Dissolved Solids Hazards in the South Platte River Basin, Vol. II: Salt Balance Analysis

by

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Resources Research Institute

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DISSOLVED SOLIDS HAZARDS IN THE SOUTH PLATTE BASIN

Volume II: Salt Balance Analysis

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ABSTRACT

The first year of this project assessed the salt flows at five stations of the South Platte River between Henderson and Julesburg, and of the three main tributary streams, the St. Vrain, the Big Thompson, and the Cache La Poudre. The analysis of fifteen years of data from 1965 to 1979 showed that salt is lost from the river between Kersey and Julesburg.

The objective of the second year of the project was to explain the negative salt balance in the Kersey-Balzac reach and to understand better the mass flows of salt within the system. Another objective was to develop basic data in preparation for development of a salt balance model involving the major components of the lower South Platte system, the long range objective.

Study of the canal diversions in the Kersey-Balzac reach indicated that the reason for the salt imbalance is due to two major canal diversions. These canals transport salt from the Kersey-Balzac reach to agricultural lands adjacent to the Balzac-Julesburg reach which, as shown in this analysis, are accumulating salts. This is indicated also by the USBR Narrows study which determined that a water deficit exists for these lands. This would corroborate that these lands may be accumulating salts. Given that these lands have potential for good drainage, which is the general assessment of the USBR, the problem should be alleviated by application of sufficient irrigation water, an objective of the Narrows Project.

Because of its long term ramifications the question of salt balance deserves continued study. A more complete delineation of what is occurring should be developed such that salt flows are understood for

the whole lower South Platte and so that predictions can be made for various scenarios of further development of water resources within the basin.

In addition to adding more water to the land for leaching, the salt balance can be improved by managing the system with this objective. One approach would be to store spring runoff water in off-stream reservoirs instead of the high TDS fall and winter flows, which is current practice. The proposed Narrows Reservoir could be managed in such manner also. Higher TDS water could be released from storage when there is prospect of replenishing this water from excess spring runoff.

ACKNOWLEDGMENTS

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Chapter 1

INTRODUCTION

1.1 Background

The objective of this project when it started was to develop an operational materials balance mathematical model for sequential water reuse. The approach contemplated was to apply materials balance concepts, as developed by Hendricks and Bagley (1969) and Hendricks, Turner and Klooz (1982), to the reach of the South Platte River system between Henderson and Julesburg and, at the same time, demonstrate how to develop a materials balance model. In this Henderson-Julesburg reach of the South Platte River some 57 canal diversions deliver water to about 500,000 acres of irrigated land. That sequential reuse is practiced is documented by the fact that diversions from this reach of the river averaged 943,600 acre feet per year between 1965 and 1977, while exogenous inflows comprised of flows from the South Platte at Henderson, the St. Vrain, the Big Thompson, and the Cache La Poudre Rivers, averaged 691,815 acre feet per year.

As we began to examine the data, and the components of the lower South Platte sequential reuse system, it became evident that development of a model would require assembly of large amounts of scattered data into a consistent format. As an example, published salinity data were given in terms of total dissolved solids as residue, total dissolved solids as sum of constituents, and as specific electrical conductivity. Further the data were not necessarily available for all stations at the same time. In addition, data were not available in any form for many component flows. The data handling was started for the river as a first step. Later, the system would be disaggregated and flows and salinity levels would be represented for inputs and outputs to and from each component.

The initial focus on the river, compiling and summarizing flow data and salinity data, revealed an interesting fact: a portion of the river, between Kersey and Balzac, showed a net loss of salt. Further the analysis of the data for the whole system showed that salt is being leached from the upper irrigated lands of the tributary streams, e.g. St. Vrain Creek, Big Thompson River, and Cache La Poudre River, and is being deposited on the lower irrigated lands below Greeley. Plots of salt mass flow at several river stations showed that the flow of salt mass increases from Henderson to Kersey due to substantial flows of salt mass from tributary streams in this reach, and is lost from Kersey to Balzac due to canal diversions. An increase occurs from Balzac to Julesburg but is not sufficient to offset the loss of the previous reaches. Some of this salt is returned again to the South Platte by subsurface drainage. But the returned salt is not sufficient to maintain a salt balance on the irrigated lands.

The distance profiles of flow, total dissolved solids, and salt mass flow, averaged by season show that fall and winter flows have the highest concentrations of salt. This fact is significant in planning a strategy for making the salt balance more favorable. One possible strategy would have as an objective to cause the slope of the Kersey-Balzac portion of the salt mass flow-distance profile to approach the horizontal. Another would have as an objective to increase the return flows from Balzac to Julesburg. The former approach requires reducing the salt load in diversions. This can be achieved by diverting more spring flows and less fall and winter flows. The latter approach requires improved drainage for those lands receiving the salts.

1.2 Purpose

The findings of year 01, depicting salt mass flows at different river stations, caused our attention to shift from development of a computer model toward confirming by other means whether a salt balance problem exists. To illustrate, the profiles of salt mass flow were generated by analysis of published data, without the benefit of field verification, and without examining the configurations of the canal systems, the locations of irrigated lands relative to diversions, the drainage characteristics of these lands, etc. At the same time this information is needed for a computer model. Another purpose of the year 02 part of the study was to indicate possible strategies for dealing with the salt accumulation problem in the Kersey-Balzac reach.

In summary, three purposes of the year 02 study were: (1) to develop further verification of the salt accumulation problem determined in year 01, (2) to indicate strategies for dealing with the problem of salt accumulation on the irrigated lands of the lower South Platte, and (3) to accumulate additional information describing the South Platte system for development of a computer model.

1.3 Objectives

The objectives of the year 02 study were: (1) to ascertain the negative salt balance problem in the Kersey-Balzac reach by canal diversion data, (2) to develop field verification that a salt accumulation problem exists for irrigated lands in the Kersey-Balzac reach of the lower South Platte River, (3) to outline approaches for dealing with the negative salt balance problem.

1.4 Scope

The year 02 project is intended to ascertain whether further studies are warranted concerning the salt imbalance problem in the lower

South Platte. The field verification was limited to a three-day survey of electrical conductivities, and observations of river reaches, reservoirs, and canals. The analysis of canal data was cursory also, as are the indications of strategies for dealing with the problem.

1.5 Significance

The year 01 analysis, depicting salt mass flows in the South Platte River between Henderson and Julesburg indicates that a salt balance problem could exist in the Kersey-Balzac reach. Identification of a salt balance problem, if it is ascertained to exist, is important in maintaining the long-term productivity of irrigated agriculture in the area affected. Also it could be important in further planning uses of the additional irrigation water to be made available by the proposed Narrows Dam.

Chapter 2

METHODS

2.1 Description of Lower South Platte System

Additional description of the lower South Platte system is required to ascertain the nature of the salt balance problem of the Kersey-Balzac reach. Desired information includes maps showing canals and irrigated lands, and tables listing water rights priorities, monthly diversions, use of groundwater, annual cycles of off-stream storage, etc. From these data the salt balance for the different river reaches can show salt mass flows in canal diversions and in return flows (which are calculated). At the same time, salt balances for affected irrigated lands can be depicted. All of this is done for the annual time period only, consistent with the scope of the study. The sources for most of the data were the "Report on the Narrows Unit, Colorado" (USBR, 1967) and Volume 1 of this study by Gomez-Ferrer and Hendricks (1982).

2.2 Salinity Survey

A three-day salinity survey of the South Platte system was done April 9, 10, and 11, 1982 to corroborate the interpretation of the salt mass flow data for the river stations. In-situ measurements of specific electrical conductivity were made on the South Platte River and its tributaries, and on off-stream reservoirs and canals of the lower South Platte to ascertain whether the winter salt levels were indeed high, whether the pattern of spatial change was as anticipated, and whether the salinity levels of the off-stream reservoirs were high due to all and winter diversions. The salinity survey was done prior to the start of spring runoff when winter flow conditions prevailed. The instrument used was a battery-powered Chemtrix Type 700 conductivity meter.

Photographs were taken to provide a visual feeling for the kind of system in operation.

2.3 Strategies for Alleviation of Salt Imbalance

Generation of strategies for alleviating salt balance problems was based upon three approaches: (1) reduction in salt mass load applied to irrigated lands, (2) application of irrigation water in excess of the consumptive use requirements, i.e. apply sufficient water for leaching, and (3) provide for adequate drainage of irrigated lands.

Chapter 3

SALT HYDROLOGY OF THE SOUTH PLATTE RIVER

Any analysis of salt balance within a river basin, or any portion of it, requires knowledge of flows and salt concentrations. The product of these two parameters, flow and salt concentration, is termed "salt mass flow," and is used to depict salt transport. The depiction in Volume 1 of salt transport by the river showed a loss of salt between Kersey and Balzac, an apparent problem for the agricultural lands adjacent to the reach. To confirm the existence of such a problem, and to understand it, additional detail must be shown relative to canal flows, e.g. when they occur, amounts, TDS levels, deliveries to agricultural lands, groundwater pumping, and return flows. All of this, depicted in whole or in part as salt mass flows, might be called "salt hydrology" as a convenient term. From a description of the salt hydrology the location and magnitude of an existing salt balance problem may be determined. As with water hydrology, salt hydrology is the same problem compounded. One must be able to trace the changes in salt concentration caused by a given component, as well as known water flows. And as with water hydrology only portions of the salt hydrology can be delineated. This chapter provides data to depict portions of the salt hydrology for the Kersey-Julesburg reach of the South Platte River system. The purpose is to determine what happens to the salt mass flow leaving the river between Kersey and Balzac. Additional information is compiled at the same time to add to the general understanding of this problem and to aid in moving further toward development of a salt balance model.

3.1 The South Platte System

Figure 3-1 shows the South Platte River and its major tributaries, and the irrigated lands and cities. The irrigated lands in 1973 totaled 1,273,954 acres and the 1970 basin population was about 1,551,418 (Hendricks et al., 1977).

The streams of the South Platte River system provide about 1.5 million acre-feet annually of surface water supply. Most of this occurs as spring runoff from the mountains of the Front Range during May and June. Imported water from the Colorado, Arkansas, and North Platte Rivers contributes another 300,000 acre-feet. Withdrawals from the system amount to about 4.5 million acre-feet annually and consumptive use is about 1.5 million acre-feet. South Platte River outflow across the Colorado-Nebraska state line is about 300,000 acre-feet annually.

Irrigated agriculture has been practiced since 1858. Little attention has been given to the question of salt balance since it is known generally that TDS levels increase toward the state line.

3.2 The Lower South Platte System

The designation "lower South Platte" is adopted for this report to designate the reach from Henderson to Julesburg. Figure 3-2 shows this reach, with the adjacent irrigated land indicated. Except for Lodgepole Creek, tributary streams from Kersey to Julesburg generally flow in response to thunderstorm activity and are not shown in Figure 3-2 nor are they considered in this analysis. In this section the major components of the lower South Platte water system are described.

Canal diversions. Some 57 canals divert water from the South Platte River between Henderson and Julesburg. Figure 3-3 shows the canals diverting water between Kersey and Julesburg. Off-stream

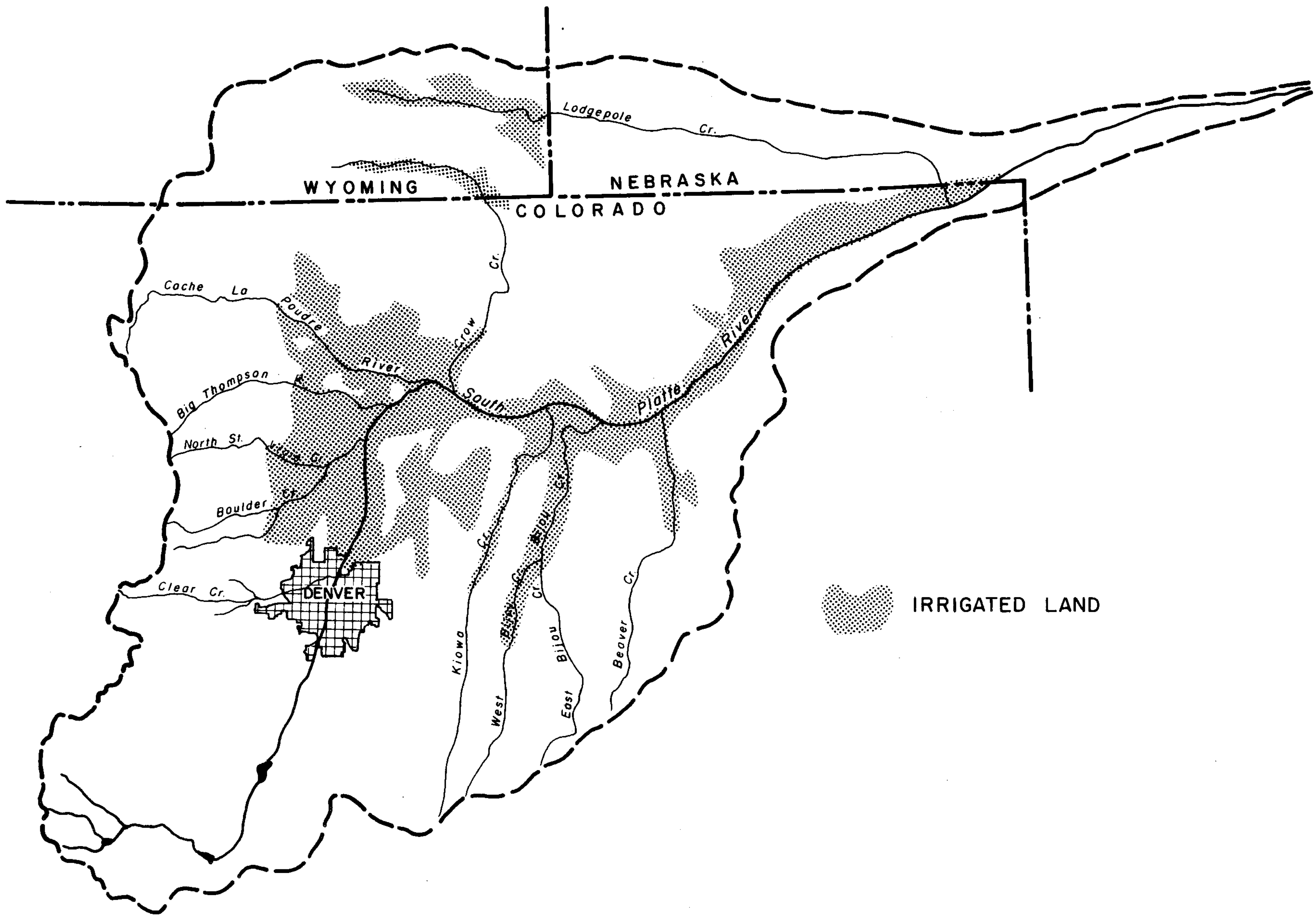

Figure 3-1. Streams and irrigated land in the South Platte River basin (adapted from Hendricks et al., 1977).

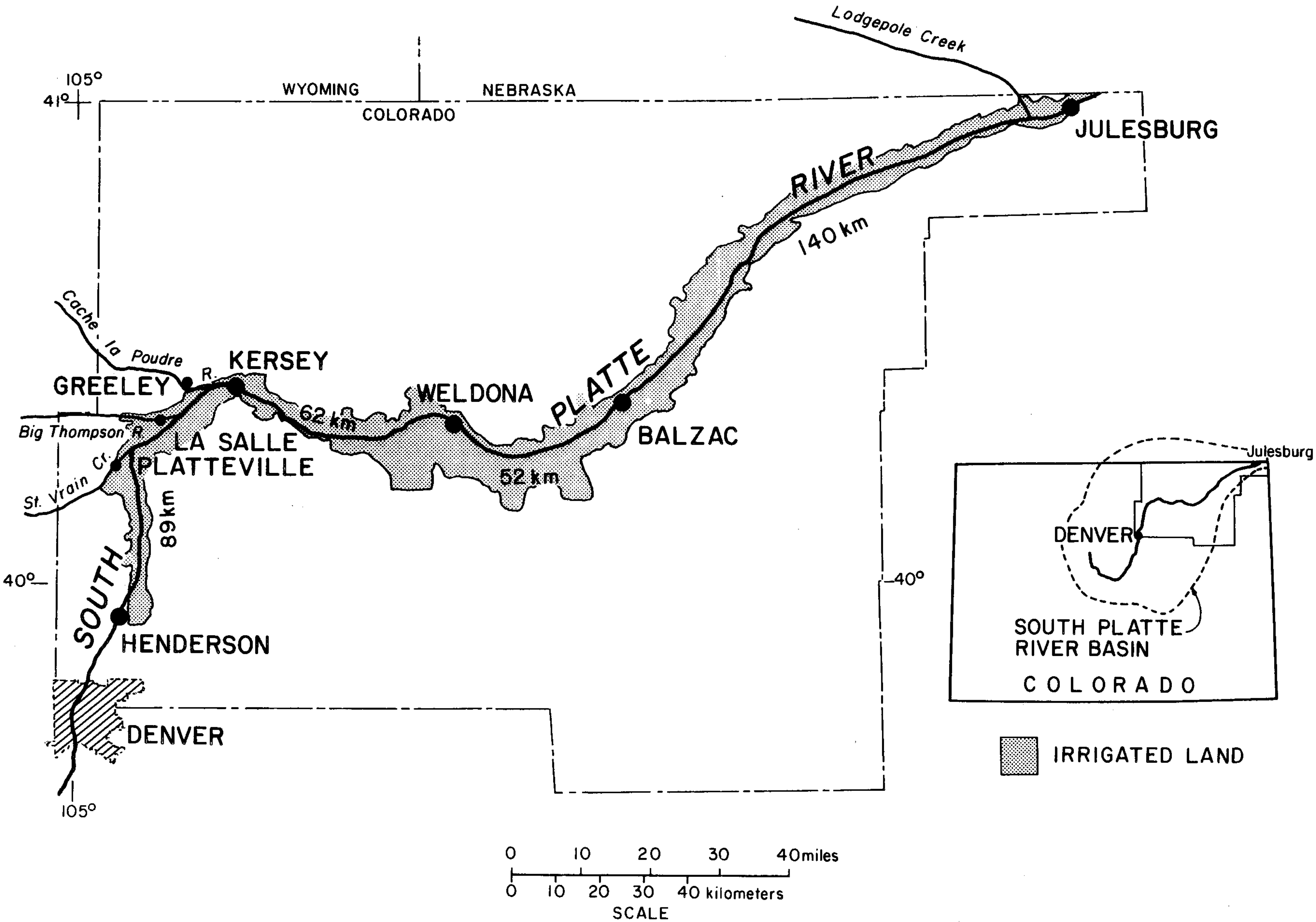

Figure 3-2. Lower South Platte River from Henderson to Julesburg (adapted from Hurr et al., 1975).

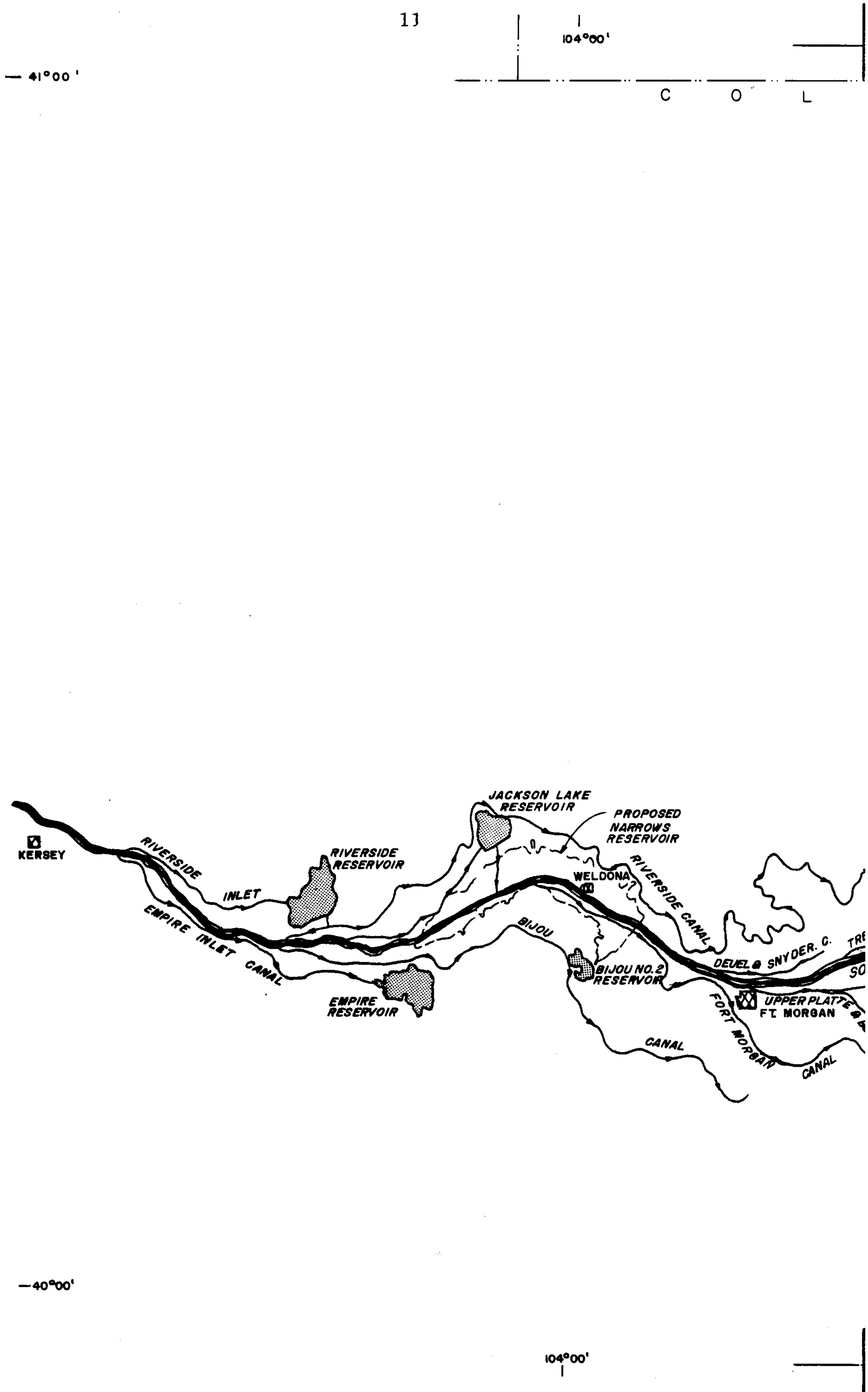

Figure 3-3. Lower South Platte River from Kersey to Julesburg showing canals

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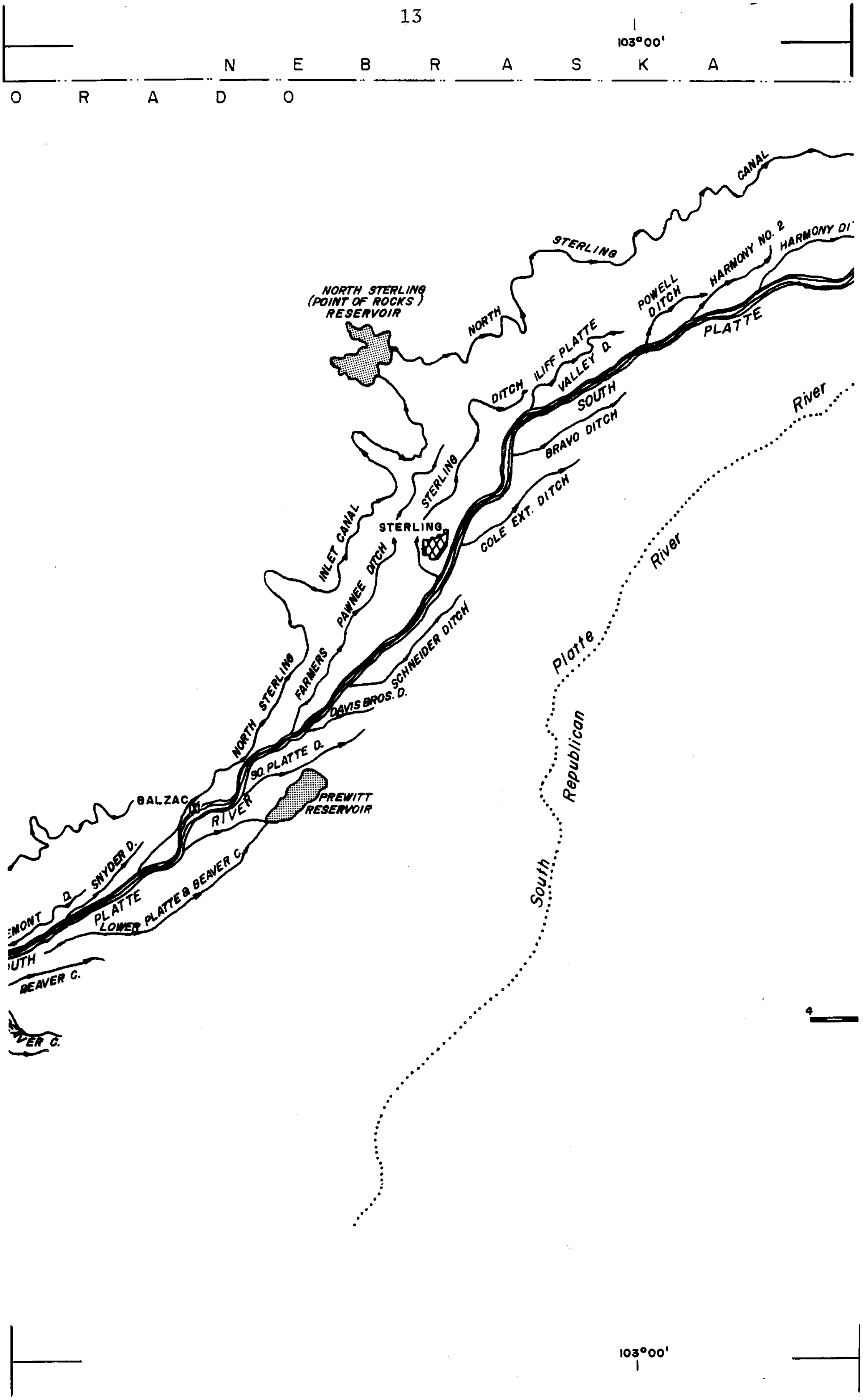

and off-stream reservoirs (adapted from General Map-Narrows Unit, Repor

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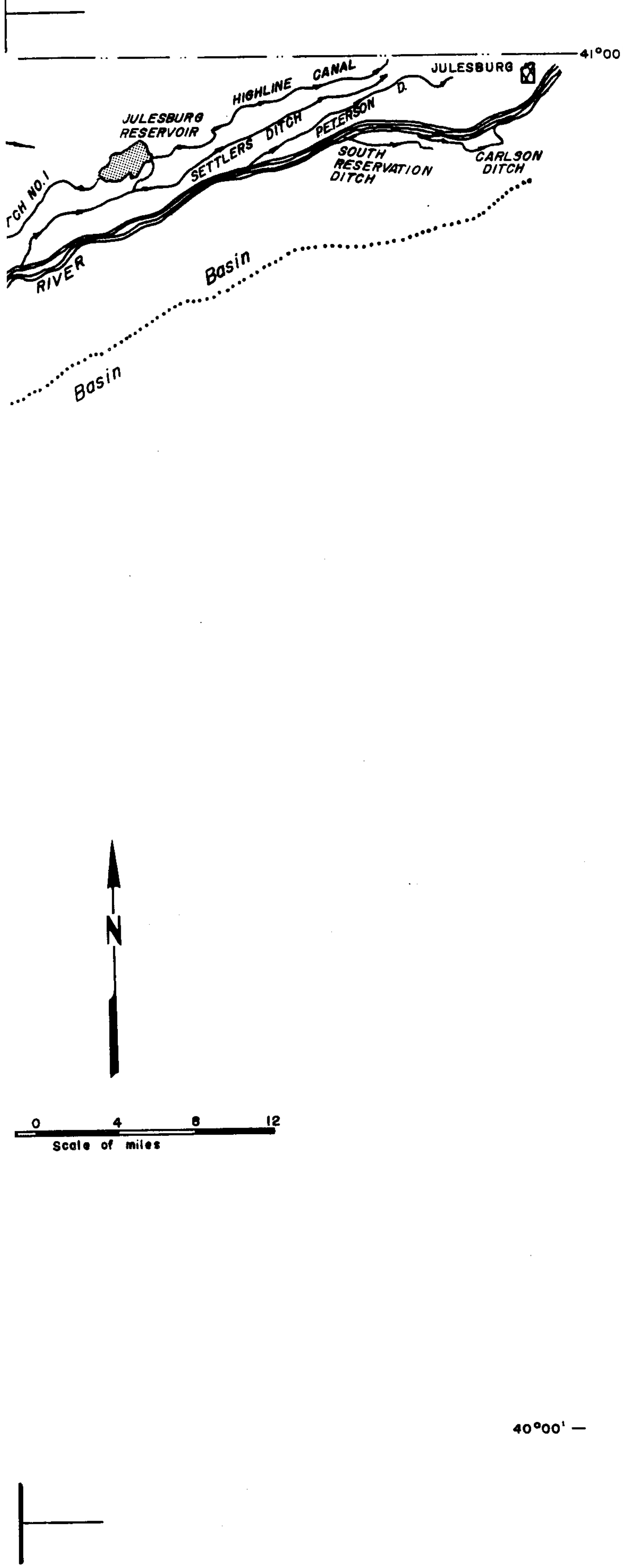

t on the Narrows Unit, USBR, 1967).

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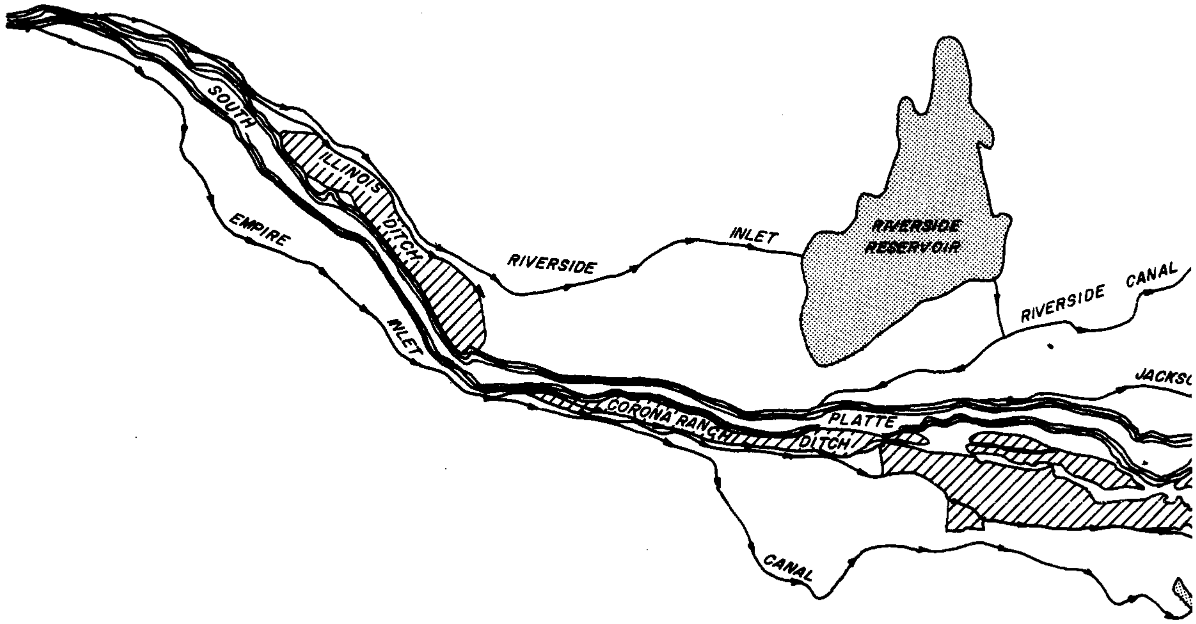

Figure 3-4a. Irrigated land in the Kersey-Fort Morgan reach, Lower South Pl

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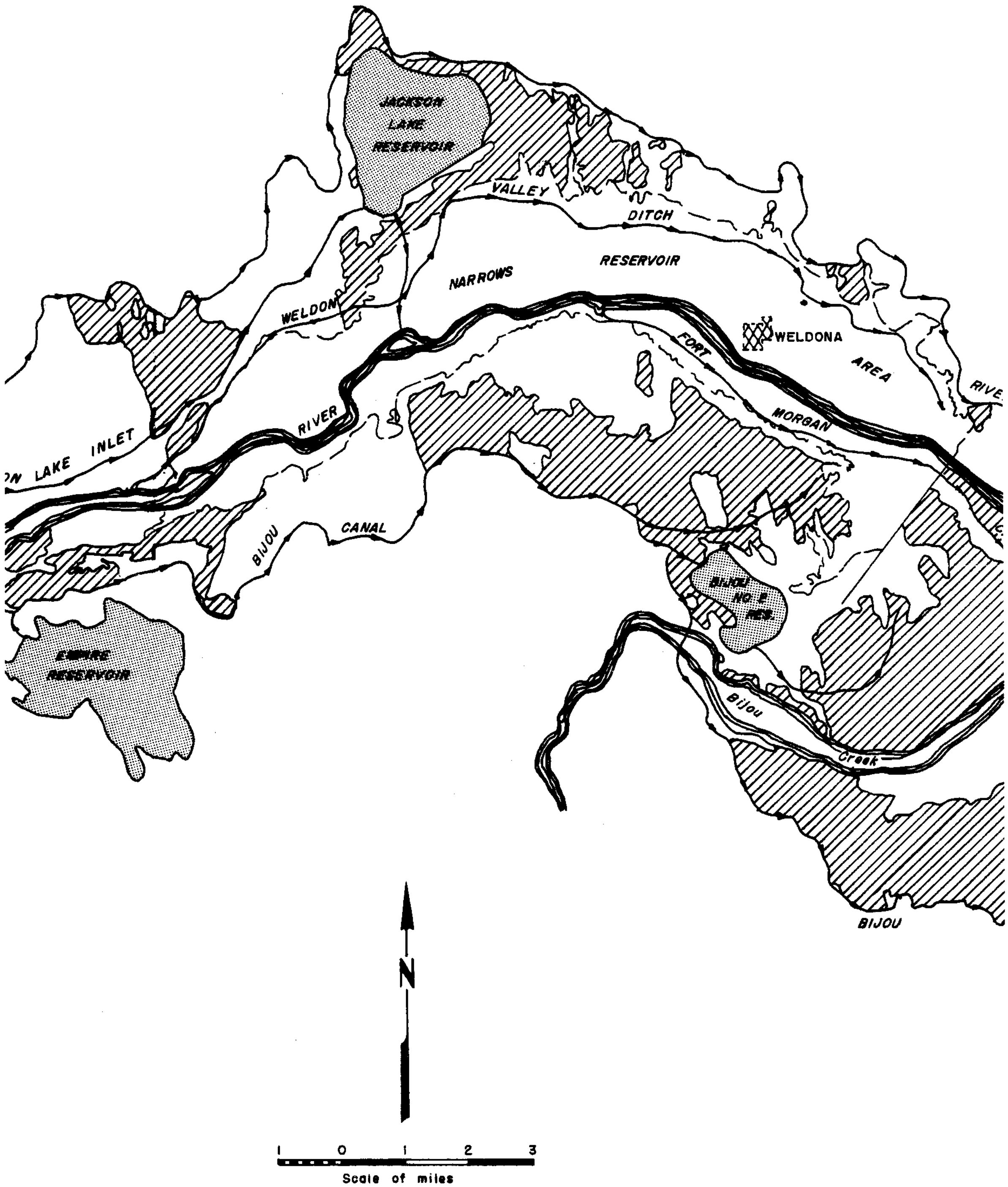

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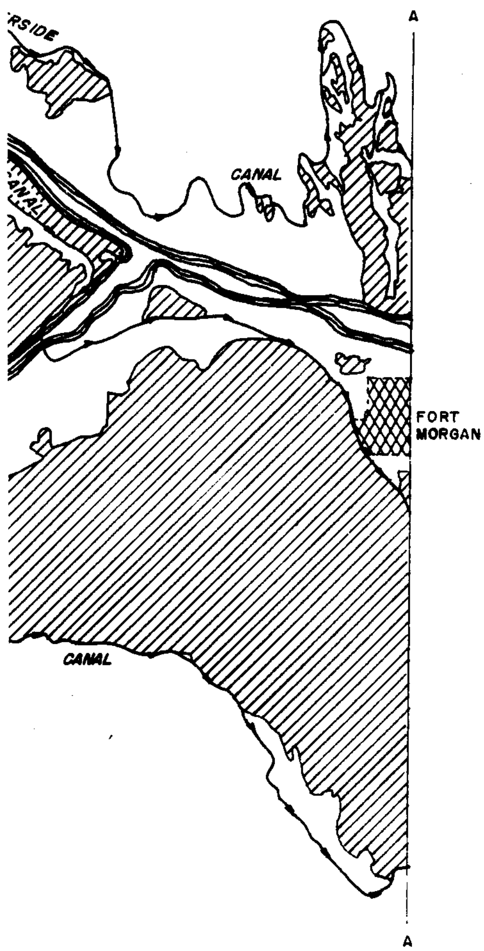

Unit, USBR, 1967).

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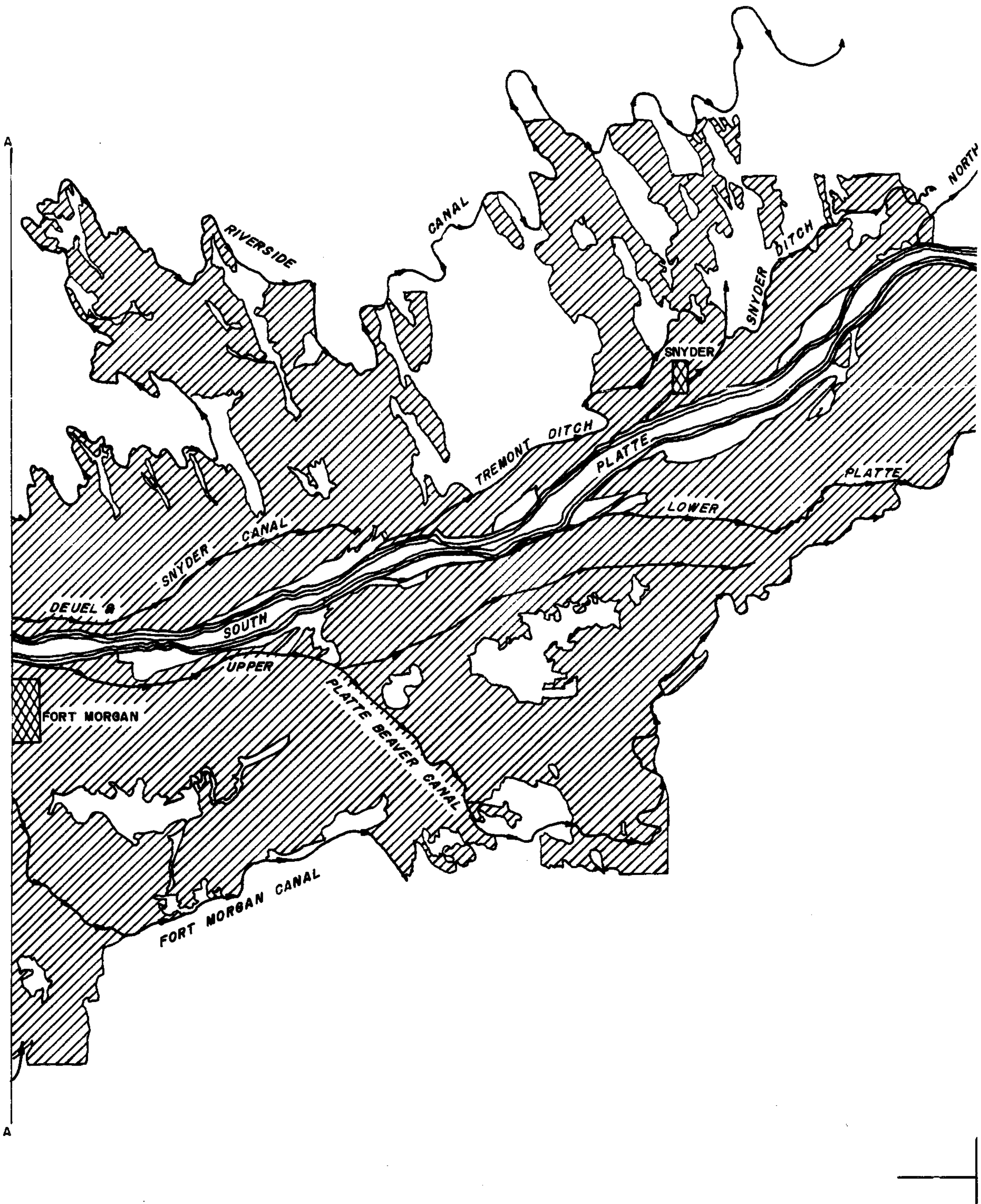

Figure 3-4b. Irrigated land in the Fort Morgan-Balzac reach, Lower South Narrows Unit, USBR, 1967).

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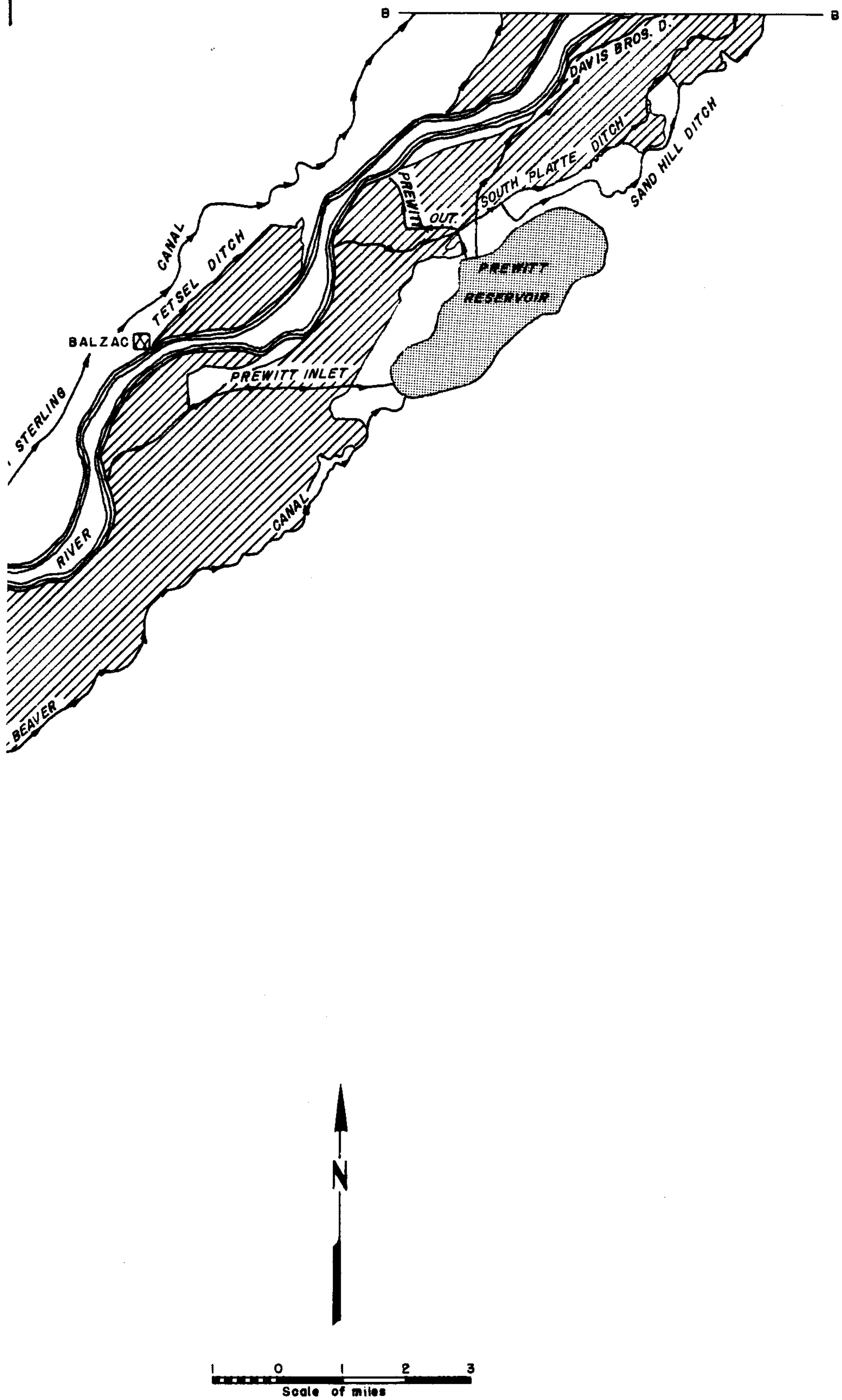

Platte River (adapted from Land Classification Map 3, Report on the

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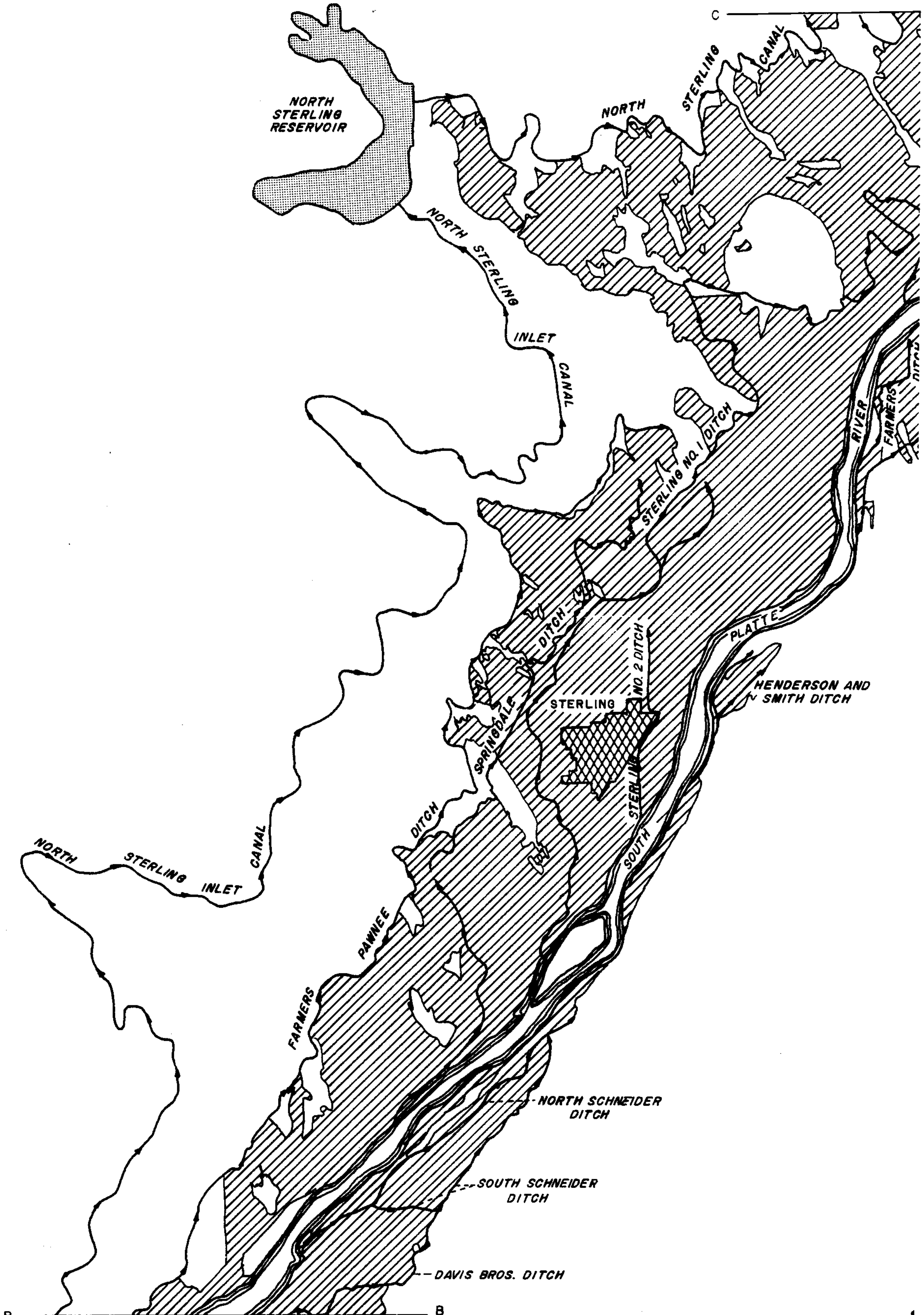

Figure 3-4c. Irrigated land in the Balzac-Proctor reach, Lower South Narrows Unit, USBR, 1967).

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Platte River (adapted from Land Classification Map 3, Report on the

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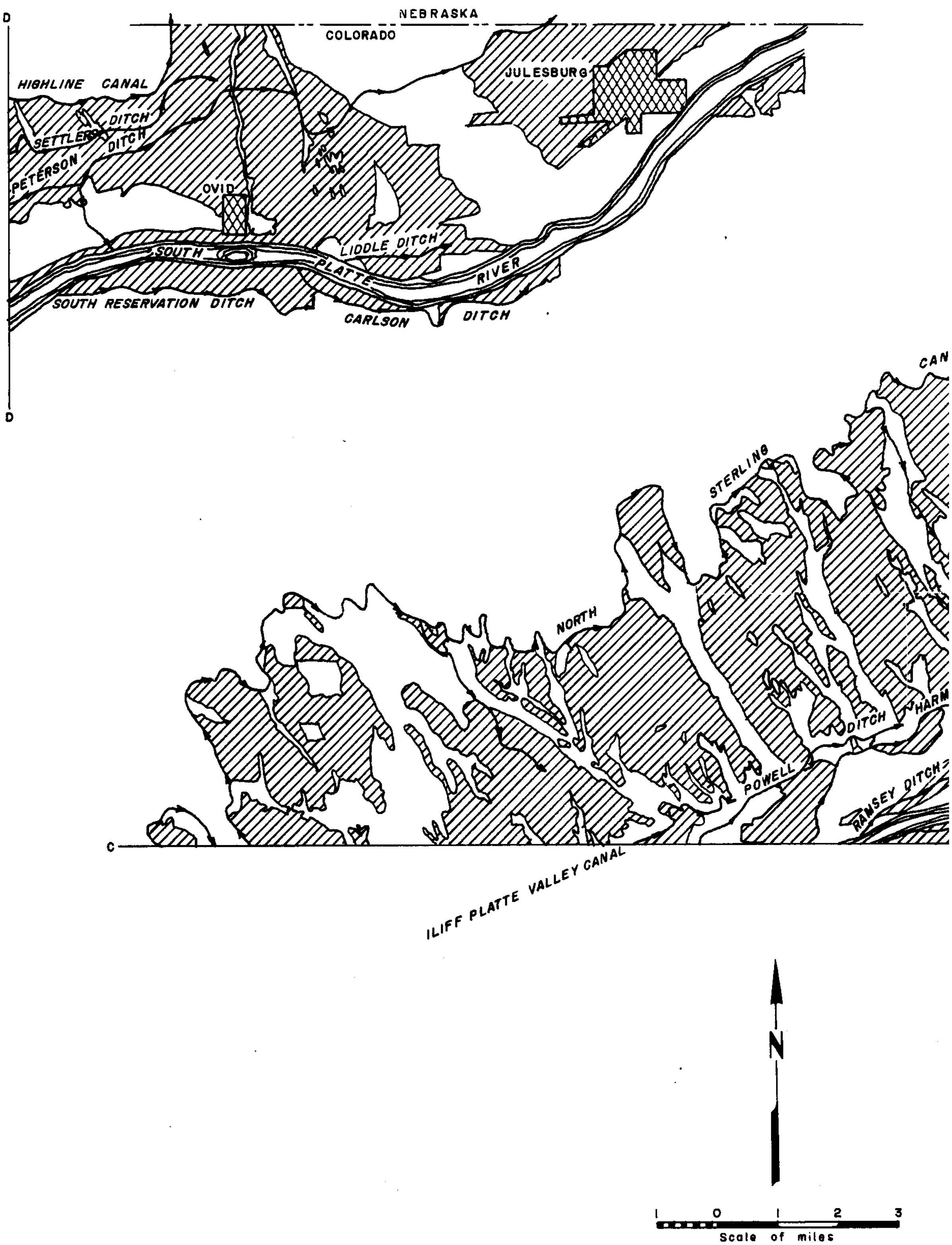

Figure 3-4d. Irrigated land in the Proctor-Julesburg reach, Lower South

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Platte River (adapted from Land Classification Map 3, Report on the

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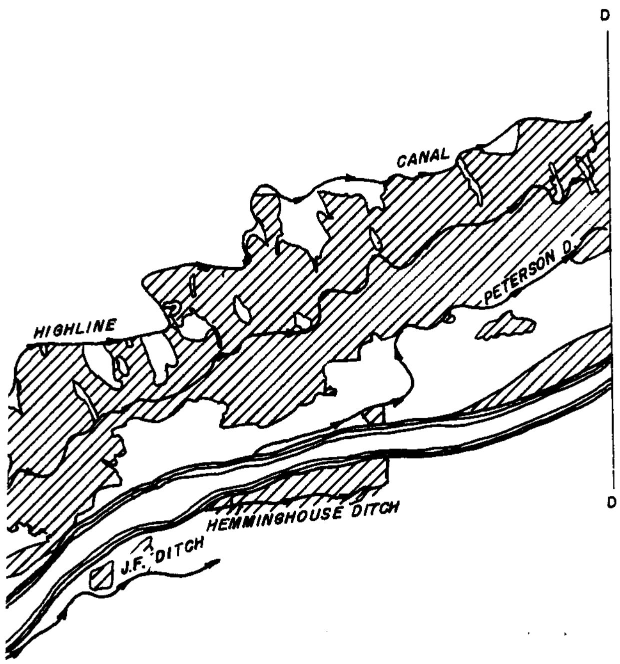

Narrows Unit, USBR, 1967).

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reservoirs are shown also. Figure 3-4 shows these canals in more detail at larger scale, and the associated irrigated lands. The study of these canals, e.g., where they deliver water, their flows, and salt levels, can help to discern the location of the salt balance problem. Table 3-1 lists these canals by reach, i.e. Henderson-Kersey, Kersey-Weldona, Weldona-Balzac, Balzac-Julesburg, and shows annual diversions during the period 1965-77. The average annual diversions for these reaches during the same period are 223,000, 360,700, 204,940, and 155,700 acre-feet, respectively, totaling 944,340 acre-feet for the Henderson-Julesburg reach.

Water rights. The water rights for both direct flow rights and storage rights between Kersey and the state line are listed in Table 3-2 in order of priority. Those rights having priority date earlier than about 1890 yield very little water from July through September. The storage rights can be filled only when water is available after the direct flow rights are met.

Off-stream reservoirs. Table 3-3 lists the off-stream reservoirs in the Kersey-Julesburg reach, showing capacities, water rights, and priority dates. These same reservoirs are shown on the map, Figure 3-3. Their total storage capacity is 274,566 acrefeet, compared with 721,340 acre-feet of average annual diversions in the Kersey-Julesburg reach (which includes the diversions to fill these same reservoirs.

Figure 3-5 shows typical annual cycles of fill and draw for three reservoirs, i.e. Prewitt, North Sterling, and Julesburg, respectively. These reservoirs are filled during the fall and winter when direct flow rights are not being exercised. The water stored is used during the summer after spring runoff, when direct flow rights are not sufficient

Table 3-1a. Location and annual diversion flow in 1000 AF units of major diversions, water years 1965-1977, South Platte River, Henderson-Kersey reach (Gomez-Ferrer and Hendricks, 1982)

Diversion	River Mile	Water Year 65	66	67	68	69	70	71	72	73	74	75	76	77
(USGS Gaging St. Henderson)	301.4													
Brighton Canal	297.5	8.6	7.7	6.8	10.0	9.2	8.3	7.9	8.0	7.5	9.7	11.3	10.1	8.8
Lupton Bottom Canal Syst.	291.9	19.9	17.4	14.2	20.3	18.9	18.7	18.5	15.7	16.2	17.2	17.3	19.8	17.6
Platteville Canal	286.9	16.9	14.1	9.9	18.0	21.7	22.2	18.3	15.4	18.1	17.0	19.5	21.0	17.1
Side Hill Canal (Inc. Meadow Island 1)	284.3	0.0	5.1	4.8	6.2	5.9	5.9	5.4	5.1	5.4	5.5	5.8	5.7	6.1
Platte Valley Canal Syst.	283.7	5.5	23.7	48.7	44.7	51.1	48.9	47.2	56.5	37.3	55.4	45.4	58.2	43.5
Mutual Canal Syst.	279.7	12.1	7.5	8.8	12.2	12.7	11.4	11.0	10.2	9.0	10.9	11.1	11.2	10.3
Bucker Canal	278.2													
Farmers Independent Canal	276.7	18.9	17.3	14.9	16.6	17.2	17.0	15.0	12.9	12.7	13.6	13.5	14.4	15.1
Western Mutual Ditch Syst.	272.2	21.1	14.3	22.3	26.5	22.7	21.0	20.3	19.1	15.1	19.0	20.1	21.9	16.6
Jay Thomas Canal	270.2	2.5	3.0	2.0	3.2	2.2	1.8	2.1	1.8	0.7	1.2	1.6	1.1	3.9
(St. Vrain Ck. confluence)	270.0													
Union Canal Syst.	265.4	37.1	22.0	34.1	29.0	23.7	23.1	23.3	24.3	21.4	26.8	24.6	26.6	30.2
Godfrey Canal	262.3	6.5	8.9	8.6	12.1	8.2	7.0	6.4	10.3	6.5	7.8	8.5	8.5	9.4
(Big Thompson R. confluence)	260.4													
Lower Latham Canal	256.7	51.8	25.4	36.1	41.3	38.4	40.2	39.8	36.2	36.1	36.5	34.9	36.2	34.6
Patterson Canal	253.8	4.6	5.6	4.4	5.3	4.9	4.7	4.4	6.0	4.2	5.2	5.4	4.6	5.8
Highland & Plum Canal	251.0	4.0	5.0	3.6	5.1	3.4	3.4	4.5	4.9	2.7	4.1	3.8	3.9	4.5
(Cache La Poudre R. confluence)	249.0													
(USGS Gaging St. Kersey)	246.1													
Total annual reach diversion flow		209.5	177.0	219.2	250.5	246.2	233.6	224.1	226.4	192.9	229.9	222.8	243.2	223.5

To obtain cubic meters per second (cms), multiply acre feet per year by the factor 3.911×10^{-5}.
Source: Battelle (1974) and WPRS (1979)

Table 3-1b. Location and annual diversion flow in 1000 AF units of major diversions, water years 1965-1977, South Platte River, Kersey-Weldona reach (Gomez-Ferrer and Hendricks, 1982)

Diversion	River Mile	Water Year												
		65	66	67	68	69	70	71	72	73	74	75	76	77
(USGS Gaging St. Kersey)	246.1													
Hoover Canal	244.1													
Empire Canal Syst.	241.0	87.9	58.9	80.3	70.7	65.9	84.4	77.7	104.1	91.9	65.3	72.3	84.6	53.7
Riverside Canal Syst.	240.2	129.3	71.4	102.2	97.1	136.3	130.0	143.4	100.3	121.3	115.9	147.2	120.8	110.9
Bijou Canal Syst.	233.0	56.6	28.8	63.5	54.4	78.6	61.9	63.1	53.8	39.4	50.8	62.6	42.7	45.0
Jackson Lake Inlet Canal	225.5	58.8	28.8	43.5	22.8	40.8	27.1	17.2	58.2	20.2	32.8	43.3	43.8	39.6
Weldon Valley Canal	220.4	30.2	20.8	30.0	32.9	29.6	25.4	31.0	31.1	28.2	35.9	35.2	41.4	36.2
Fort Morgan Canal	210.0	27.6	27.0	43.3	47.2	48.1	43.0	39.1	37.7	38.8	56.7	63.7	55.3	51.3
(USGS Gaging St. Weldona)	206.7													
Total annual reach diversion flow		390.4	235.7	362.8	325.1	399.3	371.8	371.5	385.2	339.8	357.4	424.3	388.6	336.7

To obtain cubic meters per second (cms), multiply acre feet per year by the factor 3.911×10^{-5}.
Source: Battelle (1974) and WPRS (1979)

Table 3-1c. Location and annual diversion flow in 1000 AF units of major diversions, water years 1965-1977, South Platte River, Weldona-Balzac reach (Gomez-Ferrer and Hendricks, 1982)

Diversion	River Mile	Water Year												
		65	66	67	68	69	70	71	72	73	74	75	76	77
(USGS Gaging St. Weldona)	206.7													
Devel & Snyder Improv. Co. Canal	199.0	4.2	15.3	4.4	4.2	3.8	3.7	3.5	4.8	4.4	5.9	6.7	4.1	3.6
Upper Platte & Beaver Canal	198.0	18.9	2.9	24.1	28.2	31.8	26.9	25.0	25.8	30.2	30.5	34.0	28.7	25.2
Tremont Canal	191.9	0.5	0.5	2.2	1.8	1.1	0.0	0.0	4.6	5.8	5.3	9.1	8.7	9.1
Lower Platte & Beaver Canal Syst.	190.1	26.1	10.0	19.8	16.2	10.6	23.4	17.1	13.0	22.5	19.0	23.6	17.4	18.1
Snyder Canal Syst.	185.2	0.3	0.0	0.5	1.1									
North Sterling Canal Syst.	179.4	114.3	49.4	81.6	85.0	108.4	113.3	120.2	106.2	105.5	78.4	123.9	120.0	104.6
Tetsel Canal	176.4	3.6	4.5	4.8	5.0	4.7	4.7	4.3	5.5	3.8	5.5	5.9	5.3	4.5
Prewitt Canal Syst.	176.2	55.0	37.7	50.7	37.4	54.3	48.1	51.8	35.3	57.7	47.9	40.7	35.7	37.8
(USGS Gaging St. Balzac)	173.9													
Total annual reach diversion flow		222.9	120.3	194.1	178.9	214.7	220.1	221.9	195.2	229.9	192.5	243.9	219.9	202.9

To obtain cubic meters per second (cms), multiply acre feet per year by the factor 3.911×10^{-5}.
Source: Battelle (1974) and WPRS (1979)

Table 3-1d. Location and annual diversion flow in 1000 AF units of major diversions, water years 1965-1977, South Platte River, Balzac-Julesburg reach (Gomez-Ferrer and Hendricks, 1982)

Diversion	River Mile	Water Year												
		65	66	67	68	69	70	71	72	73	74	75	76	77
USGS Gaging St. Balzac	173.9													
South Platte Ditch	172.3	7.7	6.3	7.3	10.9	9.6	11.9	9.1	8.4	9.5	11.4	14.5	12.3	9.7
Farmers Pawnee Canal	167.5	18.3	16.1	18.0	22.6	4.6	26.8	24.7	20.6	23.3	28.4	34.5	27.7	19.5
Davis Brothers Canal	166.5	2.7	2.3	1.9	1.9	1.2	3.7	1.5	1.1	1.5	2.1	1.5	1.1	1.0
Schneider Canal	161.9	5.8	5.0	6.1	11.2	9.4	9.3	8.0	7.0	6.4	11.6	10.6	11.2	9.4
Springdale Canal	158.6	7.2	4.3	5.5	4.8	5.0	8.0	8.2	4.7	6.1	6.2	8.3	6.8	4.8
Batten Canal	156.6													
Sterling #1 Irr. Co. Canal	155.3	14.7	22.9	17.9	21.8	19.6	20.8	22.6	19.7	19.5	26.1	26.9	28.2	12.8
Henderson & Smith Canal	152.4	2.0	2.1	1.7	2.2	2.5	2.8	2.5	2.5	2.4	2.8	2.5	3.3	2.6
Sterling #2 Canal	151.6	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.4	0.3
Low Line Canal	150.2	5.4	4.5	4.0	3.7	3.9	5.2	5.4	3.8	5.0	7.9	6.8	4.9	4.7
Bravo & J. B. Canal Syst.	144.7	0.0	4.5	7.1	7.8	7.5	6.5	4.1	5.5	6.4	5.0	8.0	5.2	7.4
Farmers Canal	143.7	1.7	0.9	1.6	0.9	2.4	2.3	1.7	1.3	1.1	0.7	1.6	1.1	0.6
Iliff & Platte Valley Canal System	141.0	15.9	12.5	12.2	13.3	12.4	16.7	15.3	13.5	14.6	19.8	20.8	9.9	13.4
Lone Tree Canal	137.6	4.0	2.4	5.5	4.0	4.0	2.5	2.2	2.2	1.3	2.9	2.6	1.8	0.1
Powell & Harmony #2 Canal Syst.	133.1	3.1	3.9	3.7	3.4	3.1	4.0	3.2	2.6	5.2	3.6	3.8	3.6	4.7
Ramsey Canal	131.5	0.9	1.3	1.1	1.1	0.8	1.4	0.9	0.8	0.3	1.5	0.9	1.3	1.7
Chambers Canal	127.7	3.0	0.0	1.5	2.1	4.6	5.8	5.4	3.7	4.0	3.7	0.1	0.0	0.0
Julesburg Irr. District Jumbo Syst.	125.6	45.2	20.7	30.1	27.3	35.1	54.8	20.4	27.9	40.1	32.5	53.7	33.3	41.3
Tamarack Canal	121.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.9	2.6	1.5
Settlers Ditch	117.5													
Red Lion Canal	109.8	0.7	0.0	0.7	0.8	1.0	0.7	0.0	0.6	0.0	0.7	1.2	1.0	0.4
Peterson Canal	104.7	4.5	2.4	6.8	4.6	5.6	5.7	2.6	3.3	7.1	6.8	5.9	1.1	4.0
South Reservation Canal	99.4	2.9	2.8	3.1	2.2	2.2	3.2	3.1	3.4	3.0	4.8	4.2	2.8	3.9
Liddle Irr. System	96.6	1.4	1.4	2.0	2.1	1.6	2.0	2.1	2.3	1.6	3.1	2.5	2.6	2.4
Carlson Canal	94.8	0.5	0.3	1.3	0.3	0.5	0.1	0.0	0.2	0.0	1.2	0.3	0.3	0.0
(USGS Gaging St. Julesburg)	86.6													
Total annual reach diversion flow		147.6	116.6	139.1	149.0	136.6	194.4	143.2	135.1	158.4	183.3	212.1	162.5	146.2

To obtain cubic meters per second (cms), multiply acre feet per year by the factor 3.911×10^{-5}.
Source: Battelle (1974) and WPRS (1979)

Table 3-2. Water rights priority dates, South Platte River, Kersey to State Line

Date of Right	Type of Right	Max. Rate (C.F.S.)	Volume (A.F.)	Canal or Reservoir
4-20-68	Direct	15.00	-	Upper Platte & Beaver
5-15-69	"	5.17	-	Upper Platte & Beaver
4-1-71	"	7.00	-	Schultz
4-2-71	"	13.00	-	Deuel & Snyder
10-1-71	"	40.00	-	Bijou
5-1-72	"	22.50	-	South Platte Extension
6-1-72	"	15.00	-	Johnson & Edwards
1-1-73	"	8.00	-	Hardin
4-10-73	"	11.00	-	Schneider
4-20-73	"	16.32	-	Bijou
7-15-73	"	113.90	-	Sterling No. 1
9-17-73	"	14.40	-	Farmers Pawnee
4-10-74	"	2.00	-	Davis Brothers
6-1-74	"	8.00	-	Deuel & Snyder
11-15-74	"	17.00	-	Tetsel
6-1-75	"	21.00	-	Corona Ranch or Mackey
7-15-75	"	6.90	-	Davis Brothers
7-15-75	"	18.10	-	Schneider
1-1-76	"	22.00	-	Riverside
2-15-76	"	7.50	-	South Platte Extension
4-1-80	"	10.00	-	Bijou
10-20-80	"	6.07	-	Davis Brothers
10-20-80	"	15.93	-	Schneider
11-30-80	"	12.50	-	Henderson & Smith
10-26-81	"	165.00	-	Weldon Valley
4-26-82	"	80.00	-	Bijou
6-20-82	"	50.00	-	Upper Platte & Beaver
6-28-82	"	126.00	-	Farmers Pawnee
7-1-82	"	20.00	-	Tetsel
9-4-82	"	38.00	-	Lower Platte & Beaver
10-14-82	"	39.90	-	Low Line
10-18-82	"	323.00	-	Ft. Morgan
4-21-83	"	20.00	-	South Platte Extension
10-1-83	"	150.00	-	Iliff and Platte Valley
2-21-84	"	23.00	-	Hoover
4-7-84	"	32.00	-	Deuel and Snyder
6-7-84	"	50.00	-	Sterling No. 2
4-10-86	"	48.00	-	Johnson and Edwards
7-19-86	"	62.40	-	Springdale
11-15-86	"	35.00	-	Corona Ranch or Mackey
11-29-86	"	16.00	-	Riverside
6-18-87	"	20.00	-	Snyder
4-1-88	"	21.00	-	Schultz
4-15-88	"	164.00	-	Upper Platte & Beaver
4-15-88	"	284.00	-	Lower Platte & Beaver
10-1-88	"	450.00	-	Bijou

Table 3-2. (continued)

Date of Right	Type of Right	Max. Rate (C.F.S.)	Volume (A.F.)	Canal or Reservoir
11-1-88	"	31.00	-	Deuel & Snyder
11-15-88	Storage	-	287	Iliff & Platte Valley
9-3-89	Direct	23.00	-	Gill & Stevens
5-1-90	"	37.50	-	South Platte Extension
10-22-90	"	12.00	-	Russel Sidebottom
12-1-90	"	3.00	-	Davis Brothers
10-21-91	"	10.00	-	Liddle
9-14-92	"	25.00	-	South Reservation
2-21-93	"	40.00	-	Bravo
12-12-93	"	45.00	-	Powell & Dillon
8-3-94	"	12.00	-	Ramsey
9-17-94	"	10.00	-	Lone Tree
9-20-94	"	20.00	-	Davis Brothers
9-30-94	"	25.00	-	Batten
11-15-94	"	21.00	-	Sterling Herford Cattle Co.
12-1-94	"	16.00	-	Carlson
2-19-95	"	40.00	-	Powell
3-1-95	"	184.00	-	Peterson
3-11-95	"	10.00	-	J. B. Ditch
4-28-95	"	252.00	-	Harmony No. 1
5-4-95	"	30.00	-	Chambers
7-11-95	"	16.00	-	Farmers
7-15-95	"	82.00	-	Lone Tree
10-31-95	"	52.00	-	Red Lion
4-1-96	"	50.00	-	South Platte Extension
1-22-97	"	10.00	-	Hemming House
2-10-97	"	14.50	-	Long Island
5-3-97	"	50.00	-	Harmony No. 2
10-11-97	"	350.00	-	Peterson
12-13-97	"	89.00	-	Settlers
11-10-98	"	288.00	-	Settlers
4-1-00	-	50.00	-	Bijou
11-9-00	-	162.00	-	Harmony No. 2
12-27-00	"	90.00	-	Trowell
2-16-01	"	46.87	-	North Sterling
3-1-01	"	150.00	-	Tremont
5-18-01	Storage	400.00	35,629	Jackson Lake
1-17-02	Direct	175.00	-	Snyder
2-17-02	"	24.00	-	Henderson & Smith
3-20-02	Storage	-	139	Snyder Reservoir
4-1-02	"	-	16,070	Riverside Reservoir
4-23-02	Direct	134.00	-	Tamarack
5-13-03	"	219.00	-	Harmony No. 3
5-25-03	"	102.00	-	Davis Brothers
2-12-04	"	450.00	-	Harmony No. 1
2-12-04	Storage	450.00	28,178	Julesburg Reservoir
4-28-04	Direct	35.00	-	S. B. Rice

Table 3-2. (continued)

Date of Right	Type of Right	Max. Rate (C.F.S.)	Volume (A.F.)	Canal or Reservoir
5-18-05	Storage	617.48	37,710	Empire Reservoir
3-31-06	"	575.00	11,520	Empire Reservoir
4-1-06	Direct	20.00	-	Bravo
9-20-06	"	20.00	-	Long Island
3-20-07	"	42.50	-	Cox
5-31-07	"	417.00	-	Riverside
8-1-07	Storage	1,000.00	41,437	Riverside Reservoir
6-15-08	"	300.00	69,446	North Sterling Reservoir
1-15-09	"	500.00	9,183	Bijou No. 2 Reservoir
5-15-10	"	695.00	32,300	Prewitt Reservoir
10-25-10	Direct	1,000.00	-	Riverside
5-27-14	"	460.00	-	North Sterling
8-1-15	Storage	-	11,954	North Sterling Reservoir
-	"	-	2,600	North Sterling Reservoir

Table 3-3. Off-stream reservoirs obtaining water from South Platte River, Kersey-Julesburg reach

Reservoir	Capacity[1] (acre feet)	Water Rights[2] (acre feet)	Priority[2] Date
Riverside	57,507	16,070	1902
		41,437	1907
Empire	37,710	37,710	1905
		11,520	1906
Jackson Lake	35,629	35,629	1901
Bijou No. 2	9,183	9,183	1909
Snyder	139	139	1902
Prewitt	32,300	32,300	1910
North Sterling	73,920	69,446	1908
		11,954	1915
		2,600	1915
Julesburg	28,178	28,178	1904
Total	274,566	280,112	

[1]Table 6-8, Gerlek, 1977.

[2]Taken from Table 3-2.

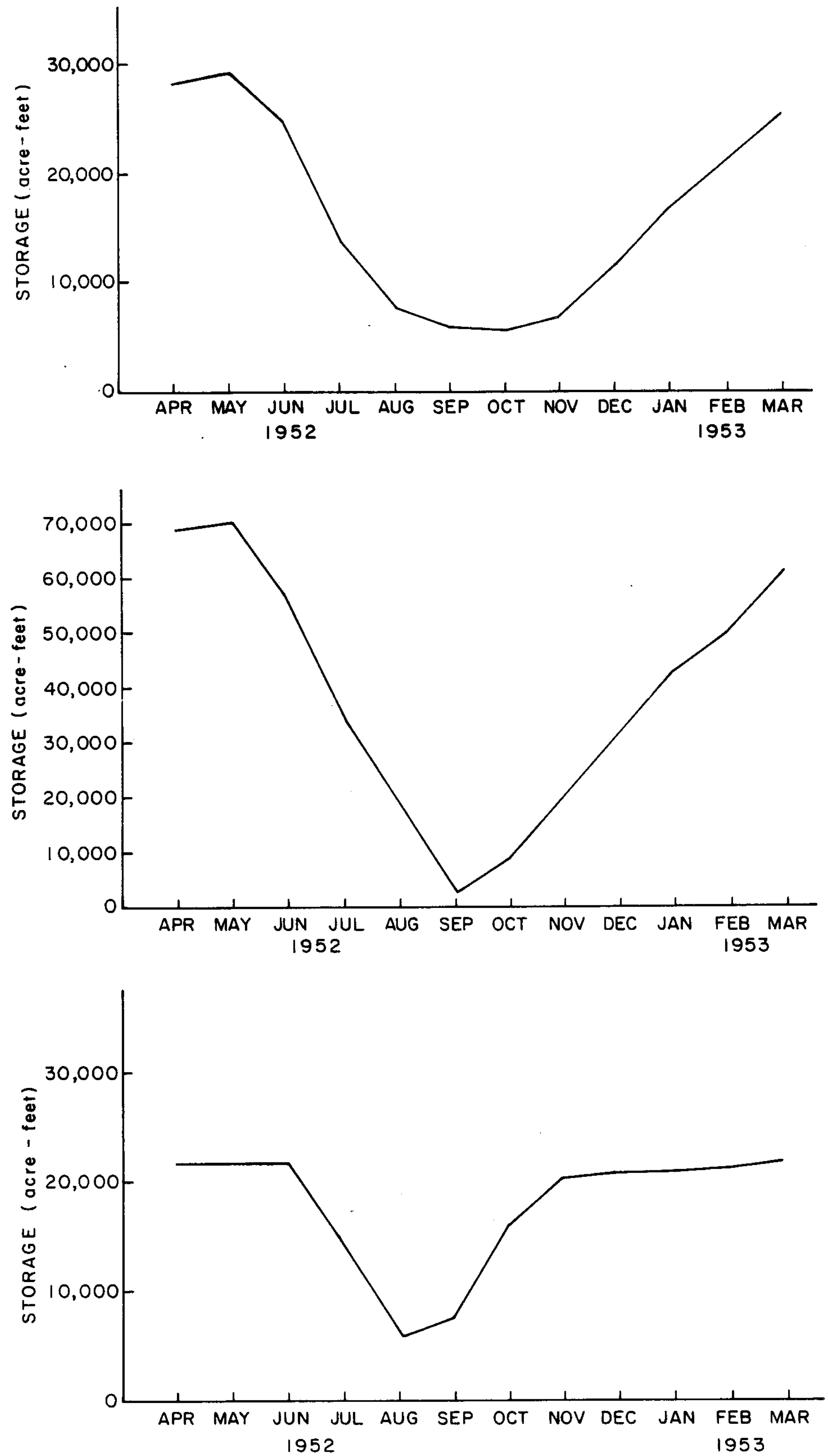


Figure 3-5. Typical cycles of filling and drawing water over and annual cycle for three reservoirs: (a) Prewitt, (b) North Sterling, and (c) Julesburg. Adapted from Labadie, et al. (1983).

to meet demands by irrigation. An important point relative to salt balance is that the fillings occur when salinity levels are at the highest. To manage their operation toward salinity improvement they might be filled in spring when river flows from snowmelt runoff may be in excess of senior direct flow rights.

Groundwater. The estimated annual groundwater pumping by ditch systems between 1947 and 1961 is shown in Table 3-4. In 1961 the estimated pumpage by 875 wells (USBR, 1967) was 107,200 acre-feet. More recent data are not available. In 1969 the legislature passed the "Water Rights Determination and Administration Act," which places groundwater hydraulically connected to a stream under the appropriative water rights system. Since the wells are not metered the pumpage is estimated using energy consumption data from the Public Service Company, the Highline Electric Association, the Morgan County REA, and the City of Fort Morgan. Most wells pump from shallow aquifers having depths to water table from 13 to 29 feet, with an additional 18 feet of drawdown due to pumping. Combined pump and motor efficiencies range between 42 and 46 percent. Using these data the yield of pumped water per unit of energy was determined by the USBR (1967) to be 1.00 acre-feet/100 kwH for the Fort Morgan-Balzac reach and 1.29 acre-feet/100 kwH for the Balzac-Julesburg reach.

Irrigated lands. Data on irrigated lands are available for the Weldona-Julesburg reach, and were compiled by the USBR (1967) as a part of the Narrows Dam study. Table 3-5 shows the acreages of land historically irrigated by canals diverting between Weldona and Julsburg. The Narrows service area is 299,425 acres. The total area historically irrigated is 171,591 acres, which inludes 27,461 acres of class 6W land,

Table 3-4. Estimated annual groundwater pumping by ditch systems, 1947-1961 (USBR, 1977)

Name of Ditch or Irrigation Company	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	MEAN
Fort Morgan Canal	9.3	10.1	12.6	15.2	14.5	16.7	15.4	23.8	22.0	26.2	10.9	13.5	16.5	23.3	17.3	16.5
Deuel & Snyder Canal	1.4	1.5	2.0	2.3	2.2	2.6	2.3	3.9	3.7	4.6	2.0	2.4	2.9	3.3	2.4	2.6
Upper Platte and Beaver	10.3	11.4	14.1	17.4	16.4	18.5	17.1	27.7	25.6	31.1	12.5	15.9	20.3	23.6	17.1	18.6
Tremont Canal	1.1	1.2	1.5	1.9	1.8	2.0	1.8	3.1	3.0	3.6	1.4	1.8	2.2	2.5	1.8	2.0
Lower Platte and Beaver	11.1	12.5	15.7	18.7	17.6	20.0	18.3	29.2	28.2	33.9	13.6	17.5	22.5	25.5	18.7	20.2
Snyder Canal	2.3	2.5	3.1	3.8	3.6	4.1	3.8	6.3	6.1	7.5	2.9	3.6	4.5	5.2	3.8	4.2
North Sterling Canal	0.2	0.2	0.3	0.4	0.4	0.4	0.4	0.9	1.1	1.5	0.6	0.6	1.2	1.3	0.9	0.7
Tetsel Canal	0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.1	0.2	0.3	0.3	0.2	0.2
Johnson and Edwards	0.3	0.3	0.3	0.4	0.3	0.5	0.5	0.7	0.8	0.9	0.4	0.5	0.7	0.7	0.6	0.5
South Platte Canal	0.3	0.4	0.5	0.6	0.6	0.7	0.7	1.4	1.7	2.3	1.0	1.0	1.9	2.0	1.4	1.1
Farmers-Pawnee Canal	1.0	1.2	1.7	1.9	1.8	2.2	2.2	4.6	5.3	7.0	3.1	3.2	6.0	6.5	4.5	3.5
Davis Brothers Canal	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.8	1.0	1.3	0.6	0.6	1.0	1.1	0.8	0.6
Schneider Canal	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.7	0.8	1.1	0.5	0.5	1.0	1.0	0.7	0.6
Springdale Canal	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.8	2.1	2.7	1.3	1.3	2.3	2.5	1.7	1.4
Sterling No. 1 Canal	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.6	0.7	1.0	0.4	0.4	0.8	0.9	0.6	0.5
Sterling No. 2 Canal	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.4	0.5	0.6	0.3	0.3	0.5	0.5	0.4	0.3
Bravo Canal	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.4	0.2	0.2	0.4	0.4	0.3	0.2
Iliff & Platte Valley	0.3	0.4	0.5	0.6	0.6	0.6	0.7	1.4	1.8	2.2	1.0	1.0	1.8	2.0	1.4	1.1
Lone Tree Canal	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.5	0.2	0.4	0.5	0.3	0.2
Julesburg Irrig. System	3.7	4.1	5.6	6.4	6.1	7.3	7.3	15.4	18.3	23.9	10.6	11.0	20.0	21.1	15.1	11.7
Liddle Canal	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.2	0.2	0.4	0.4	0.3	0.2
Subtotal	42.6	47.4	59.8	71.7	67.9	78.2	73.3	123.8	124.0	153.1	63.8	75.9	107.6	124.6	90.3	86.9
Miscellaneous[1/]	7.8	8.4	11.1	12.3	12.5	15.5	14.4	23.5	22.1	28.6	13.6	15.5	20.6	23.1	16.9	16.4
TOTAL	50.4	55.8	70.9	84.0	80.4	93.7	87.7	147.3	146.1	181.7	77.4	91.4	128.2	147.7	107.2	103.3

Table 3-5. Acreages of irrigated land served by various canals between Weldona and Julesburg (taken from Appendix 2, USBR, 1967)

Canal	Historically Irrigated		
	Class[2] 1, 2 & 3	Class[3] 6W	Total
	Acres	Acres	Acres
Fort Morgan	12,388	202	12,590
Deuel and Snyder	2,013	46	2,059
Upper Platte & Veaver	12,622	303	12,925
Tremont	970	65	1,035
Lower Platte & Beaver	14,118	229	14,347
Snyder	1,965	177	2,142
No. Sterling	31,444	4,648	36,092
Tetsel	1,035	25	1,060
Johnson & Edwards	560	316	876
So. Platte	4,709	180	4,889
Farmers-Pawnee	9,684	303	9,987
Davis Brothers	2,216	--	2,216
Schneider	2,252	86	2,338
Springdale	4,650	--	4,650
Sterling #1	7,406	1,866	9,272
Sterling #2	1,186	54	1,240
Henderson & Smith	395	255	650
Bravo	1,874	574	2,448
Iliff and Platte Valley	6,022	2,202	8,224
Lone Tree	326	714	1,040
Julesburg System	24,502	9,976	34,478
So. Reservation	212	722	934
Liddle	635	363	998
Subtotal	143,184	23,306	166,490
Sum of Small Ditches[1]	946	4,155	5,101
Total	144,130	27,461	171,591

[1]Included in sum of small ditches are Batten, Lowline, Farmers, Powell, S.B. Rice, Ramsey, Chambers, Tamarack, Hemmingkouse, and Carlson.

[2]Lands considered irrigable.

[3]Lands with severe irrigation limitations to which the USBR will not supply water.

which will not be served by the Narrows project. About 128,335 acres are dryland. Some 22,465 acres of this are under existing ditch systems which are irrigated when water is available. Table 3-6 shows the breakdown of lands by class which are served by these same canals, showing 166,657 acres of irrigable land, i.e. class 1, 2, or 3 land.

Figure 3-4(a,b,c,d) shows the irrigated lands of all classes in the Kersey-Julesburg reach. These maps were abstracted from USBR maps (1967), which show the lands coded by their respective classifications.

Irrigation deficits. Using for each canal system the irrigated acreage and the types of crops, the crop consumptive use can be calculated, e.g. by the Lowry-Johnson procedure. Then the effective precipitation must be subtracted, giving the "crop irrigation requirement." The "farm irrigation requirement" is the water needed at the farm headgate to meet the crop irrigation requirement. If 60 percent of this water is used by the crop and losses are 40 percent, the farm irrigation requirement equals the crop irrigation requirement divided by 0.60. Water losses in canals were determined by the USBR to vary from 27 percent to 44 percent, depending upon month. Thus the "canal diversion requirement" equals the "farm irrigation requirement" divided by the canal efficiency (1-loss fraction). The "canal diversion deficit" is the "canal diversion requirement" minus the historic diversion flows, e.g. as shown in Table 3-7. Table 3-7 shows the results of these calculations for the period 1947-61. Table 3-8 shows the same data averaged for the 1947-61 period, with the amount of irrigated land and average annual per acre deficit shown. Figure 3-6 is a plot, taken from data in Table 3-8, of the cumulative headgate water deficiencies with distance along river in the Narrows service area.

Table 3-6. Classification of project lands by canals (Appendix 3, USBR, 1967)

Canal	Class 1		Class 2		Class 3		Total Irrigable Acres	Class 6	Class6W	ROW Cities River	Total Acres
	Irrigated	Nonirrigated	Irrigated	Nonirrigated	Irrigated	Nonirrigated					
Fort Morgan	8,761	3	2,440	106	1,187	253	12,750	2,879	202	2,325	18,156
Upper Platte and Beaver	6,149	28	5,573	49	803	24	12,626	2,805	303	1,501	17,235
Deuel and Snyder	791	-	890	90	332	61	2,104	450	46	1,336	3,906
Lower Platte and Beaver[1]	7,679	13	5,882	70	1,117	234	14,995	2,203	545	3,033	20,776
Tremont	575	47	270	24	125	368	1,409	427	65	1,342	3,243
Snyder	976	-	767	315	222	120	2,400	634	177	1,260	4,521
North Sterling	10,802	1,074	15,035	7,755	5,573	5,855	46,094	29,180	4,648	174	80,096
Tetsel	-	-	876	2	159	34	1,071	136	25	101	1,333
South Platte	2,044	9	1,692	30	922	69	4,766	1,189	180	926	7,061
Farmers' Pawnee	4,078	11	4,541	483	1,019	386	10,518	3,529	303	2,582	16,932
Davis Brothers	1,429	-	592	13	105	69	2.207	34	-	24	2,355
Schneider	967	4	811	13	474	37	2,306	24	86	357	2,773
Springdale	1,395	-	2,895	126	361	50	4,826	721	-	987	6,534
Sterling No. 1	1,139	8	4,660	138	1,607	52	7,604	1,036	1,866	2,075	12,581
Batten	-	-	83	-	271	9	363	-	32	329	724
Sterling No. 2	-	-	924	-	262	33	1,219	-	54	836	2,109
Henderson and Smith	-	-	395	30	-	17	442	602	255	602	1,901
Lowline	-	-	-	-	-	1,369	1,369	45	281	609	2,304
Bravo	-	-	1,012	217	862	214	2,305	1,417	574	134	4,430
Farmers	-	-	148	9	181	-	338	80	-	281	699
Iliff and Platte Valley	1,404	-	2,994	74	1,624	11	6,107	501	2,202	3,063	11,873
Lonetree	-	-	206	-	120	20	346	529	714	19	1,608
Powell	-	-	-	-	-	-	-	-	1,125	281	1,406
S. B. Rice	-	-	5	56	-	-	61	410	387	-	858
Ramsey	-	-	-	-	-	-	-	32	581	930	1,543
Julesburg System	14,613	123	3,836	578	6,053	1,221	26,424	16,083	9,976	11,277	63,760
Tamarack	-	-	-	-	-	-	-	-	598	58	656
Hemminghouse	-	-	-	20	164	185	369	-	10	469	848
South Reservation	28	3	116	14	68	4	233	17	722	553	1,525
Carlson	-	-	53	-	30	-	83	38	388	-	509
Liddle	-	-	273	72	362	29	736	1,606	363	1,610	4,315
Total Acres	62,830	1,323	56,979	10,417	24,093	10,723	166,657	66,657	27,183	39,211	299,416

[1]Includes Johnson and Edwards ditch.

Table 3-7. Historic deficits in river diversion requirements, 1947-1961, Weldona-Julesburg reach. Units are in thousands of acre feet. Deficit equals actual diversion minus canal diversion requirement. (Appendix 2, USBR, 1967)

Canal	1947	1947	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	Total
Fort Morgan	0	1.9	0.7	0	0	0	0.2	15.7	7.1	6.4	0.3	2.4	8.5	1.5	4.0	48.7
Deuel and Snyder	1.2	1.3	0.7	1.2	0	0.5	0.2	1.1	1.6	0.3	0.0	1.6	0.7	0.3	0.8	11.5
Upper Platte and Beaver	0	2.8	2.1	0.3	0	0.5	1.8	3.4	3.3	4.7	1.1	1.6	3.6	1.4	3.2	29.8
Tremont	0.1	0.6	0.3	0.2	0	0.3	0.4	0.5	0.2	0.2	0	0.2	0.3	0.3	0.8	4.4
Lower Platte and Beaver	0	1.4	3.6	3.0	0	4.4	3.8	8.7	7.8	3.5	0	1.0	7.6	3.3	5.4	53.5
Snyder	0.5	0	0.7	1.1	0.3	0.5	1.1	1.0	0.5	0.5	0.5	0.2	0.7	0.5	1.4	9.5
North Sterling	36.6	31.2	29.8	58.8	19.5	40.8	46.8	78.7	132.1	84.2	11.3	29.1	33.3	52.5	27.3	712.0
Tetsel	0.7	0.5	0.9	0.4	0.1	0	0	0	0.5	0	0	0.7	0.3	0	0.5	4.6
Johnson and Edwards	0.3	0	0.3	0.7	0.0	0.2	0	0.7	1.0	0.9	0.2	0.5	0.3	0.7	0.9	6.7
South Platte	6.0	2.8	4.6	5.7	0.8	4.4	2.9	3.9	4.5	1.7	3.3	3.0	5.9	5.4	6.1	61.0
Farmers-Pawnee	3.5	5.0	3.2	3.2	0	1.9	4.0	13.7	14.7	8.1	3.2	3.5	8.2	15.1	7.6	94.9
Davis Brothers	1.9	1.5	2.1	3.3	1.1	2.5	2.5	3.6	3.8	2.1	1.6	1.4	2.1	2.3	2.3	34.1
Schneider	0.9	0.2	1.5	0.4	0	0	0	0.4	3.6	0.5	1.4	1.5	0.5	0	2.3	13.2
Springdale	6.7	5.7	5.6	8.5	2.0	7.8	8.0	9.7	8.4	6.5	3.9	4.7	8.7	9.1	7.5	102.8
Sterling No. 1	8.3	2.3	9.7	3.5	1.7	3.4	1.9	2.0	6.8	0.8	7.5	2.7	4.7	5.4	9.6	70.3
Sterling No. 2	1.4	1.7	1.4	0.3	0.3	1.0	0.9	3.0	2.4	1.5	0.7	1.9	2.7	3.1	2.0	24.3
Henderson and Smith	0.8	0.9	0.5	0.3	0.1	0.4	0.4	0.2	0.3	0	0.6	0.5	0.3	0.2	0.6	6.1
Bravo	3.2	1.5	3.7	3.7	1.6	3.5	2.0	5.9	4.7	3.3	1.4	1.6	3.1	2.2	2.4	43.8
Iliff and Platte Valley	5.6	3.9	6.4	8.2	3.5	8.8	5.7	7.2	11.4	2.9	4.0	8.0	5.5	10.6	7.9	99.6
Lone tree	1.1	0.8	0.6	0.5	0.4	0.7	0	0.4	1.0	0.3	0.7	1.0	2.1	0.9	1.6	12.1
Julesburg Irrigation System	28.7	21.2	22.5	28.0	14.3	27.4	27.0	49.4	32.8	18.0	4.6	15.7	40.0	32.2	26.6	388.5
So. Reservation	1.6	1.7	1.5	0.5	0	0.2	0	0.3	0.3	0	0.7	0.6	0.2	0.5	0.5	8.6
Liddle	1.3	1.3	2.0	0.5	0.2	0.7	0.5	1.0	1.3	0	0.2	0.8	0.3	1.1	1.4	12.6
Total	110.4	90.2	104.4	132.3	45.9	109.9	110.1	210.5	250.1	146.4	47.2	84.2	139.6	148.7	122.7	1852.6

Source: USBR, 1967, Appendix 2.

Table 3-8. Average irrigation deficits by canal system, Weldona-Julesburg (Appendix 2, Table 28, USBR, 1967)

Canal (river mile)	Average Annual Irrigation Deficit (1000's AF)	Historically Irrigated Land (acres)	Average Annual per acre Deficit (AF/acre)
Fort Morgan (210)	3.25	11,835	0.27
Deuel and Snyder (199)	0.77	1,935	0.40
Upper Platte and Beaver (198)	1.99	12,150	0.16
Tremont (191.9)	0.29	973	0.30
Lower Platte and Beaver (190)	3.57	13,486	0.26
Snyder (185.2)	0.63	2,013	0.31
North Sterling (179.4)	47.47	33,926	1.40
Tetsel (176.4)	0.31	997	0.31
Johnson and Edwards (176.2)	0.45	823	0.55
South Platte (172.3)	4.07	4,595	0.89
Farmers - Pawnee (167.5)	6.33	9,388	0.67
Davis Brothers (166.5)	2.27	2,083	1.09
Schneider (161.9)	0.88	2,198	0.40
Springdale (158.6)	6.85	4,371	1.57
Sterling No. 1 (155.3)	4.69	8,716	0.54
Sterling No. 2 (151.6)	1.62	1,166	1.39
Henderson and Smith (150.2)	0.41	611	0.67
Bravo (144.7)	2.92	2,302	1.27
Iliff and Platte Valley (141)	6.64	7,731	0.86
Lone Tree (137.6)	0.81	977	0.83
Julesburg Irrigation System (125.6)	25.90	32,409	0.80
South Reservation (99.4)	0.57	878	0.65
Liddle (96.6)	0.84	938	0.90
TOTAL	123.53	156,501	

Average Deficit = 0.79 AF/acre

[1]Deficits are the historic shortage in ability to meet the river diversion requirements at the canal headgates for the period 1947-1961 needed to meet crop consumptive use requirements, Table 2-5.

[2]The number of acres historically irrigated with water from these ditches. Does not include 19,591 acres of land that are irrigated only in years when the water supply is abundant.

[3]Average per acre irrigation water deficit if the water shortage is spread uniformly across the irrigated acreage.

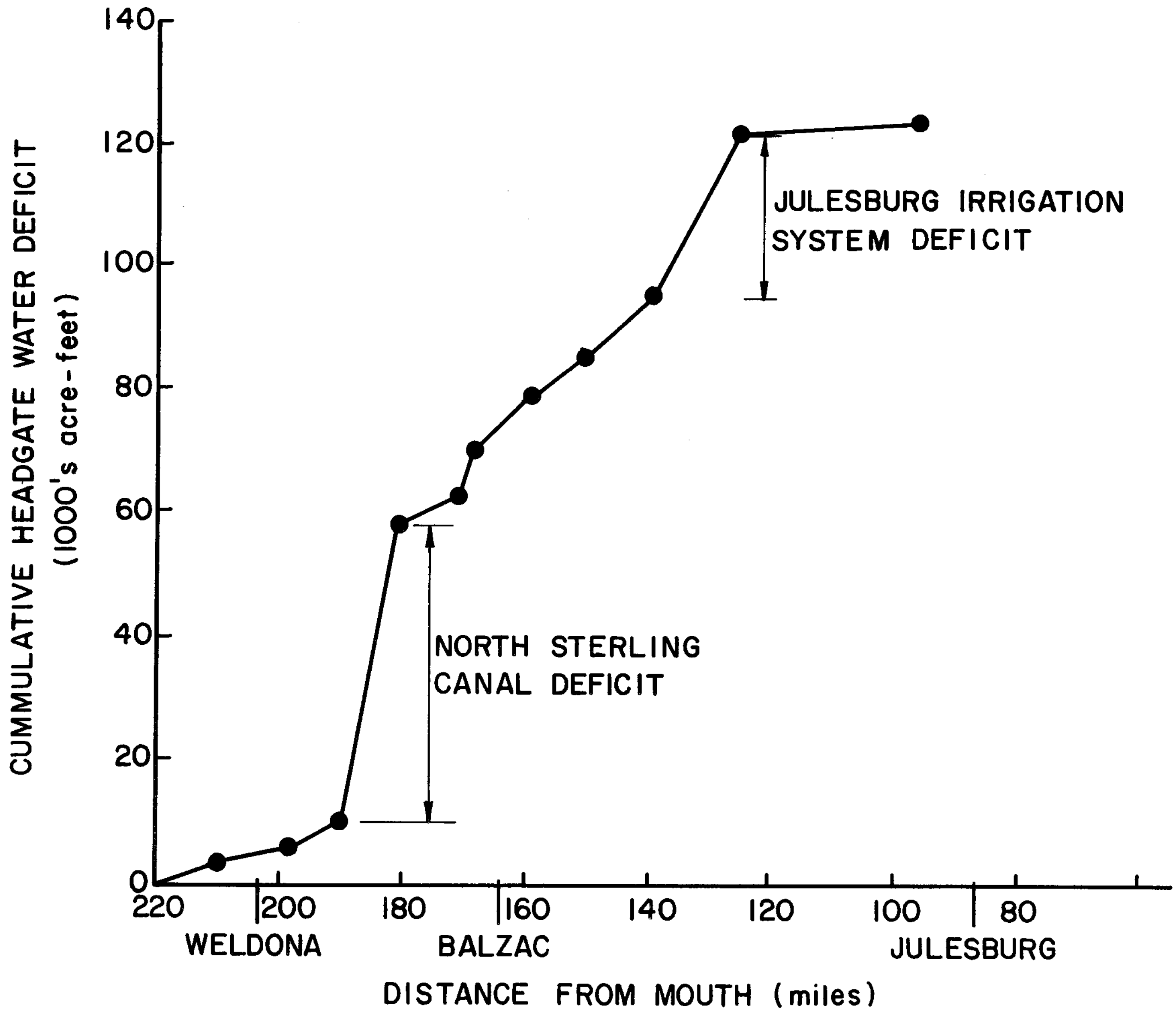


Figure 3-6. Cumulative headgate water deficiencies with distance along river in the Narrows service area (plotted from data in Table 3-8). Multiply abcissa scale in miles by 1.609 to obtain kilometers.

From Figure 3-6 one can identify the potential areas from the standpoint of salt accumulation as the North Sterling and Julesburg canals.

From the standpoint of salt hydrology it is important also to note that the average annual deficit ranges from 0.16 acre-feet/acre to 1.40 acre-feet/acre, depending upon the canal system. The 1.40 acre-feet/acre deficit, it should be noted, is for the North Sterling Canal which also has the largest deficit for land irrigated, e.g. 47,470 acre feet. The total average annual shortage for the Narrows service area is 182,800 acre feet (at the farm headgate), and 123,530 for lands associated with the canal systems listed in Table 3-8.

Drainage. The USBR report (1967) indicates that the water table tends to follow the bedrock surface and slopes toward the valleys with gradients that are as much as 100 feet per mile. Most of the irrigable lands in the uplands have adequate internal drainage. Table 3-9 shows the distribution or irrigable land by drainage limitations.

Table 3-9. Distribution of irrigable land in Narrows service area by drainage limitations (p. 27, Appendix III, USBR, 1967).

Drainage limitation	Acres
No drainage requirement	138,338
Permanent water table (48" depth)	15,114
Permanent water table (36" depth)	12,026
Inadequate internal drainage (closed basins)	887
Total irrigable land	166,165

The USBR (Appendix III, 1967) states that numerous tile drains and open drains have been constructed throughout the area by individual farmers, and drainage districts. With the supplemental irrigation from the proposed Narrows project, additional drainage will be necessary for those lands having drainage problems. But, as indicated in Table 3-9, the need could amount to only 16 percent of the total irrigable land served by the project.

Narrows Reservoir. The proposed Narrows Reservoir dam site is just above Fort Morgan, and is seen in Figure 3-3. The capacity of the reservoir will be 973,185 acre feet at elevation 4428.5 feet, with 475,000 acre-feet for flood control, 75,000 acre-feet for joint use (flood control and irrigation), 373,025 acre-feet for irrigation, and 50,160 acre-feet for inactive storage. Operation studies by the USBR have indicated an average annual project yield of 88,400 acre-feet from reservoir regulation, plus 31,000 acre-feet from the Weldona Valley water right. The Weldona Valley canal now serves about 5,100 acres which will be inundated. The reservoir surcharge of 575,373 acre-feet brings the capacity to 1,548,558 at maximum water surface elevation 4447.0 feet. The total supplemental supply for the Narrows service area is 119,400 acre-feet. In other words, the "new water" created by the Narrows Reservoir is projected to be 88,400 acre-feet. It should be noted, however, that the reservoir regulation will stabilize existing water rights, such that the year to year variability in yields of the more junior water rights will be greatly attenuated by the storage. In addition, as noted in the USBR report (1967), the average salinity level, expressed as TDS, will be attenuated also by the retention and mixing of the low TDS spring runoff. This question deserves more attention particularly in relation to how the reservoir regulation might include salinity management.

Salinity and Alkalinity. The USBR report (Appendix II, 1967) states that project lands as a whole are not severely affected by saline or alkali conditions. The largest and most severely affected area is the bottom lands at Crook, which has a high water table. Many areas of bottom lands are not suitable for irrigated crop production because of saline or alkali conditions caused by high water tables. The conductivity of the saturation extract of these soils may be greater than 4 millimhos/cm with exchangeable sodium greater than 15 percent. About 37,000 acres of the irrigable lands, or twenty percent, have reduced production due to an accumulation of soluble salts.

Quality of water. The USBR report (Appendix III, p. 33, 1967), indicates that the project has reached a salt balance for inflow and outflow. It also states that construction of the Narrows Dam will allow for a 30 percent leaching requirement, which has not been practiced due to a shortage of irrigation water. The leaching requirement for the entire project is 10 percent to retain the soil at 8 millimhos and 21 percent for 4 millimhos.

The report states that the weighted average for specific conductance in the river at the Narrows site from 1955-63 was 1173 micromhos/cm, and that this will be the approximate conductance of the reservoir water. The quality of irrigation water will improve after the flood waters are mixed within the reservoir, as these flood waters will dilute the normal flow by about 66 percent with good quality water. The report states further that the peaks of the highest salt content in the flows at Julesburg will be reduced somewhat but the total amount of dissolved solids will not change appreciably.

By way of commentary, it would seem that in light of our findings in Volume 1, the appraisal of present and future salinity problems might warrant further attention. Also, as noted, salinity management through reservoir operation should be investigated.

3.3 Salt Flows

The river was characterized with respect to salt mass flows in Volume 1 at Henderson, Kersey, Weldona, Balzac, and Julesburg. Figure 3-7 summarizes the results of this analysis. The changes in salt mass flow with distance for the river are designated by letters. The salt mass flows of the virgin tributary stream flows at the canyon mouths and by the South Platte River at Henderson, designated by "l"s, is 400 metric tons/day. The aggregate salt pickup between the canyon mouths and Kersey is shown as "f", and amounts to about 1600 metric tons/day. The river loses 640 metric tons/day between Kersey and Balzac, with a gain of 260 metric tons/day between Balzac and Julesburg. The net loss of salt to the lands between Kersey and Julesburg is 380 metric tons/day. To understand what happens to this salt is the concern of this report.

To better understand the behavior of the system some additional data are taken from the Volume 1 report. Figure 3-8 shows the annual variation in flow, salt concentration, and salt mass flow at Julesburg for the period 1965-77. Figure 3-9 shows distance profiles for the same parameters between Henderson and Julesburg for the years 1975-79. Note that between Henderson and Kersey a massive increase in the salt mass occurs due to the influx of salt from the tributaries. Between 800 and 2000 metric tons per day are added to the mainstem river. The salt buildup problem occurs due to the deposition of between 380 and 640 metric tons per day on the irrigated lands between Kersey and Julesburg. In order to maintain long term agricultural productivity, a net positive outflow of salt mass should exist. Profiles for the other years studied, i.e. 1965-74, are given in Volume 1. Figure 3-10 shows

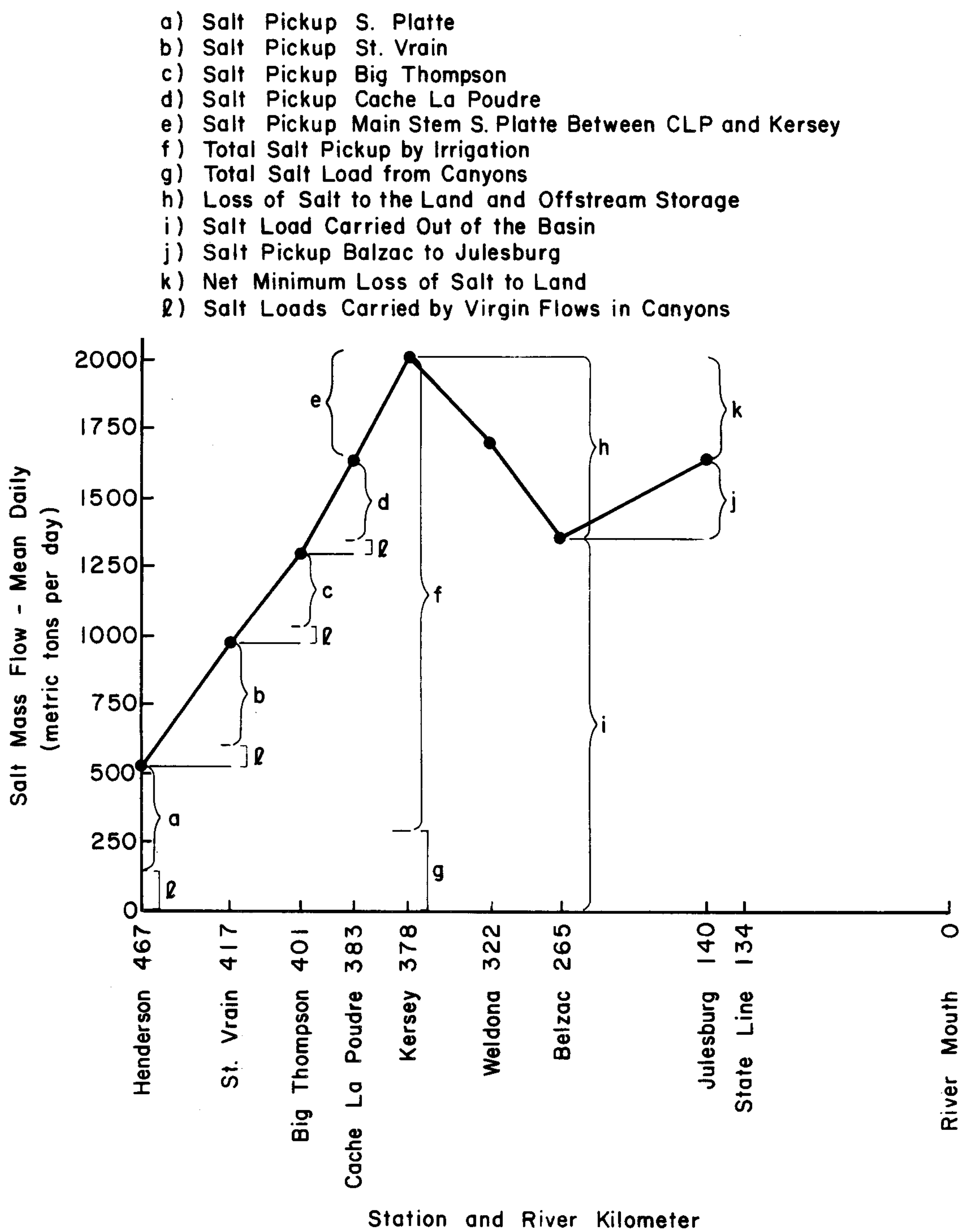


Figure 3-7. Profiles of average salt mass flows, 1965-79, lower South Platte River, showing analysis of changes.

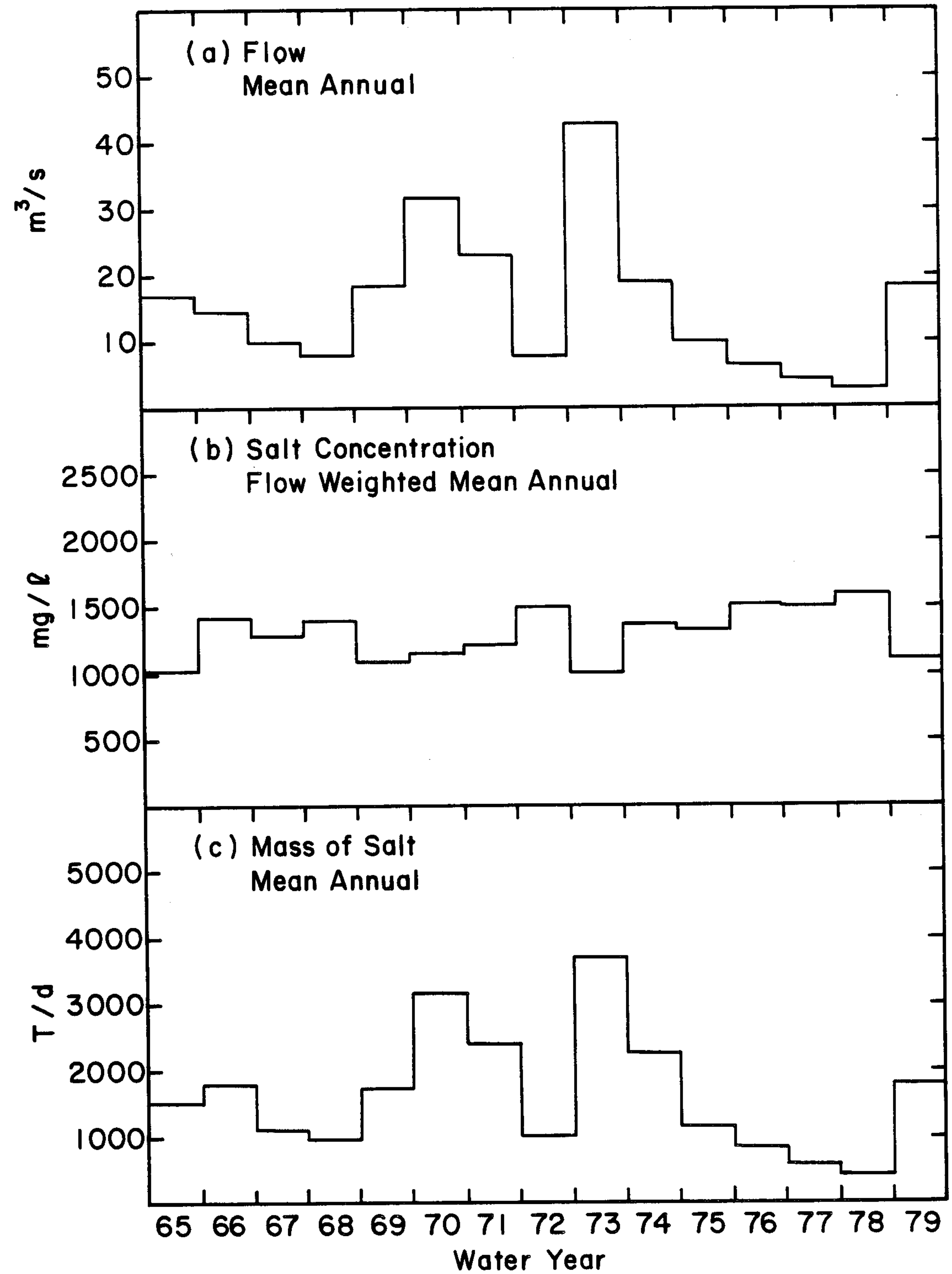


Figure 3-8. Annual variations in flow, total dissolved solids, and salt mass flow at Julesburg, 1965-77 (from Gomez-Ferrer and Hendricks, 1982).

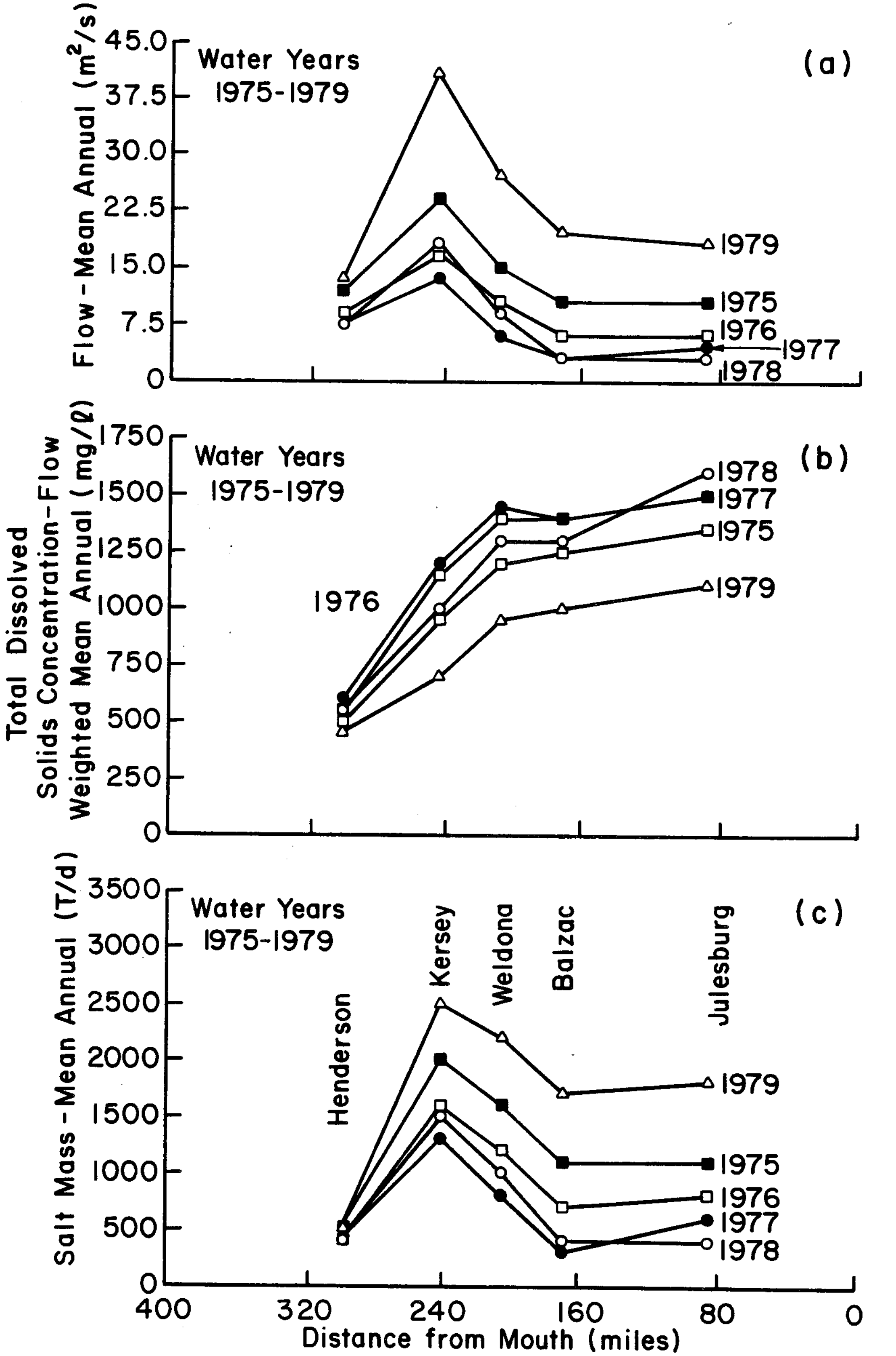


Figure 3-9. Distance profiles of flow, total dissolved solids, and salt mass flow from Henderson to Julesburg, 1975-79 (from Gomez-Ferrer and Hendricks, 1982).

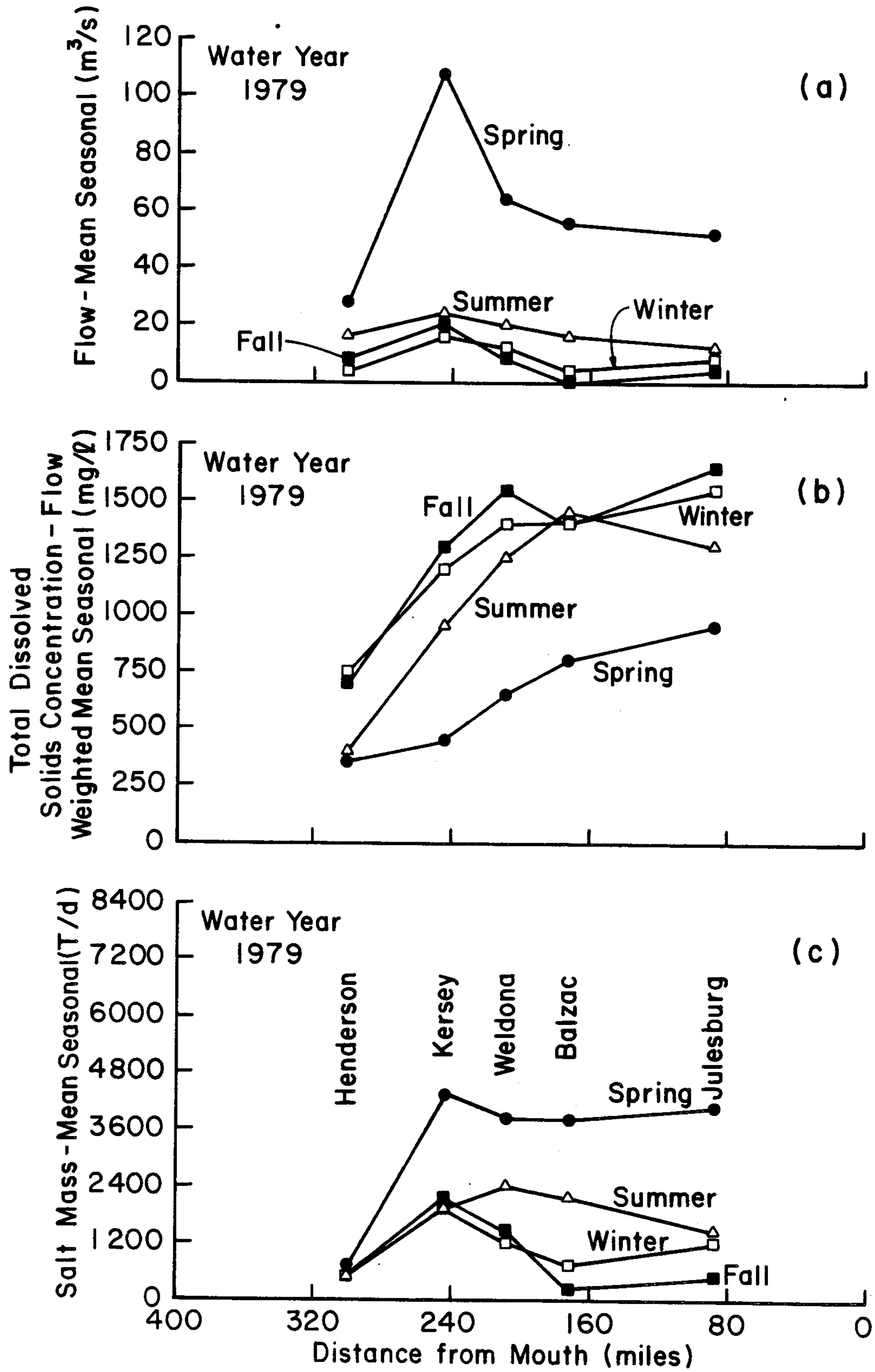


Figure 3-10. Distance profiles of flow, salt concentrations, and salt mass flow, averaged by season for 1979, lower South Platte River.

the seasonal resolution for the same parameters. Tabular data giving seasonal averages by year for these same data are given in Table 3-10, which shows these data for the three tributary streams as they enter the South Platte River and for the five measurement stations on the South Platte River, from Henderson to Julesburg.

As noted in the Figures 3-7 and 3-9, the water quality in the South Platte River at Greeley is strongly influenced by flows from the main stem and its Front Range tributaries. The largest tributaries are St. Vrain Creek, Big Thompson River and the Cache la Poudre River. The flow weighted mean annual TDS levels for thse rivers as they join the main stem are 867 mg/ℓ, 1393 mg/ℓ and 1018 mg/ℓ respectively. Comparison of these data with the 50-100 mg/ℓ TDS levels for these streams at their canyon mouths illustrates the extent of salinity pickup and concentration caused by irrigation of the tributary lands. These tributaries, have a "positive" salt mass balance, since more salt leaves these tributary subbasins than is brought into them. Therefore, salt buildup in either the soil or groundwater associated with the tributary lands is not likely to occur.

The positive salt balance is not the case, however, along the mainstem of the South Platte River between Weldona and Julesburg, as reviewed in Chapter 2. The salt concentrations shown in Figure 3-1(b) depict a continual increase from 500 mg/ℓ to the 1000-1600 mg/ℓ range between Kersey and Julesburg. The salinity concentrations profiles seem to indicate that the salts are being removed from the basin. When these concentrations are multiplied by the water flows to obtain salt mass flows, a negative mass balance is shown for the South Platte between Kersey and Julesburg.

Table 3-10. Seasonal averages of flow, flow weighted, total dissolved solids, and salt mass flow, 1965-79 for stations of the South Platte River between Henderson and Julesburg and main tributaries (Tables D-2, Gomez-Ferrer and Hendricks, 1982).

WATER YEAR	MEAN SEASONAL FLOW (CMS)				FLOW WEIGHTED MEAN SEASONAL SALINITY (MG/L)				MEAN SEASONAL SALINITY MASS (T/D)			
	FALL	WINTER	SPRING	SUMMER	FALL	WINTER	SPRING	SUMMER	FALL	WINTER	SPRING	SUMMER
			RIVER POINT : 1 - SOUTH PLATTE RIVER AT HENDERSON									
65	2.95	5.00	26.44	30.79	772.03	758.97	302.45	311.88	196.69	327.72	690.93	827.60
66	8.31	4.35	6.48	6.69	654.32	781.12	557.36	569.84	503.73	293.43	311.97	328.25
67	5.37	5.22	9.85	12.12	716.12	763.24	474.04	456.98	332.02	344.50	403.73	47[illegible].48
68	3.70	4.01	10.32	11.40	750.45	792.05	476.66	476.75	239.70	274.10	424.67	469.57
69	3.45	2.56	46.55	14.18	756.54	847.52	257.47	435.73	225.67	197.70	1035.44	539.91
70	18.47	10.20	62.15	20.04	504.44	688.04	262.20	380.61	964.41	606.08	1408.07	659.11
71	12.31	12.27	20.02	14.87	640.36	671.35	380.81	431.93	681.27	711.61	[illegible]	554.86
72	8.77	6.44	14.02	11.46	671.08	737.25	419.75	473.65	508.23	410.17	[illegible]	468.93
73	5.37	9.20	83.98	21.06	695.18	697.93	225.01	372.59	384.55	554.77	1632.58	576.01
74	11.71	16.45	21.69	11.62	643.58	639.89	373.67	470.51	651.36	902.59	700.28	472.22
75	7.98	5.82	15.64	18.96	673.07	746.50	404.59	371.87	463.88	375.68	546.95	605.30
76	5.29	5.72	9.98	14.13	659.04	734.69	474.62	438.65	375.36	[illegible]	408.16	555.37
77	5.53	5.78	9.50	7.54	693.98	743.88	491.11	537.67	391.64	371.52	[illegible]	350.40
78	5.09	5.25	10.78	9.90	719.22	757.30	453.20	500.43	316.16	343.24	422.13	428.02
79	6.19	5.76	26.07	15.89	697.29	751.95	326.90	412.70	373.20	374.01	735.42	566.75
			RIVER POINT : 2 - ST. VRAIN CREEK AT MOUTH, NEAR PLATTEVILLE									
65	2.25	2.20	12.11	16.73	1257.60	1151.07	444.99	794.07	244.98	219.19	465.47	1146.06
66	5.10	3.83	2.43	4.08	1051.89	1037.55	1204.75	1195.01	463.57	343.71	252.84	421.74
67	2.49	1.98	9.22	12.55	1225.86	1170.90	531.82	861.65	264.59	200.18	423.63	934.37
68	3.71	4.23	3.76	5.23	1128.89	1019.11	579.20	1146.52	361.96	372.12	318.31	515.11
69	3.50	2.52	26.76	5.61	1133.05	1122.74	318.51	1095.98	342.29	244.37	736.54	531.33
70	3.31	5.16	18.83	7.33	950.56	985.53	431.97	1043.17	582.85	433.62	702.33	680.52
71	6.45	4.18	18.39	6.91	1005.03	1024.06	431.31	1069.48	559.80	365.53	625.40	638.64
72	5.03	4.05	5.32	4.87	1059.82	1025.55	785.22	1168.18	460.58	359.25	360.30	491.34
73	4.63	4.45	20.35	6.62	1073.77	1010.62	355.74	1080.05	429.19	389.54	[illegible]	514.07
74	4.69	4.93	6.34	5.96	1075.48	995.40	739.03	1111.45	436.19	423.67	407.31	572.74
75	4.78	3.95	9.32	7.42	1071.26	1033.89	580.25	1051.30	442.37	352.67	467.20	673.72
76	4.80	3.35	3.03	5.42	1070.29	1061.47	1089.60	1130.36	443.32	307.31	255.50	529.03
77	3.67	3.06	2.50	3.91	1134.12	1084.06	1203.46	1209.09	359.24	295.53	260.44	408.55
78	2.95	2.93	12.06	5.79	1197.19	1092.04	521.61	1113.97	302.39	276.05	543.33	557.33
79	4.04	3.72	20.71	7.75	1107.24	1047.08	402.24	1032.07	386.56	336.25	719.84	630.90
			RIVER POINT : 3 - BIG THOMPSON RIVER AT MOUTH, NEAR LA SALLE									
65	1.93	1.45	2.39	2.10	1906.45	1941.32	887.69	1435.70	317.69	243.55	183.01	260.06
66	3.26	1.99	.61	1.27	1825.09	1927.38	1956.02	1817.04	314.47	331.29	103.75	[illegible]
67	1.88	1.34	1.28	2.42	1911.71	1944.72	1315.98	1416.48	311.13	[illegible]	[illegible].14	[illegible].72
68	2.10	1.60	1.45	1.35	1893.97	1937.61	1320.41	1754.51	343.20	257.69	165.35	205.20
69	1.76	1.41	5.08	1.55	1919.84	1942.95	610.02	1630.53	291.73	235.98	267.34	214.04
70	3.11	2.29	7.21	2.49	1832.70	1922.12	596.74	1419.60	492.30	379.97	371.70	305.76
71	2.47	2.00	11.00	3.16	1868.60	1927.77	520.60	1323.37	398.33	333.51	454.77	360.70
72	2.75	1.97	1.60	1.71	1851.82	1928.11	1196.68	1612.87	439.47	322.17	155.43	239.43
73	1.89	2.06	10.61	2.45	1906.65	1926.52	504.15	1445.49	311.02	342.72	452.35	306.72
74	3.63	2.17	2.98	3.12	1806.49	1924.27	955.35	1259.36	566.40	360.57	246.41	350.29
75	2.24	1.75	4.60	3.58	1883.09	1933.70	753.58	1248.55	364.67	232.22	299.69	385.45
76	2.35	1.78	1.32	4.70	1875.50	1932.87	1462.41	1039.11	382.95	237.45	[illegible]	446.21
77	[illegible]	1.65	.66	3.06	1822.76	1935.93	1346.32	1261.46	367.91	275.43	113.83	333.73
78	1.57	1.43	3.87	3.05	1937.18	1942.35	818.59	1331.51	263.75	239.58	[illegible]	350.74
79	2.14	2.03	11.05	3.23	1886.24	1926.80	483.24	1305.97	347.47	337.63	461.42	354.58

Table 3-10. Continued.

WATER YEAR	MEAN SEASONAL FLOW (CMS)				FLOW WEIGHTED MEAN SEASONAL SALINITY (MG/L)				MEAN SEASONAL SALINITY MASS (T/D)			
	FALL	WINTER	SPRING	SUMMER	FALL	WINTER	SPRING	SUMMER	FALL	WINTER	SPRING	SUMMER
	RIVER POINT : 4 - CACHE LA POUDRE RIVER NEAR GREELEY											
65	2.13	1.88	11.91	1.54	1427.33	1540.73	387.87	1357.56	262.40	250.72	339.04	150.40
66	3.08	3.31	.87	1.04	1371.53	1320.78	1321.89	1363.93	364.59	377.43	98.82	122.49
67	1.78	1.72	6.39	2.81	1447.53	1581.07	518.04	1326.78	223.22	274.37	285.92	321.96
68	2.69	2.18	2.40	.92	1394.11	1473.70	850.76	1379.86	322.36	279.19	176.50	109.69
69	2.37	2.10	4.40	.86	1398.26	1496.98	615.49	1378.87	310.90	272.12	233.93	102.60
70	4.26	3.75	9.85	2.34	1318.10	1280.38	494.37	1352.36	485.41	414.65	412.24	277.36
71	4.74	3.41	16.51	3.48	1301.86	1314.81	451.96	1337.50	532.71	396.94	644.33	402.57
72	5.04	3.89	4.40	1.76	1294.41	1263.69	664.85	1355.78	563.25	423.64	252.95	206.69
73	2.55	3.46	15.01	3.48	1399.06	1306.77	439.08	1338.86	308.70	390.44	569.35	402.62
74	5.48	4.10	7.25	2.37	1281.42	1245.14	550.36	1352.25	606.27	441.01	346.00	276.93
75	4.20	3.38	6.72	2.29	1321.49	1315.75	592.29	1340.63	479.31	384.47	343.72	265.18
76	3.14	2.70	1.82	1.92	1367.91	1400.28	1056.34	1340.39	370.90	326.49	155.18	221.07
77	3.26	2.28	.77	1.44	1356.30	1464.94	1365.36	1337.56	381.50	288.92	91.26	165.43
78	2.25	2.50	8.51	1.15	1421.30	1430.06	515.40	1371.03	277.58	308.90	378.79	136.11
79	2.71	2.56	21.60	3.84	1383.66	1413.89	351.48	1333.14	323.73	312.93	730.33	442.31
	RIVER POINT : 5 - SOUTH PLATTE RIVER NEAR KERSEY											
65	11.13	13.59	57.43	44.77	1382.78	1302.44	474.58	764.08	1329.48	1528.79	2354.95	2355.56
66	23.43	16.27	4.66	6.12	1220.57	1246.11	1198.35	1156.06	2998.18	1751.49	482.34	632.69
67	13.00	13.94	27.95	24.88	1356.40	1295.62	631.71	863.17	1523.44	1555.96	1525.75	1855.49
68	15.00	15.74	11.58	8.31	1335.49	1258.74	923.20	1150.91	1731.01	1712.17	923.76	926.71
69	14.60	12.84	101.91	11.11	1337.91	1320.68	448.23	1064.41	1587.87	1434.90	3945.53	1032.00
70	42.07	24.57	101.97	23.67	1160.71	1128.96	495.33	924.40	4218.79	2406.61	4363.76	1990.51
71	29.85	26.46	72.74	18.80	1218.05	1110.72	543.15	971.41	3141.34	2539.51	3413.60	1577.72
72	23.86	19.58	17.39	11.81	1255.60	1189.83	749.65	1056.93	2588.03	2013.20	1125.06	1374.97
73	18.30	22.87	184.75	24.73	1297.12	1150.93	399.57	918.91	2050.95	2273.95	6394.59	1463.04
74	29.19	30.56	33.46	15.05	1226.37	1071.62	675.12	1025.81	2587.32	2869.96	1551.57	1334.06
75	22.13	17.71	34.17	21.62	1267.15	1223.31	647.84	943.69	2423.14	1871.95	1012.53	1752.50
76	20.26	20.23	10.44	15.97	1283.24	1155.93	962.28	980.08	2246.53	2072.79	863.09	1352.02
77	19.36	15.39	7.13	9.74	1290.51	1263.29	1056.44	1078.27	2158.16	1679.51	650.52	907.73
78	14.32	15.11	32.51	10.16	1341.72	1269.05	671.09	1122.48	1659.23	1567.09	1684.31	985.70
79	18.27	17.58	106.59	22.70	1294.80	1221.39	462.57	927.80	2043.31	1855.40	4259.92	1819.83
	RIVER POINT : 6 - SOUTH PLATTE RIVER NEAR WELDONA											
65	4.26	3.98	35.47	27.62	1758.39	1514.12	718.08	1204.89	647.13	520.19	2200.34	2378.52
66	25.35	13.95	3.57	6.60	1323.87	1348.97	1459.80	1497.76	2900.75	1625.54	453.02	344.30
67	4.04	5.34	13.89	15.12	1777.47	1487.48	930.38	1292.93	620.03	686.77	1116.27	1659.71
68	5.14	10.15	5.80	6.74	1692.96	1401.21	1314.02	1490.16	751.32	1229.39	658.06	847.16
69	3.80	5.89	62.65	7.82	1790.92	1463.27	659.75	1444.60	583.76	744.96	3571.12	975.52
70	25.44	21.98	82.62	18.19	1330.21	1300.68	678.71	1305.37	2923.84	2469.69	4844.65	2051.98
71	19.35	23.13	56.07	17.94	1397.80	1299.75	772.18	1301.52	2337.15	2597.03	3547.30	2017.74
72	15.50	13.56	7.93	8.06	1419.56	1353.37	1150.56	1452.29	1901.29	1595.95	789.06	1011.42
73	9.32	22.32	136.10	23.19	1563.88	1303.89	586.98	1274.10	1259.19	2514.35	6902.22	2550.73
74	28.77	20.32	20.66	14.51	1295.62	1310.64	954.30	1354.49	3220.99	2301.28	1703.70	1557.48
75	11.02	11.79	21.61	16.24	1520.53	1375.55	885.82	1332.35	1447.73	1401.47	1653.39	1470.13
76	11.15	11.19	6.16	10.72	1505.97	1385.27	1274.29	1394.97	1451.57	1339.93	679.07	1201.53
77	5.56	9.98	4.77	5.95	1658.86	1397.79	1357.86	1499.55	797.11	1204.39	559.10	770.21
78	4.44	6.61	14.65	8.55	1750.34	1446.91	993.12	1451.11	570.59	826.71	1257.15	1071.31
79	9.95	11.02	64.31	21.31	1540.25	1375.63	673.35	1271.01	1324.70	1307.97	3741.29	2340.99

Salinity changes over time. In the 1967 Bureau of Reclamation Report on the Narrows Project, the flow weighted average for specific conductance (micromhos @ 25°C) from 1955 through 1963 was 1,173 micromhos at the damsite near Weldona (USBR, 1967, Appendix 3, p. 33). The flow weighted average at Weldona between 1965 and 1979 was 1337 micromhos (Gomez-Ferrer and Hendricks, 1982, Table D-1 and Table 4-1). This is a difference of plus 164 micromhos. At Julesburg, the Narrows report gives a flow weighted value of 1320 micromhos for 1955-1963 period while the flow weighted mean for the 1965-1979 period is 1517 micromhos. This is a difference of plus 197 micromhos. These data would seem to indicate a gradual upward movement in salinity concentrations between the 1955-1963 and 1965-1979 time periods.

3.4 Salinity Survey

Table 3-11 shows the results of a salinity survey, conducted by the authors during a three day period, April 9, 10, and 11, 1982. The survey was conducted to verify with field data the Volume 1 analysis of published data that an unfavorable salt balance exists between Kersey and Julesburg.

The survey was done during winter conditions, i.e. the river flows were due to return flows and not to spring runoff conditions, and off-stream reservoirs were full. As expected Table 3-11 shows high salinity levels, expressed as TDS, throughout the lower South Platte system, ranging from 1300 to 1800 mg/l. Table 3-11 corroborates the conclusion from published data that diversions to off-stream storage reservoirs occur in the fall and winter.

Table 3-11. Salinity Survey of South Platte River System, April 1982[1/]

Measurement Number	Date	Time	Specific Elect. Cond.[2/] (micromhos/cm)	TDS[3/] (mg/L)	Place[4/]
1	4/9/82	0650	1850	1480	Cache La Poudre River at Bracewell
2		0715	2000	1610	Cache La Poudre River at Greeley gaging station
3		0730	1740	1360	South Platte River, ½ mile above confluence with CLP
4		0745	1910	1500	South Platte River at Kersey
5		0845	1940	1540	South Platte River at Kuner
6		0900			Photographs at Empire Diversion
7		0925	1910	1500	Return flow ditch near Hardin
8		0935	1950	1540	Riverside Canal at Hardin
9		0945	2100	1670	South Platte River at Hardin
10		1030	1670	1300	Empire Reservoir
11		1040	1950	1540	Ditch below Empire Reservoir
12		1050	1870	1470	South Platte River at Orchard
13		1115	1850	1450	Jackson Reservoir near outlet
14		1125	1850	1450	Jackson Reservoir inlet canal
15		1145	1950	1610	South Platte River near Weldona
16		1200			Bijou Reservoir (dry)
17		1210	1960	1620	South Platte River at Narrows
18		1300	1950	1610	Prewett Reservoir
19		1315	2200	1840	South Platte River, Highway 6 (below Prewitt Res.)
20		1445	2300	1820	South Platte River at Julesburg
21		1525	2800	2230	Lodgepole Creek at Orid
22		1610	2300	1870	Julesburg Reservoir
23	4/10/83	1430	2000	1740	Big Thompson River at bridge ½ mile east of Elm
24		1515	1440	1130	St. Vrain River at gaging station near Fort St. Vrain plant
25		1530	1270	800	South Platte River, ½ mile northwest of Platteville
26		1625	53	40	South Fork St. Vrain, Highway 7 at Lyons
27		1635	50	40	St. Vrain River, Highway 36 Bridge above Lyons
28		1705	70	60	Lake Estes
29		1720	90	70	Big Thompson River at 2 miles below Estes Park
30		1745	90	70	Big Thompson River at mouth of canyon

Table 3-11. (continued)

Measurement Number	Date	Time	Specific Elect. Cond. (micromhos/cm)	TDS (mg/L)	Place
31	4/11/82		670	480	Cache La Poudre River at S. College St., Fort Collins
32			625	470	Cache La Poudre River at LW Canal
33			620	470	Cache La Poudre River at Overland Trail
34			340	300	Cache La Poudre River at Greeley Diversion
35			110	80	Cache La Poudre River above Fort Collins WTP
36			360	310	Cache La Poudre River below Fort Collins WTP
37			420	350	North Fork Cache La Poudre River
38			102	70	Horsetooth Reservoir
39	4/18/82		1650		Riverside Reservoir south end at dam
40			1650	1300	Riverside Reservoir, southeast shore
41			1675	1310	Outlet basin below Riverside Reservoir
42			1900	1500	Seepage below dam face into outlet basin
43			1800	1420	South Platte River at Masters Bridge

Notes

1/ Survey conducted by D. W. Hendricks and C. D. Turner, April 9, 10, and 11, 1982.

2/ Instrument used was Chemtrix Type 700 Conductivity Meter. It was calibrated with 199 EC solution and was standardized at beginning of sampling day with calibration check at end of day.

3/ Total dissolved solids calculated by relationship: $TDS = \alpha + \beta \cdot EC$, where α and β are from Table 4-1, Volume 1. Conversions for measurement numbers 26-39 were estimated.

4/ River flows were low; spring runoff was not started.

Chapter 4

RESULTS AND DISCUSSION

In this chapter the emphasis is on the utilization of empirical data. The theme of all analyses is the materials balance concept.

4.1 Materials Balance for Weldona-Balzac and Balzac-Julesburg Canals.

Figure 3-3 shows canals and reservoirs in the Kersey-Julesburg reach of the South Platte River, while Figure 3-4(a) and 3-4(b), 3-4(c), and 3-4(d) show the adjacent irrigated lands for the Kersey-Fort Morgan, the Fort Morgan-Balzac, Balzac-Proctor, and Proctor-Julesburg reaches, respectively. Figures 3-4(a) and 3-4(b) show that the canal diversions in the Kersey-Balzac reach deliver water mostly to irrigated lands within this reach. An exception is the diversion of the Sterling Inlet Canal, which occurs just above Balzac and delivers water to the North Sterling Reservoir and then almost to Julesburg. Another is the Prewitt Canal.

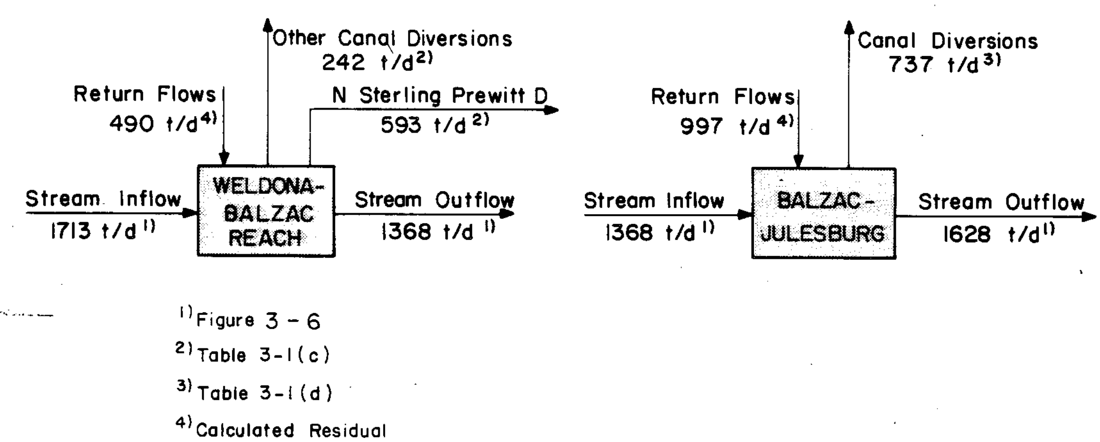


Figure 4-1. Materials balances for Weldona-Balzac reach and Balzac-Julesburg reach, showing salt mass transport by the North Sterling Canal and Prewitt Canal to agricultural lands adjacent to the Balzac-Julesburg reach. This land accumulates 333 t/d of salts.

Table 3-1(a) - 3-1(d) shows annual canal diversions, 1965-77, for the Henderson-Julesburg reach of the South Platte River. By reach the average annual diversions are 223,000, 360,700, 204,940, and 155,700 for the Henderson-Kersey, Kersey-Weldona, Weldona-Balzac, and Balzac-Julesburg reaches, respectively. The Henderson-Julesburg total is 944,340 acre feet/year. Of special interest are the diversions of the North Sterling Canal and the Prewitt Canal which averaged 100,830 and 45,400 acre feet/yr, respectively, totaling 146,230 acre feet/yr. These two canals, both of which leave the reach and enter agricultural lands adjacent to the Balzac-Julesburg reach, transport 71 percent of the total diversions in the Weldona-Balzac reach.

The yearly average total dissolved solids, TDS, concentration in the South Platte River in the Kersey-Balzac reach ranges from 1000-1300 mg/L, and 1200-1500 mg/L in the fall and winter. For estimating salt mass flows of canal diversions, the TDS is assumed to be 1200 mg/L. Applying this to the average annual canal diversions of the North Sterling Canal and the Prewitt Canal totaling 146,230 acre-feet/yr, the annual salt mass flow is 216,448 metric tons/yr (593 t/d). This salt mass flow leaves the Weldona-Balzac reach and enters the Balzac-Julesburg reach, as seen in Figure 3-3.

Figure 4-1 shows that 345 t/d of salt leaves the Weldona-Balzac reach net (e.g. 1713 t/d in streamflow entering minus 1368 t/d in streamflow leaving). This must occur by canal diversions and seepage. Figure 4-1 also shows that the salt leaving the Balzac-Julesburg reach (1628 t/d) is greater than the salt entering (1368 t/d), indicating apparently that the lands have a favorable salt balance. This is a gross picture of what occurs. The picture can be improved markedly, however, by utilizing the independent data on canal flows from Table 3-1. Figure 4-1 is a materials balance depiction of these two reaches, Weldona-Balzac and Balzac-Julesburg, with the canal salt mass flows included, and return flows calculated as residuals. The important fact to note is that in showing the North Sterling and Prewitt diversions as leaving the reach it is apparent that the irrigated lands adjacent to the Weldona-Balzac reach have a favorable salt balance; the return flows are 490 t/d while diversions to these lands are 242 t/d. The North Sterling and Prewitt canals, on the other hand, transport 593 t/d to the agricultural lands adjacent to the Balzac-Julesburg reach; these land thus accumulate 333 t/d salt (593 + 737 - 997).

The above analysis illustrates the importance of developing this greater resolution. While the analysis of salt mass flows in the stream itself indicates a salt balance problem exists in the lower South Platte, the greater resolution given by examination of specific canals shows that a problem does not exist in the Weldona-Balzac reach, as indicated by the preliminary analysis in Volume 1. A salt balance problem does not exist, however, in the Balzac-Julesburg reach, which contrary to the indications of the preliminary analysis in Volume 1. This should not be considered conclusive, however, until a canal by canal analysis is done.

The above analysis does not negate the findings in Volume 1 nor the general concern that a problem exists. Rather, it shows how the improved resolution permitted by the use of the information on the canal flows can provide a more accurate interpretation of what is occurring.

A still more accurate picture could be developed by taking into account water supplied by off-stream storage, and pumped water, and the specific lands being irrigated. Further improvement would be possible by use of a materials balance computer model. For the purposes of this initial study, however, the analysis based upon Figure 4-1 is sufficient to answer the basic question about the salt balance problems by reach.

A further corroboration of the 333 tons/day loss to irrigated lands in the Balzac-Julesburg reach can be shown partially in terms of irrigation mass balance to the irrigated lands. The North Sterling canal serves 33,926 acres (Table 3-8) and by Table 4-1c delivers 117,600 acre feet of water (Table 3-1c). This water carries 593 metric tons/day. This same land has an average diversion requirement deficit of 1.40 acre feet/acre, which means a significant portion of these salts could be deposited on the lands irrigated. This supports the materials balance analysis of the same reach.

Reservoir Operation. The annual cycle of filling and drawing water from off-stream reservoirs adjacent to the lower South Platte is important, since if the filling occurs in the fall and winter, vis a vis spring, total dissolved solids levels are highest. Table 3-3 lists these reservoirs and shows water rights and priority dates, and the storage available in each.

Figure 3-5 shows the filling and drawing of water for three of these reservoirs, Prewitt, North Sterling, and Julesburg respectively. In each case filing starts in the fall about September or October, and may continue through the winter until November to February, depending upon the size of the reservoir, the size of the delivery canal, and the priority of the water right and the flow in the stream. Water is drawn from the reservoirs during the period April or May until August or September. Probably the stored water is used to augment direct flow rights. It seems probable that this cycle is representative of the other reservoirs in the system as well. The important point relative to salt balance is that filling occurs during the fall and winter when salinity is highest. The fillings occurs with water having TDS levels of 1200-1600 mg/l. By contrast, if excess spring runoff water could be used the TDS levels would average 400 to 800 mg/l.

Table 3-3 shows the total storage right of all reservoirs in the Kersey-Julesburg reach is 280,112 acre feet. If 1400 mg/L is used as the nominal TDS level for the diversions, the salt in storage is 483,721 metric tons. If diversions were made in the spring, with a nominal TDS of 700 mg/L, the reduction in salt applied to the land would be 241,860 metric tons/year. For lands with good drainage and if adequate leaching water is applied, this kind reduction in salt load is not important. But it could be important for those lands having such difficulties.

4.2 Salinity Survey

Salinity data are published by the USGS for gaging stations along the South Platte River and its tributaries, e.g. Henderson, Kersey, Weldona, Bolzac, Julesburg, etc. Salinity data are not available, however, for canals and reservoirs. While it seems reasonable that salinity levels in lower South Platte off-stream reservoirs would be commensurate with fall and winter salnity levels, this is by no means certain until measurements are obtained. At the same time, the assertion is that low TDS water is available in the mountain streams and picks up substantial salt in the return flows from the upper irrigated lands, i.e. above Greeley.

To corroborate the above with actual data a salinity survey was done April 9, 10, and 11, 1982 for the South Platte system from mountain canyons to the lower reaches of the river and off-stream reservoirs to Julesburg. Table 3-11 shows the results of the survey. Measurements were taken with a conductivity meter and were converted to total dissolved solids by relationships established in Volume 1 (Gomey-Ferrer and Hendricks, 1982). The measurements obtained represent "winter conditions", as spring runoff had not begun, and salinity levels were at their highest.

The TDS data in Table 3-11 are consistent with the winter TDS profiles of the river shown in Figure 3-10. The low TDS data for the canyon reaches of the tributaries, e.g. St. Vrain Creek, the Big Thompson River, and the Cache La Poudre River, are consistent with data from other sources.

These data are important in that they validate the use of the published data and its interpretation. Also the data corroborate the belief that the off-stream reservoirs from Kersey to Julesburg are indeed filled during the seasons when TDS levels are highest.

Photographs. During the salinity field survey, photographs were taken which visually characterize the system. The photographs are in Appendix A. These photographs illustrate the plains character of the river and irrigated land environments, that river flow are low prior to spring runoff, and that canals and reservoir development is extensive.

4.3 Measures to Reduce Salt Accumulation on Irrigated Lands

Appendix B contains a broad discussion of options for achieving salt balance to develop an overall perspective on the topic. This discussion is more specific, but draws upon Appendix B as needed.

A problem of salt accumulation may exist on irrigated lands adjacent to the Balzac-Julesburg reach of the South Platte River, as indicated by the materials balance analysis of 4.1. Additional field studies are warranted to develop an improved understanding of the reasons. The need for such a study notwithstanding, it is advisable to address the problem at the same time in order to consider different approaches to alleviate it.

A basic axiom of irrigated agriculture is that irrigation and drainage go together; they are inseparable. The concept is that irrigation practice should be such that salt does not accumulate in the root zone of the crop. This requires that the amount of irrigation water applied to the crop is in excess of the consumptive use. The salt carried into the root zone by the irrigation water and concentrated by evapo-transpiration must be transported through the root zone by deep percolation. If the water table is too high due to poor drainage salt will accumulate. It will accumulate also if sufficient leaching water is not applied. The tabular data showing a general water deficiency over the entire lower South Platte would indicate the latter, e.g. in sufficient leaching, could be a cause. At least it should be investigated. While drainage is reported to be good in general, specific problems of poor drainage do exist. The application of excess water for leaching is particularly important when TDS levels are moderately high, as they are in the lower South Platte.

Another approach to improve the salt balance is to manage salinity levels in off-stream reservoirs. If sufficient leaching water is applied, coupled with good drainage, this is not needed. But if either of these problems exist the rate of increase of severity can be reduced by irrigating with spring runoff water, diverted to the reservoirs only during those years when the runoff is excessive.

The role of the proposed Narrows Reservoir in salinity management ought to be considered also. Delivery of excess water to provide sufficient water for leaching in addition to the consumptive use requirement would be important in maintaining a salt balance on the irrigated lands. In addition, the reservoir could be managed in ways to reduce the amount of high TDS water stored. One approach would be to release high TDS waters during early spring when there is prospect of filling the reservoir with low TDS water during spring runoff. While this could not be done each year, it would be worthwhile to implement the practice when feasible.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

The year 01 research, outlined in Volume 1, established by analysis of 15 years of data that a loss of salt occurs in the Kersey-Balzac reach of the lower South Platte River. This occurs by canal diversions which transport salt mass from the river to agricultural lands.

The year 02 research corroborated the finding of year 01 based on analysis of data. These are:

(1) Salt concentrations go TDS in the lower South Platte are generally high, ranging from 1500 to 1800 mg/L TDS, measured for the winter condition.

(2) The profile of salt concentrations in the system as determined by analysis of data start at nominally 50 mg/L in the mountain streams, rising to about 1500 mg/L as the tributary streams join the main South Platte River between Henderson and Kersey. This was confirmed by field survey.

(3) The average annual canal diversions between Henderson and Julesburg total 944,340 acre-feet, compared with and main stem inflows of 691,815 acre feet. These diversions document the loss of salts to the irrigated lands. To maintain a salt balance for any given area of land, these salts must be returned by adequate drainage back to the river.

(4) Examination of the Weldona-Balzac reach showed that the salt imbalance was caused primarily by the diversions of the North Sterling Canal and the Prewitt Inlet Canal. These canals transport the salts to agricultural lands adjacent to the Balzac-Julesburg reach, causing a salt accumulation. These lands were shown by the USBR (1967) to have a diversion

irrigation deficit of 1.40 acre feet/acre, indicating the possible problem is caused by insufficient leaching.

(5) Three approaches should be investigated to alleviate the salt balance problem. These are: (1) reduce salt concentrations in waters diverted to the irrigated lands, (2) provide adequate irrigation water to provide for leaching of salts from the root zone, (3) assure suitable drainage. The reduction of salt concentrations can e done by managing the reservoir operations to reduce salt concentrations in off-stream reservoirs. This may be done by diverting excess spring runoff flows for storage vis a vis higher salinity fall and winter flows. This same principle could apply to the operation of the proposed Narrows Reservoir. The second may be satisfied by the application of additional irrigation water; the Narrows Reservoir is designed to do this. The third approach can be handled only by careful appraisal of the drainage of each major area of agricultural land. This has been done by the USBR in their 1967 report. The other approach is to provide drainage, an expensive alternative.

REFERENCES

Gomez-Ferrer, R. V. and D. W. Hendricks, Salt Transport in the Lower South Platte River, Environmental Engineering Technical Report No. 82-83-3141-01, Colorado State University, January 1982.

Gomez-Ferrer, R. V., Hendricks, D. W., and C. D. Turner, Salt Transport by the South Platte River in Northeast Colorado, Water Resources Bulletin, Vol. 19, pp. 183-190, April 1983.

Hendricks, D. W., Janonis, B. A., Gerlek, S., Goldbach, J. C., and J. L. Patterson, Water Supply-Demand Analysis 1970-2020, South Platte River Basin, Volume 1, Main Report, U.S. Army Corps of Engineers, 1977.

Hendricks, D. W. and J. M. Bagley, Water Supply Augmentation by Reuse. In: Proceedings of the AWRA Symposium on Water Balance in North America, A. H. Laycock, M. Francisco, and T. Fisher (Editors), AWRA Proceedings Series No. 7, Urbana, Illinois, 1969.

Hendricks, D. W., Turner, C. D., and K. Klooz, Sequential Water Reuse Effect on Stream Salinity, Water Resources Bulletin, Vol. 18, No. 2, pp. 317-324, April 1982.

Labadie, J. W., Phamwon, S., and R. C. Lazaro. A River Basin Network Model for Conjuctive Use of Surface and Groundwater: Program CONSIM, Completion Report No. 125, Colorado Water Resource Research Institute, Colorado State University, Fort Collins, CO, 1983.

U.S. Bureau of Reclamation, Report on the Narrows Unit, Colorado, USBR, Region 7, Denver, January 1967 (I27,2,N234/3,DOC).

U.S. Bureau of Reclamation, Narrows Unit, South Platte Division, Pick-Sloan Missouri Basin Program, Colorado, Definite Plan Report, USBR, Lower Mississippi Region, Denver, May 1973 (I27,2,N234,DOC).

APPENDIX A

PHOTOGRAPHS OF THE SOUTH PLATTE SYSTEM

(taken April 1982)

Cache la Poudre River at Bracewell - E.C. 1850 μm/cm

Cache la Poudre River at Bracewell - E.C. 1850 μm/cm

Cache la Poudre River at Bracewell - E.C. 1850 µm/cm

Cache la Poudre River at Greeley gaging station - E.C. 2000 µm/cm

South Platte River, 1/2 mile above confluence with Cache la Poudre - E.C. 1740 µm/cm

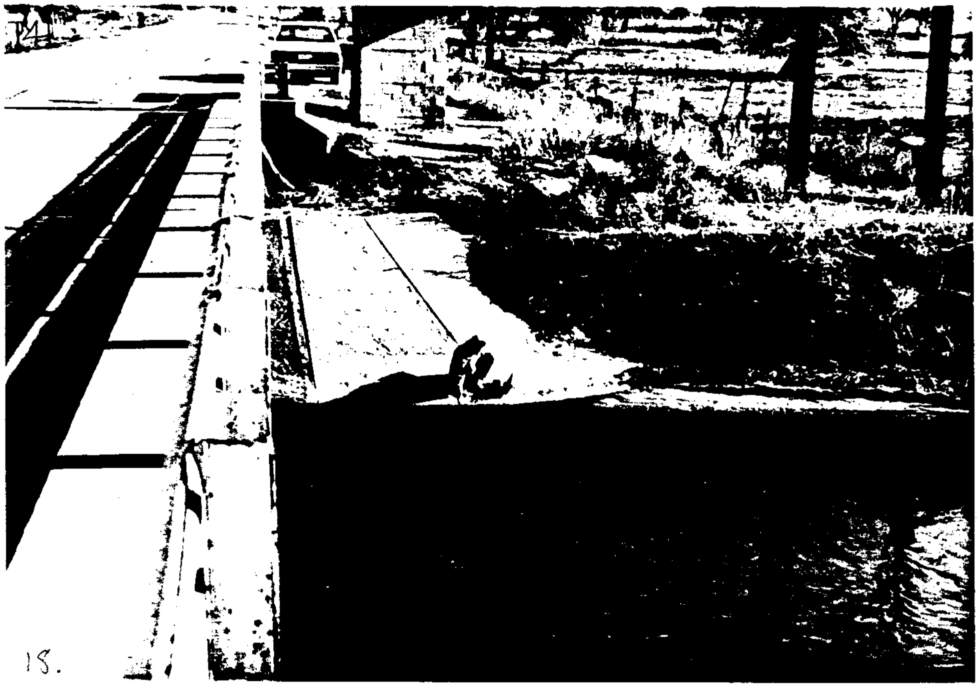
South Platte River, 1/2 mile above confluence with Cache la Poudre - E.C. 1740 µm/cm

South Platte River, 1/2 mile above confluence with Cache la Poudre - E.C. 1740 μm/cm

South Platte River at Kersey - E.C. 1910 μm/cm

South Platte River at Kersey - E.C. 1910 μm/cm

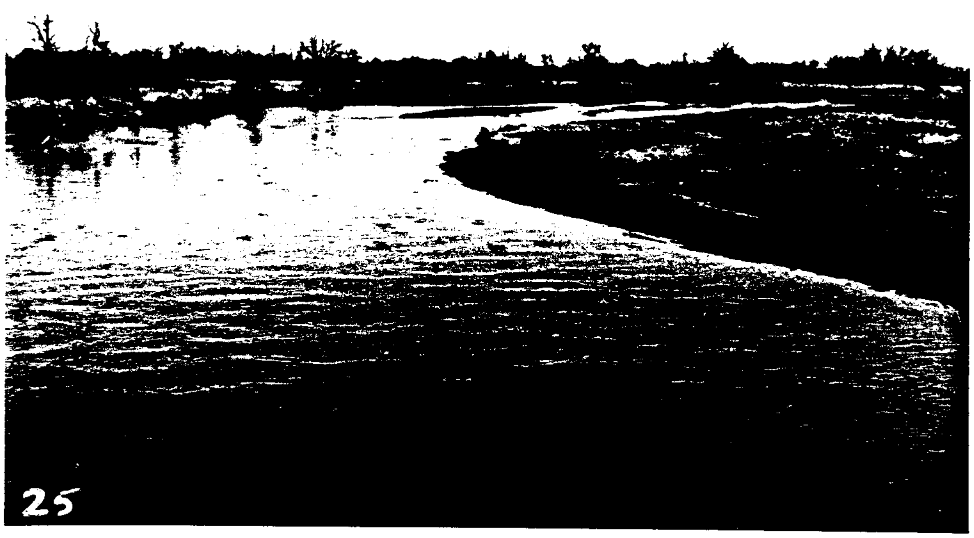
South Platte River at Kersey - E.C. 1910 μm/cm



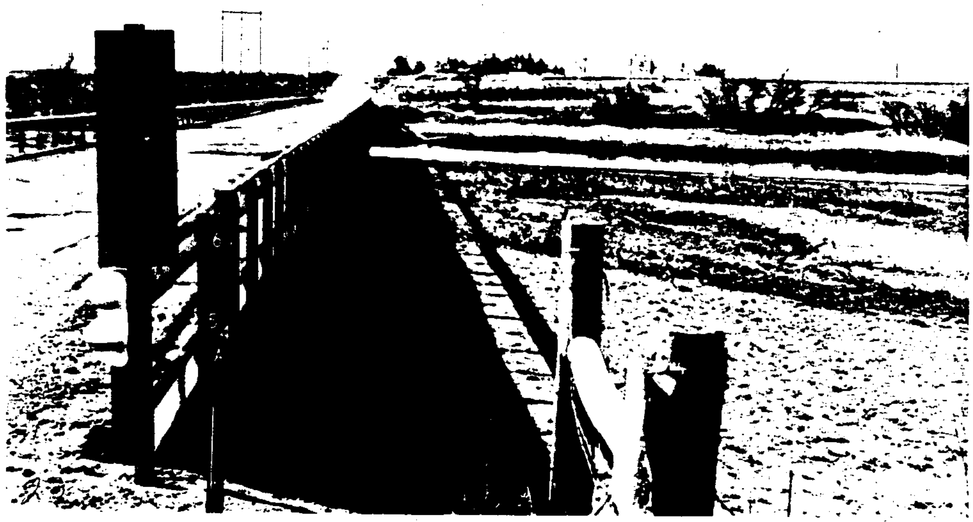
South Platte River at Kersey - E.C. 1910 μm/cm

South Platte River at Kuner - E.C. 1940 μm/cm

South Platte River at Kuner - E.C. 1940 µm/cm

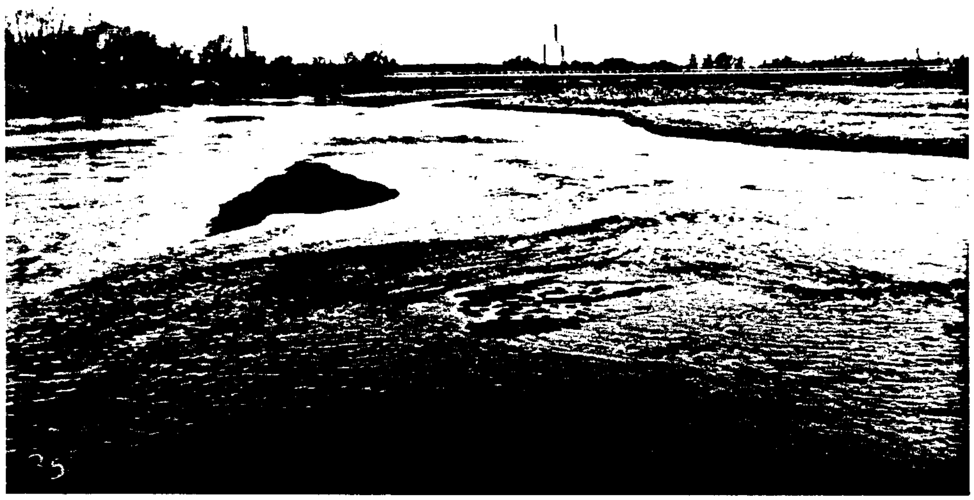


South Platte River at Kuner - E.C. 1940 µm/cm



South Platte River at Kuner - E.C. 1940 μm/cm

Empire Diversion - E.C. 1940 μm/cm



Empire Diversion - E.C. 1940 μm/cm

Empire Diversion - E.C. 1940 μm/cm

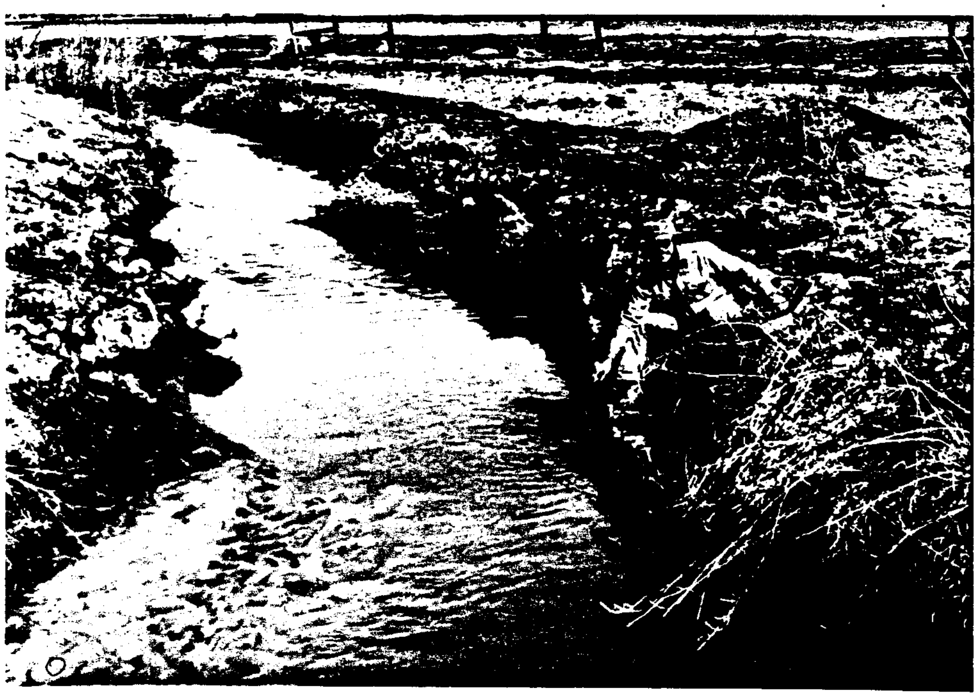
Empire Diversion - E.C. 1940 μm/cm

Empire Diversion - E.C. 1940 μm/cm

Empire Diversion - E.C. 1940 μm/cm

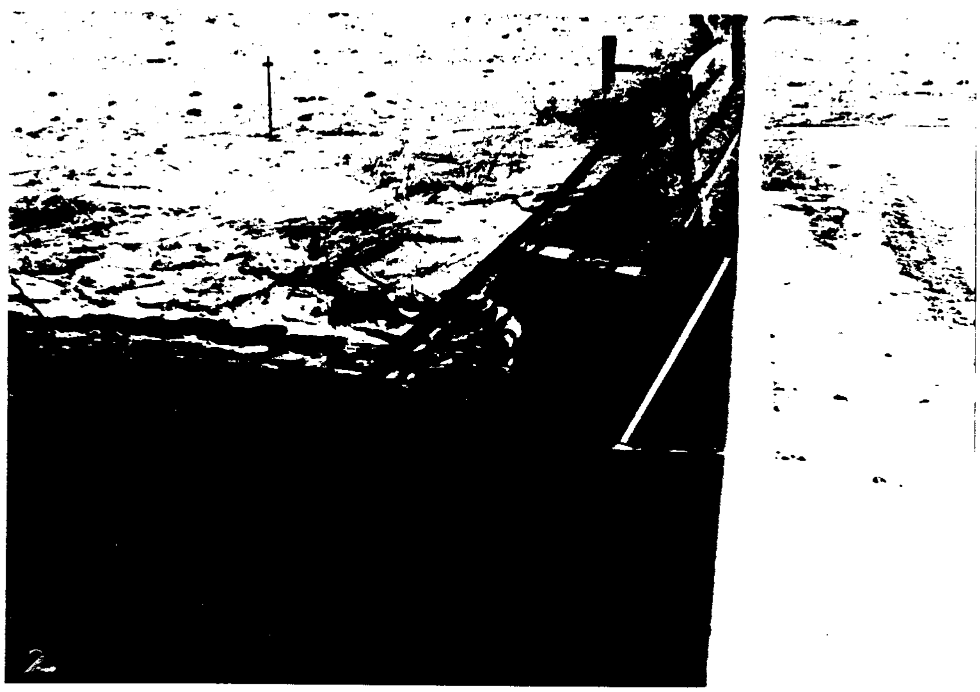
Empire Diversion - E.C. 1940 μm/cm

Empire Diversion - E.C. 1940 μm/cm



Return flow ditch near Hardin - E.C. 1910 μm/cm

Return flow ditch near Hardin - E.C. 1910 μm/cm



Riverside Canal at Hardin - E.C. 2100 μm/cm

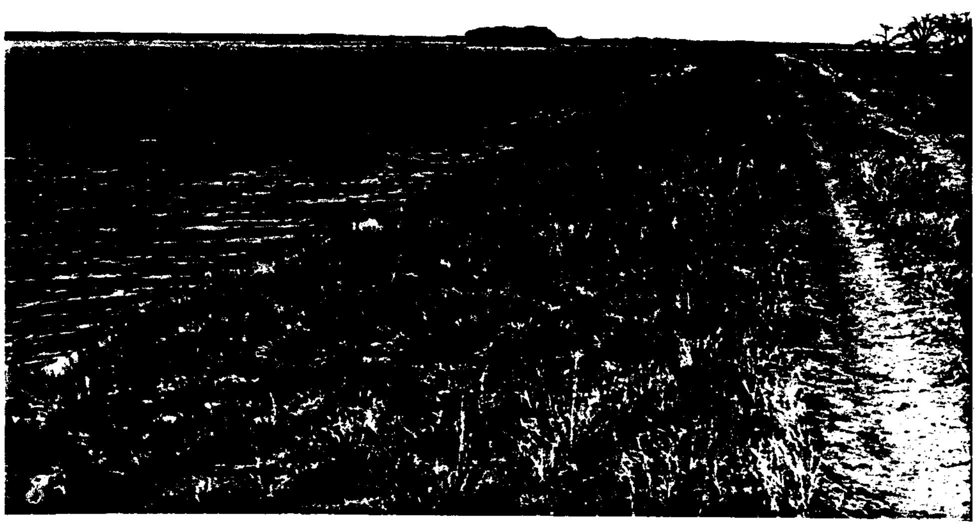
Riverside Canal at Hardin - E.C. 2100 μm/cm

Riverside Canal at Hardin - E.C. 2100 μm/cm

South Platte River at Hardin - E.C. 2100 μm/cm

South Platte River at Hardin - E.C. 2100 μm/cm

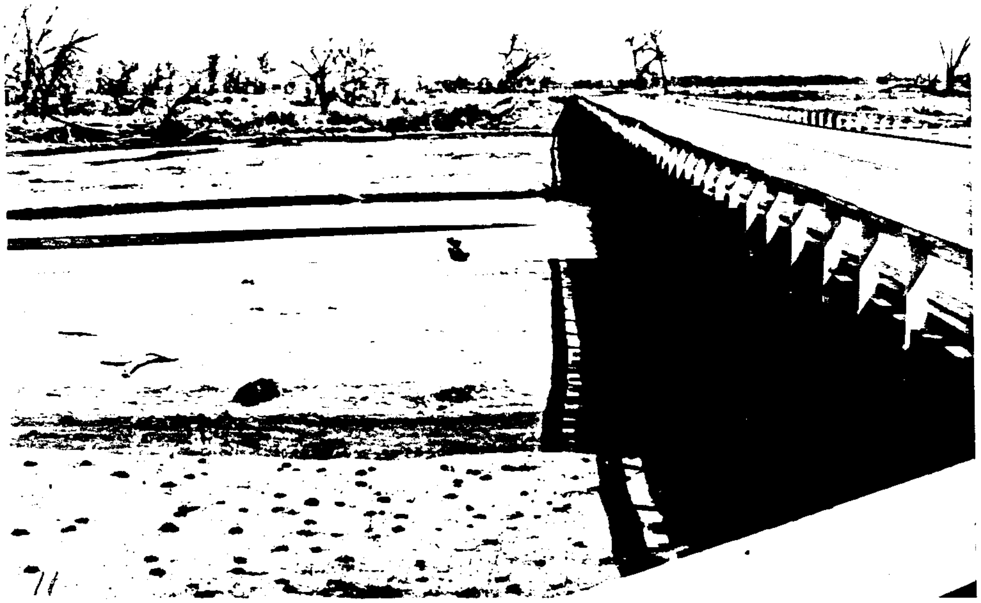
Empire Reservoir - E.C. 1670 μm/cm



Empire Reservoir - E.C. 1670 μm/cm

Empire Reservoir - E.C. 1670 μm/cm

Ditch below Empire Reservoir - E.C. 1950 μm/cm



South Platte River at Orchard - E.C. 1870 μm/cm

South Platte River at Orchard - E.C. 1870 μm/cm

Jackson Reservoir near outlet - E.C. 1850 μm/cm

Jackson Reservoir near outlet - E.C. 1850 μm/cm

Jackson Reservoir near outlet - E.C. 1850 μm/cm

Jackson Reservoir inlet canal - E.C. 1850 μm/cm

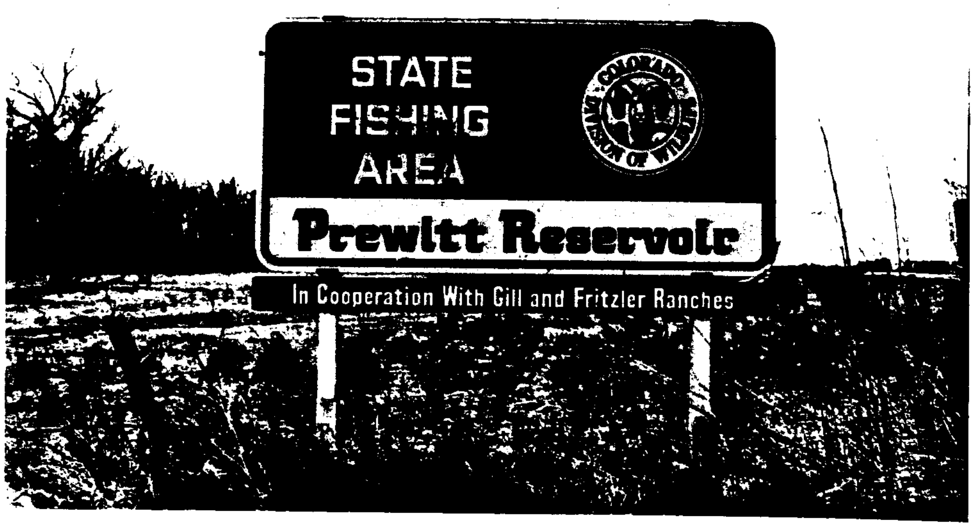
South Platte River near Weldona - E.C. 1950 µm/cm

South Platte River near Weldona - E.C. 1950 µm/cm

Bijou Reservoir (dry)

South Platte River at Narrows - E.C. 1960 μm/cm

South Platte River at Narrows - E.C. 1960 μm/cm



Prewett Reservoir - E.C. 1950 μm/cm

Prewett Reservoir - E.C. 1950 µm/cm

Prewett Reservoir - E.C. 1950 µm/cm

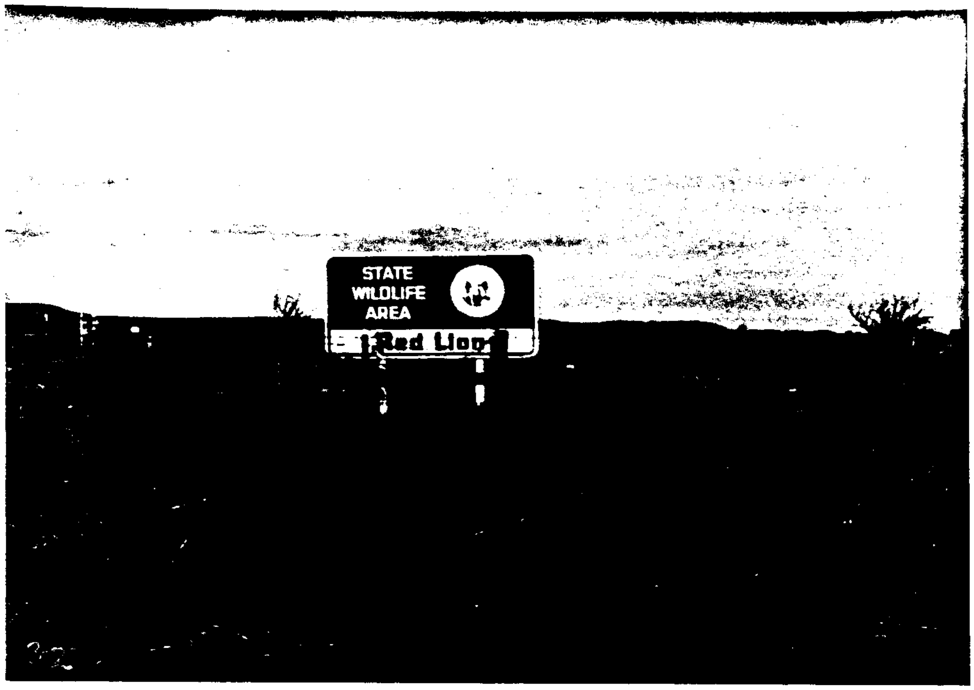
South Platte River, Highway 6 (below Prewett Reservoir) - E.C. 2202 µm/cm

South Platte River, Highway 6 (below Prewett Reservoir) - E.C. 2202 µm/cm

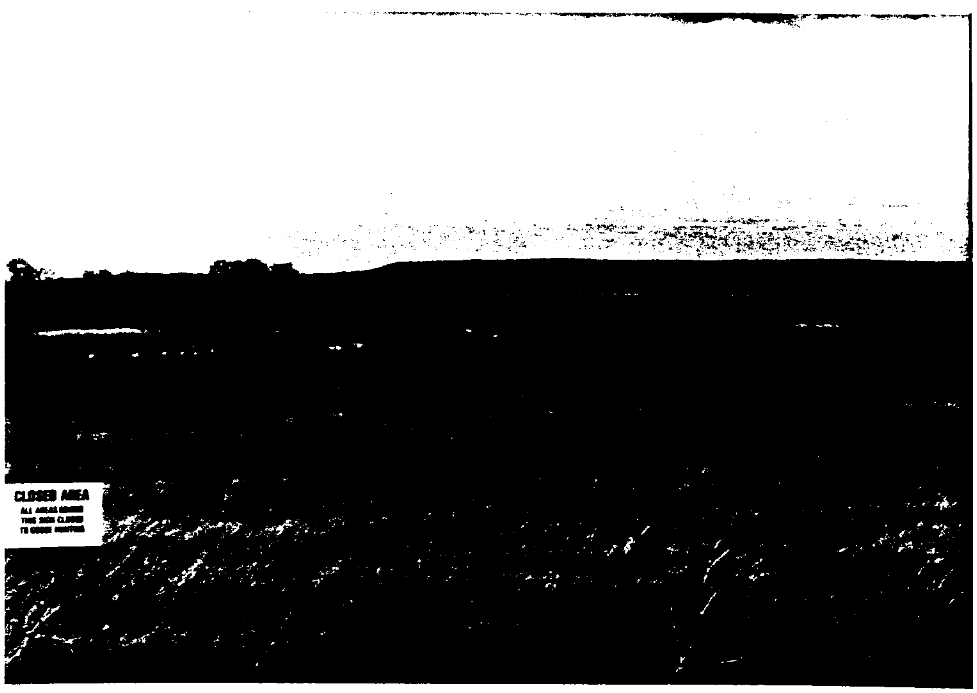
South Platte River at Julesburg - E.C. 2300 μm/cm

South Platte River at Julesburg - E.C. 2300 μm/cm

Lodgepole Creek at Ovid - E.C. 2800 µm/cm

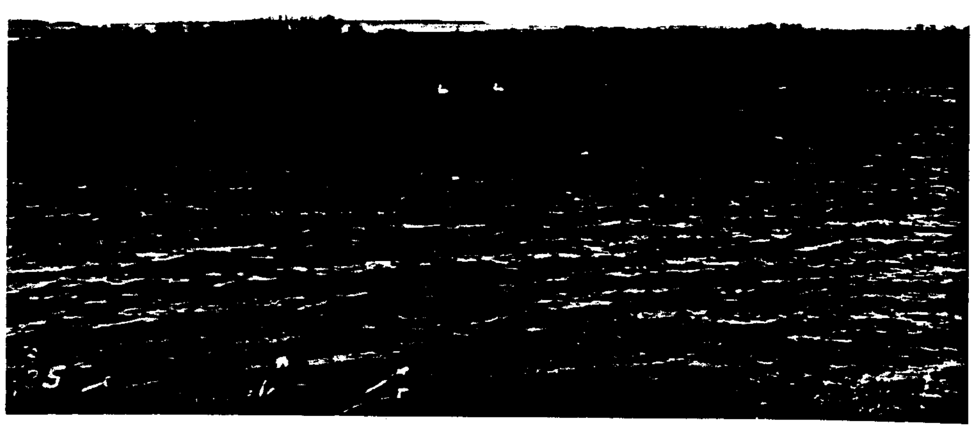


Julesburg Reservoir - E.C. 2300 μm/cm



Julesburg Reservoir - E.C. 2300 μm/cm

Julesburg Reservoir - E.C. 2300 μm/cm



Julesburg Reservoir - E.C. 2300 μm/cm

Julesburg Reservoir Inlet Canal

Salts adjacent to Highway 138 near Iliff, Colorado

Big Thompson River at bridge 1/2 mile east of Elm - E.C. 2000 μm/cm

St. Vrain River at gaging station near Fort St. Vrain plant - E.C. 1440 μm/cm

St. Vrain River at gaging station near Fort St. Vrain plant - E.C. 1440 μm/cm

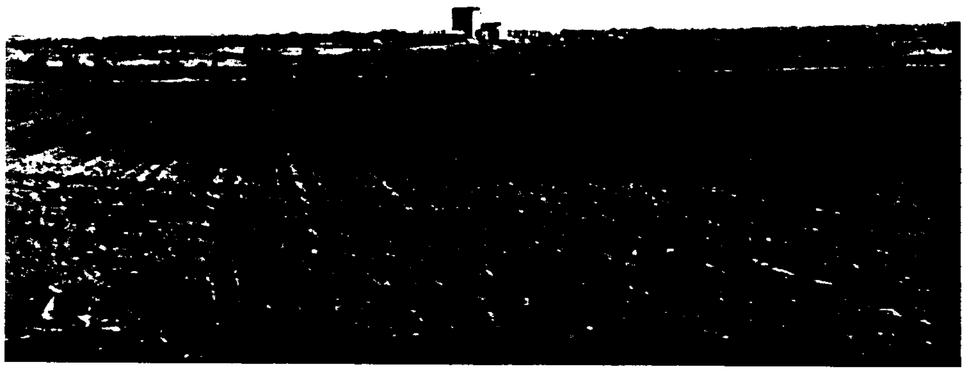
South Platte River, 1/2 mile northwest Platteville - E.C. 1270 μm/cm

South Platte River, 1/2 mile northwest Platteville - E.C. 1270 µm/cm

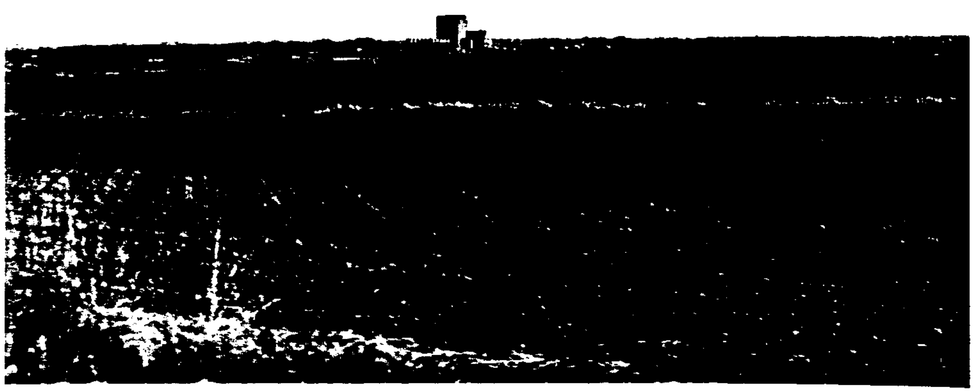
South Platte River, 1/2 mile northwest Platteville - E.C. 1270 µm/cm

South Platte River, 1/2 mile northwest Platteville - E.C. 1270 μm/cm

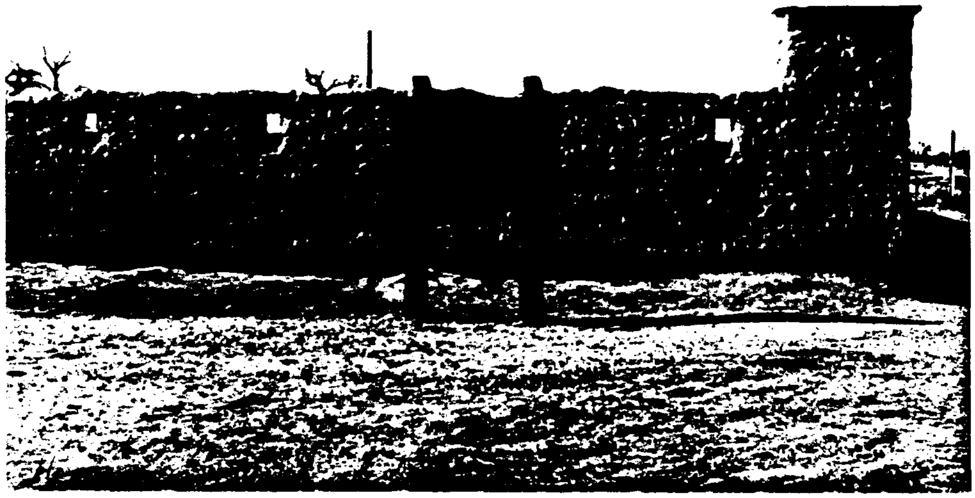
South Platte River, 1/2 mile northwest Platteville - E.C. 1270 μm/cm



Agricultural land near Fort St. Vrain N. Power Plant

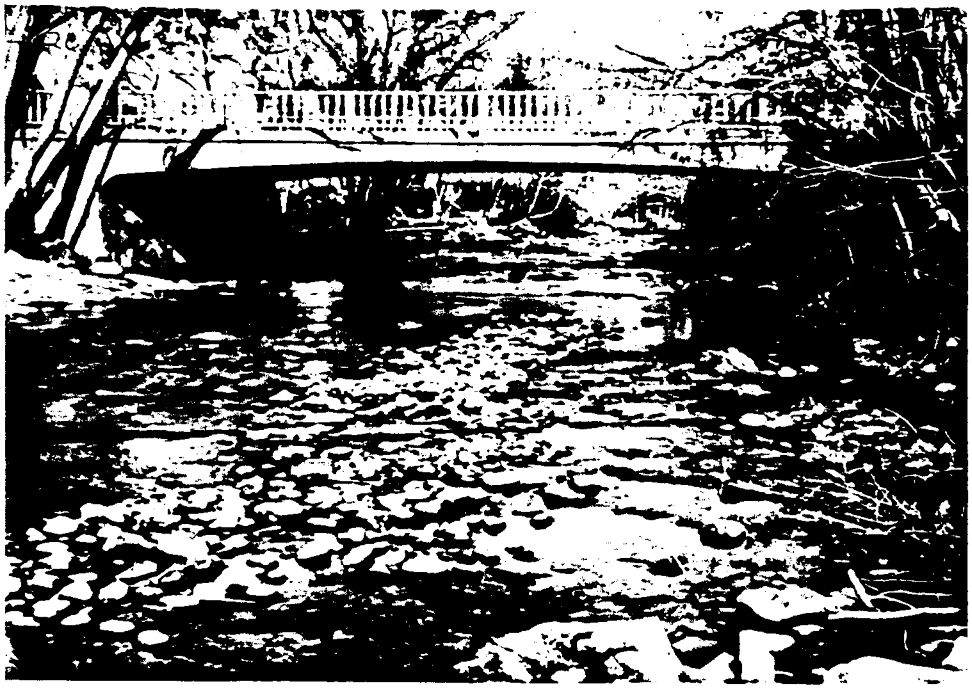


Agricultural land near Fort St. Vrain N. Power Plant



Fort St. Vrain at Platteville, Colorado

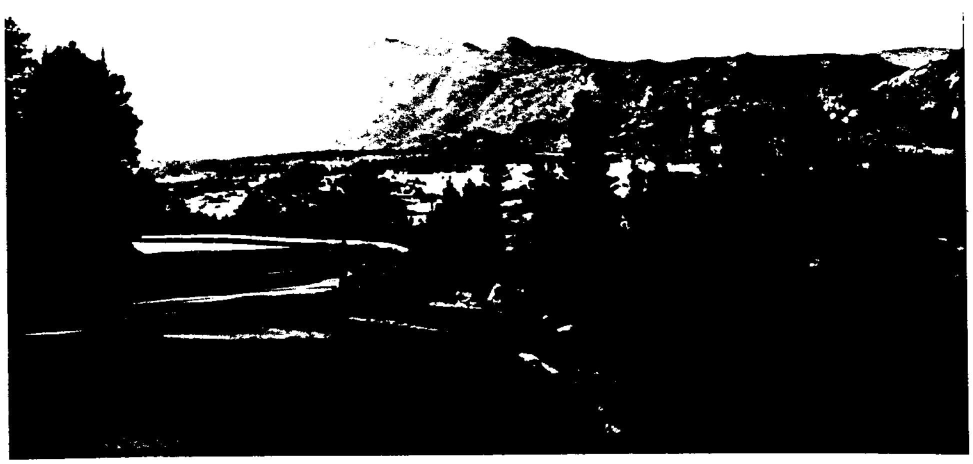
Agricultural land from Colorado Highway 66 west of Longmont



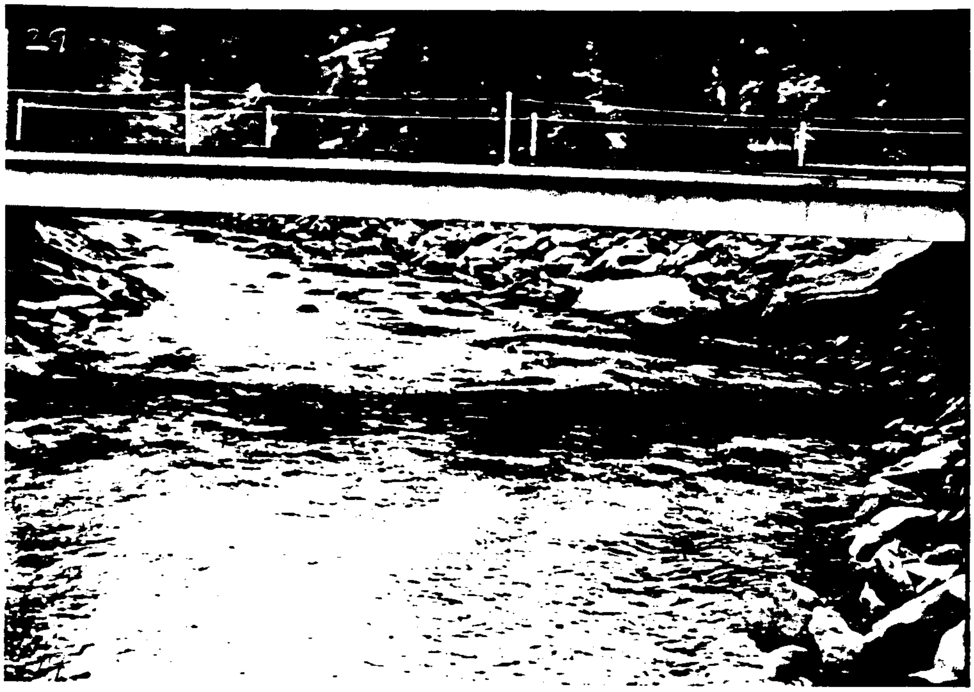
South Fork St. Vrain Highway 7 at Lyons - E.C. 53 µm/cm

South Fork St. Vrain Highway 7 at Lyons - E.C. 53 µm/cm

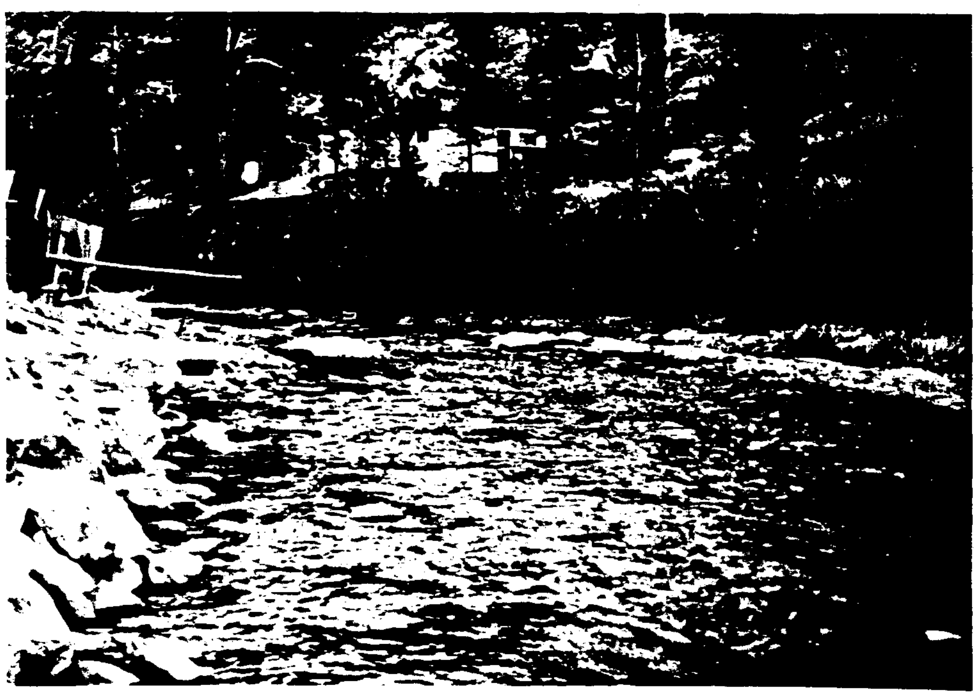
St. Vrain River Highway 36 Bridge above Lyons - E.C. 50 μm/cm



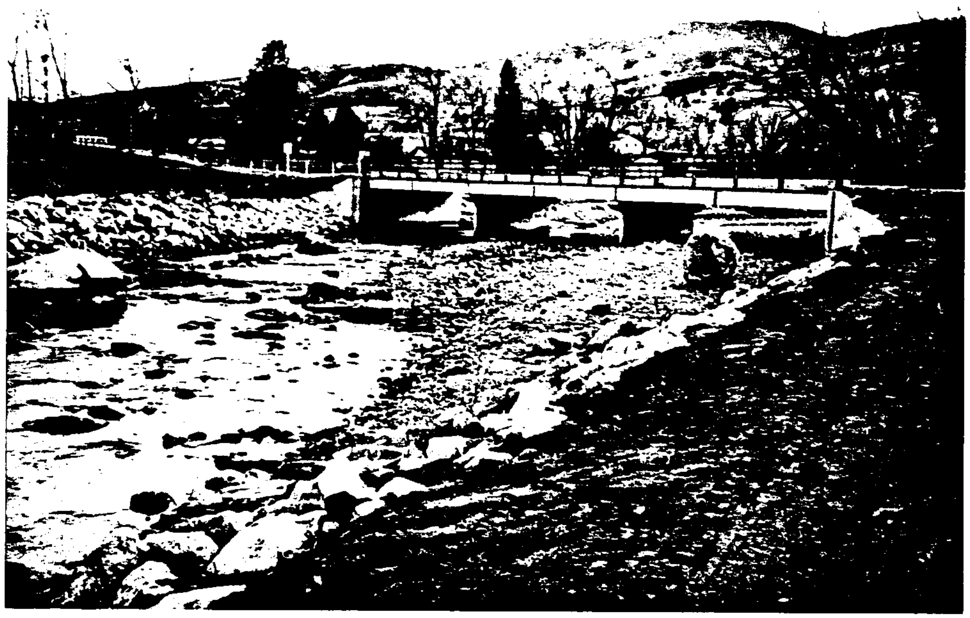
Lake Estes - E.C. 70 μm/cm



Big Thompson River at 2 miles below Estes Park - E.C. 90 μm/cm



Big Thompson River at 2 miles below Estes Park - E.C. 90 μm/cm



Big Thompson River at mouth of canyon - E.C. 90 μm/cm

Center pivot irrigation near Wiggins

APPENDIX B

DISCUSSION OF OPTIONS FOR ACHIEVING A SALT MASS BALANCE

In Chapter 1, three basic approaches were identified for the reduction or elimination of the salinization process occurring on irrigated lands along the lower reaches of the South Plate River. These approaches were (1) provision of supplemental irrigation water for leaching, (2) improved drainage and (3) reduction of the salinity of the irrigation water. Any alternative that is to be successful must utilize some combination of these methods. The provision of supplemental irrigation water for lands with poor drainage will not reduce the salt accumulation in poorly drained soils. Neither will reduction of TDS levels from return flows in the upper portion of the basin eliminate the need for leaching in the lower irrigated lands.

A set of alternatives for achieving a salt mass balance is not developed in this paper. Rather, a number of options are reviewed that when combined or structured could form one or more economically achievable alternatives. These options are listed as follows:

1. Construction of Hardin or Narrows Reservoirs to provide supplemental irrigation water.

2. Removal from irrigation of the 27,183 acres excluded by the USBR from receiving Narrows project water due to serious drainage and salinity problems and subsequent reallocation of water currently used for irrigation of these lands to lands of higher quality.

3. Allow the fall and winter high TDS level flows in the South Platte River to flow downstream and out of the basin without being diverted for storage thereby reducing the average TDS level of the water used for irrigation.

4. Improve the quality of irrigation return flows from the major upstream tributaries such as the Cache la Poudre River.

5. Provide adequate drainage for lands with high water tables, and use improved irrigation methods and delivery systems.

6. Plant new varieties of salt sensitive crops that are being specifically developed for salt tolerance and/or plant crops that are naturally salt tolerant.

Supplemental Water from Narrows or Hardin Reservoir

The proposed Narrows Reservoir near Weldona or the alternate Hardin Reservoir would be a source of supplemental water for lands currently under irrigation. The Narrows Reservoir would provide an increase in the annual water supply of 93,000 acre-feet to 120,000 acre-feet. This would be "new water" which currently flows into Nebraska. The Narrows project has been specifically designed to provide supplemental water to existing irrigated lands. The supplemental water calculations provide for adequate leaching as shown in Table 3-2. Overall, between 10,000 and 24,000 acre feet of the total project water supply exclusive of losses was calculated as necessary for leaching. The actual water quantity would be dependent on the salinity level of soil extract determined to be acceptable. This level is a function of crop type, soil and chemical makeup of the irrigation water. During the interim period since the 1967 USBR Narrows study, the average water conductance values for the South Platte River have increased by 164 micromhos to a flow weighted average of 1337 microhos. This is an increase of 14 percent. The percentage of water used for leaching would have to be increased accordingly to a range of 11,400 to 27,440 acre-feet for leaching on the 166,000 project acres. This quantity of water is in addition to the water determined necessary to provide full plant growth and does not include any transportation losses in the canal or on-farm distribution systems.

Redistribution of Irrigation Water

Approximately 27,200 acres of currently irrigated land were identified in the Narrows plan as not being suitable for receiving supplemental project water due to high water tables, drainage and saline-alkaline conditions. Water used on these marginal lands could be purchased and reallocated for use as leaching water on the higher quality lands. Assuming that approximately 2 acre-feet per acre of water is currently applied to these lands, 54,000 acre-feet of water would be made available for leaching.

Specific information would have to be gathered on the location of these lands and their water rights, water quality, and water storage facilities. Most of these "unsuitable" acres are probably low lying lands adjacent to the river bottom. Transfer of water rights to different lands irrigated under the same ditch company is relatively easy. On the other hand, transfer of a water right from one ditch company to another or from one point of diversion to another entails complex legal action involving multiple parties. When the point of diversion is changed, only the water consumptively used can be transferred to a new loaction. Often times, only 30-40 percent of the original water right may be utilized after the transfer. Out of the original 54,000 acre-feet only 20,000-30,000 acre-feet of water may be available for leaching.

Bypass of Fall and Winter Flows

Examination of the seasonal salt mass flows in Figure 4-1 reveals another potential method for achieving a salt mass balance for the river and adjacent lands. Flows are diverted from Kersey to Balzac in the fall and winter in addition to the spring and summer seasons. The highest salinity occurs during the fall-winter period. If the fall and winter flows were not diverted but instead were allowed to flow downstream and transport salt loads from the basin, the salt mass balance might be improved. The fall and winter salt mass profiles would become nearly horizontal from Kersey to Julesburg. This, in turn, would cause the annual profile to become nearly horizontal between these two stations. The net result is that the salt mass transport would be constant rather than losing along this reach of the stream.

Figure B-1 shows the mean seasonal salinity data at Weldona on the South Platte River near the Narrows dam site for the years 1965-1979. Figure B-1(a) shows mean seasonal flows for this 15 year time period are 12.2 cubic meters per second, 12.7 CMS, 36.8 CMS and 13.9 CMS, for the fall, winter, spring and summer seasons, respectively. Figure B-1(b) shows the corresponding mean seasonal TDS levels are 1555 mg/l, 1384 mg/l, 959 mg/l and 1370 mg/l. During the fall and winter the TDS levels are on the average 750 mg/l higher than during the spring runoff period. Figure B-1(c) shows the tons per day of salt transported are 1522 T/D, 1491 T/D, 2254 T/D and 1595 T/D in the fall, winter, spring and summer, respectively.

When the seasonal salinity mass is divided by seasonal flows, a clearer picture of salt mass transport phenomena is gained. In the fall, 125 tons per of salt is transported for each cubic meter per second of flow. In the spring this number drops to 63 T-S/D-m^3 or one-half of the fall value. In the winter 117 tons of salt are contained in each cubic meter second of flows over a days time. This volume is also approximately double the salt load contained in spring flows.

If the fall and winter flows were allowed to move downstream without diversion, the average annual TDS level would have been reduced from 1205 mg/l to 1074 mb/l for the 1965 to 1979 period. The TDS level would have been reduced by 131 mg/l but 77,760 acre feet of water should

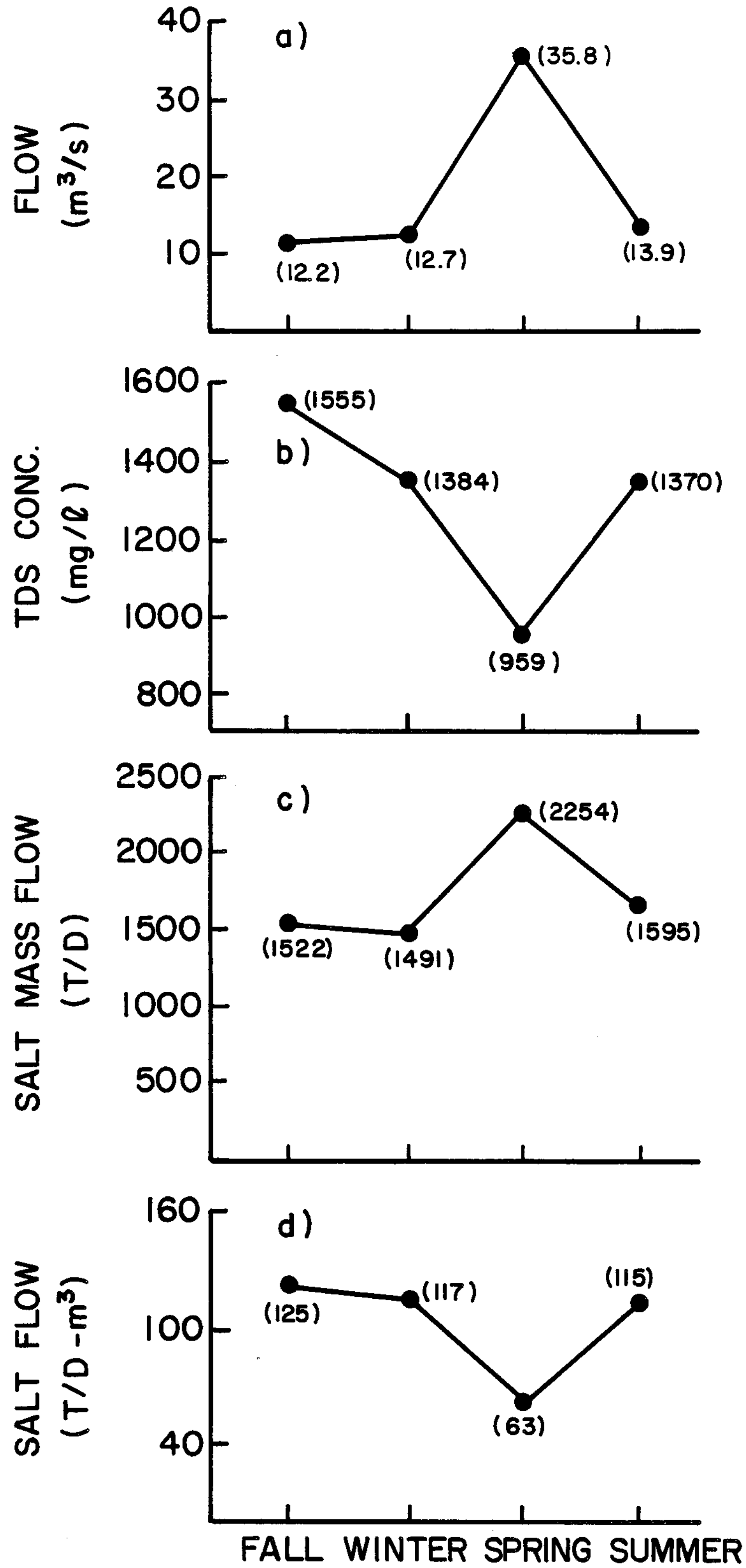


Figure B-1. Mean seasonal data for South Platte River near Weldona (1965-79).

have been lost in the fall and 81,203 acre feet in the winter. Approximately 159,000 acre feet of water sould be lost each year in order to gain the 131 mg/l TDS level reduction. This reduction is gained only if all the spring and summer flows are captured near Weldona behind the Narrows dam. Any release of water during the high spring runoff would reduce the dilution effect.

One assumption inherent with this option is that the Narrows or the Hardin dam be constructed to capture the spring runoff in excess of current diversions. The 93,000-120,000 acre-feet of water gained from the dam would be used to replace the fall and winter flows lost. This option does not however provide any additional water to meet crop and leaching requirements.

Reduction of Tributory TDS Levels

The flow weighted mean annual TDS levels of the St. Vrain, Big Thompson or Cache la Poudre Rivers jump from 50-100 mg/l TDS at the canyon mouths to 867 mg/l, 1393 mg/l and 1018 mg/l, respectively at points close to their confluence with the South Platte River. The corresponding TDS level of the South Platte River at Henderson is 488 mg/l. The increase in TDS levels is attributable to irrigation return flows from irrigated land between the canyon mouths and the South Platte River. The leaching of salt from these lands is not uniform and the lands contributing heavily to the increased TDS levels have been identified in the Larimer-Weld 208 Area-wide Plan.*

Figure B-2 displays the water flow and salinity mass for the tributaries and the mainstem of the South Platte River. The three

*Larimer-Weld 208 Area-wide Plan, Larimer-Weld Regional Council of Governments, Loveland, Colorado, 1978.

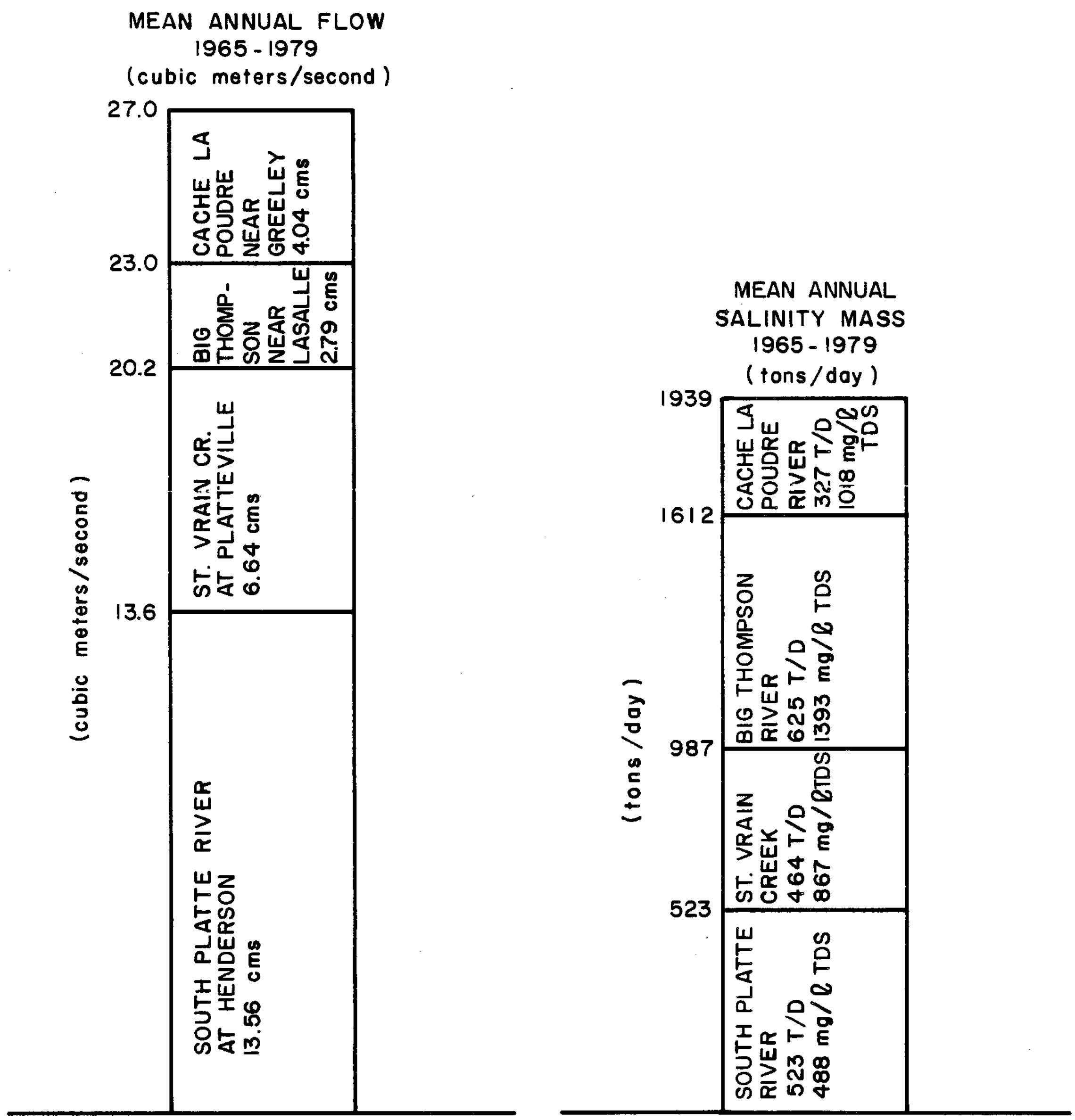


Figure B-2. Water flow and salt load for the South Platte River and major tributaries (data from Table D-1, Gomez-Ferrer and Hendricks, 1982).

tributaries have contributed an average annual mean flow of 13.47 cubic meters per second during the 1965 to 1979 time period. During the same years, the South Platte River at Henderson has had an average annual mean flow of 13.6 cubic meters per second. The combined flow in the South Platte below the tributaries has been approximately 50 percent from the mainstem above Henderson and 50 percent from the tributaries. The St. Vrain has had an average flow of 6.64 cms while the Big Thompson has been 2.79 cms and the Cache la Poudre 4.04 cms.

While these three tributaries have contributed only 50 percent of the flow, the salt mass in the 13.47 cms from the tributaries has been three times that contained in 13.6 cms in the South Platte River at Henderson. Figure B-2 shows a bar graph of average annual mean salt mass in tons per day for each tributary and the mainstem at Henderson. The total daily salt mass in the tributaries and the South Platte River at Henderson was 1939 tons per day while the South Platte flows contained only 523 tons per day of the total. Therefore, 73 percent of the salt mass load along the reach of the river between Henderson and Greeley is contributed by the tributaries.

Water Delivery and Drainage

Canal losses vary from 26 percent to 44 percent depending on the month of delivery. These losses occur between the point of diversion and delivery to the farm. Reducing these losses would reduce salinity pick up through leaching that now occurs. The lining of canals improves delivery efficiency for the canal system but it also alters the long-term groundwater recharge pattern. The removal of canals as a source of recharge on an extensive basis changes aquifer characteristics and has serious implications for the irrigation that is dependent on groundwater and the canal system as a source of recharge. The quantitative evaluation of the effects of canal lining on salinity is not undertaken in this paper.

Drainage provides a root environment that leads to maximum plant growth. Drainage is divided into two types--surface and subsurface. Poor drainage leads to an accumulation of salts in the upper zones of the soil profile and restricts the aeration of the root zone. Out of the 163,000 Narrows Project acres, 28,000 acres were identified as needing drainage corrections. Lands with adequate drainage can utilize high TDS water with fewer crop production problems.

Crop Selection

Although selection of salt resistant crops is an approach, it is not a long-term solution. The salinity imbalance will continue to salinize the lands involved and eventaully the salt tolerance of the more salt resistant crops will be reached. Neither does it provide the farmer with the best range of economic options.