A DROUGHT RELIEF STUDY IN THE SOUTH PLATTE RIVER VALLEY EMPHASIZING CONJUNCTIVE USE

FUNDED BY THE
United States Bureau of Reclamation
IN ACCORDANCE WITH
Public Law
95-107

BY
OFFICE OF THE STATE ENGINEER
STATE OF COLORADO

JANUARY, 1978

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INTRODUCTION

The Bureau of Reclamation and the Office of the State Engineer entered into an agreement on September 27, 1977, whereby the Office of the State Engineer was to develop a plan to facilitate supplemental well pumping in order to optimize the use of ground and surface water supplies in the South Platte River Valley during drought conditions and to provide a method of allocating operating costs of this plan among various beneficiaries.

Funds for this study were provided by the Emergency Drought Act of 1977 as amended by Public Law 95-107. The agreement required that the Office of the State Engineer complete the study by January 31, 1978.

Objectives

The objectives of the study as set forth in the agreement are as follows:

1. Identify developable sites for supplemental ground-water withdrawals to provide short-term drought relief at times when insufficient surface water is available for diversion by ditches and canals.
2. Identify depletions resulting from the supplemental ground water pumping program in various reaches of the South Platte River from Chatfield Dam to the State Line.
3. Determine a method of allocating operating costs to the various beneficiaries based upon the results of the study.

Procedure

In order to complete the study within the allotted time frame, the Office of the State Engineer elected to utilize consulting engineers who could, under the guidance of the Office of the State Engineer, utilize their larger staffs to investigate the South Platte River.

The study area (Figure 1) was divided into 3 reaches coinciding primarily with the 3 former mainstem Water Districts in the South Platte River in order to facilitate the collection of data and the coordination of work.

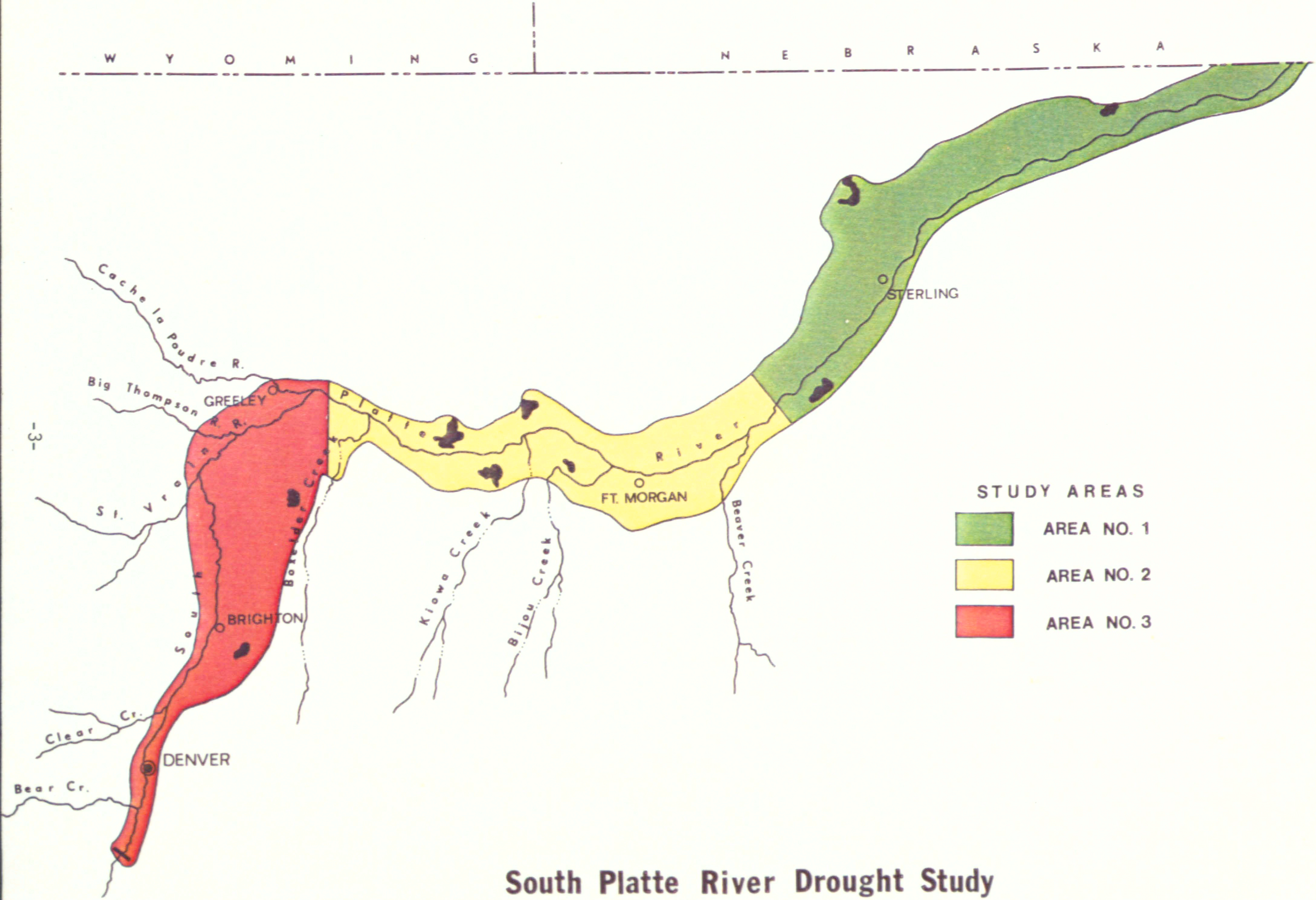
A request for a proposal was sent to 10 regional consulting engineering firms with capabilities in water resource engineering and with knowledge of the South Platte River system. Proposals were received from 7 of these firms and 3 of those firms were selected to conduct the field investigations aspects of the study in the following reaches:

1. URS Company - Study Area No. 1 - State Line to Balzac - Water District 64.
2. Toups Corporation - Study Area No. 2 - Balzac to Kersey - Water District 1.
3. Hydro-Triad, Ltd. - Study Area No. 3 - Kersey to Chatfield Dam and Beebe Draw - Water Districts No. 2 and No. 8.

In addition, the URS Company was selected to provide base maps of the entire study area using aerial photography flown in late October, 1977. These photographs, in conjunction with U.S. Geological Survey Topographic Maps, were used to prepare 133 base maps of the study area with a scale of 1 inch equals 2000 feet (1" - 2000").

The consultants were directed to perform 9 tasks related to obtaining up-to-date data on the South Platte River system which could be utilized by the Office of the State Engineer in developing a supplemental well pumping program. These tasks were as follow:

1. Prepare accurate and up-to-date mapping of all ditch systems on URS base maps.
2. Determine location and map on URS base maps all irrigation wells that irrigate land which is situated under a ditch system. Depicted information should include yield, acres irrigated, depth and permit or water court case number.



South Platte River Drought Study

FIGURE 1

3. Define irrigated areas under the various ditch systems and wells using available aerial photography and field methods.
4. Identify ditch systems which have little or no supplemental irrigation water provided by wells.
5. Locate areas along or near ditches and canals that have the potential for large well yields which could be utilized for additional ground water withdrawals. Determine ditch and canal seepage rates for transportation losses.
6. Identify existing wells situated near ditches, canals or major laterals that could pump water into these facilities for delivery to other water users.
7. Indicate ditches which normally have a full supply of irrigation water without the use of ground water, but have the potential for the installation of wells for alternate sources of supply.
8. Indicate the ditches within the study area that could be most seriously affected by continuing drought conditions such as were experienced during the past irrigation season.
9. Suggest alternatives within the study area to optimize the use of surface and ground water supplies taking into consideration constraints imposed by time, economics, and effect of alternatives upon senior vested water rights. Include the costs of alternatives including capital and operating expenses.

The reports from the consultants addressing these tasks are included as appendices to this report. In addition, a set of reproducible sepia maps for each reach are included with this report. These maps contain the information set forth in tasks 1 through 3 above and are an invaluable tool in defining the present irrigated lands in the South Platte River system.

The recommendations of the consultants, if found acceptable, were utilized along with conclusions reached by the Office of the State Engineer in developing a supplemental well pumping plan for alleviation of drought related water shortages.

CONSTRAINTS TO DEVELOPING A SUPPLEMENTAL WELL PUMPING PLAN

Legal Constraints

Probably the most important constraint to developing a supplemental well pumping program is the requirement that injury to senior surface water rights cannot be allowed. Additional unmanaged pumping by existing wells or by new wells cannot be permitted if the amount of water available to another water right is reduced. Of course, if additional water is provided to the injured water right by some other means, it may be possible to allow additional pumping by existing wells or permit the installation of new wells at desirable locations for temporary drought relief.

In addition to the legal constraint on expanded pumping by existing wells or new wells as part of a supplemental well pumping plan, there is the present constraint on existing irrigation wells in the South Platte River system which are subject to the Amended Rules and Regulations of the State Engineer. These Amended Rules and Regulations are the outcome of lengthy Water Court proceedings held in 1973 and 1974 in which the right of the State Engineer to regulate well pumping to protect senior surface water rights was upheld.

These Amended Rules and Regulations state that an irrigation well pumping tributary ground water is subject to total curtailment by the Division Engineer of Water Division No. 1 unless operating under one of the following procedures:

1. The well is operating pursuant to a decreed plan for augmentation.
2. The well is operating pursuant to a decree as an alternate point of diversion to a surface water right which is in priority.
3. The well can be operated under its own priority without impairing the water supply to which a senior appropriator is entitled.
4. If a well is not capable of operating in accordance with one of the above, it can operate provided it is in compliance with a temporary

plan for augmentation approved by the Division Engineer after it has been filed in the Water Court.

The minimum criteria for a temporary plan for augmentation operating in accordance with the Amended Rules and Regulations is that replacement water shall be made available to the Division Engineer in an amount equal to 5 percent of the projected annual volume of well pumping. This water may be used by the Division Engineer to compensate for any adverse effect of the well pumping on a lawful senior requirement as evidenced by a valid senior call.

If the Division Engineer finds that replacement water is not sufficient, based upon the minimum criteria of 5 percent, he can order modification of the temporary plan for augmentation to provide more replacement water up to the maximum stream depletion as calculated by the method shown in The Pumped Well by Robert E. Glover, Technical Bulletin 100, Colorado State University or by other accepted engineering formulae.

The majority of the irrigation wells in the study area are operating under temporary plans for augmentation approved annually by the State Engineer and administered by the Division Engineer. A few plans for augmentation have been decreed by the Water Court but the majority are still awaiting adjudication.

Valuable experience and knowledge have been gained in the past four irrigation seasons with respect to the problems of administering these various temporary plans for augmentation in order to protect senior surface water rights. In a year with normal streamflow such as 1975, it was found that the basic requirement of the Rules and Regulations of providing augmentation water to affected senior surface water rights equivalent to maximum stream depletion caused by the well pumping was not always required to satisfy senior surface water rights. In a drought year, however, with reduced streamflow such as in 1977, problems were encountered and could have become quite serious except that sufficient precipitation in late July and August increased streamflow and reduced irrigation water requirements.

If the drought continues into 1978, it is certain that senior surface water rights will be materially injured by junior well pumping since augmentation on the basis of 5 percent of pumping will not provide sufficient water to augment stream depletions. It should be pointed out that some irrigators are not as seriously affected as others because many land owners under irrigation ditches also have irrigation wells to provide alternate sources of water in the event of a drought. Most surface water rights, therefore, are reluctant to demand strict administration of junior irrigation wells in the priority system because of the effect upon their own supplemental supply. There are some surface water rights, however, which will be affected by continuing drought and junior well pumping, and it is the intent of this study to evaluate a plan to provide augmentation water to these injured water rights which is legally viable and which will permit continued pumping of the numerous junior wells for supplemental irrigation water.

Time Available for Implementation

Any supplemental well pumping plan or plans must be capable of being fully implemented by June 15 of this irrigation season if water is to be available for the most critical portion of the irrigation season. Therefore, any proposal involving construction of wells, pipelines, etc. can be acceptable only if it can be completed prior to that time.

Any proposal involving the exchange of water rights for a supplemental well pumping plan or a plan requiring an agreement between water rights owners pertaining to a method of payment to permit supplemental well pumping must be consummated prior to the initiation of irrigation which is approximately the first of April of each irrigation season.

Various water users must be willing to fully cooperate in a water management plan involving well pumping to minimize drought effects and permitting conjunctive use of the South Platte River water resources. It is expected that numerous meetings between various water users will be necessary to reach agreements on a procedure to implement the recommendations of this report.

In the past, mutual agreements between water users have been difficult to attain and it is in this area that the major difficulty with a supplemental well pumping program may be encountered, especially due to the short time for implementation.

Economics

Any supplemental well pumping program must consider the annual cost of the project and evaluate whether beneficiaries of the program are willing and capable of paying for the annual operating costs of the program as well as any annualized costs related to capital expenditures for construction of new facilities.

The major problem may be related to funding for construction of new wells along affected ditches. These facilities are increasing in cost every year and are estimated to cost $25,000 to $30,000 per well (page 32, Appendix I). This estimated cost appears somewhat high and probably can be reduced if local water users negotiate the well construction costs. Even if this reduction is accomplished, funds may have to be provided to ground water user entities in the form of grants or loans to fund capital costs necessary to alleviate drought conditions.

DESCRIPTION OF THE SOUTH PLATTE RIVER SYSTEM

As stated above, the consultants were directed to individually investigate a reach of the study area to provide specific information and to prepare mapping depicting irrigated acres, wells, ditch systems, and the approximate boundary of the alluvium of the South Platte River system. In addition, each map contains a table listing the registration number or water court case number for each well along with depth, yield, and irrigated area if known.

This mapping, consisting of 133 sheets, is an invaluable tool in identifying the various ditch systems and the existence of supplemental ground water available to irrigated lands under each ditch system. With the knowledge of the amount and location of irrigated lands under the various ditch systems without supplemental ground water, the amount of supplemental water which must be provided to these ditches in order to prevent the owners of this irrigated land from being seriously affected by the on-going drought can be estimated.

A careful inspection of these maps indicates that a large percentage of irrigated lands under the ditches in the study area have the capability of being irrigated by approximately 4250 existing wells in the event sufficient surface water is not available. There are ditches in each reach, however, which do not have supplemental wells and have been identified by the consultants or this office as possibly not having sufficient surface water rights to provide the water necessary to irrigate the entire land under the ditch or whose water rights have been affected by the stream depletions resulting from the increased use of ground water in the study area in the past 27 years.

The Amended Rules and Regulations of the State Engineer are intended to materially lessen the impact of these junior ground water diversions upon senior water rights but will require several years before the injury to senior water rights can be eliminated since water management plans cannot be quickly developed due to the limited nature of the resource. In a drought year, the reduction in streamflow due to well pumping is even more obvious and creates critical problems in certain ditches which do not have supplemental ground water available to reduce the effect of the drought. Ditches with headgates in the indicated reach which lack sufficient well capacity are as follows:

1\. Reach No. 1 - Water District No. 64

   a. Liddle Ditch

   b. South Reservation Ditch

   c. Peterson Ditch

   d. Harmony No. 1 Ditch

   e. Powell-Blair Ditch

   f. Sterling No. 1 Ditch

2\. Reach No. 2 - Water District No. 1

   a. Tetsel Ditch

   b. North Sterling Irrigation District - land in District No. 64

   c. Weldon Valley Ditch

   d. Riverside Irrigation District

3\. Reach No. 3 - Water Districts No. 2 and No. 8

   a. Evans No. 2 Ditch

   b. Fulton Ditch

   c. Burlington Ditch - Brighton Lateral

The reports prepared by each consultant present additional information on the water administration and management practices within each reach as well as detailed information on each of the active ditches to include decreed water rights, irrigated acres, historic diversions, seepage losses, effect of drought conditions and additional mapping. A careful inspection of each report attached as an appendix to this report is recommended to obtain general knowledge of the South Platte River system.

PRESENT WATER MANAGEMENT PRACTICES WITHIN THE STUDY AREA

Irrigation water use practices have changed considerably since the initial development of the irrigation ditch systems taking water directly from the South Platte River with no supplemental source of water. As more and more land was brought under irrigation, late seasonal streamflow increased due to return flows from the infiltration of this surface water from irrigated lands and canals into the alluvium of the river. This increased return flow resulted in the development of additional ditches downstream of the original ditch systems and in the development of reservoirs to take advantage of this additional water in the non-irrigation season as well as to store water available during the spring runoff season. Most of these reservoirs were constructed in the period of 1900 to 1910 which was approximately 30 to 35 years after the most senior irrigation systems were constructed.

Most of the reservoirs were developed to provide supplemental water to lands under existing systems with junior direct flow rights which were affected by calls from more senior water rights in drought years. Two irrigation systems, the Riverside Irrigation District and the North Sterling Irrigation District, obtain their water almost entirely from reservoirs and not from direct flow water rights which divert during the irrigation season. As a result, these two systems are affected more seriously than other water rights in a drought year, since most of the irrigated lands under these systems lie outside the alluvium of the river and cannot develop adequate wells.

The use of irrigation water did not change significantly from the period of reservoir construction until about 1950 when irrigation well technology advanced to the point that wells were a feasible and economical method of developing a supplemental water supply. The number of irrigation wells increased steadily in the study area through the early 1950's with the annual increase averaging about

60 to 65 wells per year (Colorado Water Resources Circular No. 28, 1975). Most of the wells were constructed to provide a supplemental supply to junior ditches affected by drought.

In 1954 through 1957 the number of irrigation wells constructed increased considerably due to the shortage of surface water during the serious drought of 1953 through 1956 and the increased need for supplemental water. Another period of increased well construction occurred in 1963 through 1965, probably in response to two drought years, 1964 and 1965, and in anticipation of the change in Colorado Statutes restricting the construction of additional wells within the alluvium of an over-appropriated stream or its tributaries. After this statute was enacted in 1965, new well construction decreased significantly.

In 1969, Colorado Water Law was recodified by the Colorado General Assembly in the form of the "Water Rights Determination and Administration Act of 1969." Under this Act wells were permitted to be adjudicated by the Water Courts with the priority date granted being the date of well construction, provided the application was filed prior to July 1, 1972. These tributary wells were then integrated into the existing priority system with surface water rights.

The State Engineer was required to administer these wells along with any other surface water right in the priority system and to curtail use of these wells if a downstream senior water right was demanding that his water right be fulfilled. The Act did, however, allow the State Engineer the prerogative of adopting Rules and Regulations to assist in the very difficult task of administering the wells within the priority system. The first attempt at promulgation of Rules and Regulations was thwarted by an injunction and declaratory judgment of the Division Water Court in the South Platte River against Rules and Regulations adopted in 1969. This injunction was in effect from July 29, 1969 until it was reversed by the Colorado Supreme Court in late 1971. New Rules and Regulations were promulgated in 1972 to become effective February 19, 1973. These Rules and Regulations stated that well diversions would be curtailed, initially, four-sevenths (4/7) of the time unless operating pursuant to a decreed plan for augmentation, alternate point of diversion, or under an approved temporary plan for augmentation and provided for ultimate curtailment if no such plan was developed. The intent of the State Engineer in adopting Rules and Regulations, including those adopted in 1969, was to gradually curtail ground water diversions and to allow well owners time to develop plans for augmentation.

The 1973 Rules and Regulations were protested by several parties and as stated previously, considerable time was spent in hearings before the Division Water Court before the concept was upheld by stipulation among the parties and the Amended Rules and Regulations adopted by decree. These Amended Rules and Regulations are the basis for the legal criteria for any conjunctive water management plan now in effect in the South Platte River.

Due to these Amended Rules and Regulations, well owners are required to develop a permanent plan for augmentation that must be approved by the Water Court. This plan for augmentation must be capable of providing replacement water to the river at a rate, time, and place of depletion during a time of call by an injured senior water right. In the interim period while the plan for augmentation is pending action by the Water Court, the State Engineer can approve operation of a temporary plan for exchange on a year to year basis.

In order to comply with the Amended Rules and Regulations, numerous well owners joined together to form organizations to develop plans for augmentation to assure continued pumping of their wells. These organizations varied in size from a few individuals under a ditch system to as many as several hundred well owners located throughout the study area.

The largest organization of this nature is GASP (Groundwater Appropriators of the South Platte River, Inc.). GASP is a not-for-profit corporation established to develop a plan for augmentation to assure continued pumping of members' wells. Since 1974, GASP has developed several water management projects to increase the amount of water available to senior water rights that are affected by ground water depletions of members' wells.

GASP leases available reservoir and direct flow water and releases this water to the stream system for delivery to affected senior water rights. In addition to acquiring reservoir water, GASP has installed wells along the upper end of two ditches particularly affected by well depletion. By pumping a portion of the senior ditch's water rights, GASP not only replaces its depletion to the ditch but indirectly benefits affected upstream senior surface water rights.

As an example, GASP has constructed 10 wells along the upper end of the Sterling No. 1 Ditch (Reach No. 1) which is a large and very senior ditch near Sterling. When the Sterling No. 1 Ditch is calling for water, several upstream ditches are regulated or curtailed by the Division Engineer. The most seriously affected of these is the Weldon Valley Ditch which has few wells to provide supplemental water. Prior to 1969 when wells were not administered within the priority system, the Weldon Valley Ditch was regulated to provide water to Sterling No. 1 but junior wells were not curtailed. Now that wells are required to provide replacement water as part of a permanent or temporary plan for augmentation, the Weldon Valley Ditch benefits by virtue of the fact that GASP pumps 37 cfs into the ditch. During 1977, approximately 100 cfs was available for diversion by the Weldon Valley Ditch which would have been required to be passed downstream since the river is a losing stream in this reach of the system during the irrigation season.

GASP has also constructed 3 wells above the headgate of the South Reservation Ditch (Reach No. 1) to provide replacement water to this ditch which is affected by well depletions. Water could not be delivered to this ditch through a 31 mile reach of the stream even though in excess of 150 cfs was passing the curtailed Powell-Blair Ditch headgate. This problem is evident in all but a wet year when river flows are above average and indicates the drastic stream depletions that can be caused by wells.

By pumping 14 cfs to the South Reservation Ditch, GASP, along with junior upstream ditches (page 23, Appendix I), was able to satisfy the demands of irrigators under the South Reservation Ditch. Again, with the South Reservation Ditch not calling, upstream ditches benefited by not having to pass large amounts of water through a losing reach of the river.

In 1977, GASP members enrolled 2648 wells in the organization with an expected maximum pumping volume of 369,550 acre-feet. GASP members pay an annual fee which is based upon the number of units pumped annually with one unit being 100 acre-feet. In 1977, the fee was $25 per unit.

Another large organization developing a plan for augmentation is the Ground Water Subdistrict of the Central Colorado Water Conservancy District, hereafter referred to as Central. In 1977, Central had 845 wells in its temporary plan for augmentation with an expected maximum pumping volume of 103,694 acre-feet. In that Central is a statutorily created water conservancy district, it obtains funds for operating its temporary plan for augmentation primarily through ad valorem taxes. The majority of Central's members are in Reach No. 1 of this study along the South Platte River and in Beebe Draw.

These two organizations along with several smaller organizations operate temporary plans for exchange approved by the State Engineer on a year to year basis and administered by the Division Engineer.

To aid the Division Engineer in administering temporary plans for augmentation or exchange, the Engineering Section of the State Engineer's Office has provided the Division Engineer with a listing of the average rate of stream depletions (cfs) for each month of each temporary plan. The South Platte River has been divided into 29 critical reaches (Figure 2) and the rate of depletion for each reach is calculated based upon the locations of wells, number of wells, and expected pumping volumes. An example of the stream depletion listing for GASP for 1977 is shown in Table 1. These stream depletion rates are the maximum rates and are based upon a 40 percent irrigation efficiency unless otherwise specified.

As stated previously, the administration of the temporary plans by the Division Engineer has started on the basis of the 5 percent minimum criteria unless facts indicated larger replacement amounts. In an extended drought, however, as may be the situation for 1978, the administration of these temporary plans may require the provision of additional replacement water, or worse, curtailment of the junior wells if a senior surface water right calls for water and the stream depletion by junior wells is not replaced at the proper rate, time and place. The following section of this report will present the temporary emergency plan proposed to alleviate the injury to senior surface water rights and to discourage them from demanding curtailment of junior wells.

In addition to the above methods of providing replacement water to the river for temporary plans for augmentation, several organizations have developed artificial recharge projects to permit additional pumping.

These recharge projects take advantage of the free water available during certain times of the year when there is no demand for water by other water users. The recharge sites are located a sufficient distance from the river to permit the water introduced into transient storage in the alluvium to return to the river at the proper place, time and amount to compensate for well depletions.

During the past irrigation season, several thousand acre-feet of ground water accretions by recharge were credited to various organizations. This amount of water is an important contribution to the water available for augmentation purposes and due to the success and low cost (less than $2/AF) of the projects, several additional projects are being developed.

CONSUMPTIVE DEPLETION, IN CFS, BY REACH AND TIME FROM START OF PUMPING
SECOND LINE SHOWS CUMULATIVE DEPLETION FROM ALL UPSTREAM REACHES

	MONTHS FROM START OF PUMPING													AF
REACH	0	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
29	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	735.
	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	735.
28	1.94	2.24	2.82	3.38	3.49	3.25	2.98	2.74	2.54	2.37	2.22	2.09	1.99	1936.
	3.0	3.3	3.8	4.4	4.5	4.3	4.0	3.8	3.6	3.4	3.2	3.1	3.0	2671.
27	.70	1.84	2.40	2.70	1.82	1.46	1.25	1.11	.99	.90	.82	.76	.71	1014.
	3.7	5.1	6.2	7.2	6.3	5.7	5.2	4.9	4.5	4.3	4.1	3.9	3.7	3685.
26	.78	.95	1.17	1.35	1.30	1.19	1.10	1.02	.96	.91	.86	.82	.78	749.
	4.5	6.0	7.4	8.5	7.6	6.9	6.3	5.9	5.5	5.2	4.9	4.7	4.5	4434.
25	4.28	6.70	8.62	9.95	8.27	7.05	6.29	5.75	5.34	5.01	4.74	4.50	4.29	4615.
	8.8	12.7	16.0	18.5	15.9	14.0	12.6	11.6	10.8	10.2	9.7	9.2	8.8	9049.
24	8.94	9.30	10.06	10.82	10.95	10.71	10.44	10.17	9.90	9.65	9.40	9.17	8.95	7211.
	17.7	22.0	26.1	29.3	26.8	24.7	23.1	21.8	20.8	19.9	19.1	18.4	17.7	16260.
23	5.76	7.59	8.61	9.50	8.25	7.84	7.52	7.18	6.86	6.55	6.27	6.01	5.77	5304.
	23.5	29.6	34.7	38.8	35.1	32.5	30.6	29.0	27.6	26.4	25.3	24.4	23.5	21564.
22	6.29	8.00	9.30	10.31	9.17	8.47	7.96	7.55	7.22	6.93	6.69	6.48	6.29	5693.
	29.7	37.6	44.0	49.1	44.3	41.0	38.6	36.5	34.8	33.3	32.0	30.8	29.8	27257.
21	3.66	7.00	8.56	9.59	6.85	5.83	5.20	4.77	4.45	4.20	4.00	3.82	3.67	4097.
	33.4	44.6	52.6	58.7	51.1	46.8	43.8	41.3	39.3	37.5	36.0	34.7	33.5	31354.
20	2.44	3.53	4.14	4.57	3.78	3.42	3.19	3.02	2.86	2.76	2.65	2.56	2.48	2350.
	35.8	48.2	56.7	63.3	54.9	50.2	46.9	44.3	42.2	40.3	38.7	37.2	35.9	33705.
19	.63	.65	.69	.74	.76	.75	.74	.72	.69	.68	.66	.65	.63	504.
	36.5	48.8	57.4	64.0	55.7	51.0	47.7	45.0	42.9	41.0	39.3	37.9	36.6	34209.
18	.28	.37	.42	.47	.39	.36	.36	.34	.31	.30	.28	.26	.25	249.
	36.8	49.2	57.8	64.5	56.1	51.4	48.0	45.4	43.2	41.3	39.6	38.1	36.8	34458.
17	11.26	12.96	14.00	14.74	13.56	12.97	12.58	12.29	12.05	11.84	11.65	11.47	11.30	9136.
	48.0	62.2	71.8	79.3	69.6	64.3	60.6	57.7	55.2	53.1	51.3	49.6	48.1	43594.
16	7.10	8.56	10.11	11.27	10.48	9.61	9.03	8.59	8.22	7.89	7.61	7.35	7.12	6385.
	55.1	70.7	81.9	90.5	80.1	74.0	69.7	66.3	63.4	61.0	58.9	57.0	55.2	49980.
15	4.61	8.68	11.70	13.56	10.45	8.31	7.10	6.34	5.81	5.42	5.11	4.85	4.64	5546.
	59.7	79.4	93.6	104.1	90.5	82.3	76.8	72.6	69.2	66.4	64.0	61.8	59.9	55525.
14	5.30	7.61	9.25	10.45	8.83	7.85	7.18	6.68	6.30	5.93	5.73	5.51	5.31	5228.
	65.0	87.0	102.9	114.5	99.4	90.1	83.9	79.3	75.5	72.4	69.7	67.3	65.2	60754.

TABLE I

GASP ONLY 1977 DATE: 5/9/1977

CONSUMPTIVE DEPLETION, IN CFS, BY REACH AND TIME FROM START OF PUMPING
SECOND LINE SHOWS CUMULATIVE DEPLETION FROM ALL UPSTREAM REACHES

REACH	MONTHS FROM START OF PUMPING 0	1	2	3	4	5	6	7	8	9	10	11	12	AF TOTAL
13	8.17 73.2	12.64 99.6	15.18 118.0	16.80 131.4	13.22 112.6	11.52 101.6	10.56 94.5	9.91 89.2	9.42 85.0	9.03 81.4	8.71 79.4	8.44 75.8	8.20 73.4	8058. 68812.
12	4.37 77.6	6.45 106.1	8.03 126.1	9.13 140.5	8.01 120.5	7.15 108.8	6.47 101.0	5.93 95.1	5.51 90.5	5.15 86.6	4.86 83.3	4.60 80.4	4.38 77.8	4565. 73377.
11	4.48 82.1	10.15 116.2	13.73 139.8	16.03 156.5	11.60 132.2	9.16 117.9	7.72 108.7	6.76 101.9	6.07 96.5	5.54 92.1	5.12 88.4	4.78 85.1	4.49 82.3	6099. 79476.
10	4.32 86.4	6.94 123.2	8.73 148.5	9.97 160.5	8.04 140.2	6.86 124.8	6.11 114.9	5.60 107.5	5.23 101.6	4.94 97.1	4.70 93.1	4.50 89.6	4.33 86.6	4580. 84056.
9	2.51 88.9	3.41 126.6	4.26 152.8	4.83 171.3	4.23 144.5	3.66 128.5	3.30 118.1	3.06 110.6	2.89 104.7	2.77 99.8	2.67 95.8	2.58 92.2	2.51 89.1	2423. 86479.
8	3.90 92.9	10.65 137.2	13.39 166.2	14.84 186.1	8.80 153.3	6.75 135.2	5.75 123.9	5.15 115.7	4.75 109.4	4.46 104.3	4.24 100.0	4.06 96.3	3.91 93.0	5231. 91709.
7	1.76 94.6	2.43 134.7	3.02 159.2	3.54 189.7	3.21 156.5	2.91 138.1	2.65 126.5	2.44 118.1	2.26 111.7	2.10 106.4	1.98 102.0	1.87 98.2	1.77 94.8	1820. 93529.
6	2.22 96.9	2.19 141.9	2.53 171.7	3.03 192.7	3.44 159.4	3.42 141.5	3.23 129.7	3.02 121.2	2.83 114.5	2.66 109.1	2.50 104.5	2.36 100.5	2.23 97.0	2018. 95547.
5	2.44 99.2	7.17 149.0	9.43 181.2	10.71 203.4	6.64 166.6	5.01 146.5	4.16 133.9	3.63 124.8	3.27 117.6	2.99 112.1	2.77 107.2	2.60 103.1	2.44 99.5	3667. 99214.
4	.78 100.0	3.43 152.5	4.30 185.5	4.76 208.2	2.33 168.9	1.70 148.3	1.42 135.3	1.24 126.0	1.11 118.9	1.01 113.1	.92 108.2	.84 104.0	.78 100.2	1435. 100649.
3	1.58 101.7	5.29 157.8	6.74 192.2	7.58 215.6	4.41 173.3	3.42 151.7	2.93 138.2	2.59 128.6	2.34 121.2	2.14 115.2	1.96 110.1	1.81 105.8	1.68 101.9	2583. 103232.
2	3.65 105.3	5.41 163.2	7.16 194.4	8.35 224.1	7.24 180.5	6.10 157.8	5.41 143.7	4.94 133.6	4.58 125.9	4.29 119.5	4.05 114.2	3.84 109.6	3.66 105.6	3922. 107154.
1	.32 105.7	.38 163.5	.47 190.8	.57 224.7	.57 181.1	.53 158.3	.49 144.1	.45 134.0	.41 126.2	.38 119.9	.36 114.5	.34 109.9	.32 105.9	318. 107471.

6 PAGES PRINTED.

TABLE I (Cont'd)

RECOMMENDED PLAN TO FACILITATE SUPPLEMENTAL WELL PUMPING FOR DROUGHT RELIEF

Concept of the Plan

The plan developed from this study is based upon the concept of identifying those surface water rights which will be most seriously affected by drought and junior well depletions and of developing a method to alleviate the detrimental effect of well depletions and drought for each affected ditch.

Each selected method must meet the constraints imposed by time and economics as well as the fact that injury to downstream senior water rights cannot be permitted.

A very important consideration is that numerous ditch systems have existing irrigation wells which were constructed during previous drought periods to provide a supplemental water supply. It is assumed that for the on-going drought conditions being planned for in this study that these ditch systems will use their wells for a supplemental water supply as in the past and will not demand curtailment of upstream wells which could in turn affect their own wells.

It is also assumed that the various organizations operating plans for augmentation or exchange will continue to do so with similar amounts of replacement water being provided and that the existing water management plans involving pumping of ground water to certain ditches will continue.

Plan for Reach No. 1

In general, Reach No. 1 has been affected the most seriously of the three study reaches by reduction of return flows due to massive upstream well depletions and reduced flows during drought conditions. The method to be used for drought relief within this reach is to provide supplemental water to affected ditches by pumping water into the ditch above those irrigated farms which do not have wells for a supplemental supply. The recommended plans for providing supplemental water for each ditch previously identified as being affected are as follows:

1. Liddle Ditch

This ditch has a need for approximately 5 to 10 cfs during the months of July and August. This water can be provided by the existing GASP wells at Ovid by construction of a pipeline or improvement of an existing lateral which GASP intends to do this year. Therefore, no additional wells are needed to aid this ditch.

2. South Reservation Ditch

This ditch has been provided up to 14 cfs of water by three wells installed by GASP prior to the 1977 irrigation season. These wells can divert under the priority of the South Reservation Ditch since it is the senior ditch in the reach to the State Line. The ditch has wells to irrigate a portion of its farms and 14 cfs is sufficient to satisfy the ditch and satisfy its call for surface water. A pipeline is to be installed by GASP to deliver water to the ditch rather than using the river to transport the water which will increase delivery efficiency.

3. Peterson Ditch

The Peterson Ditch has approximately 1000 to 1200 acres of irrigated land above the Julesburg Highline Feeder Canal which appear not to have wells for supplemental water and cannot obtain Julesburg Reservoir water. In July and August of the past two years, the ditch has received very little water from the river. A well field is feasible along the first two miles of the ditch where transmissivities range between 200,000 to 400,000 gal/day/ft. It is recommended that five wells with individual capacities of 5 to 6 cfs be constructed to alleviate this shortage. The capital cost of this well field would be about $100,000 to $125,000. Operating cost of this well field would be approximately $2.25 per acre-foot of water pumped and maintenance costs of $216.00 per year (page 34, Appendix I). This pumping is legally feasible as an alternate point of diversion to the surface water rights because the downstream senior water right, the South Reservation Ditch, is not calling because of water supplied by the supplemental well field of GASP. No other source of supplemental water is available in this reach other than Prewitt Reservoir water but the transportation losses on this water is very high, being approximately 50 percent, or greater, because of the large number of wells in the reach. Furthermore, this ditch is not within the Iliff Irrigation District and is precluded from obtaining water from Prewitt Reservoir.

4. Harmony No. 1 Ditch

Harmony No. 1 Ditch has approximately 3000 acres above Julesburg Reservoir which cannot obtain supplemental water from wells because this farm land lies outside the river alluvium. Historic diversion records in drought periods prior to major well development, such as 1939 and 1940, indicate that the ditch was considerably affected by drought conditions during July and August. In 1940, July diversions were 791 acre-feet and August diversions were 653 acre-feet.

In 1976, July diversions were 293 acre-feet and August diversions were 152 acre-feet. In 1977, the ditch did not have any water available for 20 days in July indicating the effect of well depletions upon the ditch.

A well field is feasible along the first 2 1/2 miles of the ditch where the transmissivity averages 200,000 gal/day/ft. It is recommended that five wells with a capacity of 5 to 6 cfs each be constructed along this section of the ditch to provide approximately 1500 to 1800 acre-feet of supplemental water to the ditch. Since this is more water than the ditch received in 1939 and 1940, the ditch company should be expected to pay for the amount of water delivered which exceeds drought deliveries in July and August of years prior to well development. Additional study on this aspect of the plan should be performed if this recommendation is implemented. The capital and operating costs for this plan would be the same as for the Peterson Ditch well field.

These new wells could pump as alternate points of diversion to the surface water rights of the ditch since no senior call would exist downstream due to the previously discussed supplemental well pumping.

Some supplemental water is available to specific lands near the head of the ditch from Prewitt Reservoir as part of the Iliff Irrigation District. In 1977, 471 acre-feet of water was delivered to the headgate with a transportation loss of approximately 50 percent (Table III-A, Appendix I). Additional deliveries would violate the District's bylaws concerning lands not in the District.

5. Powell-Blair Ditch

This ditch has approximately 1500 acres without supplemental water available from existing wells; however, these lands are in the

Iliff Irrigation District and obtain supplemental water from Prewitt Reservoir. Again, the transportation losses approach 50 percent during July and August which discourage the use of this reservoir water.

This ditch benefited from the GASP wells at the South Reservation Ditch during the past season by not having to pass water at its headgate for delivery through a losing reach in July and August. The ditch paid for 16 days of pumping for the third GASP well in order to receive 20 cfs of river water. Based upon the success of this operation, no additional well construction is recommended.

6. Sterling No. 1 Ditch

This ditch normally receives all of its water requirements from its very senior surface water right and is not impacted directly by drought or well depletions since it can call for additional water from ditches located above Kersey if necessary. Because of the added well depletions, the ditch is calling at a greater frequency. This affects upstream junior water rights, such as the Upper Platte and Beaver, who are curtailed more often now than before the large well development.

The management plan of GASP whereby up to 47 cfs of water has been pumped into the ditch in order to remove the call of the Sterling No. 1 Ditch from the river has worked quite well and must be continued under drought conditions.

Plan for Reach No. 2

Reach No. 2 has some irrigation systems which can receive benefit from a supplemental well pumping plan but it also has two large irrigation systems which rely entirely upon reservoir water during drought years, the Riverside Irrigation District and the North Sterling Irrigation District.

There appears to be little that can be done for these two systems since the addition of well fields near the ditch headgates would injure downstream senior water rights. Thus, prudent use of the available resource and making every effort to store all water available in the storage season may be the only recourse available to these systems.

The recommended plans for the remaining affected ditches are as follows:

1. Tetsel Ditch

   The Tetsel Ditch has a senior surface water right for 17.0 cfs which would normally be sufficient water for the 1073 acres of irrigated land under the ditch, except that it loses approximately 4 cfs in seepage losses. A well or wells near the point of use on the ditch and some canal lining would help alleviate this problem. The ditch company has obtained a U.S. Bureau of Reclamation loan for drought relief assistance to construct wells.

   It must be realized that these wells could be operated only as alternate points of diversion to the surface water right when it is in priority. If the wells are to be operated at other times, then they must be incorporated into a plan for augmentation.

2. Weldon Valley Ditch

   The Weldon Valley Ditch is located such that nearly all of the irrigated land associated with the ditch lies outside the alluvium of the river and is very dependent upon surface water to irrigate the 9000 acres presently irrigated. It should be pointed out that originally about 6400 acres were irrigated under the ditch but recently an additional 2500 acres have been brought into production above the ditch by using lift stations.

As previously discussed, the Weldon Valley Ditch has benefited by the pumping of replacement water at the Sterling No. 1 Ditch by GASP. During the 1977 irrigation season, the Weldon Valley Ditch was able to divert approximately 100 cfs during July when the river was very low. In a serious drought situation, the ditch could be affected more by upstream ground water diversions; therefore, a plan should be available for implementation in the event the ditch is affected. This plan should be flexible and should not rely on a well field below the headgate of the ditch. In this reach of the river, only the first two miles of the ditch overlie the alluvium and the ditch is 3000 feet from the river. Any pumping by new wells near the river would affect downstream senior surface water rights rather rapidly.

The plan proposed for the Weldon Valley Ditch to alleviate the effect of junior well pumping is based upon the use of Jackson Lake Reservoir water owned by the Fort Morgan Irrigation Company. This water could be released to the river at the Jackson Lake Outlet and an equivalent amount diverted at the Weldon Valley Ditch headgate five miles upstream. The exchange would also require that certain shareholders under the Fort Morgan Canal, who would have used the Jackson Lake Reservoir water, must pump an equivalent amount of water from wells located two miles or more from the river. By pumping wells as far as possible from the river, the major effect upon streamflows of the additional pumping by these junior wells will not be during the critical part of the same irrigation season. There will still be some affect upon the stream which must be calculated and replacement water provided through release of additional shares of Jackson Lake Reservoir water which are normally available for lease.

Those upstream well owners belonging to organizations operating temporary plans for augmentation or exchange would have to pay for the pumping and maintenance costs of those well owners under the Fort Morgan Canal system. The critical period when the exchange would be necessary would probably be approximately 30 days at an average rate of 30 to 50 cfs. This would require approximately 1800 to 3000 acre-feet to be pumped to permit the exchange to operate. The approximate pumping costs of the plan would be $2.25 to $2.50 per acre-foot, including maintenance costs.

Plan for Reach No. 3

Reach No. 3 is probably the least affected during a drought by junior well depletion because the majority of the ditches have numerous wells to provide supplemental water to compensate for both effects and, since it is in the upper reach of the South Platte River, well stream depletions are less. There are, however, two ditches, the Evans No. 2 and Fulton Ditches, with senior water rights which do not have wells throughout their systems that would be affected by low streamflows and could demand that upstream wells be curtailed when their more senior rights are injured. Fortunately, these ditches are located in the upper end of the study reach and maximum depletions by junior wells are calculated by this office to be approximately 13 cfs at the Evans No. 2 Ditch headgate. GASP and Central are expected to be capable of providing replacement water in this amount which precludes the need for providing supplemental water; however, an additional plan is recommended for each ditch in order to provide more water to these ditches.

The proposed plan for Evans No. 2 Ditch is based upon an exchange with the calling downstream senior water right which normally would be the Farmers Independent Ditch or the Western Ditch during drought conditions. Both of these ditches are relatively close to the Evans No. 2 Ditch headgate, being respectively

5.75 miles and 7.75 miles downstream. The Evans No. 2 Ditch could pay some of the farmers with wells under the calling ditch to pump their water requirements rather than taking surface water, and the Evans No. 2 Ditch could divert an equivalent amount of surface water at its headgate. The stream depletion from the additional pumping could be minimized by selecting wells as far as possible from the river. The replacement water for the stream depletion could be provided by CBT water owned by irrigators under the Evans No. 2 Ditch.

The proposed plan for the Fulton Ditch would involve an intra-ditch exchange of ground water and surface water. Approximately 5000 acres of the 13,000 acres under the ditch do not have the capability of obtaining supplemental water from existing wells. It is recommended that the shareholders without wells offer to pay a portion of the pumping costs of shareholders with wells and use the surface water normally diverted by the well owners to prevent loss of crops in a drought year. The additional depletions resulting from this plan would have to be calculated and replaced by an existing organization such as GASP or Central, assuming additional replacement water is available. If replacement water is not available, then the plan may not be feasible.

There are ditches in the study reach which normally are called out during periods of low streamflow which have been identified in Appendix III as needing supplemental water; however, those ditches have numerous wells located under them and should be able to obtain a supplemental supply from these wells if they continue operating as part of an approved temporary plan for augmentation or exchange as most of them have done in the past four years.

There are some ditches such as the Brighton Ditch, the Brantner Ditch, the Lupton Bottoms Ditch, and the Side Hill Ditch which do not have wells throughout their systems but these ditches have very senior water rights which have enabled them to divert water in a drought year with minimum impairment to production. Assuming junior well depletions are replaced by temporary plans for augmentation, and it appears that this can be accomplished, these ditches must expect to accept the effects of the drought as they have in the past.

The Burlington Ditch is a large irrigation system with several canals, laterals, and reservoirs utilized to deliver water from the South Platte River to an estimated 83,553 acres of irrigated land. The majority of this land is provided water from reservoirs such as Barr Lake and from existing wells in Beebe Draw with no direct flow rights of any seniority available from the South Platte River. The ditch does have one lateral, the Brighton Lateral, which receives only direct flow water from the river in the amount of 27.4 cfs with a 4-1-1864 priority during periods of low streamflows. The next junior water right owned is in the amount of 300 cfs with a 12-28-1877 priority. The senior water right is nearly always in priority during the irrigation season and provides a dependable supply; however, the Brighton Lateral irrigates approximately 18,000 acres of land which indicates how seriously this ditch can be impacted by drought. Furthermore, at least 12,000 acres of this land does not have any alluvium below it capable of supporting supplemental wells. This study cannot offer any feasible plan to reduce the impact of drought on this ditch unless a conservation pool of about 50,000 acre-feet could be established in Chatfield Reservoir under the operational control of the State Engineer. This pool could be filled during periods of excess flow and emptied at times of need.

COST ALLOCATION AND IDENTIFICATION OF BENEFICIARIES

The beneficiaries of the drought relief plan proposed by this study are obviously the owners of junior wells that would be permitted to continue to pump during a drought when the need for ground water is the greatest.

The recommended procedure for allocating costs of the program would be to use each organization's annual depletion in the reach divided by the total annual depletion of all plans for augmentation in the reach in order to calculate the percentage of the annual operating cost of the plan to be allocated to each individual organization.

Each temporary plan for augmentation or exchange administered by the Division Engineer has been evaluated by the Engineering Section of this office. A table or listing for each temporary plan for augmentation has been prepared which contains the rate of depletion by month, cumulative rate of depletion for all upstream reaches by month, the annual depletion for each reach, and the cumulative annual depletion for all upstream reaches. An example of this listing for GASP in shown in Table 1. These listings can be used to quickly allocate the costs of each plan recommended for implementation. The 29 reaches indicated on the listing are shown on Figure 2.

It appears that the best procedure would be to start at the upper end of the South Platte River system in reach no. 29 and move downstream to the first plan recommended for implementation, which is the Weldon Valley Ditch exchange with the Fort Morgan Canal located at the upper end of reach no. 17. The cumulative annual depletion for each organization shown on the listing for reach no. 18 would be used to allocate the proportional annual cost of this exchange plan.

The next proposed plan to be implemented is the continuation of the pumping of replacement water to the Sterling No. 1 Ditch located at the upper end of reach no. 9, which is funded by GASP. Any costs attributable to GASP based upon the total annual depletion between reach no. 18 and reach no. 9 have been negated; however, any other organization with wells between reach no. 18 and reach no. 9 should be required to include its annual depletion in this reach in the allocation of operating costs for the next plan to be implemented, which is for the Powell-Blair Ditch located at the upper end of reach no. 6.

The cost of pumping the third well at the South Reservation Ditch to provide replacement water to the Powell-Blair Ditch should be apportioned on the basis of GASP annual depletions in reach nos. 7, 8, and 9 and other organizations' total annual depletions between reach nos. 18 and 6.

The next plan recommended for implementation is the construction and operation of a well field along the upper end of the Harmony No. 1 Ditch which is located at the upper end of reach no. 5. The annual costs of operating this plan would be the primary responsibility of GASP since it is the only organization presently operating in reach no. 6; however, since more water is being provided than is necessary, the Harmony No. 1 Ditch shareholders should be required to pay a proportionate amount of the cost.

The final downstream plan to be implemented is the construction and operation of a well field along the upper end of the Peterson Ditch which is located at the upper end of reach no. 3. The annual costs of operating this plan would be provided by GASP since it is the only organization with members in reach nos. 4 and 5.

In summary, the allocation of costs will be to those junior water right owners who benefit from the program.

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WATER SUPPLY AND WATER QUALITY GOALS IN THE NORTHERN DISTRICT

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Introduction

The Northern Colorado Water Conservancy District (Northern District), with its office in Loveland, Colorado, operates and maintains the water delivery features of the Colorado-Big Thompson Project. The Colorado-Big Thompson Project was built by the U.S. Bureau of Reclamation from 1938-1957 and provides supplemental water to about 720,000 irrigated acres within the boundaries of the Northern District in the South Platte River Basin below Denver.

The Northern District is actively involved in the protection of the water supplies and water quality needed for beneficial uses. This paper discusses two Northern District programs available to assist farmers and irrigation companies in the water management decisions that can assure the adequacy, reliability, and quality of ground water supplies. These programs are the Irrigation Management Service (IMS) program and the Augmentation/Recharge Accounting (ARA) program. With more than 5,000 wells in the South Platte River Basin, ground water supplies are an important water resource to the constituents and economy of the Northern District. A goal of IMS is the protection of ground water quality and a goal of ARA is the maintenance of ground water levels and supplies. The Northern District is well suited to provide these programs throughout the lower South Platte River Basin because of its existing computer resources, regional weather station network, and diverse engineering staff.

The IMS program strives to improve on-farm water and fertility management with the goals of reducing non-point pollution, such as ground water nitrates, and increasing a farmer's net profit. IMS works cooperatively and directly with farmers on practical field demonstrations. The IMS program has been in existence since 1981 and currently works with over 50 different farmers in providing them the soil moisture instruments, crop water use data, and water measurement techniques needed to monitor and improve their irrigation efficiency. IMS has shown that Best Management Practices (BMPs) will be voluntarily used by farmers when educational programs and field studies demonstrate the BMP's applications and benefits.

The ARA program works with farmers and irrigation companies in monitoring and doing the accounting for ground water recharge programs associated with augmentation plans. A goal of ARA is to assist entities to optimize and maximize deliveries to artificial ground water recharge areas so ground water levels and return flows are maintained and enhanced. Managing the timing and location of deliveries to recharge basins has the potential to also protect ground water quality by establishing localized ground water mounds or ridges that can mitigate the effect of pollutants and keep them away from pumping wells.

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These two programs uniquely complement each other in addressing the interrelationship of improving ground water quality and maintaining aquifer water levels in the South Platte River Basin. The IMS program promotes increased water use efficiency as a means to achieve the goal of improved ground water quality. Improvement of water application efficiency can result in less deep percolation or seepage than has historically occurred and that is required to maintain the level of the ground water aquifer. A consequence of the IMS program could be declining aquifer water levels. To minimize declining ground water levels, increased and better managed water deliveries to ground water recharge areas need to be encouraged as the ARA program is doing with irrigation companies. Aquifer water levels must be protected in the South Platte River Basin because the water rights of wells have come to rely on adequate ground water levels for pumping. A sustained aquifer also provides the historic return flows to surface streams that surface water rights have come to rely on and are entitled to under Colorado water law (Hobbs and Raley, 1986).

These two programs have established good working relationships with farmers and irrigation companies because the programs utilize a practical and cooperative approach of direct involvement with these entities. The resulting trust and open-mindedness have led to the voluntary acceptance of new ideas. These programs are succeeding in the implementation of solutions to maintain and improve the quantity and quality of future water supplies without the need for regulations. Mandated programs and regulations promote defensiveness and alienation which prevent the cooperation and joint resolve required to achieve the water quality and water supply goals of the IMS and ARA programs.

IRRIGATION MANAGEMENT SERVICE (IMS) PROGRAM

The Northern District's IMS is an educational program promoting improved irrigation and nutrient management practices. IMS provides farmers with the information needed to monitor their irrigation practices and determine their level of efficiency. The program demonstrates improved irrigation management techniques and tools that can result in greater net profit and less non-point source pollution (Crookston, 1993).

Each summer IMS provides field-by-field irrigation scheduling demonstrations. IMS has experienced steady growth since its inception in 1981. In 1993, the Northern District will assist over 50 different farmers with soil water instruments (tensiometers) in over 110 fields. Additionally in 1993, a maximum of 24 farmers will be assisted in adopting surge irrigation. Using grant funds from the Colorado Department of Health, the Northern District will pay the first annual rental fee for a surge valve for each farmer. The farmers will be assisted in learning to program the surge valve for their fields and in monitoring their application efficiencies. Higher water application efficiencies can be obtained by surging water down the furrows because less water goes to deep percolation and/or runoff.

Beginning in 1993, grant funds are being used to conduct studies on a demonstration farm near Loveland, Colorado. Fertility rate studies on corn and sugar beets will be conducted utilizing both commercial fertilizer and compost. Extensive soil and plant tissue testing for nutrient levels will determine accurate fertility requirements. Side-dressing liquid fertilizer in split applications will be demonstrated as a more efficient nutrient management practice. "Spoon-feeding" nutrients by split applications and/or application through the irrigation water can be cost-effective and help reduce nitrate leaching below the crop root zone.

The plots at the demonstration farm will be irrigated using surged furrow methods, with all water on and off the field being measured so that application efficiencies, deep percolation, and surface runoff can be determined. Soil moisture will be monitored with a neutron probe and tensiometers. Observation wells will be used to observe ground water levels and to sample ground water quality.

Application Efficiency

A key aspect of irrigation management is the monitoring and improvement of irrigation application efficiency. Application efficiency is simply the ratio (%) of water needed to fill the root zone divided by the water applied to the field. Application efficiencies of around 65% are very good for well-managed furrow or border irrigation when there is no reuse of surface runoff or cutback of the inflow rate during irrigation. When using a reuse or tailwater recovery system, cutback methods, or surge methods, efficiencies can be as high as 85% for furrow irrigation (Merriam, 1977). Good application efficiencies for sprinkler systems are around 80%.

A low application efficiency of 20% to 30% for furrow or border flood irrigation means over-irrigation and is an indicator of potential nitrate leaching. An application efficiency of 25% means that 75% of the applied water is going to deep percolation below the root zone and/or surface runoff from the end of the field. Low irrigation efficiencies can be an indicator to a farmer of lower net profits because of yield loss from waterlogging and higher production costs caused by wasted water, higher energy costs for well pumping, leached fertilizer, higher labor, or loss of topsoil.

The amount of water needed to fill the soil profile of the root zone is the net crop water use (ET, evapotranspiration, minus effective rainfall) since the last irrigation, assuming the common scenario of a full soil profile after an irrigation. ET information is derived from a network of 10 IMS weather stations located throughout the Northern District. Each station monitors air temperature, relative humidity, precipitation, wind speed, wind direction, and solar radiation. This data is transmitted daily by cellular phone to the Northern District's headquarters. The collected weather data is then used to compute crop water use (ET) values in inches. The ET information is disseminated to farmers through weekly mailings, newspapers, and phone and satellite data links.

The amount of water applied to a field at an irrigation is measured by instruments such as propeller meters and flumes, determined from flowrate tables of sprinkler nozzles or siphon tubes, or estimated by simple techniques such as floating a stick down a ditch (ie, flowrate in cubic feet per second (c.f.s.) equals surface velocity in feet per second multiplied by 0.8, multiplied by the square feet of ditch cross-sectional area). The inches of water applied is the flowrate in c.f.s. multiplied by the hours of irrigation application time divided by the acres irrigated. The IMS program demonstates water measurement procedures on individual farmers' fields and at the demonstration farm. Many farmers typically know their flowrate based on their share ownership in an irrigation canal company and the delivery rate per share.

Furrow Irrigation

When application efficiency is monitored along with Advance Ratio for furrow irrigation, an indication can be made of the split between deep percolation and surface runoff. Leaching of nitrate into the ground water is directly related to the deep percolation of water below the root zone. The Advance Ratio is the ratio of the Time of Advance (ie, how long for water to reach the lower end of the field) to the Time of Irrigation (ie, how long water is at the lower end of the field for soaking). Figure 1 shows data from field studies on a typical relationship between deep percolation and runoff for different Advance Ratios.

Furrows are the major irrigation method employed by farmers in the Northern District, with typical furrow application efficiencies in the range of 35% to 55%. On reasonably uniform soils and slopes and when designed properly and well-managed, furrow practices can be very efficient, reaching application efficiencies of 65%. Efficiencies can be even higher if a return flow system, cutback system, or surge system is utilized. High application efficiencies with minimum deep percolation are accomplished by using a small Advance Ratio (ie, 1 to 4) and turning water off when the soil profile is full (ie, ET replaced). However, for furrow irrigation to be uniform and to adequately soak and refill the crop root zone at the lower end of the field, some runoff from the field and deep percolation at the top of the field will occur. Two of the more important management aspects for obtaining efficient and uniform furrow irrigation are minimizing advance time by utilizing the largest non-erosive furrow flowrate and irrigating only when the soil moisture has been depleted to an allowable soil water deficit (Merriam, 1977).

Through the ET data provided by the IMS program, by measuring applied water, and by keeping track of advance and irrigation times, a farmer can monitor his irrigation practices and become aware of wasted resources, lost dollars, and the potential of his practices causing pollution. However, even with the best irrigation and fertilizer management, the practical aspect of achieving uniform furrow irrigations, or the occurrence of large rainstorms, can cause the highly mobile nitrates to leach below the root zone and potentially reach the ground water aquifer. Depending on crop variety and salt tolerance, some leaching may also be required to prevent the buildup of salts in the root zone from salts in the irrigation water and from soil weathering (Ayers and Westcot FAO, 1976).

AUGMENTATION/RECHARGE ACCOUNTING (ARA) PROGRAM

The Northern District, through its Augmentation/Recharge Accounting (ARA) program, provides the accounting and ground water modeling that is required by Water Court decreed augmentation plans. The ARA program assembles the data, does the accounting/modeling, and files the monthly reports with the Division Engineer. In addition, the ARA program helps manage the timing and location for recharge so that maximum ground water return flows or accretions to the river are obtained.

Augmentation plans allow wells to be pumped out-of-priority. A major component of augmentation plans used in the South Platte River Basin is artificial recharge through surface basins. Recharge replaces the net ground water extraction by wells and results in accretions to the South Platte River which cancel out the depletions to the river caused by the well pumping. Ground water pumping by wells intercepts and reduces return flows, causing a depletion of stream flows. These depletions can injure senior surface water rights. Augmentation plans are designed to negate such injury.

The South Platte River is a gaining stream because of return flows from the ground water "reservoir" or aquifer--an aquifer that exists mainly due to deep percolation of applied irrigation water (Warner et al CSU, 1986). Senior surface water rights rely on these return flows. Junior ground water rights of wells must not deplete the historic return flow condition. By statue, junior ground water rights are to be curtailed or be part of an augmentation plan so that their net ground water extractions are replaced, negating injury to senior water rights.

The Northern District has provided this accounting service to decreed augmentation plans within the Northern District boundaries since 1985. Currently, the accounting is done for a total of 15 plans including major augmentation/recharge plans in the South Platte River Basin below Denver. Seven of these plans are associated with seven different irrigation companies while the other eight plans are for individual farmers. The two largest recharge projects were developed by the Fort Morgan Reservoir and Irrigation Company and the Bijou Irrigation Company. These irrigation companies developed their recharge programs to replace the depletions caused by their shareholders' irrigation wells. The Fort Morgan Reservoir and Irrigation Company's plan has 92 wells and the Bijou Irrigation Company's plan has 212 wells that are protected by their respective augmentation decrees. Since irrigation companies have river diversion headgates and canal delivery systems in existence, it is very practical and economical for such companies to also divert water to recharge sites.

<u>ARA Procedure</u>

Once each month, the ARA program assembles and processes data collected by the augmentation plan operators and the Water Commissioner of the State Engineer's Office. Diversion flows to recharge sites are compiled by the Water Commissioner from recording measurement flumes and are reported as an average flowrate per day. Recharge sites are all surface basins or depressions such as canals, ponds, creeks, and/or draws. Seepage from irrigation canals can only be claimed as recharge when there are no deliveries being made for irrigation. The diversions for recharge from the South Platte River have junior priorities (ie, 1970 or later) and are in priority mainly during spring runoff when there is plenty of water or during winter months when there is no irrigation demand.

The net monthly recharge is the diversion to a recharge site minus evaporation and changes in storage in the recharge basin. Evaporation is computed from the water surface area of the site, days of inflow or evaporation during the month, and a monthly reference pan evaporation. Pan evaporation is computed from weather data (Doorenbos and Pruitt FAO, 1977) derived from the same network of 10 weather stations that the Northern District utilizes for the IMS program.

The net ground water extraction by the wells is assumed by the decrees to be that part of the crop consumptive water use (ET) supplied by the wells. It is computed as the total crop water use minus the portion supplied by surface water deliveries from a canal company. Total crop water use is computed from data obtained from the weather station network. Crop acreage, crop type, irrigation method (sprinkler or flood), and monthly surface water deliveries are reported to the ARA program and the accounting is done for each individual well. To obtain the portion of crop water use supplied by the surface water deliveries, surface deliveries are multiplied by an assumed application efficiency which is specified in the decree. As an alternative approach, some augmentation plan decrees allow the use of well flowmeters to get monthly volume pumped which is multiplied by the assumed application efficiency to get net ground water extraction.

The computed net recharge and net ground water extraction in acre-feet are used in ground water flow models to determine the accretion or depletion effect at the river. The goal of augmentation plans is for the net effect at the river to be positive meaning there are more accretions than depletions. The ground water model specified by most decrees is the Stream Depletion Factor (SDF) method (Jenkins, 1968). Each well and recharge site is assigned an SDF value which characterizes the time lag between recharge or pumping and the respective resulting accretion or depletion effect at the river. The SDF value in days is computed from the perpendicular distance to the river from the well or recharge site and from the aquifer properties of specific yield and transmissivity. From the mathematical formulation, the SDF value is defined as the time when the volume of stream depletion is equal to 28 percent of the volume pumped. The SDF value for a recharge site or well can be obtained directly from contour maps of SDF values for the South Platte River Basin developed and calibrated by the U.S. Geological Survey (Hurr and Schneider, 1972). Recharge sites or wells that are 1 mile from the South Platte River typically have SDF values of around 100 days or less compared to recharge sites or wells on the fringe of the alluvial aquifer 6 miles from the river which have SDF values of around 5000 days.

Recharge projects have continued to expand because good recharge sites with adequate permeability and depth to water table are plentiful. Net recharge has increased from less than an estimated 5,000 acre-feet in 1978 to 46,700 acre-feet as an average annual value for the 1985 to 1992 period for the 15 recharge projects involved with the ARA program. For the 1985 to 1992 period, the average annual net recharge of the Ft. Morgan Reservoir and Irrigation Company project was 9,300 acre-feet, while the net recharge of the Bijou Irrigation Company project was 16,800 acre-feet.

Figure 2 illustrates the average annual net recharge from the period of 1985 to 1992 for different recharge projects in the lower South Platte River Basin as a function of the project's recharge capacity expressed as total average annual acre-days. Acre-days of a recharge site is the maximum surface area in acres multiplied by the days of inflow to the site. Total acre-days is the sum of acre-days for all recharge sites of a given project.

Recharge Management

An important recharge management decision is the timing of deliveries to the various recharge sites. The April through October diversion period for senior surface water rights is when well depletions to the surface stream must be replaced. The ARA program utilizes ground water models to develop operational strategies for recharging that maximize the river accretions during this critical period.

These operational strategies consider the recharge sites' SDF factors and what range or combination of values is available. Recharge at sites with low SDF values (100 to 300 days) results in most of the return flows at the river occurring mainly in the 2 to 3 months following the diversion to the recharge site. Recharge sites with large SDF values provide small but constant return flow rates or accretions to the river--diversion to these sites are developing a "long term bank account" that will provide return flows many years into the future.

If there is a limited water supply for diversion to recharge sites during the spring runoff months of April, May, and June, then it is best to put the supply in recharge sites close to the river with low SDF values so that river accretions are available in that same year. Diversions for recharge from a plentiful spring runoff or winter time river flows should be spread among sites with medium to large SDF values. By such "ground water reservoir banking", wells can continue pumping in future years of drought even though the surface water supplies of those drought years will limit the amount of recharging that can be accomplished in those years.

By increased operations and improved management, the larger recharge projects have become so extensive that there are now excess return flows or accretion credits at the river for others to purchase. The Ground Water Appropriators of the South Platte (GASP) and the Central Colorado Water Conservancy District are two water user organizations that purchase these excess accretion credits as one of their sources of water to augment the stream for mitigation of the depletions of their member wells.

An increasing role for the ARA program is educating entities that artificial recharge of the ground water aquifer is essential for the long-term maintenance of adequate and reliable ground water supplies. Managing recharge not only produces desired river returns but also maintains and enhances aquifer water levels and supplies. The ground water aquifer or reservoir will be the major water supply for future years of severe drought. The ARA program is increasing the awareness among ground water recharge projects that their efforts are also needed to compensate for the reduction in deep percolation that can result as ground water quality concerns promote improvements in irrigation application efficiencies. As previously stated, the ground water in the lower South Platte River Basin of Colorado exists because of the deep percolation and seepage from irrigated agriculture. Artificial recharge is a practical and cost-effective way to compensate for the reduction in deep percolation or irrigation recharge, thereby maintaining ground water levels and supplies.

Recharge and Water Quality

The ARA program of the Northern District is beginning to encourage irrigation companies to consider recharge management objectives that would benefit surrounding municipalities. The ground water mounding that occurs under recharge sites can control local gradients for ground water flow thereby influencing the movement of compounds such as nitrates. These mounds or ridges could provide a higher quality ground water for municipal wellfields and be used to create hydraulic barriers which would keep pollutants away from the wellfields. In addition, recharge systems can utilize constructed wetlands technology to remove biodegradeable material (BOD), nitrates, and suspended solids that may be in the water used as recharge, thereby assuring that the cleanest water possible infiltrates into the aquifer near municipal wellfields (Groves, 1993).

Ground water mounding to control salt movement is used extensively in Southern California where artificial recharge projects establish ground water mounds, ridges, or barriers to prevent salt water intrusion from the Pacific Ocean that could pollute local ground water supplies. Thirty-nine percent or more than 250,000 acre-feet of the water supply of Los Angeles County comes from ground water pumping. A Replenishment District was established in 1960 with its main management principles being: (1) the balancing of long-term recharge against withdrawls for municipal use; and (2) the recharge and injection to form a hydraulic sea water intrusion barrier. The water supplies in Los Angeles County used for recharge are local runoff, imported sources, and reclaimed water (Welch, 1988).

Managing artificial recharge to protect or enhance water quality is a method that water quality agencies in Colorado should promote. The Water Quality Control Commisssion (WQCC) is currently considering the adoption of regulations assigning regulatory boundaries around municipal wellfields of the four cities of Brighton, Ft. Lupton, Ft. Morgan, and Sterling along the South Platte River. Domestic use classifications and standards would apply within the designated boundaries. For such regulations to achieve their objectives, they must implement solutions that address the underlying water quality concerns. Classification boundaries without a program that implements solutions to the water quality concerns create a vacuum that invites and justifies the labeling of all activities inside the boundary as a potential pollutant problem and results in the imposition of generic state and federal regulations for control and cleanup.

These four cities do not want to unnecessarily regulate the surrounding agricultural activities--activities that are the cities' major economic base. These cities want to work jointly with irrigated agriculture to minimize the negative impacts irrigated agriculture may have on ground water quality but would like to assure the continuing maintenance of ground water levels resulting from the deep percolation of applied irrigation water. Agricultural practices can impact ground water, but such impacts may be unavoidable, including such impacts as deep percolation and leaching of nitrates that could occur even with well-managed, 65% efficient furrow irrigation, or nitrates that leach into the ground water because of large rainstorms even with the best fertilizer management. Municipalities may wish to rely on additional treatment methods or alternative water supply sources rather than threatening the agricultural economy by imposition of ineffective regulatory measures. Generic regulations that do not recognize agriculture's unavoidable impacts nor its positive impacts of maintaining ground water levels will do more harm than good to the agricultural economy and to the ground water resources.

Rather than being viewed as simply regulators, these four cities want to be cooperators on solutions that address all concerns associated with the ground water resources which they utilize. Working with irrigation companies to manage artificial ground water recharge for the improvement and protection of municipal wellfields is a practical, simple, and cost-effective solution that the cities are ready to implement. Grant funding from the WQCC for artificial recharge projects would be a great encouragement for the implementation of such programs and would be viewed as a positive, solution-oriented step by the municipal and agricultural communities. Grant money could be used for monitoring ground water levels and water quality associated with recharge activities and to defray the increased canal maintenance costs associated with using the canals for a longer time period to accommodate recharge activities. The two main goals of such projects would be: (1) maintenance of historic ground water levels--ground water levels that could drop because of decreases in deep percolation due to improvements in water application efficiency; and (2) protection of ground water quality by site specific recharge and the establishment of hydraulic mounds or barriers to prevent the flow of pollutants to wellfields.

Northern District staff along with the staff of the Central Colorado Water Conservancy District (Central District) are promoting the implementation of such a program. These agencies are working on site specific ground water modeling with these four cities to understand the ground water hydraulics of the cities' wellfields and the potential for wellfield quality protection. When ground water quality is 10 mg/l N-nitrate or higher and the surface water quality available for diversion into recharge sites is 2 to 5 mg/l N-nitrate, then the potential exists for improving ground water quality through artificial recharge projects.

A site specific example of artificial recharge causing ground water mounding and ground water quality improvement has been implemented by the Central District. In March and April of 1993, 2,200 acre-feet of net recharge was infiltrated into the ground water aquifer at a 14 acre recharge basin located on Kiowa Creek near Ft. Morgan, Colorado. This recharge resulted in up to a 10 foot rise in ground water levels under the basin and a reduction in average ground water nitrate concentrations from 16 mg/l N-nitrate to 8 mg/l N-nitrate. The water diverted from the South Platte River to this recharge basin had a concentration of 4.5 mg/l N-nitrate (Leaf, 1993).

ARA program staff is encouraging communications between the irrigation companies and the municipalities. When it comes to ground water issues, the concerns of these entities are so interrelated that only constant communications and the resulting cooperation will lead to resolutions. Farmers are realizing that protecting the ground water quality of a municipality or domestic user is in the farmer's best interest. Voluntarily utilizing new irrigation and fertility practices or cooperating on the utilization of their canal systems for artificial recharge is a workable solution when compared to the imposition of generic and unrealistic regulations.

Conclusion

The IMS and ARA programs of the Northern District have different but complimentary goals. A goal of IMS is improvement of ground water quality while a goal of ARA is the maintenance of ground water supplies and ground water return flows to the river. The IMS program strives to increase irrigation application efficiencies and improve fertilization practices. As a result, ground water quality concerns associated with irrigated agriculture are positively addressed. However, the improvement of irrigation efficiencies can result in reduced deep percolation which, in turn, may cause a lowering of ground water levels. The ARA program positively addresses the maintenance and enhancement of ground water levels by promoting well managed artificial recharge. In addition, ARA encourages municipal and agricultural interests to view artificial recharge as a means for protecting and improving ground water quality.

The four cities of Brighton, Fort Lupton, Fort Morgan, and Sterling and other cities in the South Platte River Basin faced with ground water quality concerns at their municipal wellfields, along with their surrounding agricultural interests, should become more involved with programs like IMS and ARA as an effective way to address ground water quality and quantity issues. Implementation of cooperative programs like IMS and ARA develops the understanding and trust which can lead to long-term solutions for the protection of ground water quality and quantity. Utilizing only regulatory measures to address ground water issues could unnecessarily impact surrounding agricultural activities and likely have a negative impact on the local economy. Regulations tend to promote defensiveness and not cooperation. Regulations do not provide the educational foundation that is required for long-term solutions.

Effective implementation of proactive solutions to ground water quality and ground water level concerns must be through the cooperation of all entities involved including, but not limited to, the municipalities, agricultural interests, the Water Quality Control Commission, irrigation companies, and other water user groups. The Irrigation Management Service (IMS) and Augmentation/Recharge Accounting (ARA) programs of the Northern District can provide the technical basis for developing practical solutions to ground water issues. Effective communications and cooperation, not regulatory measures, will assure the practical solutions are properly implemented and provide the desired results and benefits.

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FIGURE 1

DEEP PERCOLATION versus RUNOFF

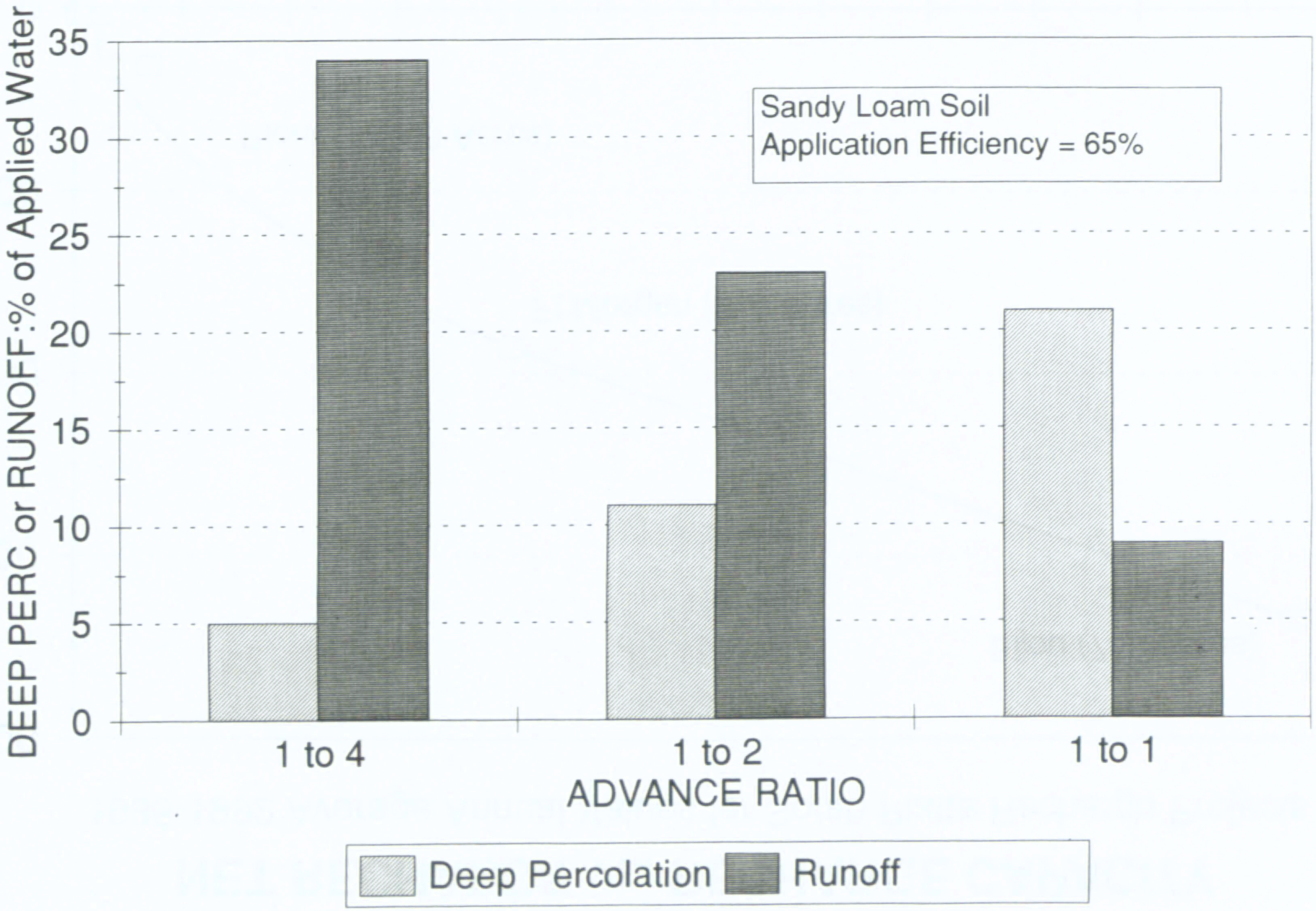
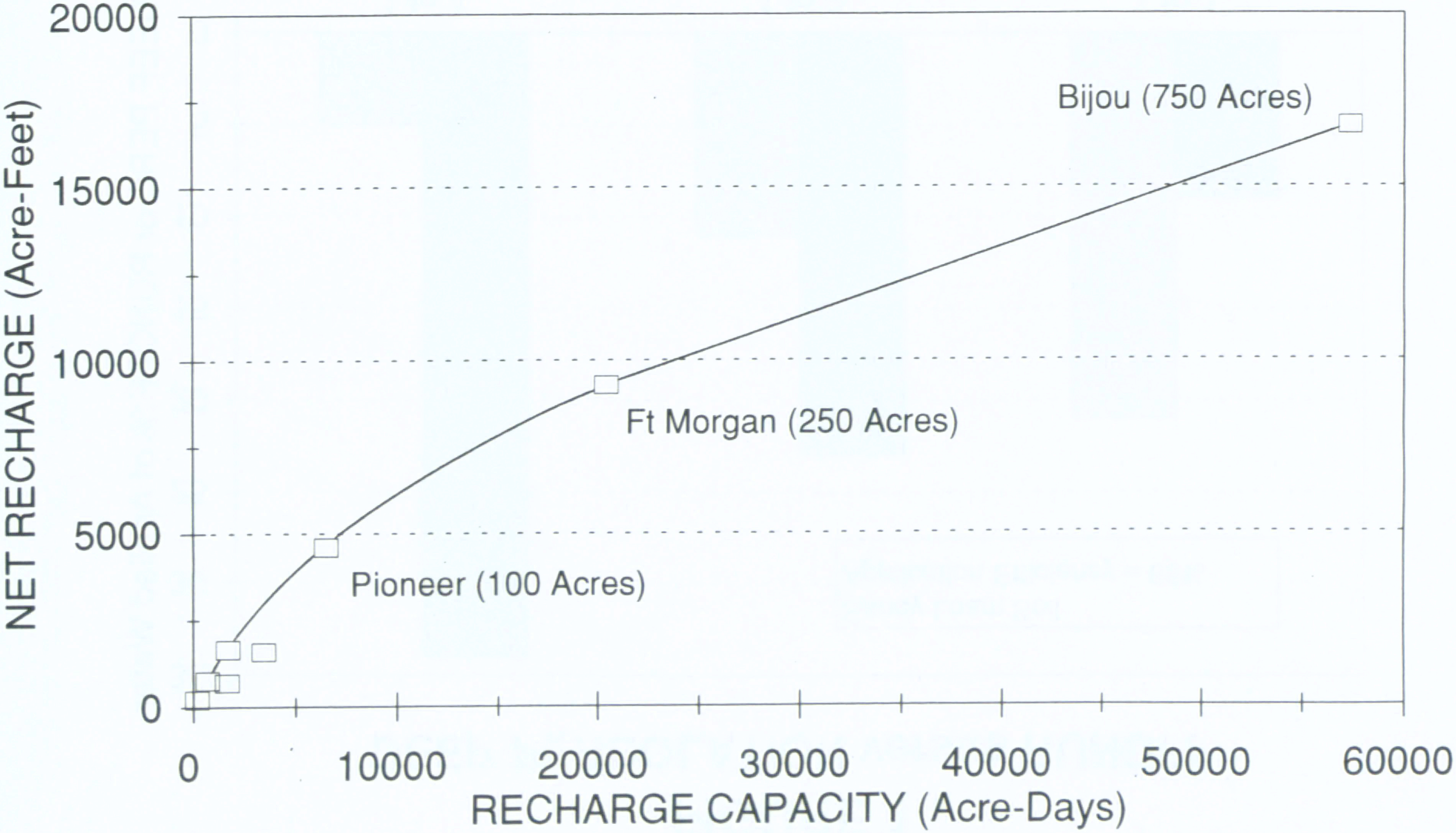


FIGURE 2
NET RECHARGE vs. RECHARGE CAPACITY

1985-1992 Average Annual Values for South Platte Recharge Projects



[Recharge Project Name and Acres of Recharge Sites]