Sheffield (1977) has given detailed costs for center-pivot irrigated cornfields. Extracting costs for the center-pivot system itself, the irrigation pump and gearhead, a diesel engine, other minor fixed costs, taxes and insurance, the annualized cost is $53.29 per acre. To this must be added a fuel cost at $6.06 per acre, and maintenance at $4.05 per acre. There should be a reduction in labor. Sheffield (1977) indicates that irrigation labor for center pivots is about $1.20 per acre (labor charged at $3.50 per hour). If center-pivot replaces a gated pipe system, Eisenhauer and Fischbach (1977) estimate labor charges for gated pipe systems at $4.13 per acre (at $4.00 per hour). Syphon systems, which are popular in the study area, take more labor but at a lower hourly labor cost. It is therefore probable that the labor saving would be about $4.13 minus $1.20, or $2.93 per acre. Thus, the total increased cost for center-pivot irrigation is about $60.47 per acre per year.

The yearly increased cost for a reuse system may be relatively small. Eisenhauer and Fischbach (1977) state that the annual fixed costs for a gated pipe system with a reuse system is $26.98. The increased fixed costs for reuse are only $1.71 per acre per year. Fuel and oil costs were estimated to decrease by $0.78 and $0.15 per acre per year, and maintenance costs were estimated to be increased by $0.15 per acre per year. Labor was assumed to be unchanged. Thus, the net increase in cost for reuse would be $0.93 per acre per year.

The estimated increased annual cost for obtaining a farm irrigation system efficiency of 75 percent is (under the assumption of half the area in center pivots and half the area in surface irrigation with reuse systems) the arithmetic mean of the two figures ($60.47 and $0.93) or $30.70 per acre per year.

Using the foregoing information, the cost of raising the average farm irrigation efficiency in the study reach to 60 percent by irrigation could be as little as $3 or $4 per acre per year--or a total of $375,000 to $500,000 on 125,000 acres. This can only be done, of course, with the full cooperation of the farm operators in adopting and following improved management techniques. The cost of increasing efficiencies on up to an average of 75 percent (one of the efficiency scenarios used in this study) requires more capital investment and operating costs. This could amount to a total annual cost for the study reach of $3.75 to $4.5 million.

Canal Efficiency Improvement Costs

Estimated costs for lining selected canals and ditches are given in Table 9. Ditches or canals having an estimated seepage loss in excess of 25 percent were considered for lining. For each of the 10 canals or ditches, wetted perimeter measurements were made at selected locations along the reach of each system. These data were used to establish an existing wetted area. Cross-sectional width and depth and slope of the various reaches were also established.

In the cost estimate, five different lining processes were considered: (1) bentonite; (2) 12 inches of compacted earth; (3) .010 inch PVC with 12 inches of compacted earth cover; and (5) 3-1/2 inch thick unreinforced concrete. Costs per square foot for each of these treatments (including material and installation costs) were established from experience, interviews with suppliers, cost data supplied by the U. S. Bureau of Reclamation, Denver Federal Center, and construction cost trends. The unit costs for each of the five processes are enumerated in Table 9.

The bentonite lining is the least expensive of the five, but it would be expected to require more annual maintenance and supplemental replenishment. An application rate of 5 pounds/square foot applied by the wash-in method was considered. This method application requires very little preliminary work and a minimum of expense and time to install. With the wash-in method, only a near-surface seal would be achieved and should not be used where velocities are excessive or where considerable bed material transport is anticipated. It is recommended that only three of the ten ditches be considered for this treatment process--Springdale, Bravo, and Peterson.

The compacted earth, the PVC, and the catalytic blown asphalt treatments would require that the cross section be shaped on a 2:1 side slope with a variable base width. A small amount of bentonite could be add-mixed with the compacted earth process in order to insure a more impermeable boundary. The ten mill PVC and the 1/4-inch thick catalytic blown asphalt should be covered with 12 inches of compacted earth.

Table IV-9

Estimated Costs for Lining Selected Canals and Ditches

Ditch or Canal	Length (Miles)	Existing Wetted Area (Sq Ft)	Bentonite	Compacted Earth (12 in. thick)(1)	.010" PVC (12 in. Compacted Cover)	Catalytic Blown Asphalt (¼ in. thick) (12 in. Compacted Cover)	Unreinforced Concrete (3½ in. thick)(2)
			$0.10/ft^2	$ 0.22/ft^2	$ 0.33/ft^2	$ 0.39/ft^2	$ 1.16/ft^2
South Platte	11.3	750,000	--*	$ 148,500	$ 222,750	$ 263,250	$ 652,500
Pawnee	28.0	3,400,000	--*	673,200	1,009,800	1,193,400	2,958,000
Schneider (South only)	3.6	230,000	--*	45,540	68,310	80,730	200,100
Springdale	16.1	1,600,000	160,000	316,800	475,200	561,600	1,392,000
Sterling #1	26.5	2,900,000	--*	574,200	861,300	1,017,900	2,523,000
Bravo	7.4	510,000	51,000	100,980	151,470	179,010	443,700
Iliff and Platte Valley	15.0	1,900,000	--*	376,200	564,300	666,900	1,653,000
Harmony #2	7.9	750,000	--*	148,500	222,750	263,250	652,500
Highline	16.2	1,900,000	--*	376,200	564,300	666,900	1,653,000
Peterson	17.2	1,600,000	160,000	316,800	475,200	561,600	1,392,000

* Wash in bentonite method not recommended.

(1) Wetted area reduced by 10% to account for smoother canal boundary (Mannings' "n" = 0.022).

(2) Wetted area reduced by 25% to account for smoother canal boundary (Mannings' "n" = 0.014).

The 3-1/2 inch thick unreinforced concrete section would be a trapezoidal cross section having side slopes of 1-1/2:1.

The costs enumerated in Table 9 are current estimates and would be expected to change with time. These costs do not reflect the additional work that may be required for hydraulic structures such as turnouts, drop structures, and gates and valves.

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V. COMPUTER MODEL ANALYSIS

General Description of Model

The answers to the many and varied questions which naturally come to mind regarding a system's behavior under different physical or managerial circumstances are very difficult to secure for a complex water use system such as the South Platte basin, particularly if the answers are to be quantitative at the *operational* level. A computer program was written to represent (*simulate*) in great detail the physical and operational characteristics of the prototype system. The resulting developed program (*model*) simulates a reach of the South Platte from a point slightly upstream of the Balzac U.S.G.S. stream gaging station to a point slightly downstream from the Julesburg gate at the Colorado Nebraska state line. The length of the simulated river is approximately 90 miles which, for modeling purposes, is subdivided into a total of 93 sub-reaches. Figure 1 (in the pocket at back of report) displays the grid system superimposed on the study area. The behavior of the aquifer (e.g., water table elevation) can be predicted at more than 1,000 gridpoints, but for purposes of this study water table elevations are calculated only in cells which the river crosses where the information is needed to calculate return flows. These return flows are directly proportional to the difference in mean cell aquifer level and river stage.

Pumping from wells located in the same cell of one square-mile size is assumed to be distributed uniformly over the entire cell. Loosely speaking, the pumping is assumed to be concentrated at a single point at the center of the cell. This point is referred to as a *grid* point. The square with the grid point at its center is sometimes referred to as the square of influence of the grid point.

The computer model specifically developed for the study consists of several components. On a tape are stored the influence coefficients of aquifer drawdowns at one grid point due to pumping at another grid point, for sets of discrete time values (e.g., one week, two weeks, three weeks, etc.). The amount of information gathered on this tape is enormous, since the system consists of 1057 grid points and behavior of the system is simulated at *weekly* intervals for a period of 10 years. However, with various techniques and simplifications it was possible to considerably reduce the amount of information on the tape. The procedure by which the influence coefficients (*discrete kernels*) are generated has been discussed in the literature (Morel-Seytoux and Daly, 1975; Illangasekare and Morel-Seytoux, 1977). (For the interested reader a summary of the mathematical basis for the concept and the generation of the *discrete kernels* is presented in Appendix A.) The discrete kernels on the tape are read in the computer whenever aquifer water-table levels are needed in the calculations.

On a second tape is stored all the known historical information about the system, such as: (1) weekly diversions from the South Platte at each of the 13 major diversions (as estimated by a Bureau of Reclamation study for the period 1947-1961); (2) weekly streamflows at the two gages of Balzac and Julesburg as recorded by the U.S. Geological Survey; (3) weekly effective precipitation; and (4) crop irrigation water requirements.

The main program performs the same sequence of calculations for every week and calls the tapes for information as necessary. Schematically the steps in the calculation are as follows:

1. Given the river inflow into the system the *legal* water availability is determined at each diversion point. This legal water availability is calculated as the upstream river inflow plus the aquifer return flows upstream of the diversion point minus the sum of all diversions of higher seniority, regardless of location. The calculations are performed starting with the diversion of highest seniority down to the one with lowest priority. Note that the *physical* water availability at a diversion point *exceeds* the legal water availability by the downstream diversions of more senior rights.

2. Given the just calculated legal and physical water availabilities, a decision is made as to the actual amount of water to be diverted for the week from each diversion point. The decision is reached from an *a priori* specified set of rules. This set of rules constitutes a *water allocation* strategy. For example, a *purely historical* water allocation strategy consists of reaching precisely the decision that was made by the river commissioner historically on that date. A *purely legal*

strategy consists of diverting exactly the full water right (no more, no less of the irrigation ditch company if legally available at the diversion point.

3. Given the diversion amount decided upon by the *water allocation strategy*, availability on the farm served by the ditch is calculated. It is the diversion amount reduced by canal seepage losses. This water availability (expressed by then as a depth) on the farm is compared to the irrigation water requirement (also expressed as a depth) which is determined from the effective precipitation, crop evapotranspiration and farm irrigation efficiency.

If the calculated irrigation water requirement exceeds the surface water availability on the farm, pumping from the aquifer to supplement the surface water supply is considered. Again a predetermined set of rules is used to calculate the amount of pumping. For example, under a *purely historical* strategy the known historical volume would be pumped from the ground whether or not in fact it was needed by the crops. Under a *purely unconstrained* strategy, pumping would be limited only by the pumping capacity up to irrigation requirement.

4. Given the just determined seepage losses, pumping volumes and irrigation applications on the land, aquifer recharge rates and net withdrawal rates from the aquifer are calculated for every cell of the model.

5. Given the just calculated net withdrawal rates from the aquifer in every cell, water table elevations in every reach cell (i.e., a cell crossed by the river) are calculated. Given the river flows in every reach cell, namely upstream inflow into the reach plus return flow into the reach less diversion (if any) in that reach, river stages (elevations) are calculated from a stage-discharge curve. Based on the difference in elevation between the water table and the stream surface, return flows in each river cell are calculated. These return flows are used for the sequence of calculations to be performed for the following week.

6. Various outputs of interest are saved on tape or printed out for later analysis. For example, predicted stream outflow from the system and percentage degree of satisfaction of irrigation water requirement for the various irrigated areas are calculated. The cycle of calculation is repeated for the next week until the complete selected time horizon has been covered. By changing system efficiency (canal losses, farm

irrigation efficiencies, etc.) and water allocation strategies, one can evaluate the influence of such changes on streamflow, satisfaction of irrigation water requirements, etc.

Description of Model Runs

Runs of the mathematical model of the Lower South Platte river reach described above were made in several series. The first series used historical data in order to calibrate the model with the hydrologic situation which existed in the 1952 through 1961 period as closely as possible. Series II through V runs were designed to evaluate the sensitivity of the river reach efficiency to efficiency improvements in various components of the irrigation systems. The following sections describe the runs in more detail.

Series I run--historical data

The purpose of the Series I run was to duplicate the historical return flow situation in the study area as closely as possible for the study period of 1952 through 1961. It was particularly of interest to duplicate the situation during times of inadequate water supply to meet the irrigation needs, such as the 1954 through 1956 drought period.

The actual measured weekly volume of streamflow at Balzac was used in all Series I runs as well as the later series runs. The volumes of water diverted by ditches and estimates of ground water pumped under each ditch system by months during the study period were obtained from the USBR Farm Water Utilization Study (1965). The estimates of canal seepage losses and reservoir losses described earlier as developed by Dr. Skinner were used, as were the estimates of deep percolation from on-farm irrigation activities developed by Dr. Danielson and Dr. Hart. Weekly estimates of irrigation requirements by crops during the study period were used as discussed earlier.

The principal calculation of interest in the Series I runs was the estimated weekly flow at Julesburg. The estimated or calculated values were compared with actual measured values in the 1947 through 1961 study period. Minor adjustments were made and a final Series I run was conducted which was used as the comparison run for the later series.

Series II run--varying canal losses

The purpose of the Series II run was to evaluate the sensitivity of water use efficiency in the reach to changes in canal seepage losses. The input data used for the Series II run was the same as the final Series I run with the exception of changes assumed in canal losses with corresponding adjustments in ditch diversion explained below.

In this run, canal seepage was assumed to be zero in selected canals: The North Sterling Outlet Canal, the South Platte Ditch, the Sterling No. 1 Ditch, the Harmony No. 1 Ditch and the Highline Canal. These are principally canal systems with relatively senior rights and large diversion. In the Series II run, diversions by these canals were reduced so that the deliveries to the farm headgates remained the same as in the Series I runs. Water saved by such diversions was made available to any downstream canals (according to priority) which were then receiving less than the irrigation water requirement delivery at the farm headgates adjusted for on-farm efficiencies.

Series III run--varying on-farm efficiencies

The purpose of the Series III run was to evaluate the sensitivity of irrigation water use efficiency in the reach to changes in on-farm efficiencies. The input data for Series III run were the same as for the final Series I run with the exception of changes in on-farm efficiencies with corresponding adjustments in ditch diversions.

In this run it was assumed that all on-farm efficiencies which historically were estimated to be lower than 75 percent were raised to the 75 percent level. Ditch diversions were adjusted so that the crop received the same soil-moisture situation as in the Series I or historical run. Any reduction in diversions resulting from this assumption was allocated to downstream canals in accordance with the priority if said canals were receiving less than the estimated irrigation water requirement for that time period adjusted for on-farm efficiencies. As was done in the Series II runs also, the historical pumping was assumed to have taken place. The unfilled irrigation requirement adjusted for on-farm efficiency was used to determine the amount of canal water required to be delivered at the farm headgate.

Series IV run--varying groundwater pumping

The purpose of the Series IV run was to evaluate the sensitivity of irrigation water use efficiency in the reach to changes in use of groundwater. The input data for the Series IV run was the same as the final Series I run with the exception of the amount of groundwater pumped. In the Series IV run, it was assumed that sufficient groundwater was pumped under each canal system to meet the irrigation water requirements not satisfied by historical diversions. Under this assumption the groundwater reservoir was being used as a supplemental supply, pulled upon heaviest during drought years and replaced during years of good surface water supplies.

Series V run--combinations of Series II, III and IV runs

The purpose of the Series V run was to evaluate the change in irrigation water use efficiency in the reach attributable to the combination of improvements in canal seepage, on-farm efficiency and groundwater pumping as assumed in the Series II, III and IV runs.

Summary of Results

As described in Chapter III, five model runs were made. In the first run (Series I or *Reference* run) the system was the historical system as it existed during 1952 through 1961. The diverted and pumped volumes are the historical ones. The calculated outflow at Julesburg was compared with the measured historical flow of the Julesburg gaging station for model calibration. A full discussion of the calibration process is presented in Appendix B.

In the second run (Series II or Lined Canals Run) some of the canals were lined with the result that along these canals seepage losses were zero. The canals that were assumed lined are: North Sterling Outlet Canal, South Platte Ditch, Sterling No. 1 Ditch, Harmony No. 1 Ditch and Highline Canal. The results are also shown for comparison on Figures 2, 3 and 4. The water allocation strategy in this case consisted of allowing for the diversion of the minimum of the four quantities: water need, water right, legal water availability and historical diversion. Pumping is limited to its historical (1952-61) value.

In the third run (Series III or 75% Farm Irrigation Efficiency Run) it is assumed that, by whatever means, the farm efficiency has been uniformly improved over the entire system from a historical value of 40-50% depending on areas to a value of 75%. The water allocation strategy for diverted surface water and for pumped aquifer water is the same as for Series II.

In the fourth run (Series IV or Increased Groundwater Pumping) the system is the historical system (no lining, no improved farm efficiency, etc.) but the water allocation strategy for pumped water is more liberal. The surface water allocation strategy is the same as in Series II and III. However, pumping is allowed in excess of historical value but not to exceed the pumping capacity (as estimated from well records in 1975) and just enough to meet the crop water need not satisfied by the available surface water at the farm. Results are graphically displayed on Figures 2, 3 and 4.

In the fifth run (Series V or Combination Run) the same canals that were lined in Series II are lined, the farm efficiency has improved to the value of 75% as in Series II, and the water allocation strategy for surface and groundwaters is the same as in Series IV. Results are shown on Figures 2, 3 and 4.

Interpretation of Results

Merit of Series II Strategy (Lining of Canals)

The impact of this management strategy on the outflows is negligible for the entire duration of the simulation period (1952-1961). It cannot be seen graphically on Figure 2. The reduction in outflow was at most of the order of 5 cfs. The conclusion to be drawn is that lining of the canals (as assumed in this run) would not result in significantly more water being consumptively used in the study reach. Although the lining may improve the delivery efficiency of each system where it is applied, it does not make more water available for the reach - there is merely a relocation of water use and groundwater recharge.

It is possible that the lining as assumed (of major senior-priority canal systems) would have some beneficial effect upstream from the study reach. This would occur at times one or more of the senior-priority canals would otherwise be causing a call to be placed against upstream junior priorities if it were not for the water saved by the canal lining.

Lining of the canals as assumed improved the satisfaction of irrigation water requirements by, at most, an absolute 10%[1/] (see Figure 3). Naturally during the periods of particularly severe shortage (e.g., 9-12th week of 1952 irrigation season or 4-7th week of 1954 season) lining of canals does not provide much absolute relief to the acute water shortage. For instance, the water saved by lining the Sterling No. 1 canals is used entirely by this senior water right and no relief is felt at all by the junior downstream Settlers Ditch area (Figure 4).

Merit of Series III Strategy (75% Farm Irrigation Efficiency)

This management strategy reduces the downstream outflows noticeably late in the irrigation season (see Figure 2, 1955 and 1970 irrigation season) and also after the irrigation season. As opposed to the Series II (lining of canals) result, there is now a clear reduction in system outflow. This is evident, e.g., in the pattern of outflow following the 1953 or the 1960 irrigation season. It is noteworthy that the relative position of the Series I line (Reference Run) and of the Series III line does not change much from year to year and that the magnitude of the effect is about the same in 1960 as it was in 1953. One is tempted to say that a new stream-aquifer equilibrium position has been found as a result of the new strategy and that the new equilibrium is reached within a couple of years. Essentially, then, the reduction in system outflow is equal to the increased consumptive use of water on the farms.

The improvement in irrigation water requirement satisfaction is clear on Figures 3 and 4, e.g., for the 1953 irrigation season. However, when water is really scarce, e.g., as for weeks 9-12 in 1952 or 4-7 in 1954, the strategy does not help much. Little water used efficiently is still little water. Surprisingly, in late 1955 and 1956, after a net improvement in satisfaction of irrigation need early in the season, worse results are

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[1/] For instance, if the historical percentage of satisfaction were 60% for a particular time period the canal lining as assumed improved it to no more than 70%.

obtained as compared to Series I and II. This effect occurred only in 1955 and 1956. It may be due to a significant reduction in streamflow, thus water availability for diversion, caused by the very low aquifer recharge occurring early in the season. Generally a clear improvement is realized, but not when it is needed most. Improved farm efficiency is not, therefore, an effective remedy under a severe surface water drought condition as experienced in 1952, 1954, 1955 and 1957.

Merit of Series IV Strategy (Increased Groundwater Pumping)

Under this strategy the system outflow is further reduced because much more water is available on the farm *even* when surface water supply is very scarce. Irrigation water requirements are more fully met, resulting in a decrease of system outflow. Note that the steady application, starting in 1952, of this pumping strategy leads promptly to a new equilibrium between the stream and the aquifer, apparently in a couple of years. The relative pattern of the outflows is very much the same in 1960 as it was in 1953. In other words, the strategy does not result in a continued mining of the aquifer but rather in a new equilibrium. To save computer costs, at some point in the duration of the study it was considered to make runs only for a few years. Now with hindsight it is fortunate that a 10-year horizon was chosen because the fears of a continuous decline in aquifer storage with time as a result of increased ground water pumping appear unfounded. This is a very significant result with important management implications.

With this strategy, satisfaction of irrigation water requirement is drastically improved as compared to the previous strategies (see Figures 3 and 4) even during periods of severe surface water drought (e.g., weeks 4-7 of 1954 season, 5-7 of 1955 season, etc.). Lining of canals and increased farm efficiency are only relative remedies. With these strategies the extra amount of available water is proportional to the amount available. If it is small, the water saving is also small. A strategy of increased pumping making better use of the ground water reservoir is an absolute remedy. Except for pump capacity limitations, water is made available as needed.

Merit of Series V Strategy (Combination Run)

Under this combination strategy downstream flows are further reduced and irrigation satisfaction is increased. With this strategy 100% irrigation satisfaction is achieved practically every year for the irrigation season. Notice that the same result could have been achieved with increased pumping capacity alone. Where pumping capacity is limiting (see weeks 5-7 of 1955 season) improved (75%) farm efficiency brings the system to perfect performance. With more pumped water available the same result could be achieved.

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VI. SUMMARY AND CONCLUSIONS

1. Irrigation water use efficiency can be viewed from a number of different standpoints. The individual farmer is primarily concerned about how efficiently he can use water on his farm. Officials of canal and reservoir companies are principally concerned about delivering a high percentage of the amount of water diverted from the river to the farm turnouts. On a larger scale, the efficiency of water use within a river reach or river basin is important. This study was directed at evaluating the effects of improved farm and canal system efficiencies upon river reach water use efficiency.

2. Existing farm irrigation efficiencies in the study area were evaluated by the study team using technical guidelines of the Soil Conservation Service together with opinions of professionals experienced in the area. The estimated farm irrigation efficiency ranges from 31 percent to 50 percent with an average of 41 percent.

3. Estimates of existing canal and reservoir system efficiencies were obtained from canal and reservoir company personnel and other individuals knowledgeable in the study area. The delivery efficiencies of the systems vary considerably, but most are in the 60-80 percent range. One system delivers less than 30 percent of the water it diverts from the river, but most of the losses from the system are recovered by downstream ditches and wells.

4. Costs of improving farm and canal system efficiencies were estimated. The cost of raising the average farm irrigation water use efficiency from 41 percent to 62 percent by improved water management (scheduling) may be only a few dollars per acre per year. The cost of further increasing the average farm efficiency to 75 percent would be on the order of $30 per acre per year because significant capital investments and operation costs would be required.

5. The computer model analysis in which major senior-priority ditches were assumed to be lined showed little gain in the overall efficiency of water use in the study reach (lower 90 miles of the South Platte River in Colorado). Although the satisfaction of irrigation need on individual ditch systems that were lined was improved, no additional water was made available to other appropriators.

6. The computer model analysis in which the average farm irrigation efficiency in the study reach was raised to 75% resulted in slightly improved river reach efficiency. However, during times of water shortage the reach efficiency was improved very little. Obviously, the improvement of farm irrigation efficiency can help an individual farmer use limited water, but a large-scale program of farm irrigation efficiency improvement would not make significantly more water available to a reach or river basin at those times of the season or in dry years when additional water is most needed.

7. The computer model analysis in which additional groundwater pumping was allowed to supplement surface water supplies showed the greatest increase in overall water use efficiency in the river reach of any of the changes from historic conditions that were tested. The improvement is due principally to the fact that water can be made available when and where it is needed through conjunctive use of the groundwater reservoir. In effect, water is saved for additional beneficial uses in the reach. Improvements in ditch conveyance and farm irrigation efficiencies do not accomplish the same result. An important finding from this analysis is that under increased pumping a new equilibrium was rapidly (2 years) established in groundwater level and return flow. This means that increased pumping on a sustained basis is possible.

VII. FUTURE STUDIES

The improvement in efficiency of water use in a river basin or reach has many physical, legal, economic, social and institutional ramifications. The study reported herein only addresses a portion of the physical aspects and should be considered only the beginning of studies necessary for a basis of making major water management decisions. Brief descriptions of further studies needed follow:

1. Optimal use of the groundwater reservoir in conjunction with surface water supplies to meet specific goals should be determined. The study reported herein shows the potential for increasing overall water use efficiency in the study reach, but does not necessarily assume the most optimum combination of conjunctive uses for various water availability situations.

2. Model studies should be extended to upstream reaches of the South Platte River in order to evaluate the total effect of water use efficiency and management changes in the basin. The influence of such changes can reach upstream because of changes in calls by senior appropriators.

3. The potential of increased control of surface water flows by on-stream storage reservoirs in conjunction with planned groundwater storage and use should be explored. Such studies could evaluate proposed reservoirs, such as Narrows, for capturing flood flows and releasing same for planned groundwater storage. Substitution of groundwater storage for surface storage could also be evaluated.

4. The increased consumptive use of water and increased water use efficiency in a reach or river basin can also have negative aspects, such as the increase in salinity that may result. Also, consideration should be given to interstate compact obligations.

5. Many legal and institutional problems need to be solved in implementing a conjunctive use plan. For instance, flexibility in water withdrawals from surface and groundwater sources (still in harmony with water right ownership) will be necessary to implement improvements in utilization of the annual combined supply which are found to be possible by this model study. This model did not differentiate areas served only by surface sources. To accomplish the satisfaction of

irrigation water requirement calculated in the model, transfers of water under each ditch system would be required such that at times all or most of the surface water would supply lands where wells cannot be obtained. Similarly, during times of surplus surface water those lands overlying the alluvial aquifer should take additional ditch water for purposeful recharge. The techniques and authorities for accomplishing and financing these kinds of transfers need to be worked out, with the roles of the ditch and reservoir companies, the Conservancy District and the Colorado Division of Water Resources defined. Legislative action may be required.