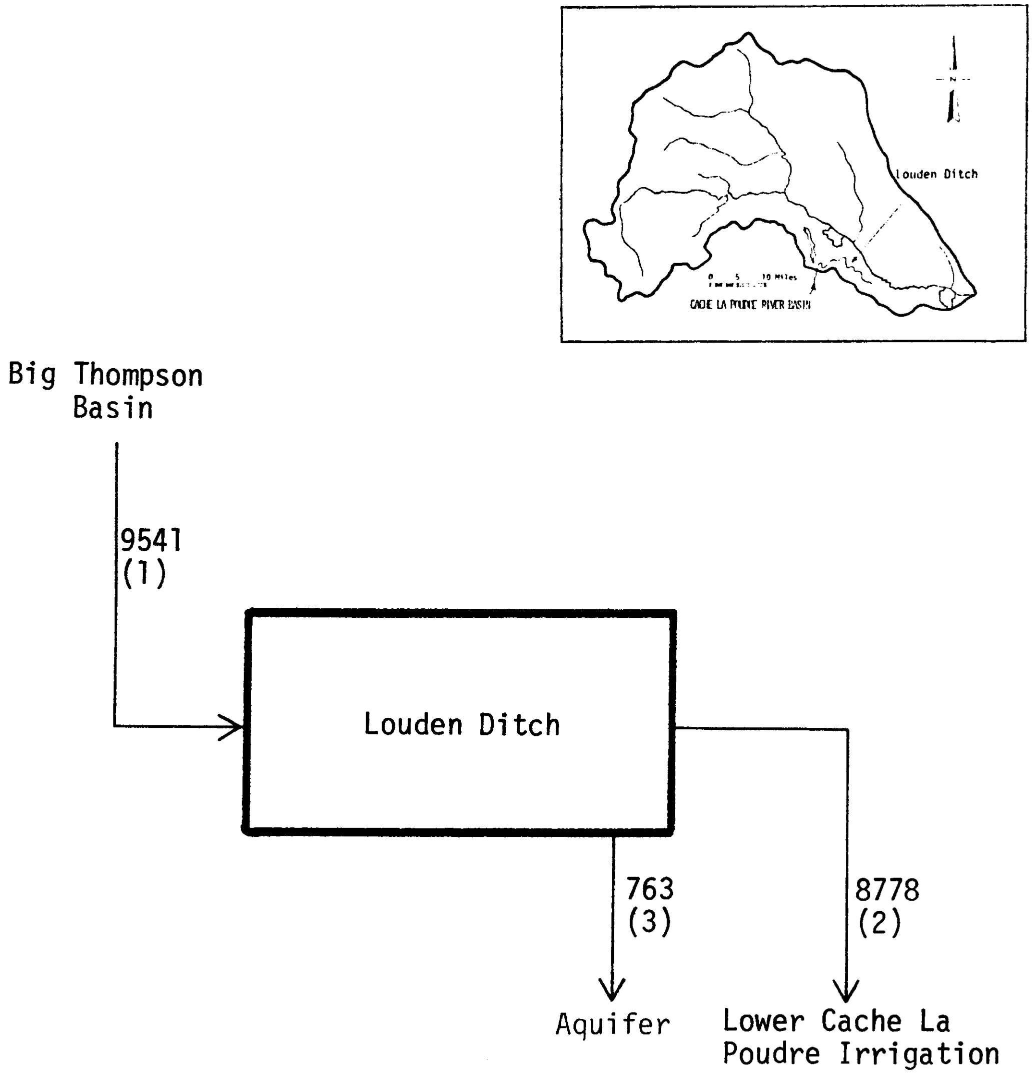
(1) See Figure D-9.
(2) Northern Colorado Water Conservancy District, "Summary of Delivery Operations for 1970."
(3) 1970 Annual Report, Colorado State Engineer, Division 1.
(4) No seepage, since the canal is concrete lined.
(5) Computed through mass balance of Charles Hansen Canal.

Figure E-29. Water Balance of "Charles Hansen Canal."



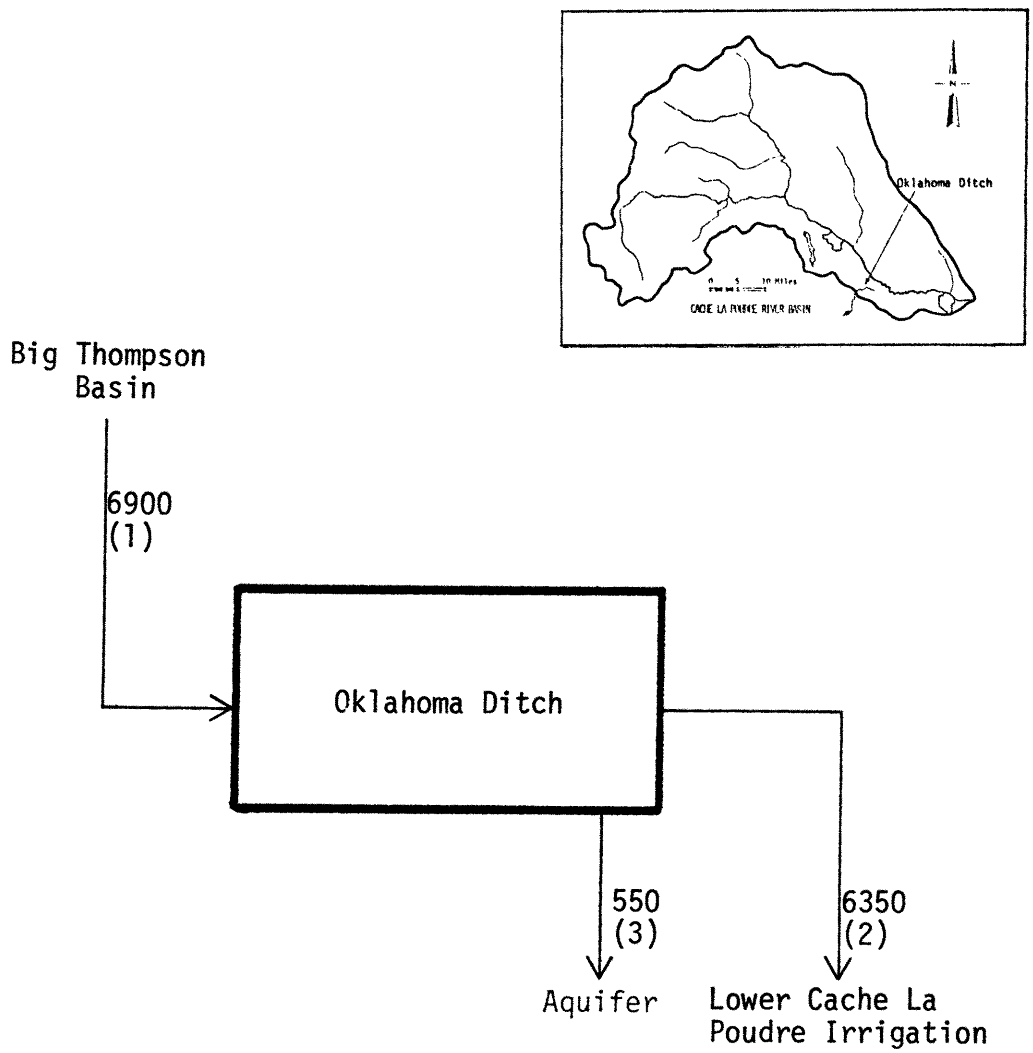
(1) Northern Colorado Water Conservancy District, "Summary of Delivery Operations for 1970."
(2) Computed through mass balance of "Dixon Feeder Canal."
(3) Estimated (concrete lined canal).
(4) Information supplied by Duane Davis, Manager of the plant.

Figure E-30. Water Balance of "Dixon Feeder Canal."



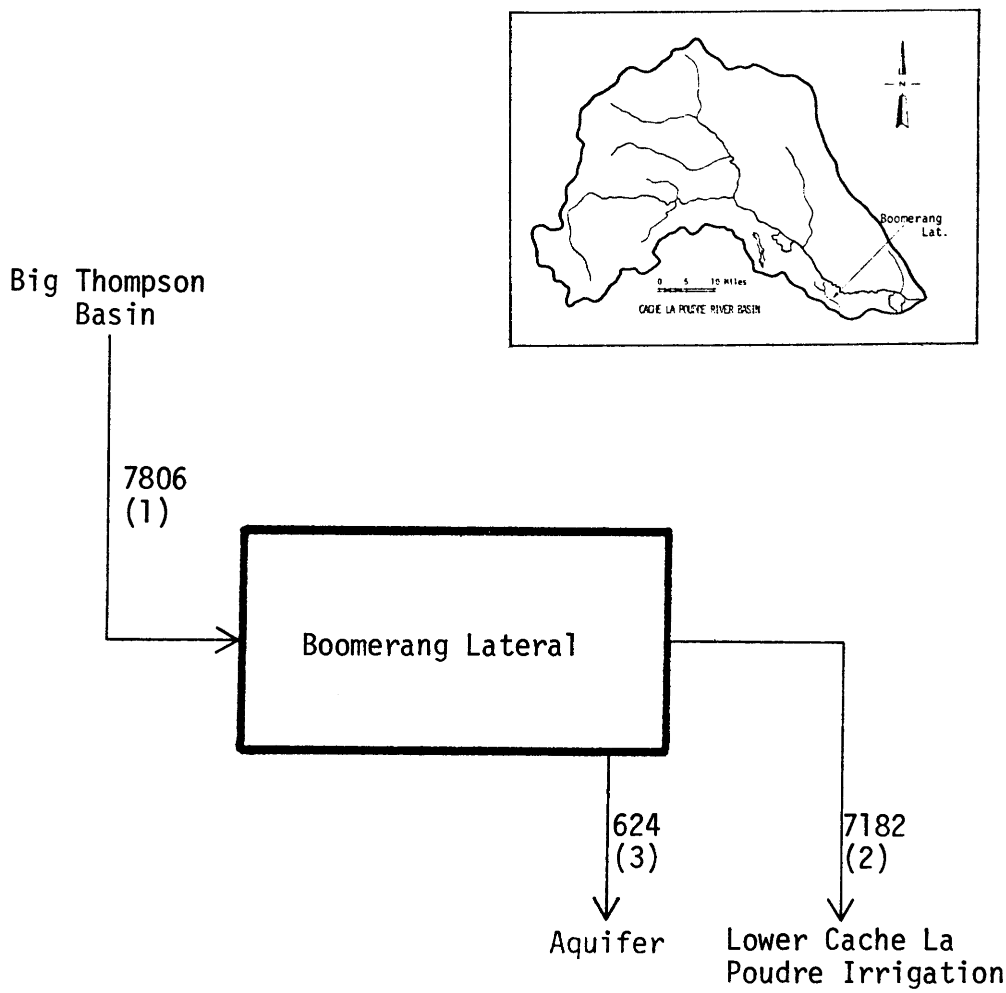
(1) Gerlek (1977).
(2) Computed through mass balance of Louden Ditch.
(3) Estimated as 8% of the inflows.

Figure E-31. Water Balance of "Louden Ditch."



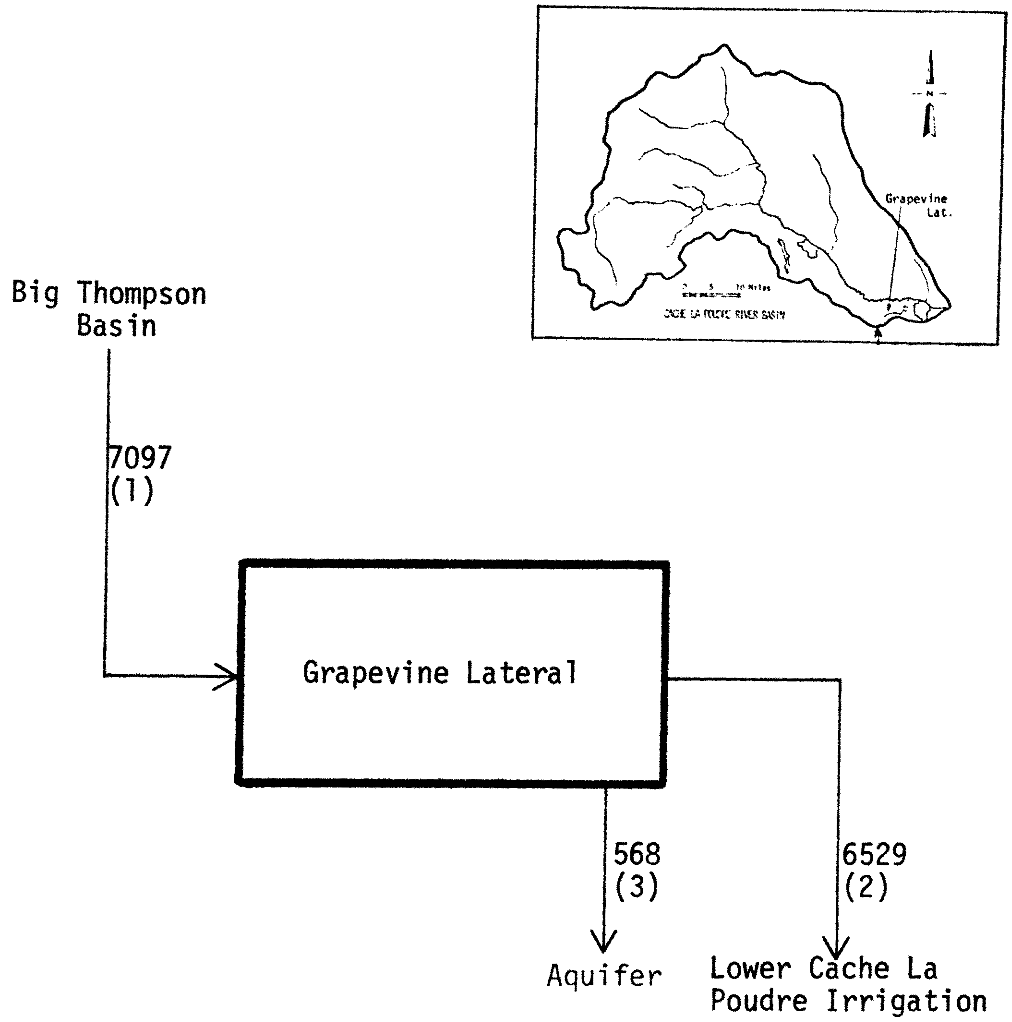
(1) Gerlek (1977).
(2) Computed through mass balance of Oklahoma Ditch.
(3) Estimated as 8% of the inflow.

Figure E-32. Water Balance of "Oklahoma Ditch."



(1) Gerlek (1977).
(2) Computed through mass balance of Boomerang Lateral.
(3) Estimated as 8% of the inflow.

Figure E-33. Water Balance of "Boomerang Lateral."

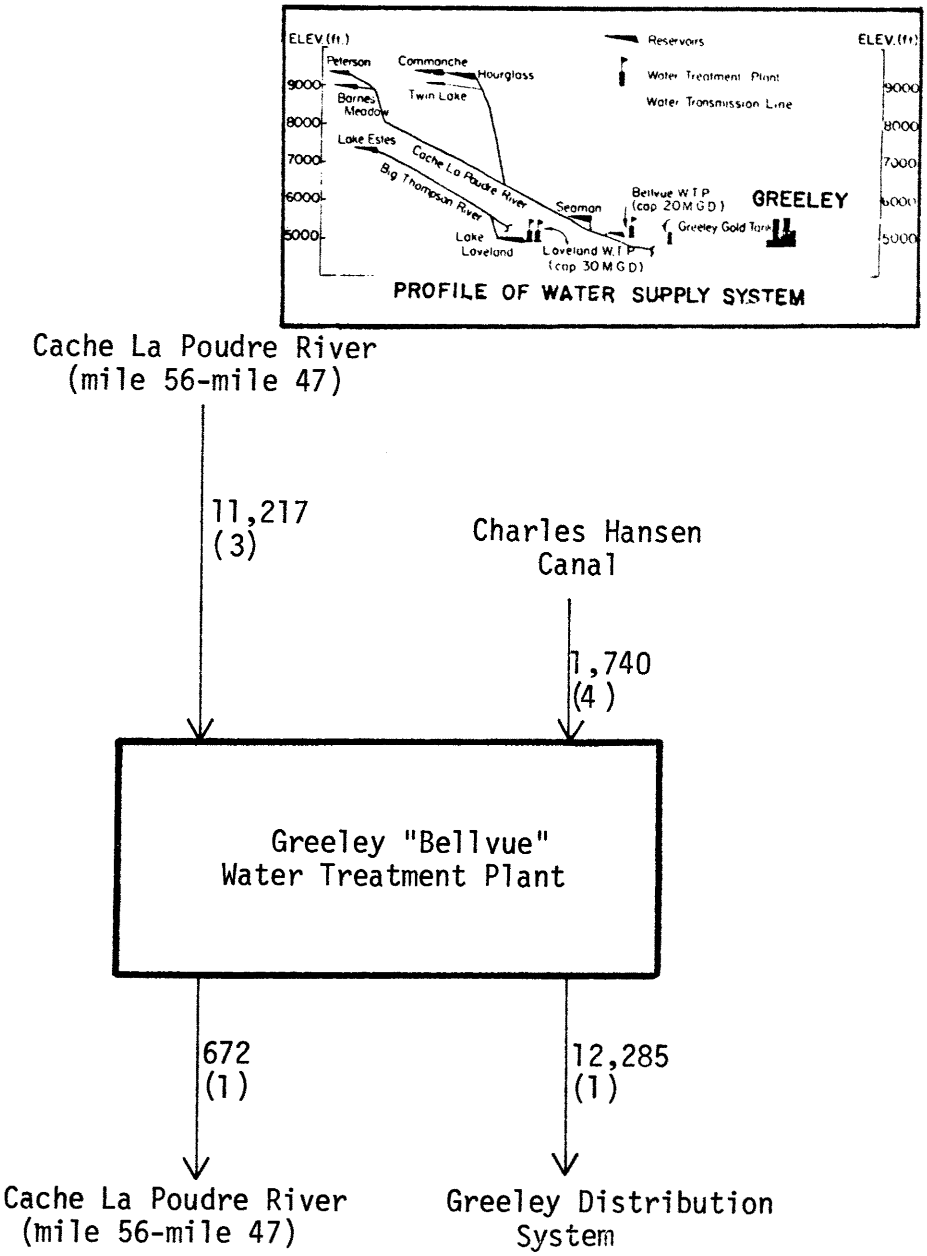


(1) Gerlek (1977).
(2) Computed through mass balance of Grapevine Lateral.
(3) Estimated as 8% of the inflow.

Figure E-24. Water Balance of "Grapevine Lateral."

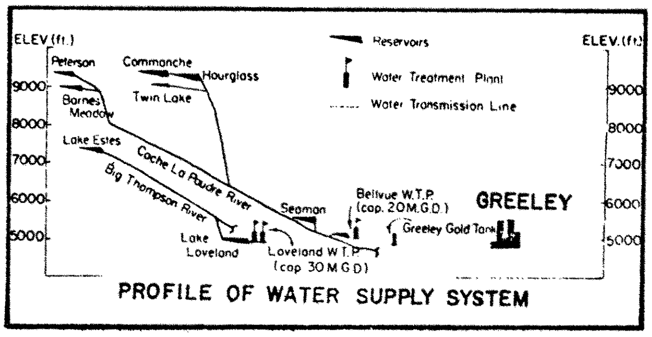
APPENDIX F

WATER BALANCES OF MUNICIPAL SECTOR



(1) Janonis (1977).
(2) The Water Commissioner for Cache La Poudre stated that part of this plant supply was conveyed through Charles Hansen Canal. The amount of 1,740 ac-ft was drawn from the "Summary of Delivery Operations for 1970, "Northern Colorado Water Conservancy District."
(3) Computed through mass balance. However, Janonis (1977) reported a total inflow of 12,957 ac-ft to this plant.

Figure F-1. Water Balance of "Greeley-Bellvue Water Treatment Plant."



Big Thompson
Basin

↓ 1,740 (1)

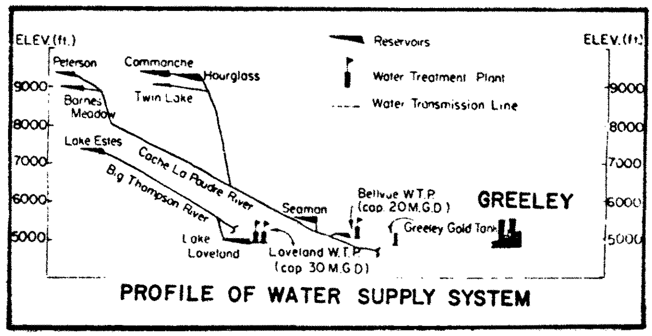
Greeley "Boyd Lake"
Water Treatment Plants

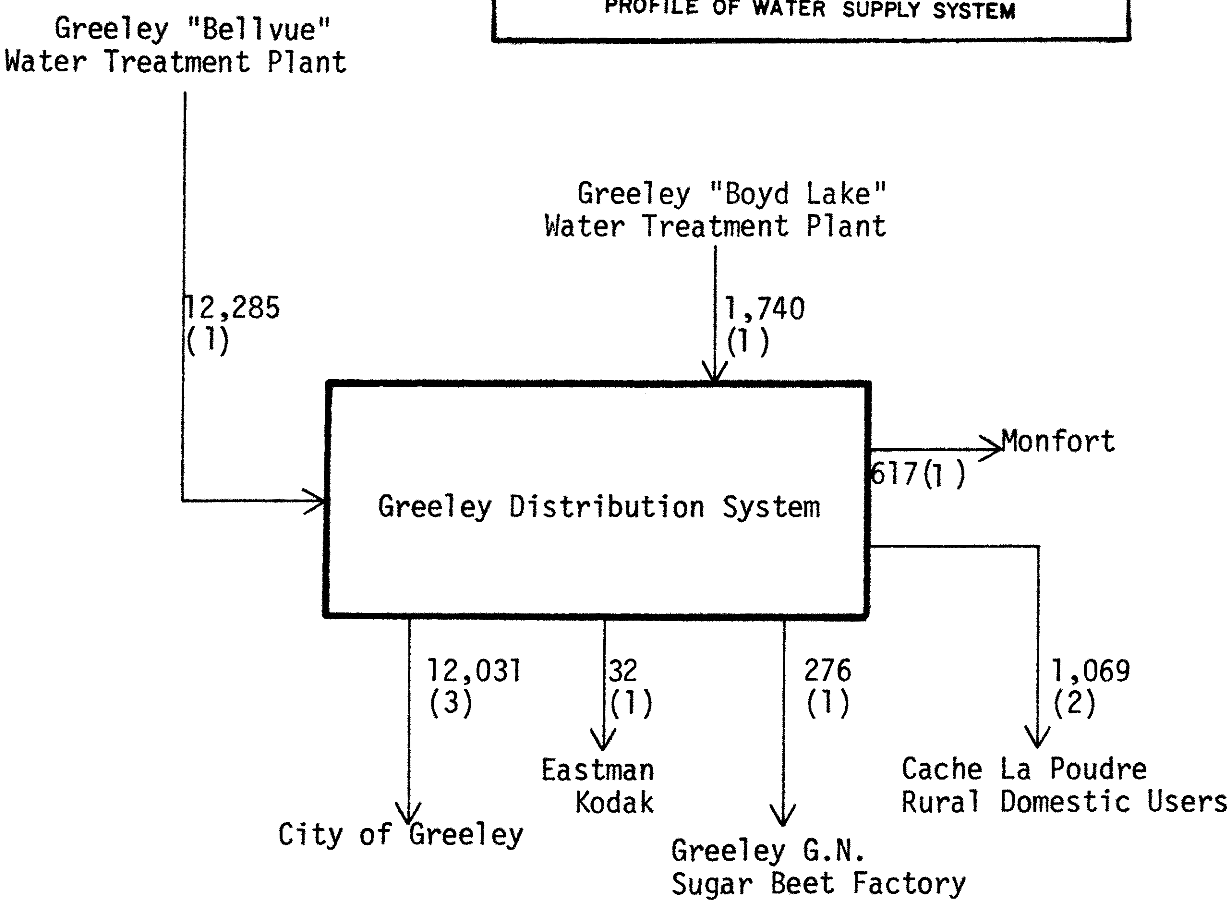
↓ 1,740 (1)

Greeley Distribution
System

(1) Janonis (1977).

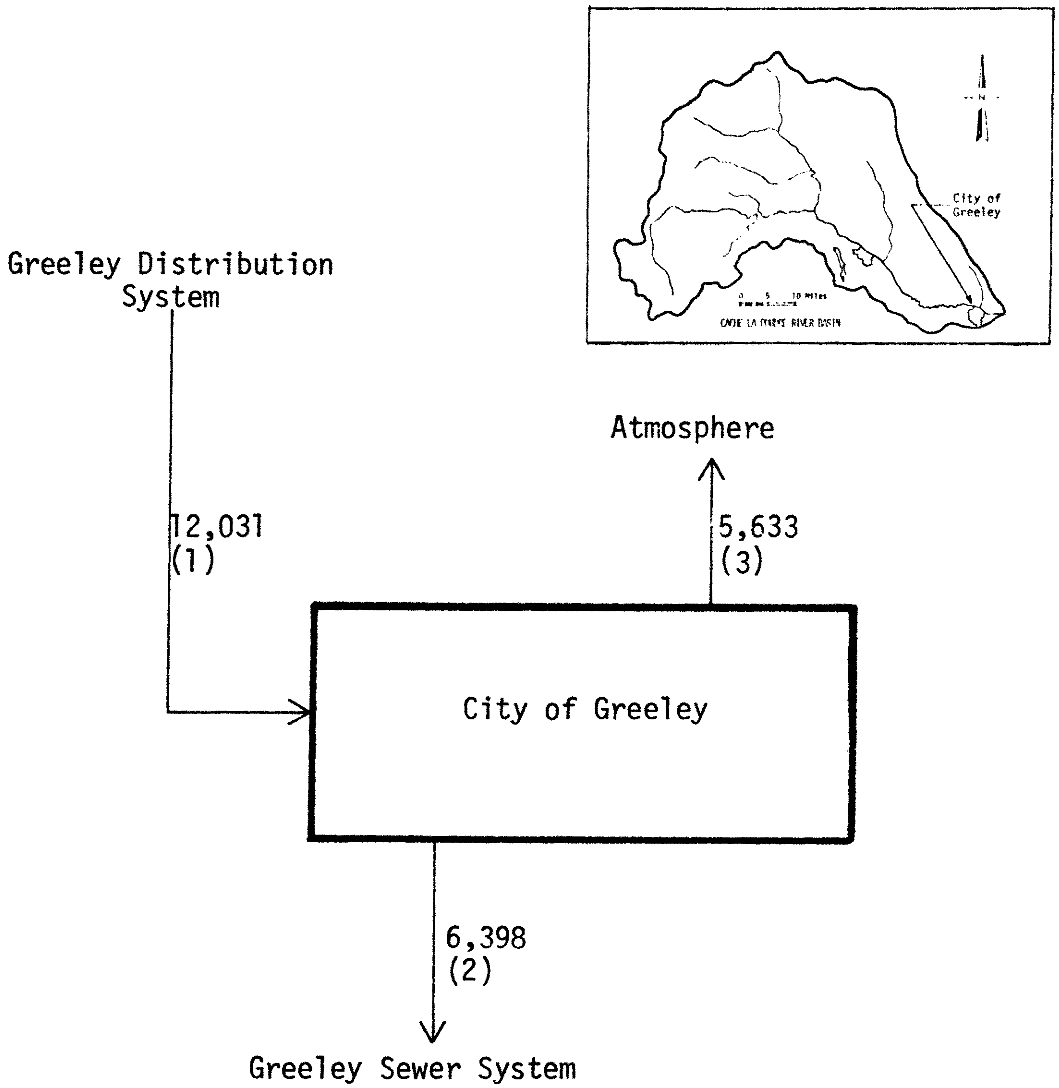
Figure F-2. Water Balance of "Greeley-Boyd Lake Water Treatment Plants."





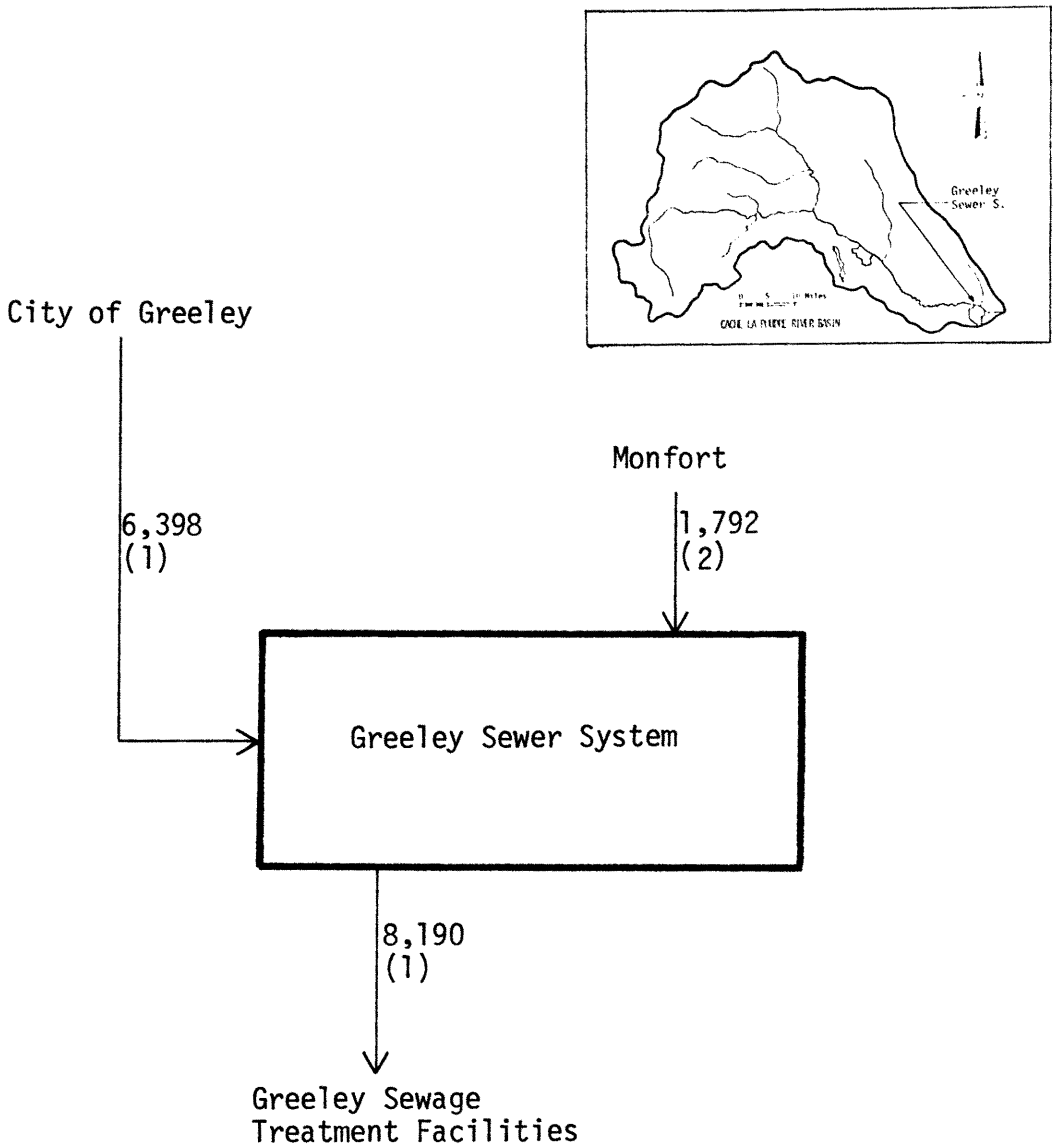
(1) Janonis (1977).
(2) See paragraph 5.2.3.
(3) Computed through mass balance of Greeley Distribution System.

Figure F-3. Water Balance of "Greeley Distribution System."



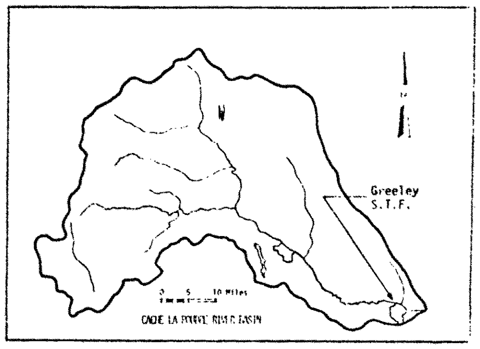
(1) Computed through mass balance of Greeley Distribution System.
(2) Computed through mass balance of Greeley Sewer System.
(3) Computed through mass balance of City of Greeley.

Figure F-4. Water Balance of "City of Greeley."



(1) Computed through mass balance of Greeley Sewer System.
(2) Janonis (1977).

Figure F-5. Water Balance of "Greeley Sewer System."



Greeley
Sewer System

8,190
(1)

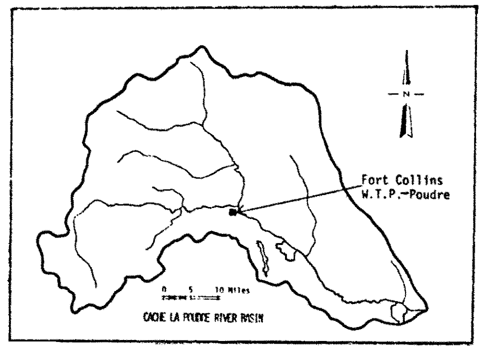
Greeley Sewage
Treatment Facilities

8,190
(1)

Cache La Poudre River
(mile 21-mile 00)

(1) Janonis (1977).

Figure F-6. Water Balance of "Greeley Sewage Treatment Facilities."



Cache La Poudre River
(mile 61-mile 56)

9,701
(1)

Fort Collins Water
Treatment Plant- Poudre

784
(1)

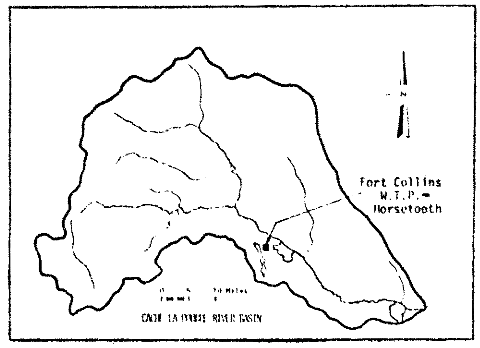
8,917
(1)

Cache La Poudre River
(mile 61-mile 56)

Fort Collins
Distribution System

(1) Janonis (1977).

Figure F-7. Water Balance of "Fort Collins Water Treatment Plant - Poudre."



Dixon Feeder Canal

2,506
(1)

Atmosphere

276
(3)

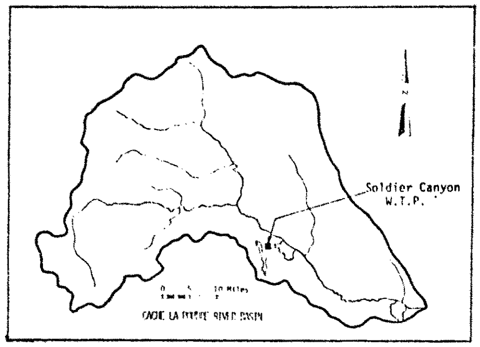
Fort Collins Water
Treatment Plant- Horsetooth

2,230
(2)

Fort Collins
Distribution System

(1) Northern Colorado Water Conservancy District, "Summary of Delivery Operations for 1970."
(2) Janonis (1977).
(3) Computed through mass balance of this plant.

Figure F-8. Water Balance of "Fort Collins Water Treatment Plant - Horsetooth."



Dixon Feeder Canal

3,034
(1)

Soldier Canyon
Water Treatment Plant

2,887
(3)

147
(2)

Cache La Poudre
Rural Domestic Users

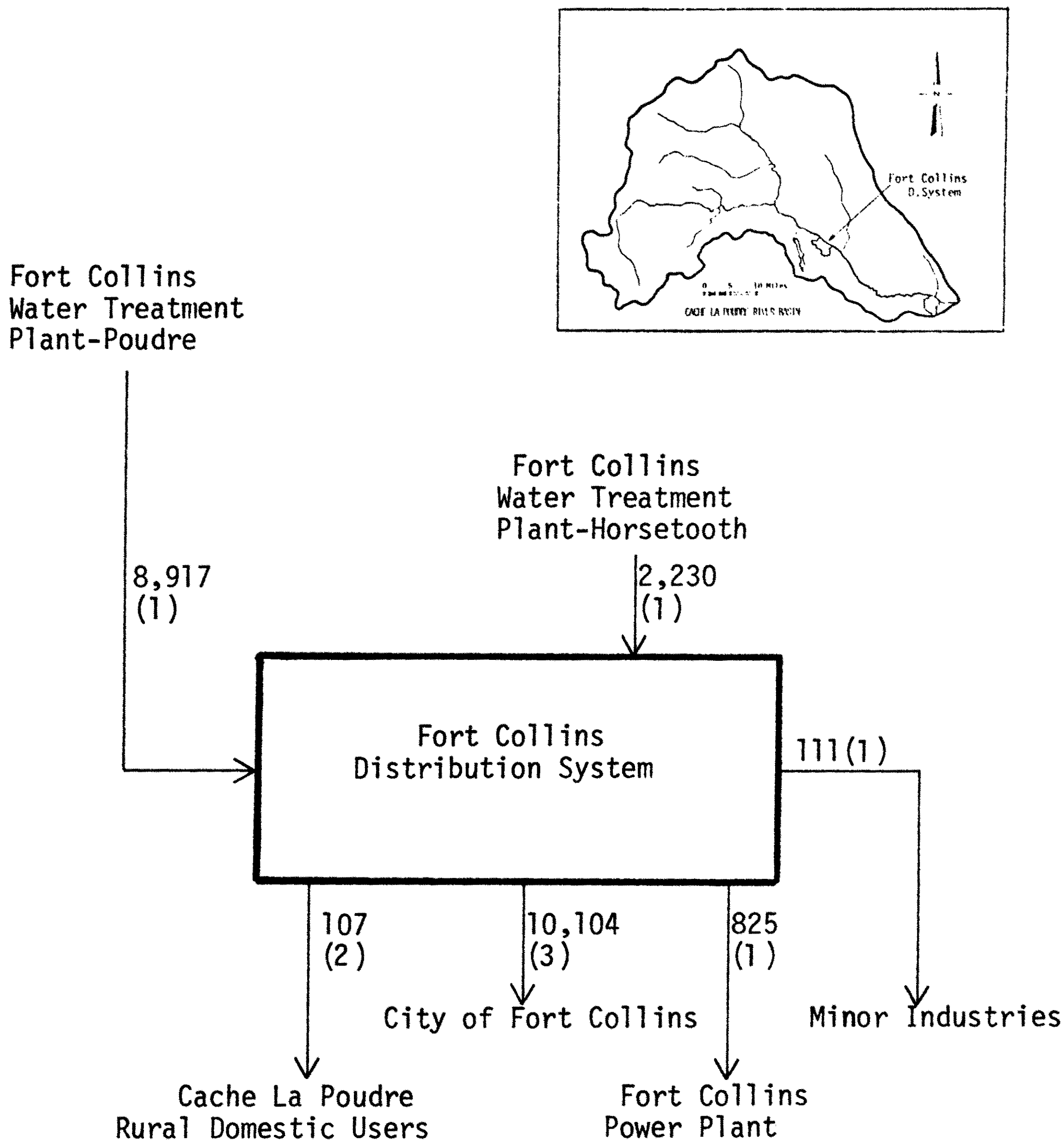
Eaton G.W.
Sugar Beet Factory

(1) Computed through mass balance of Soldier Canyon Water Treatment Plant.

(2) Patterson (1977) reported that the town of Eaton supplied 147 ac-ft to Eaton G.W. Sugar Beet Factory. Actually, this water originated from the Soldier Canyon Plant.

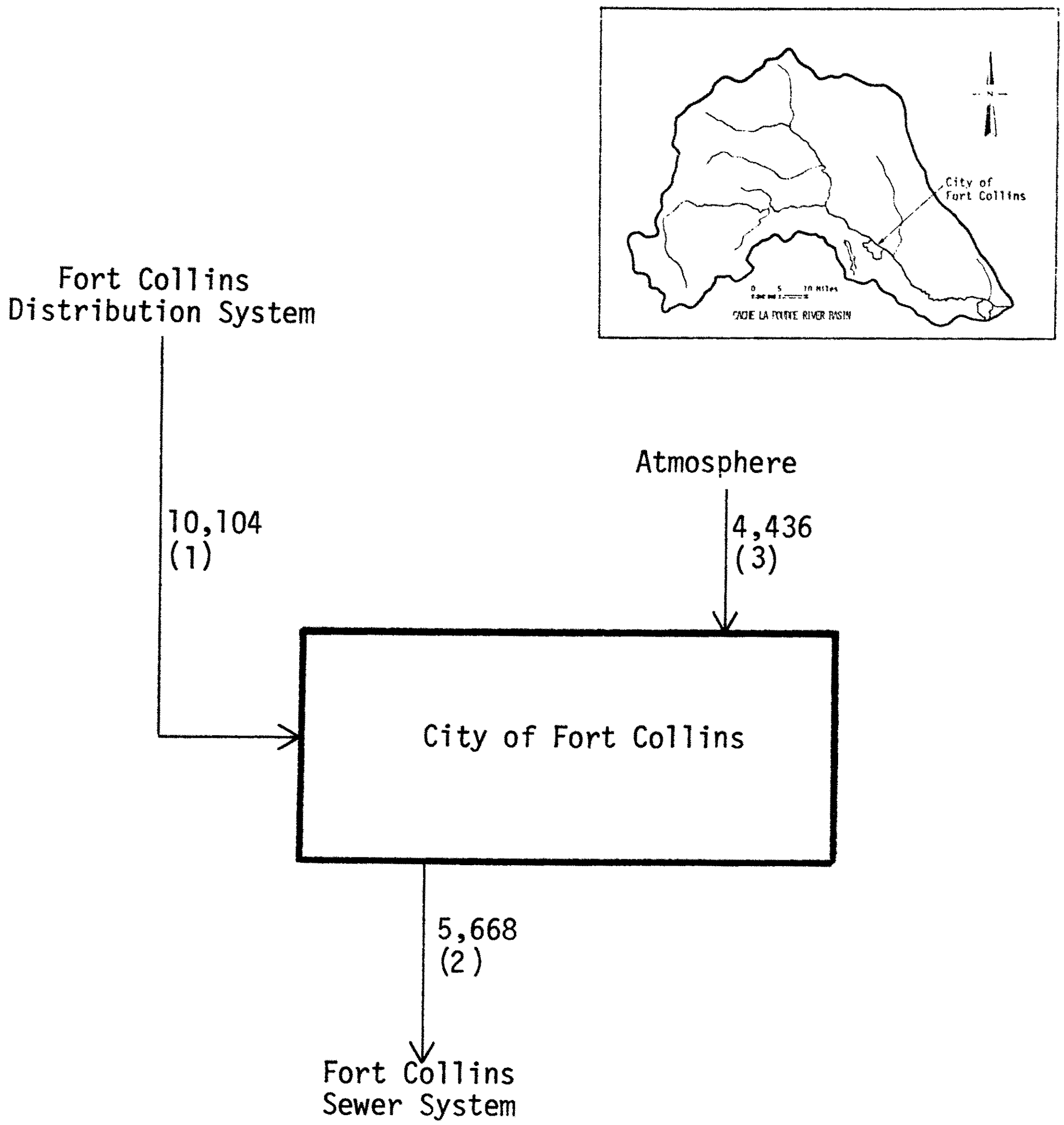
(3) Duane Davis, Manager of the plant, reported a total supply of 3,040 ac-ft, 3,040-147=2,887.

Figure F-9. Water Balance of "Soldier Canyon Water Treatment Plant."



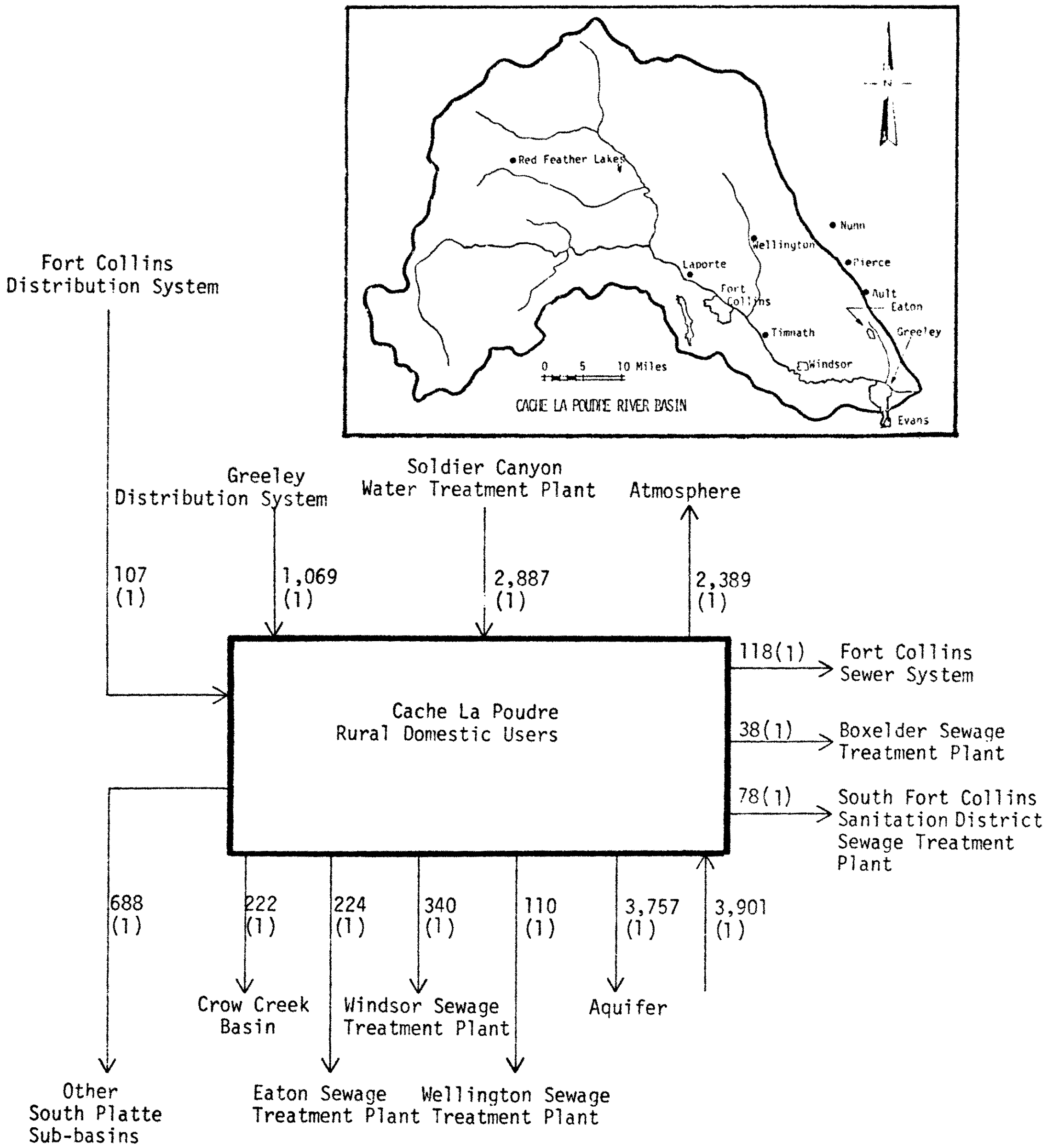
(1) Janonis (1977).
(2) See paragraph 5.2.3.
(3) Mass balance of Fort Collins Distribution System.

Figure F-10. Water Balance of "Fort Collins Distribution System."



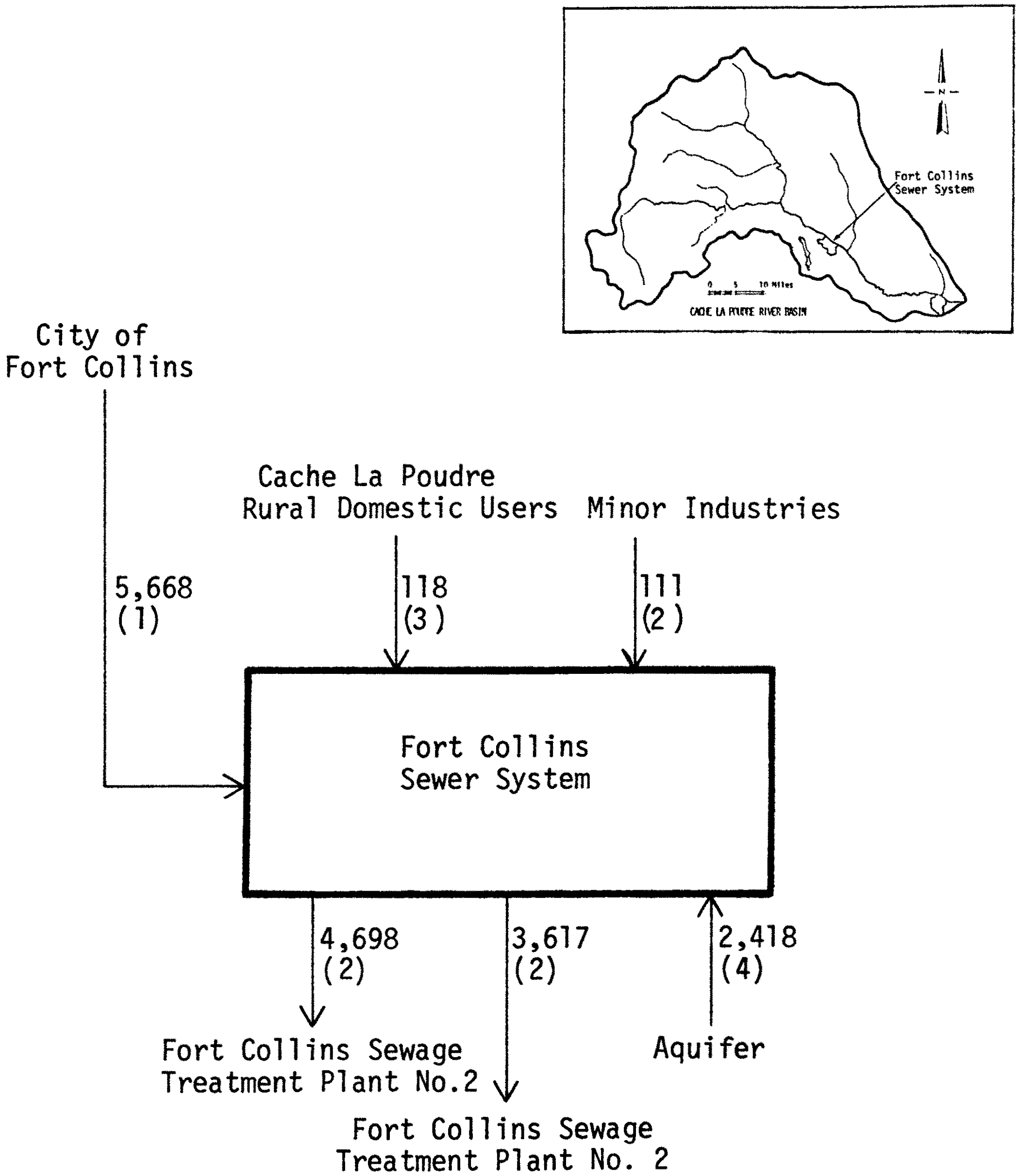
(1) Mass balance of Fort Collins Distribution System.
(2) Mass balance of Fort Collins Sewer System.
(3) Mass balance of City of Fort Collins.

Figure F-11. Water Balance of "City of Fort Collins."



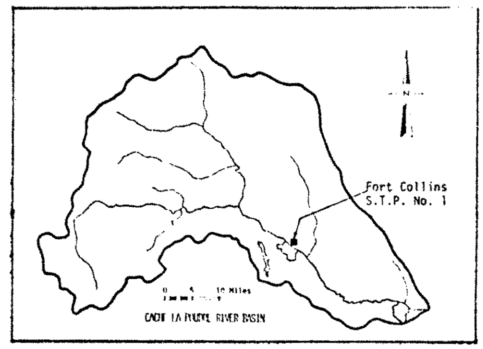
(1) All these amounts are explained and justified in paragraph 5.2.3.

Figure F-12. Water Balance of "Cache La Poudre Rural Domestic Users."



(1) Mass balance of Fort Collins Sewer System.
(2) Janonis (1977).
(3) See paragraph 5.2.3.
(4) See paragraph 5.2.1.

Figure F-13. Water Balance of "Fort Collins Sewer System."



Fort Collins
Sewer System

4,698
(1)

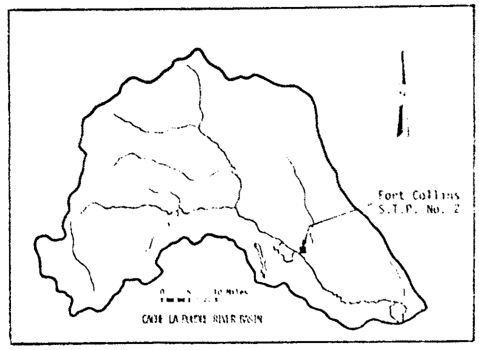
Fort Collins
Sewage Treatment Plant No. 1

4,698
(1)

Cache La Poudre River
(mile 47-mile 21)

(1) Janonis (1977).

Figure F-14. Water Balance of "Fort Collins Sewage Treatment Plant No. 1."



Fort Collins
Sewer System

3,617
(1)

Fort Collins
Sewage Treatment Plant No. 2

1,893
(2)

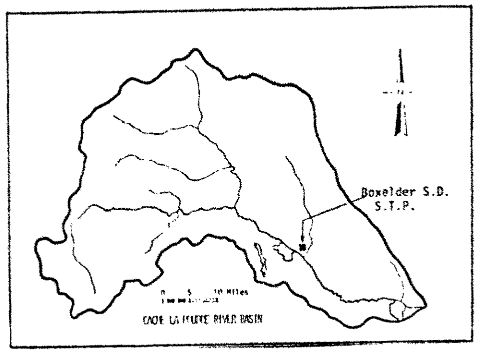
1,724
(2)

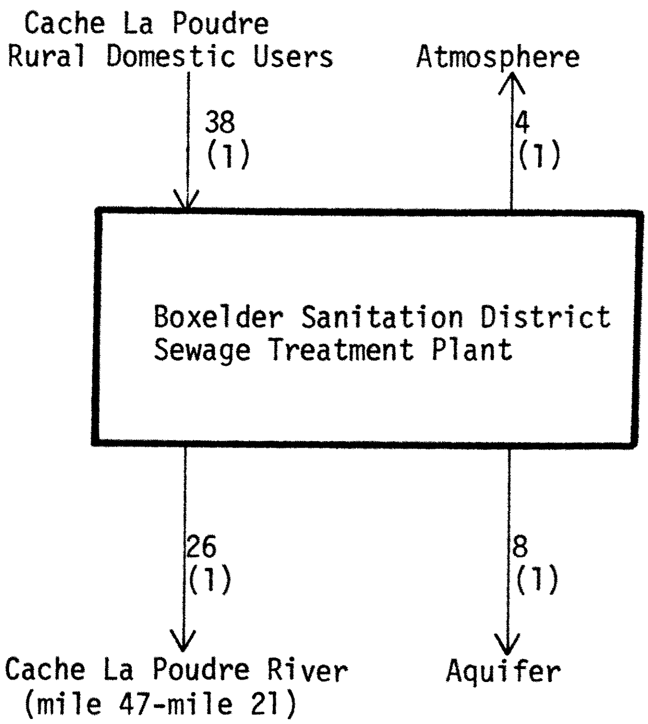
Fossil Creek
Reservoir Inlet

Cache La Poudre River
(mile 47-mile 21)

(1) Janonis (1977).
(2) See paragraph 5.2.1.

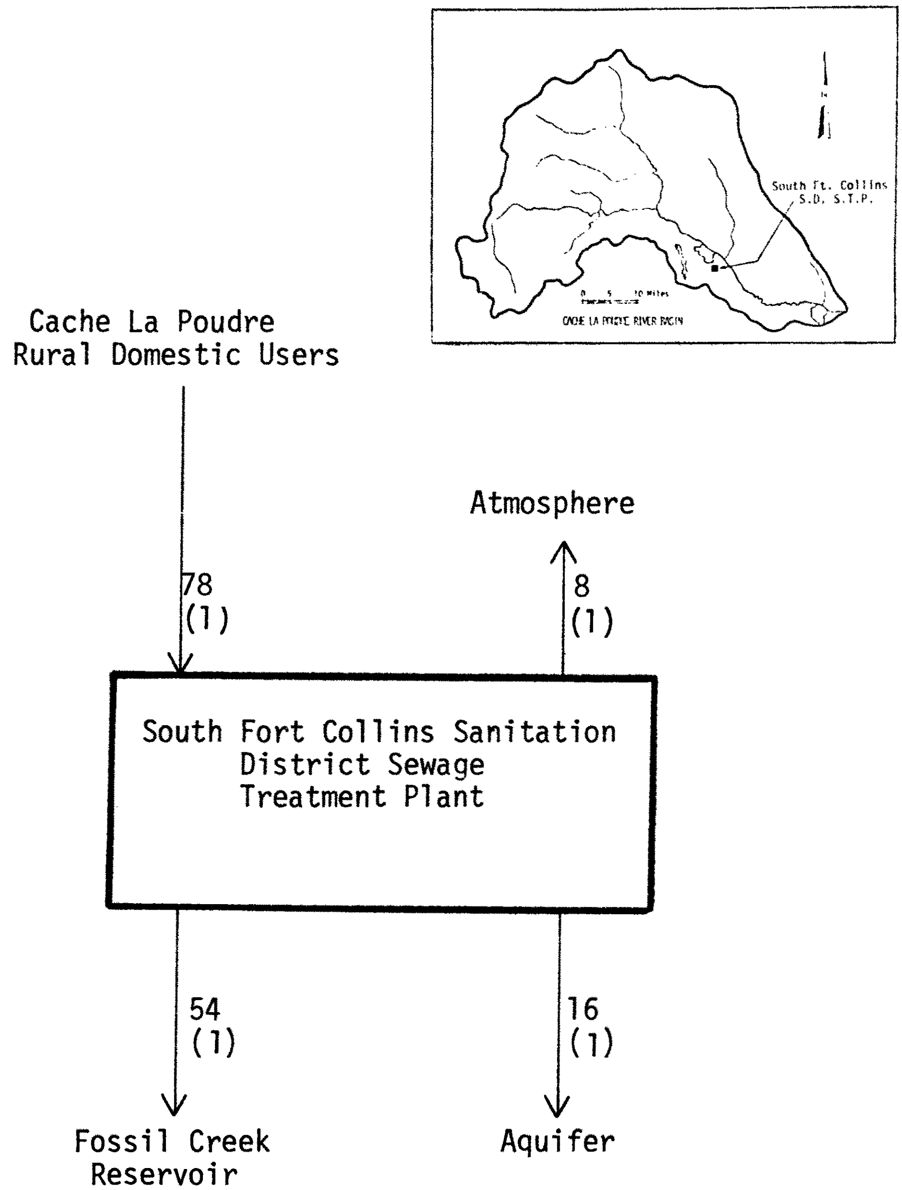
Figure F-15. Water Balance of "Fort Collins Sewage Treatment Plant No. 2."





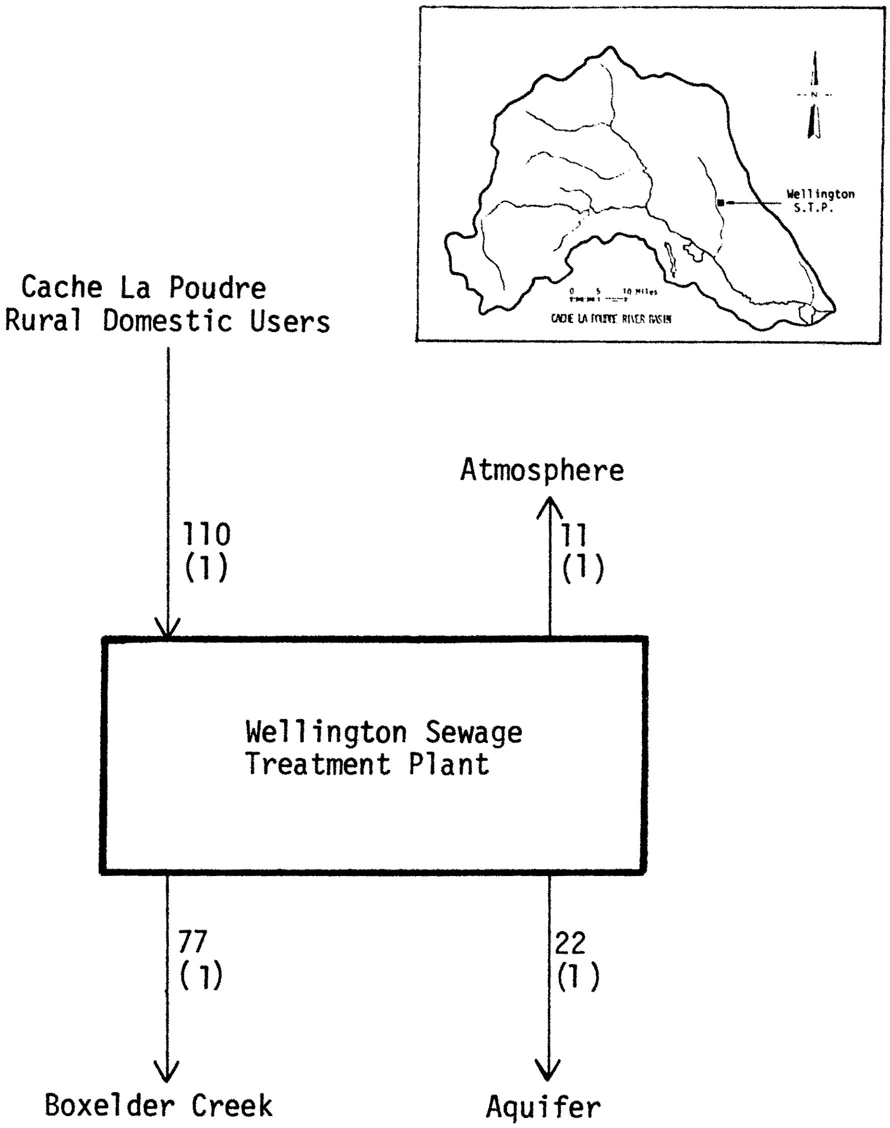
(1) See paragraph 5.2.3.

Figure F-16. Water Balance of "Boxelder Sanitation District Sewage Treatment Plant."



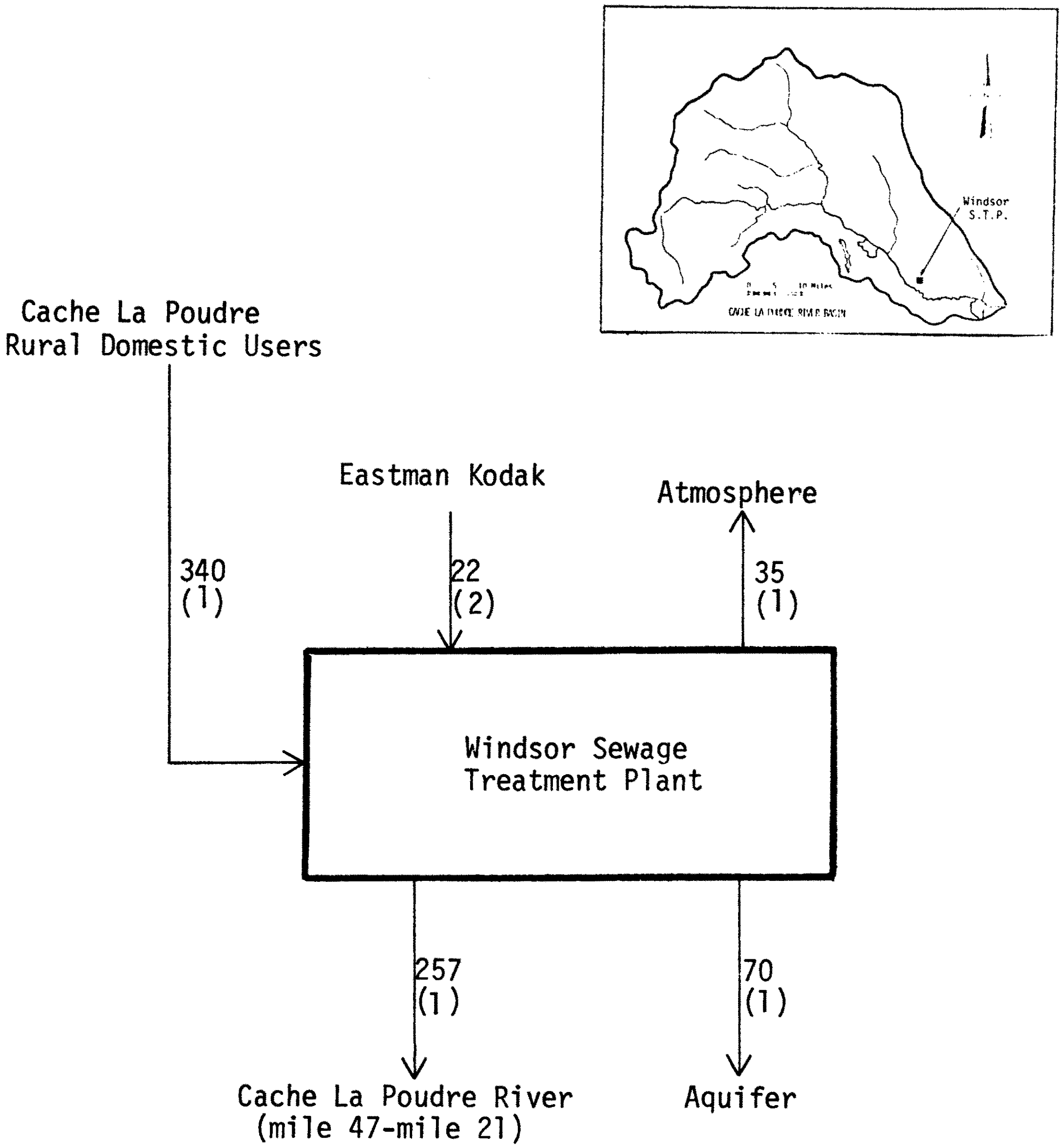
(1) See paragraph 5.2.3.

Figure F-17. Water Balance of "South Fort Collins Sanitation District Sewage Treatment Plant."



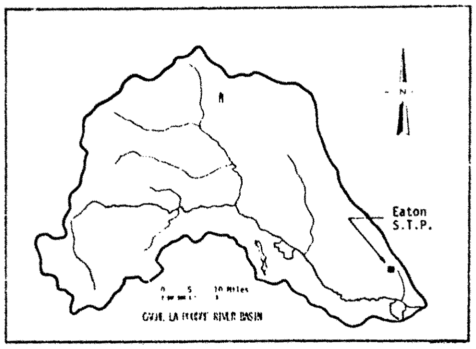
(1) See paragraph 5.2.3.

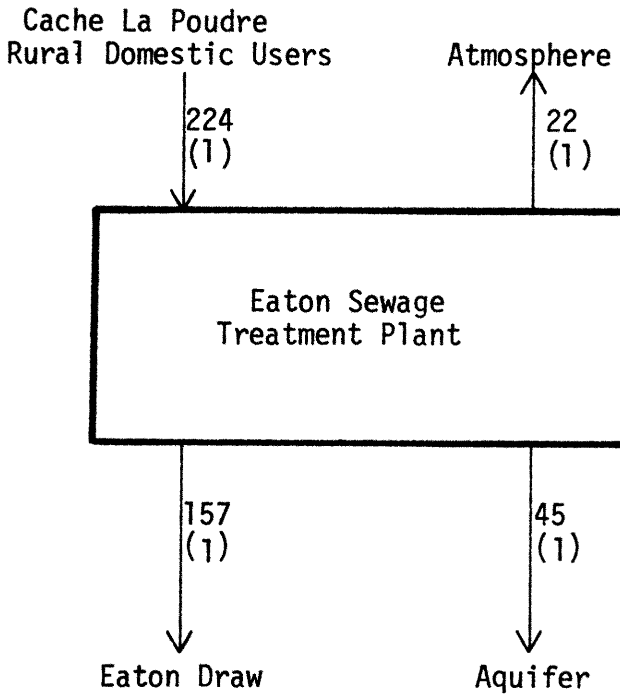
Figure F-18. Water Balance of "Wellington Sewage Treatment Plant."



(1) See paragraph 5.2.3.
(2) Janonis (1977).

Figure F-19. Water Balance of "Windsor Sewage Treatment Plant."



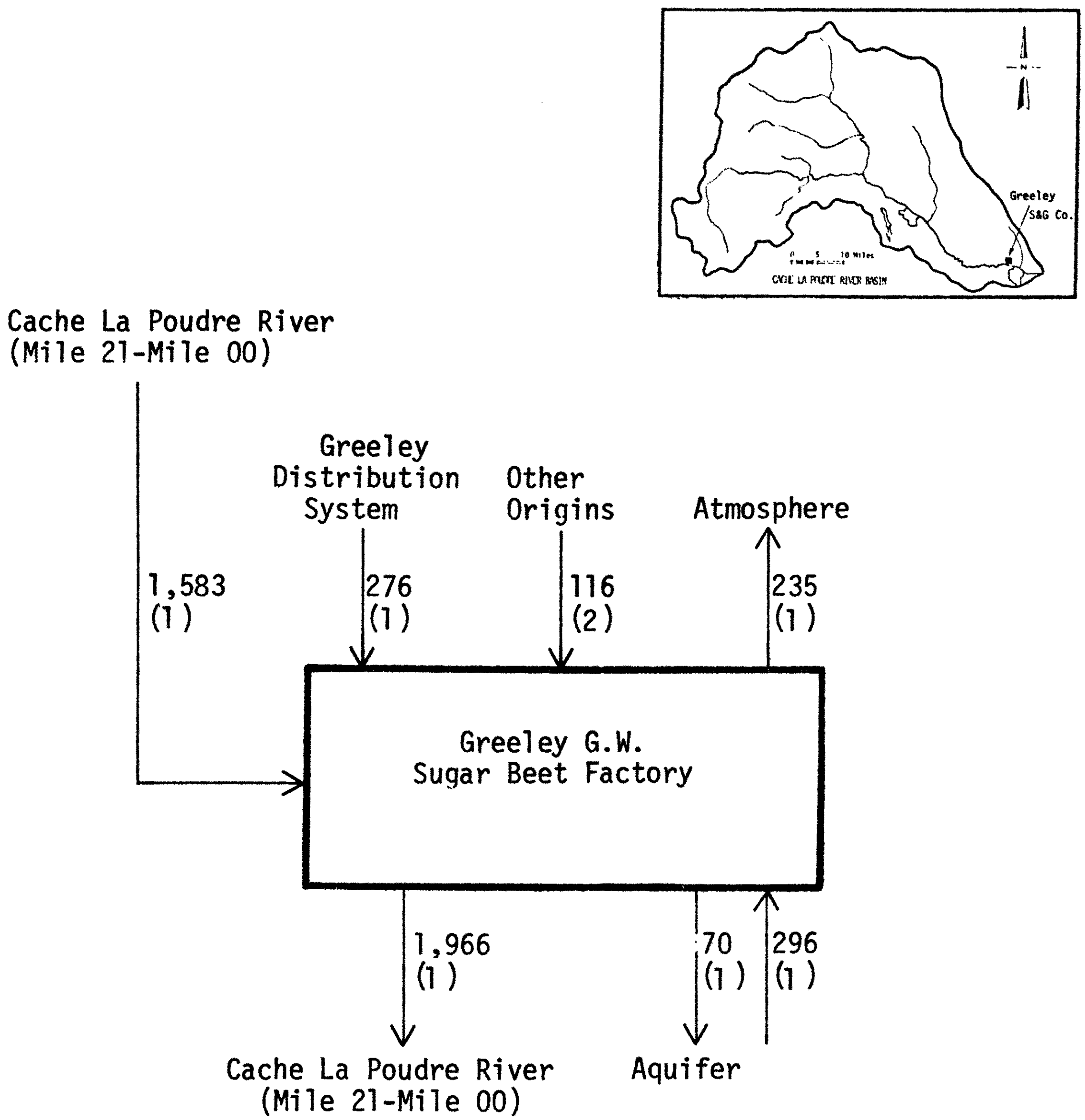


(1) See paragraph 5.2.3.

Figure F-20. Water Balance of "Eaton Sewage Treatment Plant."

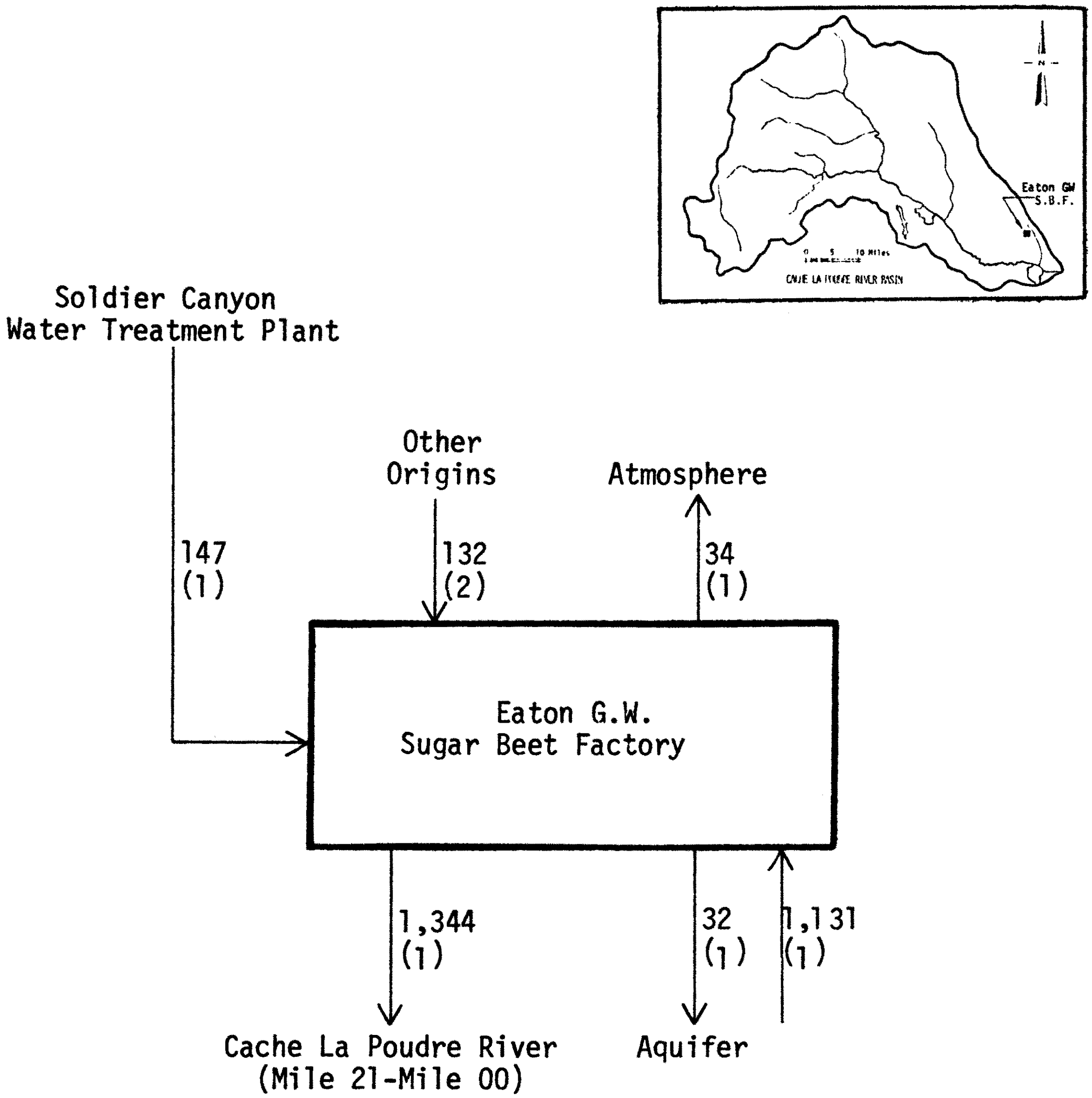
APPENDIX G

WATER BALANCES OF INDUSTRIAL SECTOR



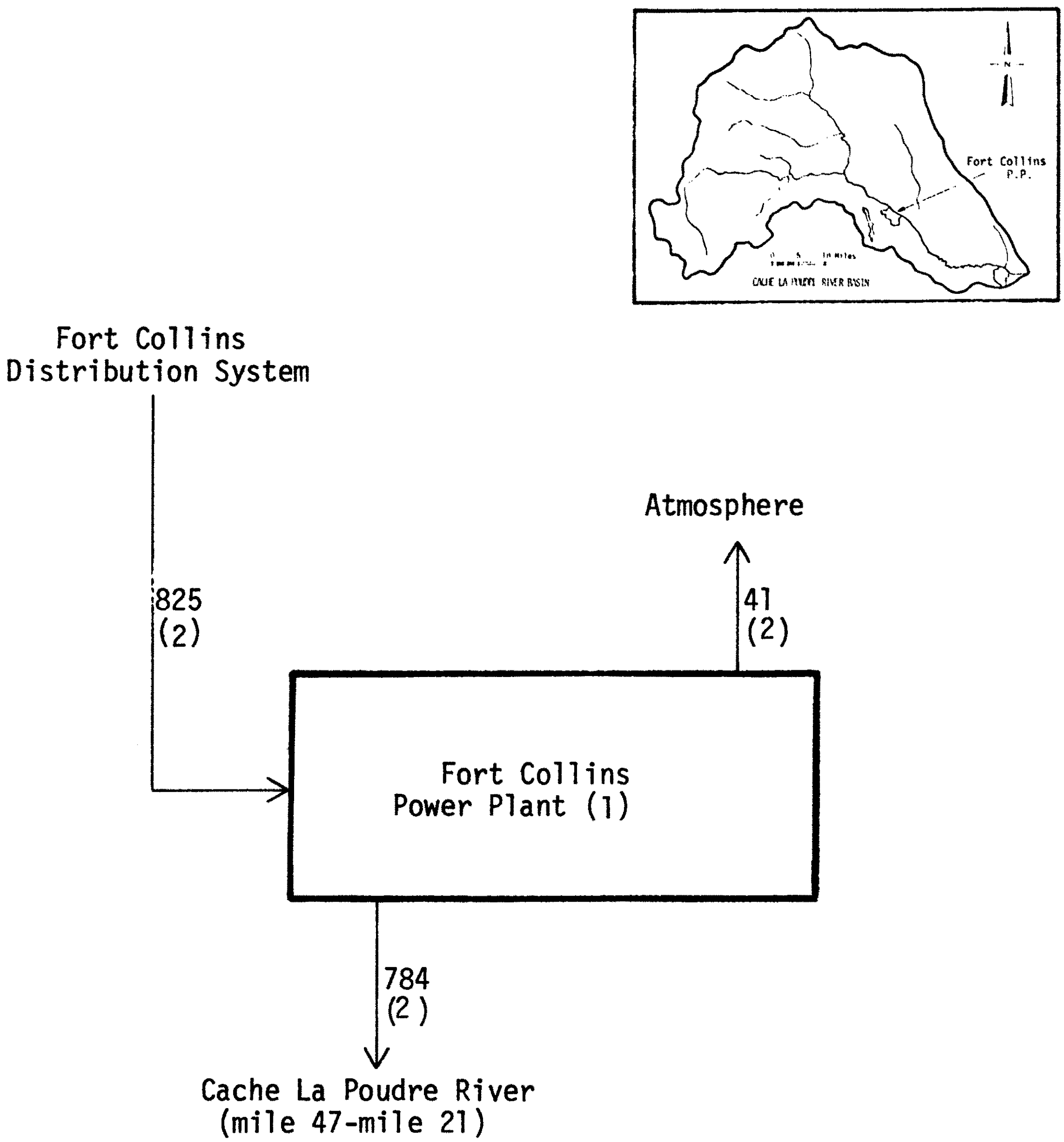
(1) Paterson (1977).
(2) Computed through mass balance of Greeley G.W. Sugar Beet Factory.

Figure G-1. Water Balance of "Greeley G. W. Sugar Beet Factory."



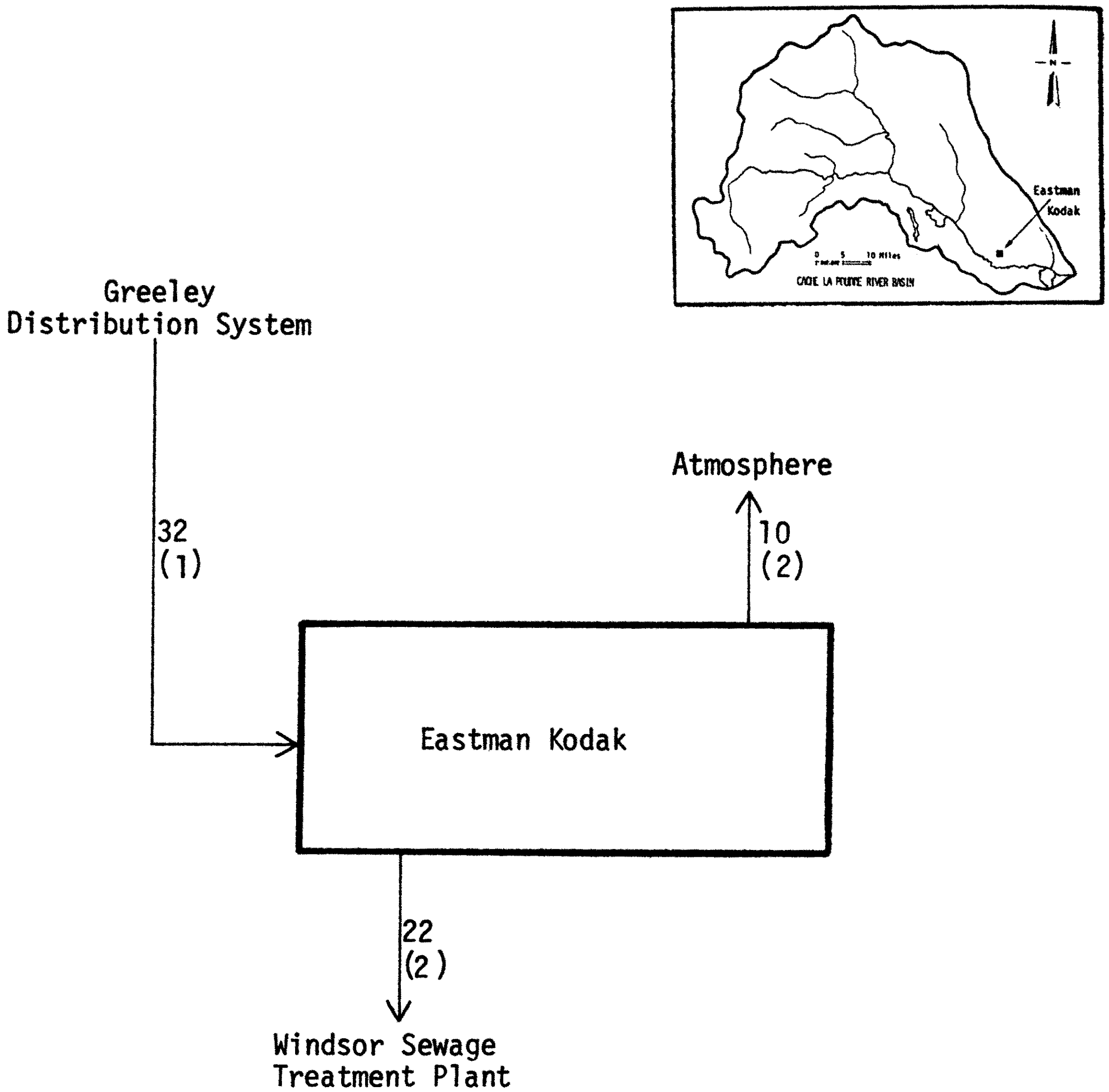
(1) Patterson (1977).
(2) Computed through mass balance of Eaton G.W. Sugar Beet Factory.

Figure G-2. Water Balance of "Eaton G. W. Sugar Beet Factory."



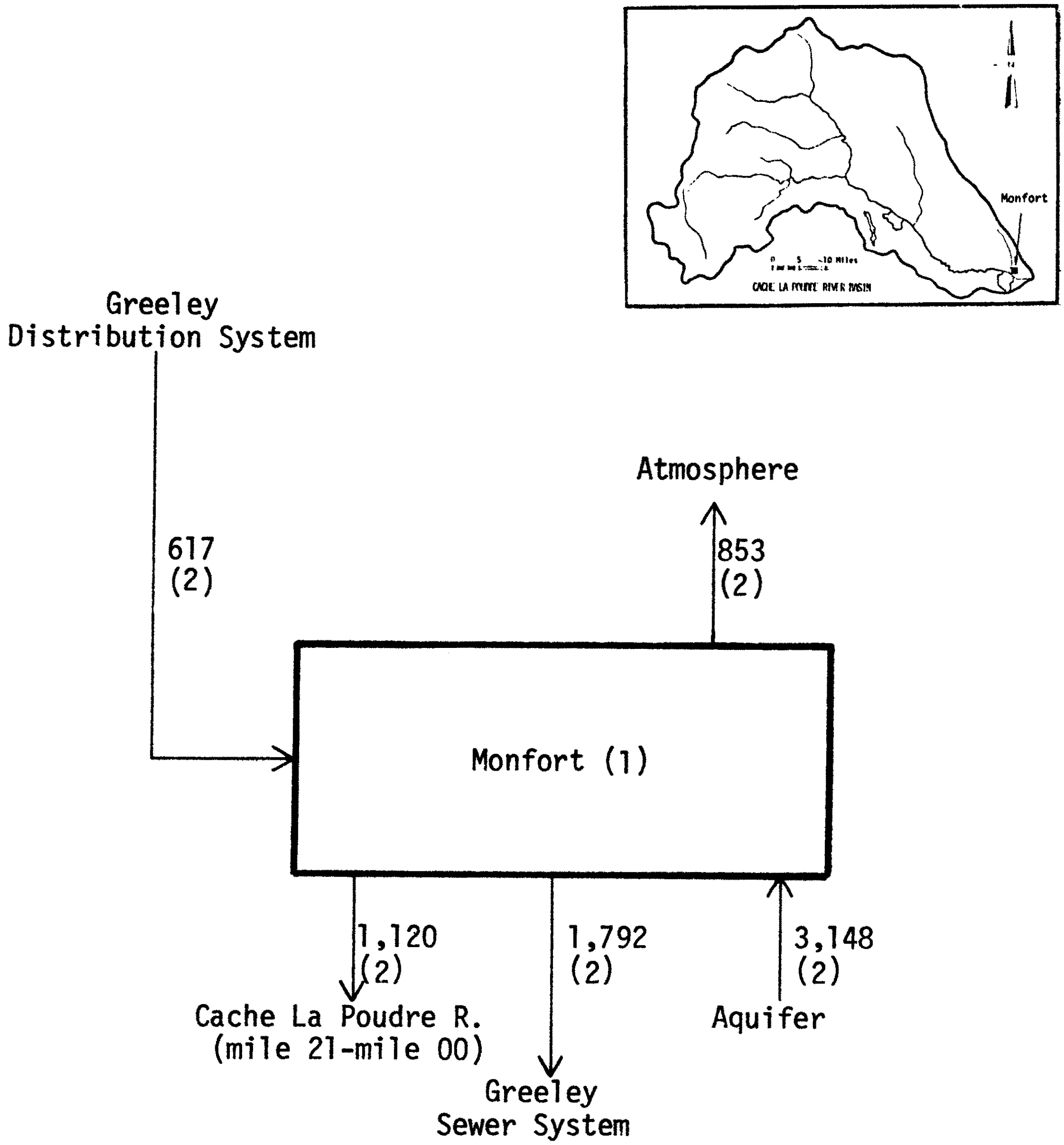
(1) The Fort Collins Power Plant is not active anymore.
(2) Janonis (1977).

Figure G-3. Water Balance of "Fort Collins Power Plant."



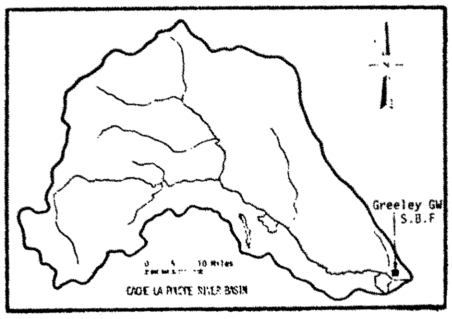
(1) Janonis (1977).
(2) The destination of the Kodak used waters was evaporation (30%) and Windsor Sewage Treatment Plant (70%).

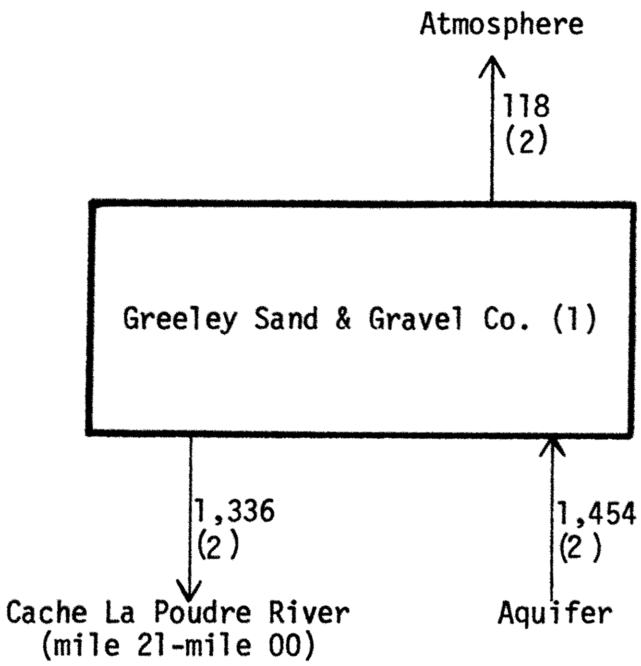
Figure G-4. Water Balance of "Eastman Kodak."



(1) Since 1973 Monfort has its own sewage treatment plant discharging out of Cache La Poudre Basin.
(2) Patterson (1977) and Janonis (1977).

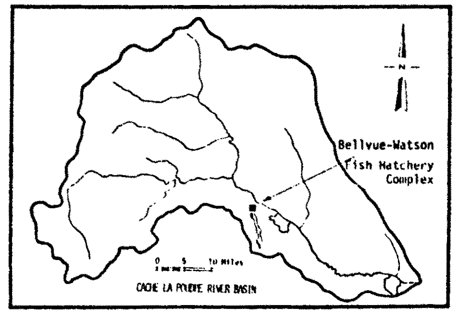
Figure G-5. Water Balance of "Monfort."

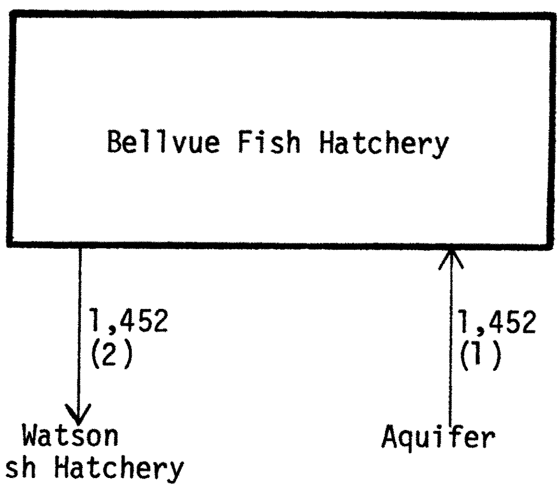




(1) The water transfer from "Aquifer" to "Greeley Sand & Gravel Co." is essentially due to the dewatering operations of the pits.
(2) Patterson (1977).

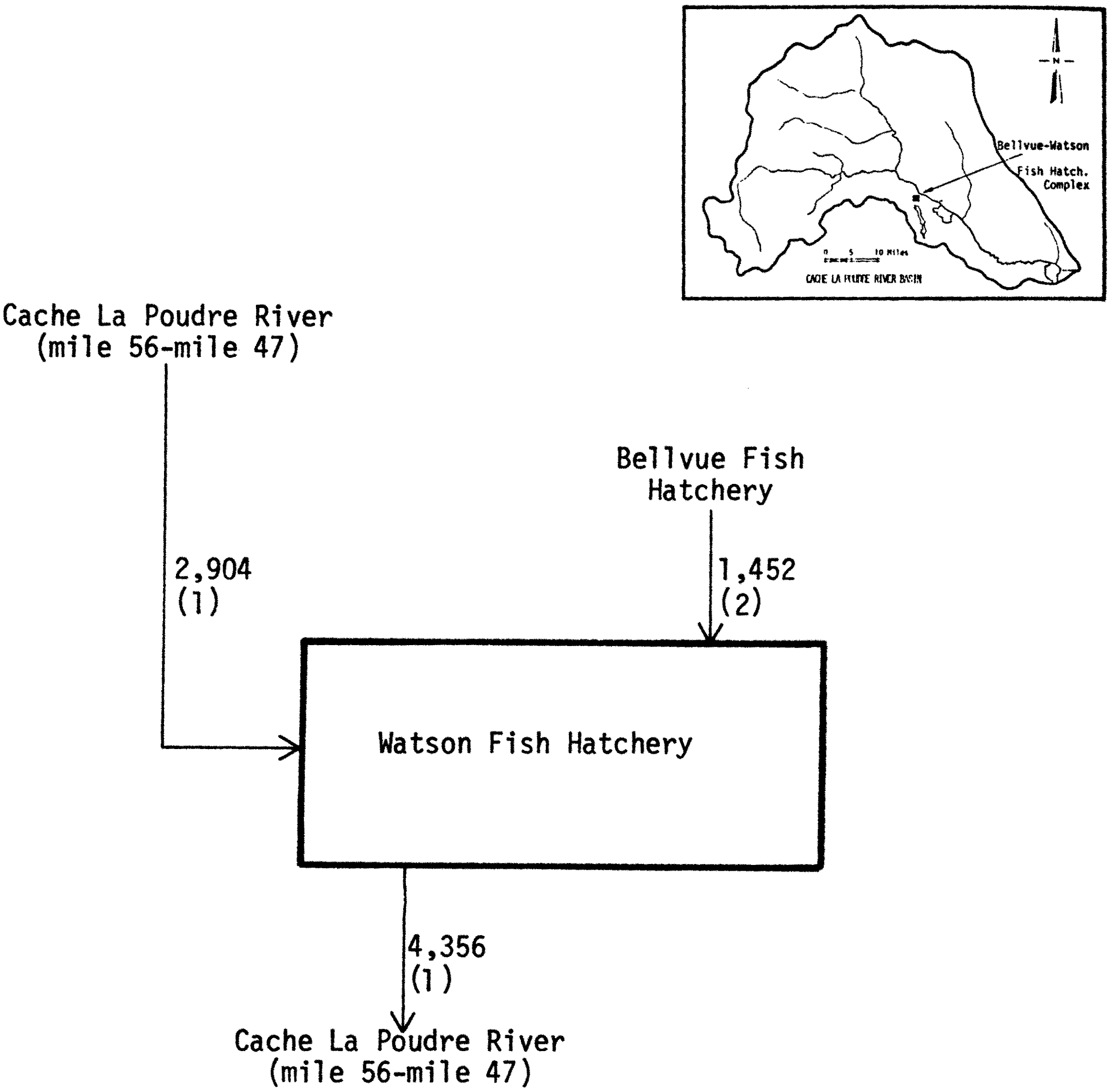
Figure G-6. Water Balance of "Greeley Sand & Gravel Co."





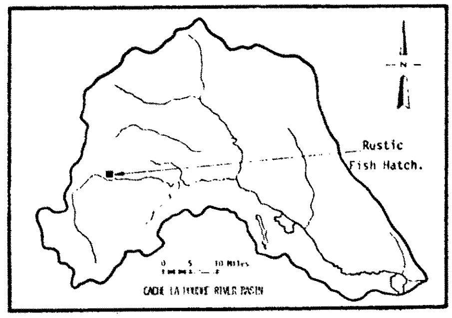
(1) Patterson (1977).
(2) This amount of water was first used at Bellvue Fish Hatchery and then transferred to Watson Fish Hatchery for reuse (Patterson 1977).

Figure G-7. Water Balance of "Bellvue Fish Hatchery."



(1) Patterson (1977).
(2) This amount of water was first used at Bellvue Fish Hatchery and then transferred to Watson Fish Hatchery for reuse (Patterson, 1977).

Figure G-8. Water Balance of "Watson Fish Hatchery."



Cache La Poudre River
(source-mile 94)

4,356
(1)

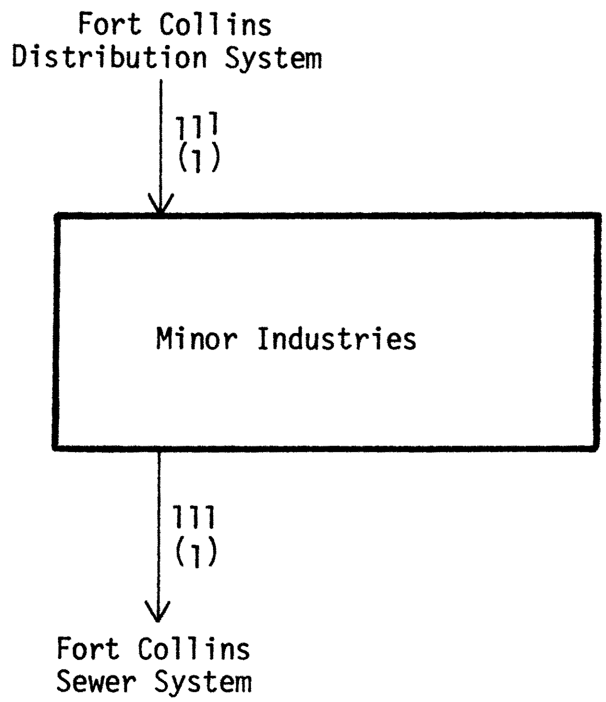
Rustic Fish Hatchery

4,356
(1)

Cache La Poudre River
(source-mile 94)

(1) Patterson (1977).

Figure G-9. Water Balance of "Rustic Fish Hatchery."

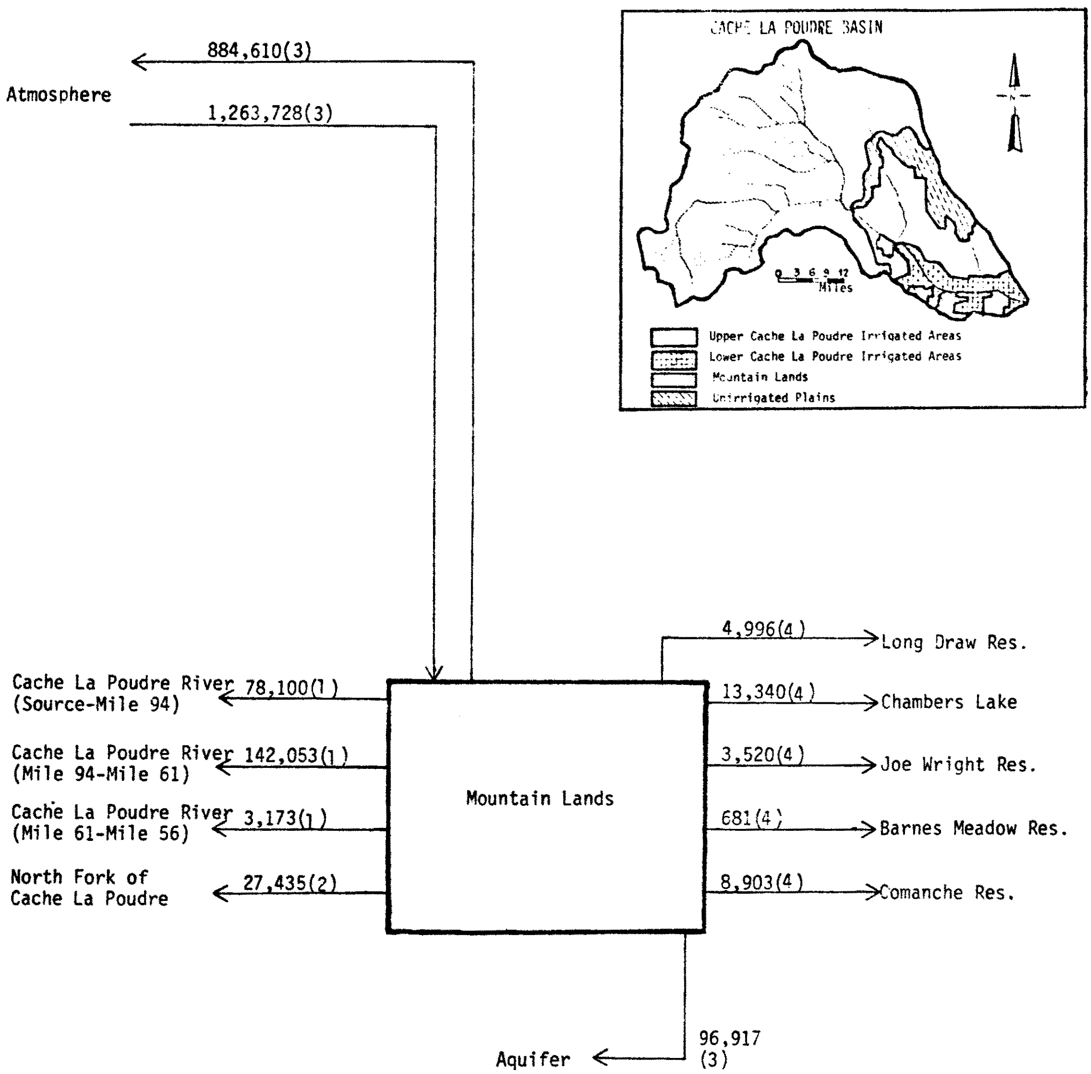


(1) Janonis (1977). See also paragraph 5.3.2.

Figure G-10. Water Balance of "Minor Industries."

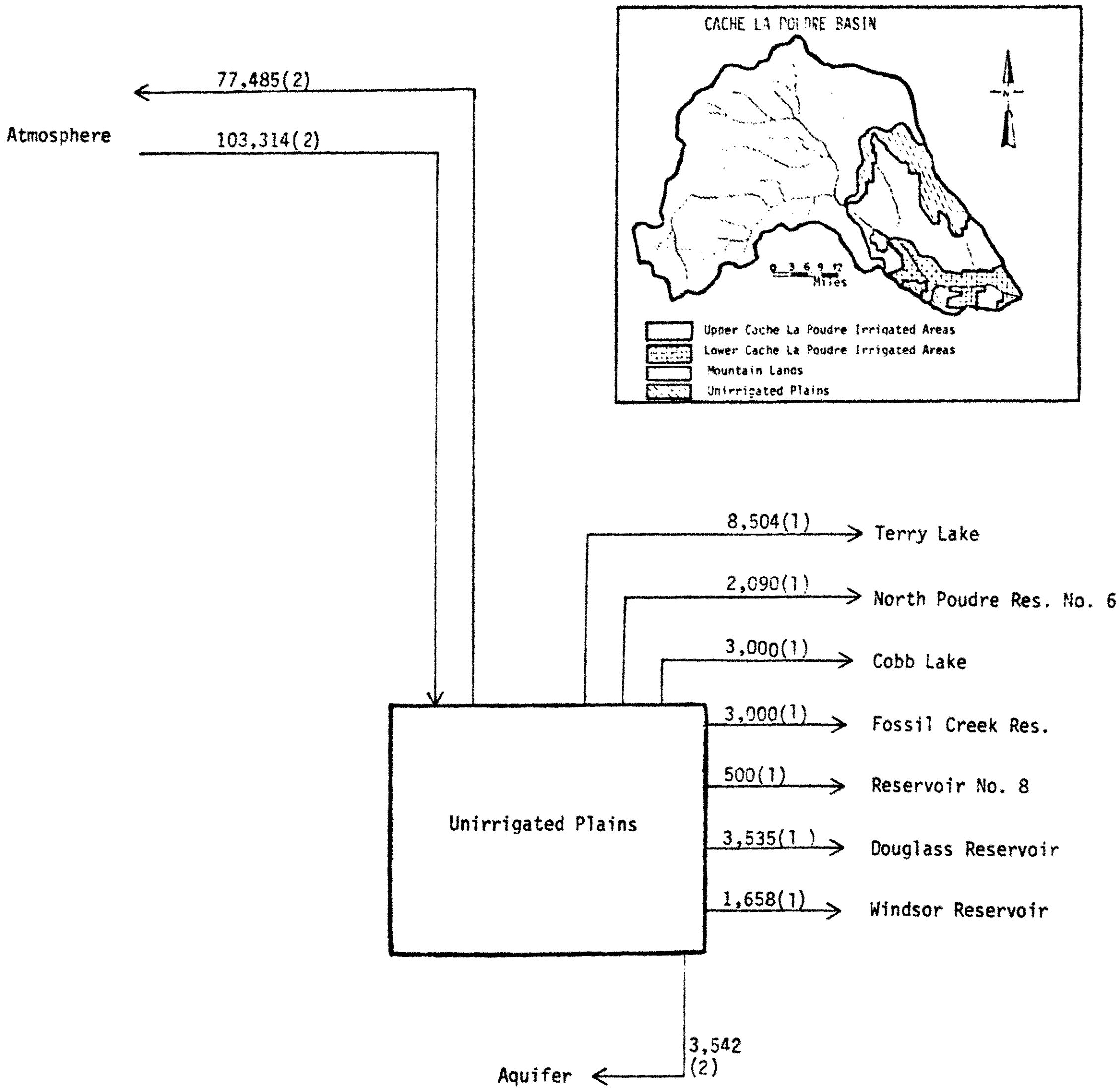
APPENDIX H

WATER BALANCE OF AGRICULTURE SECTOR AND OTHER LANDS



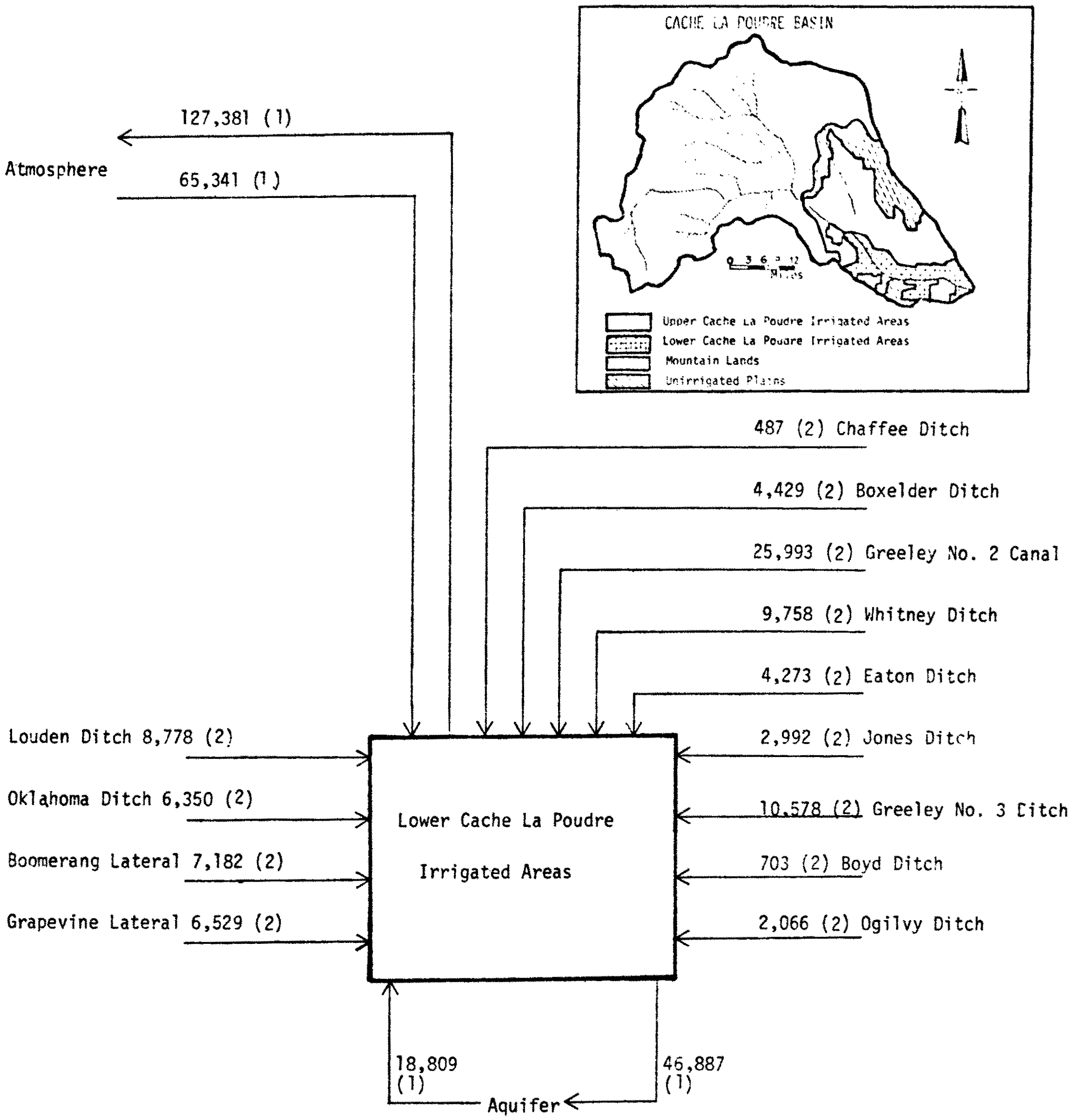
(1) These values are explained and justified in paragraph 5.5.2.
(2) This value is explained and justified in paragraph 5.5.1.
(3) These values were derived in paragraph 5.1.1.
(4) See the mass balance of the correspondent lake or reservoir.

Figure H-1. Water Balance of "Mountain Lands."



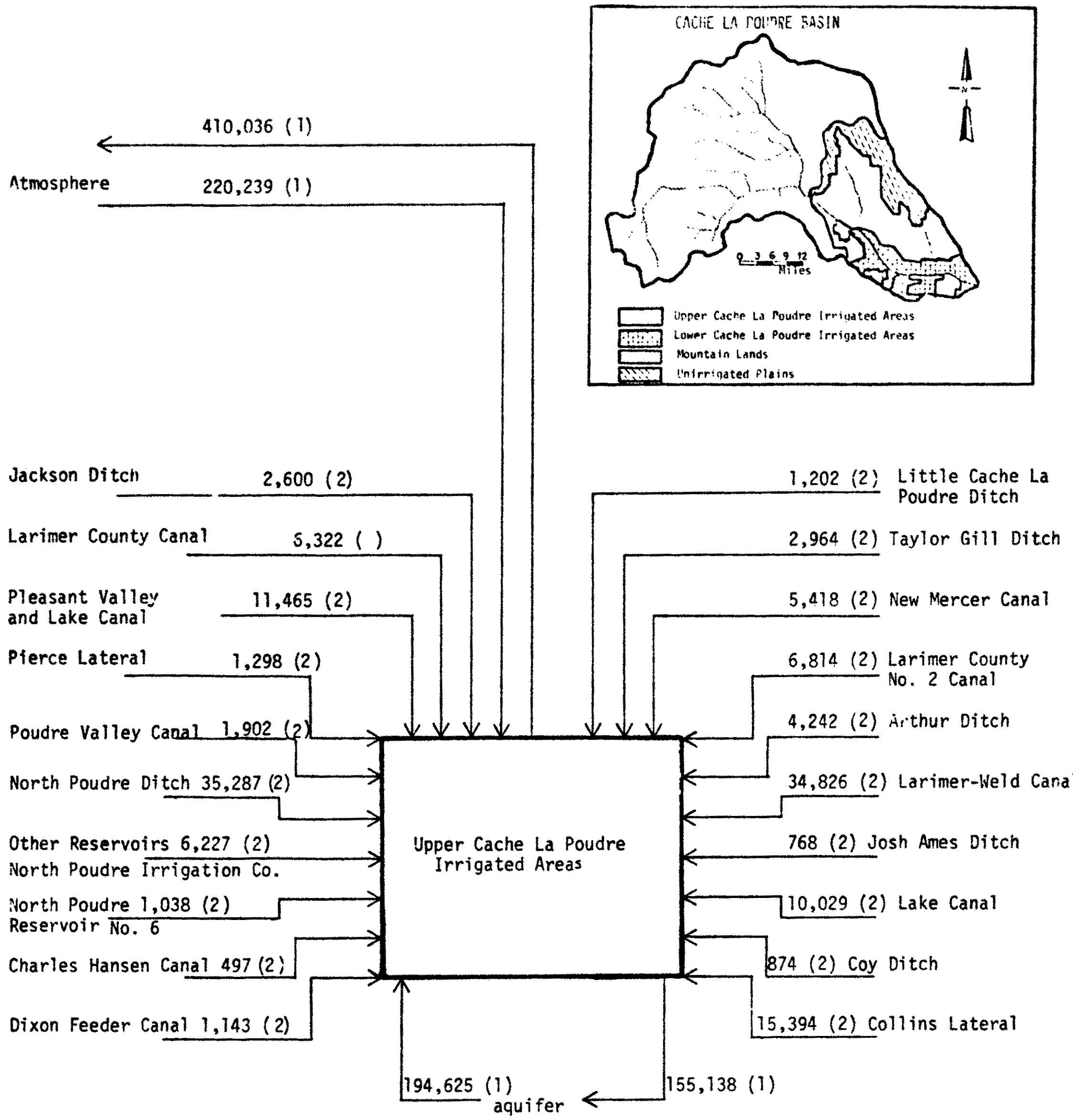
(1) See the water balance of the correspondent lake or reservoir.
(2) These values were derived in paragraph 5.1.1.

Figure H-2. Water Balance of "Unirrigated Plains."



(1) These values are explained in paragraph 5.4.3.
(2) See the water balance of the correspondent ditch or canal.

Figure H-3. Water Balance of "Lower Cache La Poudre Irrigated Areas."

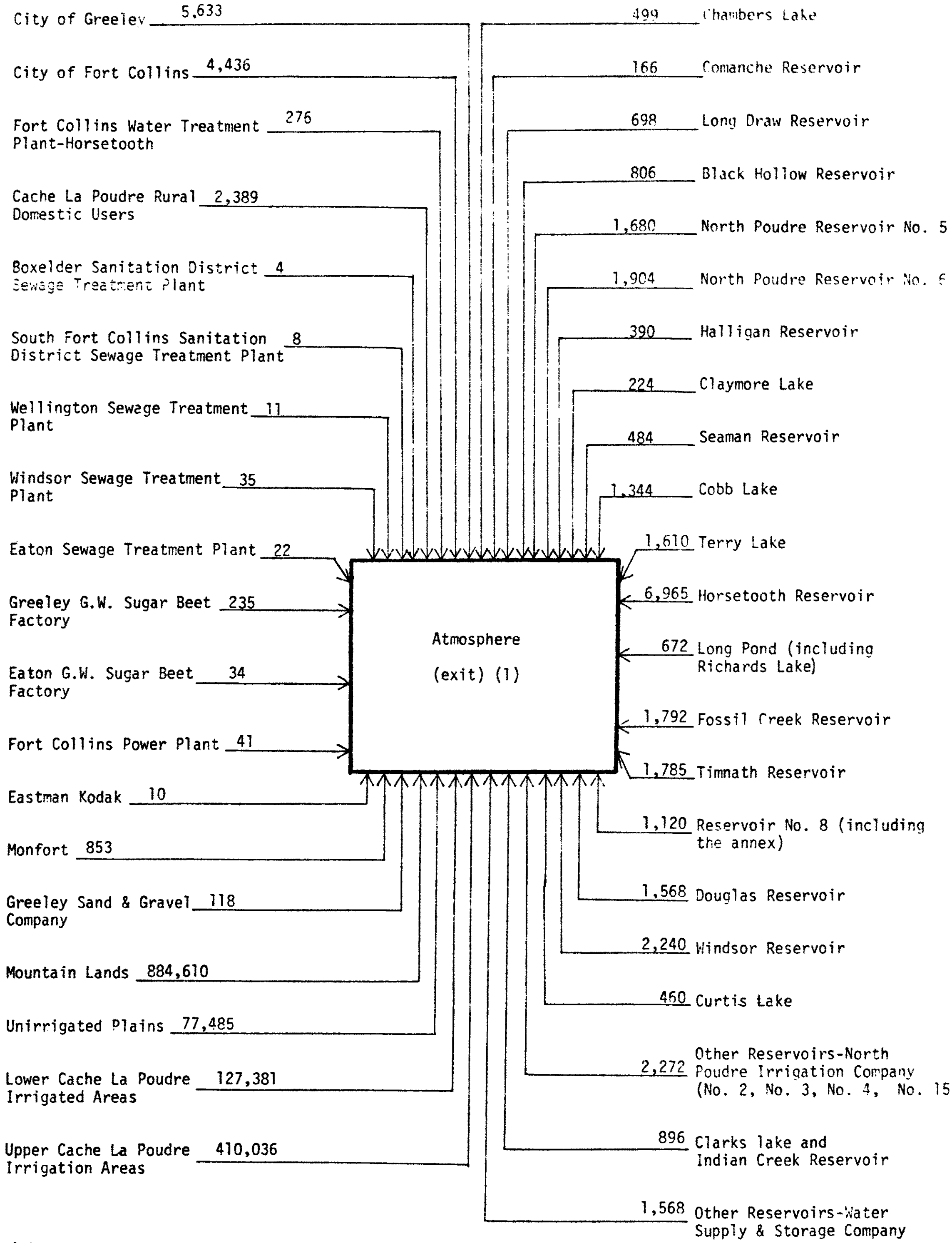


(1) These values are explained in paragraph 5.4.3.
(2) See the water balance of the correspondent ditch or canal.

Figure H-4. Water Balance of "Upper Cache La Poudre Irrigated Areas."

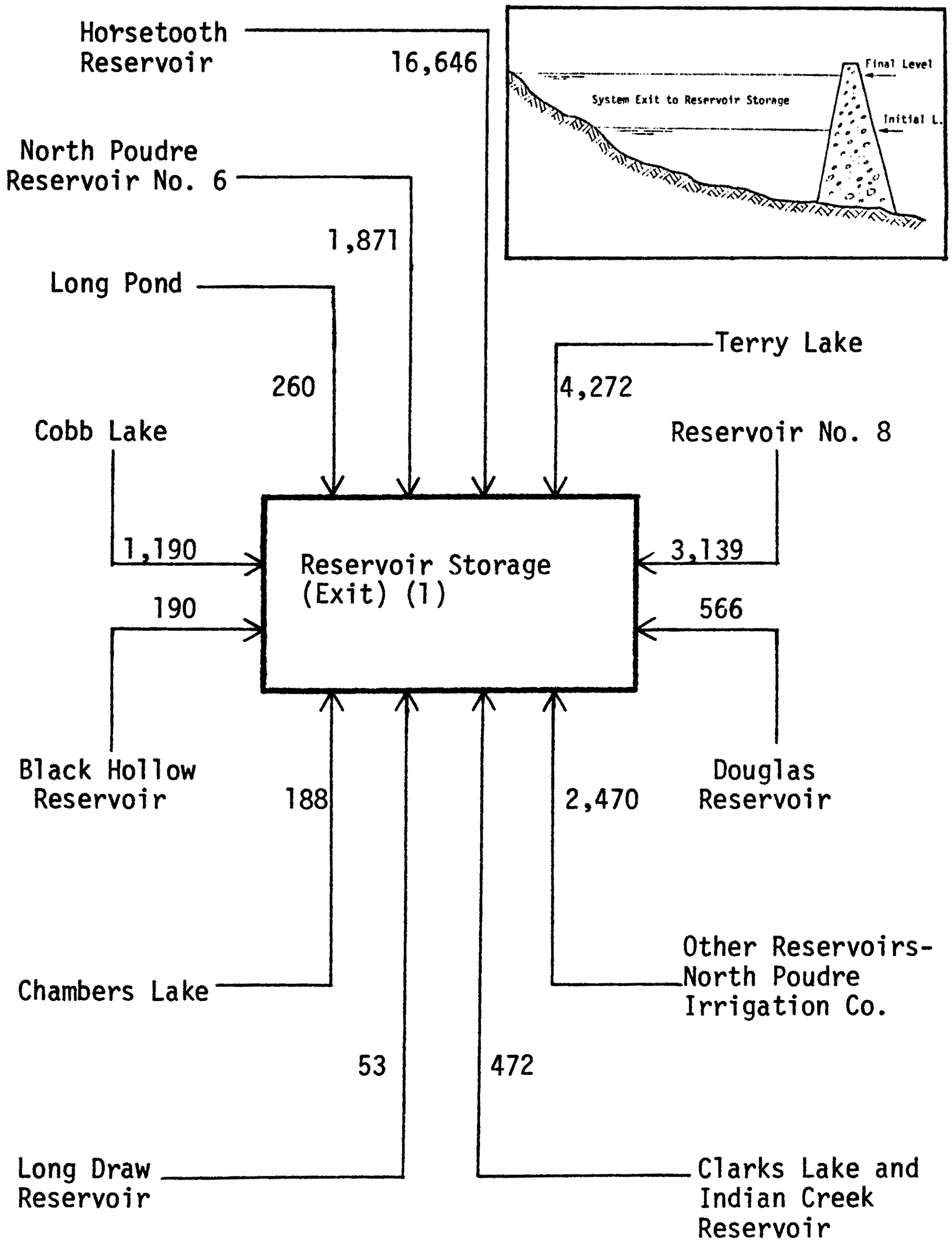
APPENDIX I

WATER EXITS FROM THE CACHE LA POUDRE WATER SYSTEM



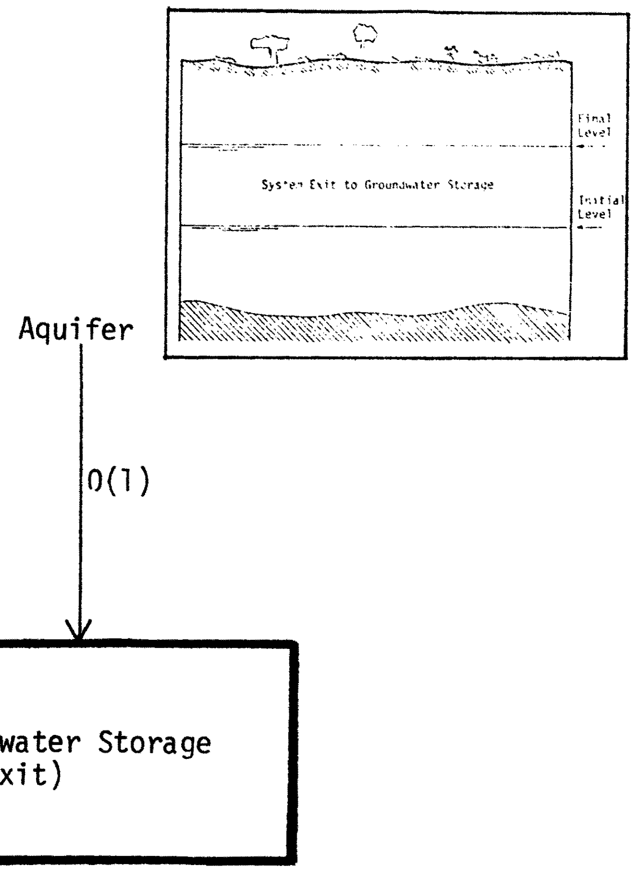
(1) See the correspondnet system element for full explanation of the evaporated amounts.

Figure I-1. Water Volumes Returned to "Atmosphere."



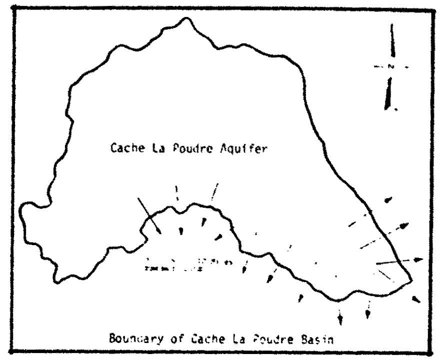
(1) See the water balances of the correspondent elements of the water system for full explanation of these water exchanges.

Figure I-2. Water Volumes Put in "Reservoir Storage" for Next Year Carryover.



(1) Due to the relatively stable conditions and steady operation of the Cache La Poudre Aquifer, the volumes put in groundwater storage for next year carryover were considered negligible.

Figure I-3. Water Volumes Put in "Groundwater Storage" for Next Year Carryover."



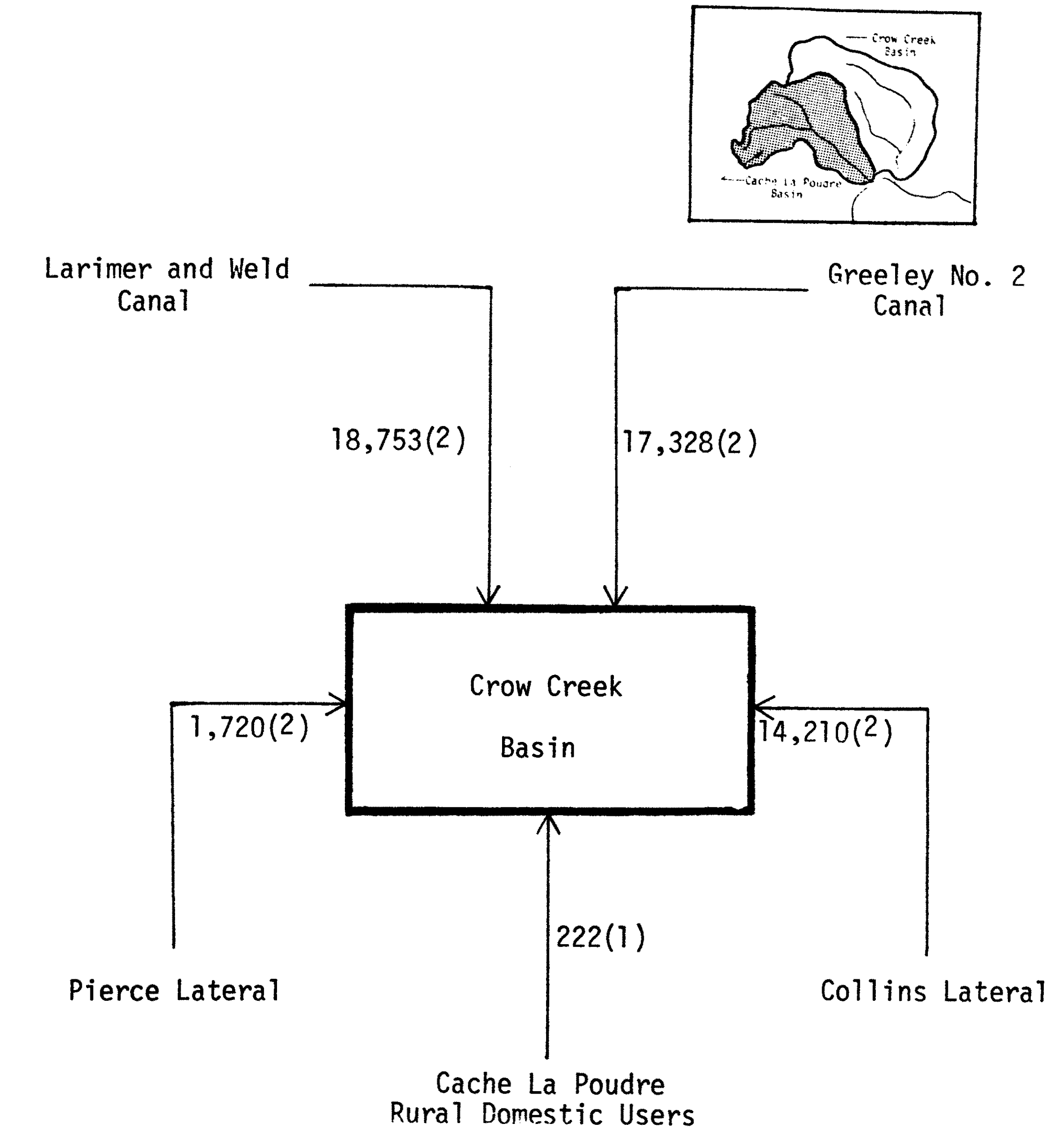
Aquifer

72,077(1)

Out of Basin Aquifers

(1) This amount was computed through the mass balance of the aquifer. These volumes are likely to have flowed to the lower South Platte alluvia.

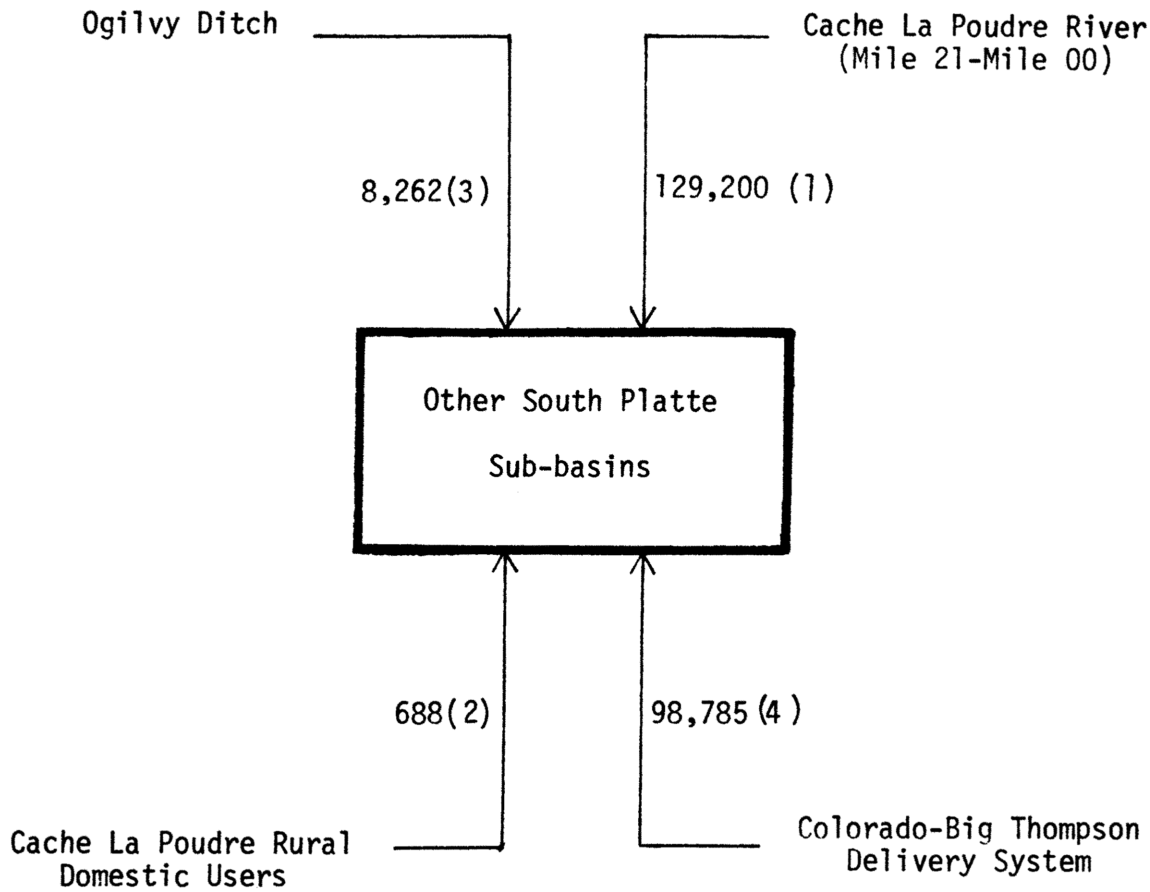
Figure I-4. Groundwater Volumes Flowing to "Out of Basin Aquifers."



(1) This volume is seeped wastewater from those domestic users which are located out of the Cache La Poudre basin boundary but are considered within the Cache La Poudre Water System.

(2) These exports through agriculture ditches were estimated from the total delivery values proportionally to the served areas within and outside the Cache La Poudre basin. See also paragraph 5.4.2 and Table 5-17.

Figure I-5. Water Export to "Crow Creek Basin."



(1) This is the river outflow at the South Platte confluence (USGS Water Resource Data for Colorado, 1970).
(2) This volume is seeped wastewater from domestic users which are located out of the Poudre basin but are considered within the Cache La Poudre Water System.
(3) See Figure E-27.
(4) Computed through mass balance of Colo.-Big Thompson Delivery system.

Figure I-6. Water Exports to "Other South Platte Sub-basins."