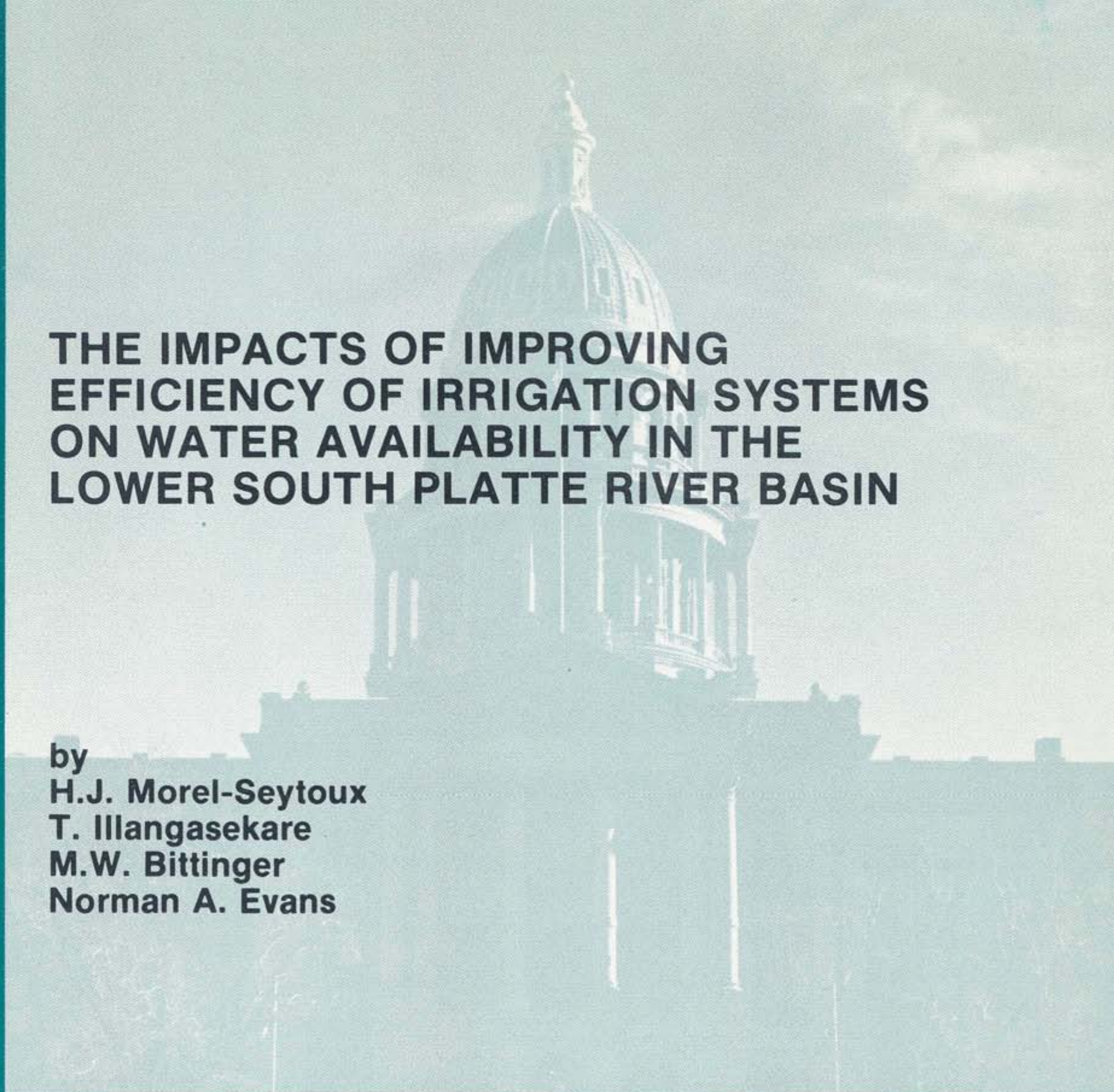

THE IMPACTS OF IMPROVING EFFICIENCY OF IRRIGATION SYSTEMS ON WATER AVAILABILITY IN THE LOWER SOUTH PLATTE RIVER BASIN

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ACKNOWLEDGEMENT

This brief document examines water supply management possibilities for improving the overall water use efficiency of the lower South Platte River basin water supply--surface and ground water. It is made possible by support from the Legislative Council which enabled the Colorado Water Resources Research Institute to test hydrologic impacts of several water management strategies.

A computer model of the surface and ground water hydrology of the lower South Platte basin was used for this analysis. Development of the model was previously accomplished with fiscal support from the Office of the Governor, State of Colorado, made possible by a contract with the U.S. Bureau of Reclamation under the Drought Emergency Act of 1977 (Contract No. 7-07-70-X0009). A full report on model development and the data from tests described here are available from the Institute in Technical Report 13.

The technical basis for the conjunctive surface-ground water model was developed by Dr. H. J. Morel-Seytoux with fiscal support from the Office of Water Research and Technology, U.S. Department of Interior, through a series of four matching grant research projects which are reported in Completion Reports 50(1973), 53(1973), 68(1975) and 82(1977) available from the Institute.

"Anybody who can solve the problems of water will be worthy of two Nobel prizes - one for peace and one for science."

John F. Kennedy

FOREWORD

This is one in a series of publications designed to help meet the challenge of providing information on how the natural water system works and how it can be reconciled to the complex demands placed on water by society today. It was prepared by the Colorado Water Resources Research Institute to assist legislators, policy makers, and water resources planners and managers to better understand specific problems and issues.

The most predictable feature of water policy at the present time is change. Changes are occurring in the demands on water supplies, in the values people place on water resources and also in the institutional and legal foundations of public water administration.

This era of change emphasizes water resources administration and management rather than water resources project development. The focus is upon <u>improving management</u> of existing water supplies rather than on the development of new supplies.

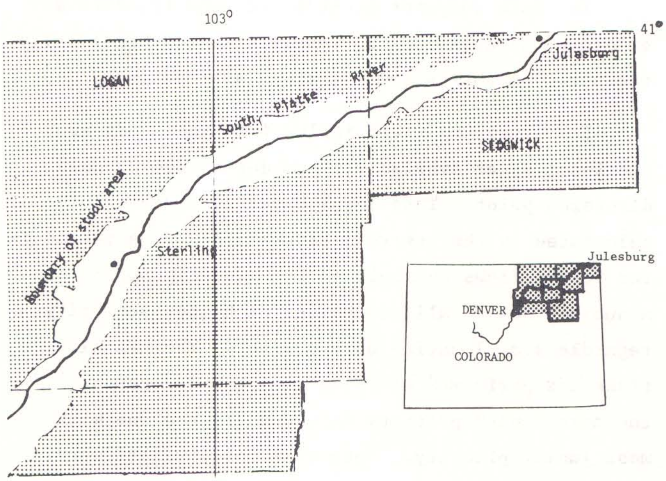
Through these publications and other means, the scientists of Colorado's universities hope to meet the challenge of providing information which will be useful in assessing options and impacts or proposed water policy changes.

Norman A. Evans, Director
Colorado Water Resources Research Institute

THE IMPACTS OF IMPROVING EFFICIENCY OF IRRIGATION SYSTEMS ON WATER AVAILABILITY IN THE LOWER SOUTH PLATTE RIVER BASIN

SUMMARY

The impacts on overall water supply resulting from different water management strategies for conjunctive use of surface and ground waters were studied for a 90-mile section of the South Platte River, roughly between Balzac and Julesburg. A computer simulation study was conducted using data for the 10 years between 1952 and 1961. A drought period in the early '50s is included.



Study Area

The management strategies considered included: 1) lining some of the canals to improve conveyance efficiency; 2) improving water use efficiency on the farm; 3) pumping with relaxed restrictions; and, 4) a combination of all these strategies.

The study indicates that the most effective strategy by far to alleviate the serious consequences of a drought on irrigated agriculture is to fully use the ground water reservoir capacity of the stream-aquifer system. Under increased pumping the stream and the aquifer quickly reach a new equilibrium and after two years there is no indication of a continued mining condition in the aquifer. This strategy is not only very effective in the short term but also quite safe in the long term.

Improving farm irrigation efficiency from its current average 41 percent to 75 percent does not improve substantially the overall water use efficiency in the reach of the river studied. That is, the volume of water annually passing downstream out of Colorado is reduced very little, and the junior priority water rights continue to be short of water, just as now. The degree of irrigation need satisfaction on individual farms served by priority rights is increased.

Lining of canals having seepage losses exceeding 25 percent is likewise of little benefit to the overall water use efficiency in the study reach. No additional water is made available to junior priority right owners nor is water made available for new beneficial uses. However, the irrigation water requirement is more nearly satisfied for irrigators served by the lined canals.

Neither of the two improved efficiency strategies enables the full irrigation water requirement to be met. However, it can be met by allowing increased pumping or by a combination of increased pumping with efficiency improvements. In this case the overall efficiency of water use in the study reach of the river is improved and less water is "lost" downstream out of the state.

INTRODUCTION

The objective of the lower South Platte River Basin study is to assess the benefits that could be realized from improvements in irrigation system efficiencies and changes in management strategies on the overall water use effectiveness of the system, particularly under drought conditions. For example, if irrigation canals were lined in one area of the system, one would like to answer (at least) two questions: Will the water savings from the reduction of canal seepage losses lead to a significant increase in degree of satisfaction of irrigation water requirements? Will canal lining result in a significant decrease in aquifer return flows to the stream?

Other questions should be raised if farmers invest in measures which will increase farm irrigation efficiency. Will the result be a significant amount of "new" water available for other beneficial uses? What effect would be seen in aquifer return flows to the river and in the amount of water flowing out of the state?

If pumping from the aquifer were allowed to increase, would the result be chaos in the priority water rights system? Would less water be lost downstream out of the state?

A COMPUTER MODEL OF THE WATER SYSTEM

The answers to the many and varied questions which naturally come to mind regarding the system's behavior under changed 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. The only feasible approach is to simulate the water system with a model in which various elements can be manipulated.

A computer program was written to represent (simulate) in great detail the physical and operational characteristics of the lower South Platte basin. 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 gauging station to a point slightly downstream from the Julesburg gauge at the Colorado-Nebraska state line. The length of the simulated river is approximately 90 miles.

The model is able to predict behavior of water in the aquifer (flow and water table elevation) at 1057 points on a grid 93 cells long by 14 cells wide superimposed on the study area. The river is thus divided into 93 separate reaches, each of which is modeled to predict ground water inflow (return flow), diversions, and instream flow. Pumping from the existing wells in each grid cell is included in this model.

Hydrologic conditions of the river-aquifer system are computed at weekly intervals for a period of 10 years. Historical data form the basis for the model. These include weekly diversions at 33 points on the river, weekly streamflows at Balzac and Julesburg, weekly precipitation and crop consumptive water requirements, etc.

The main computer program performs the same sequence of calculations for every week. Schematically, the steps in the calculations are as follows:

1. Given the river inflow into the study area 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 on the river. The calculations are performed starting with the diversion of the most senior priority date down to the one with most junior priority. Note that the physical water availability at a diversion point exceeds the legal water availability by the amount of rights more senior located farther downstream.

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. For example, a purely historical water allocation strategy consists of the precise diversion that was made historically on that date. (The model was calibrated using this data). 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 just decided upon diversion amount, the water availability on the farms 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 farms is compared to the irrigation requirement (also expressed as a depth) determined from effective precipitation, crop mix, evapotranspiration and farm irrigation efficiency. The ratio of depth available to depth required expresses the degree of satisfaction of irrigation need.

If the irrigation requirement exceeds surface water availability on the farm, pumping from the aquifer to supplement the surface water supply is introduced. For example, under a purely historical strategy the known historical volume is pumped from the aquifer. Under an *as needed* strategy pumping is limited only by installed pumping capacity.

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 square cell of the model.

5. Given the just calculated net withdrawal rates from the aquifer in every cell, water table elevation in every cell crossed by the river is calculated. Given the river flows in each of these cells (upstream inflow into the cell plus return flow into the cell less diversion [if any] in that cell) river stages (elevations) are calculated from a stage-discharge curve. Based on the difference in elevation between the ground water level and the stream surface, return flows in each river cell for the next are calculated.

6. Various computer outputs of interest are saved on tape or printed out for later use including: predicted river outflow at Julesburg and percentage degree of satisfaction of irrigation requirement for the various irrigated areas. The cycle of calculation is repeated week by week until the selected time horizon has been covered.

POTENTIAL MANAGEMENT STRATEGIES

A management strategy is viewed here as a combination of (1) planned measures taken to improve the system's performance through capital expenditures (lining of canals, increased farm efficiency) and (2) operational water allocation procedures (full respect for water rights, etc.). The measures considered for the physical improvement of the system were: partial or complete lining of the canals, increased off-channel surface storage, improved farm-efficiency and increased pumping capacity. Some of the considered water allocation strategies were: historical allocation, strict surface water-right allocation, surface water-need allocation and pumping as needed. Numerous combinations are possible. Ultimately due to fund limitations, only a few combinations were tried.

FIVE MANAGEMENT STRATEGIES TESTED

Five runs of the model were made. In the first run (Series 1 or Historical run) the system was the historical system as it existed during the 10 years 1952-1961. The diverted and pumped weekly volumes are the historical ones. The river flow at Julesburg calculated by the model was found to be comparable to historical recorded flows. The historical degree of satisfaction of the irrigation requirement ranges from 25 percent to 80 percent for the Sterling No. 1 area and from 15 percent to 45 percent for the Settlers Ditch area.

In the second model run (Series 2 or Lined Canals run) canals having seepage losses of 25 percent or more 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 water allocation strategy in this case consisted of allowing the diversion of the minimum of four quantities: water need, water right, legal water availability and historical diversion. Pumping is limited to its historical value.

In the third run (Series 3 or 75 percent Farm 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 percent (depending on areas) to a value of 75 percent. The water allocation strategy for diverted surface water and for pumped aquifer water is the same as for Series 2.

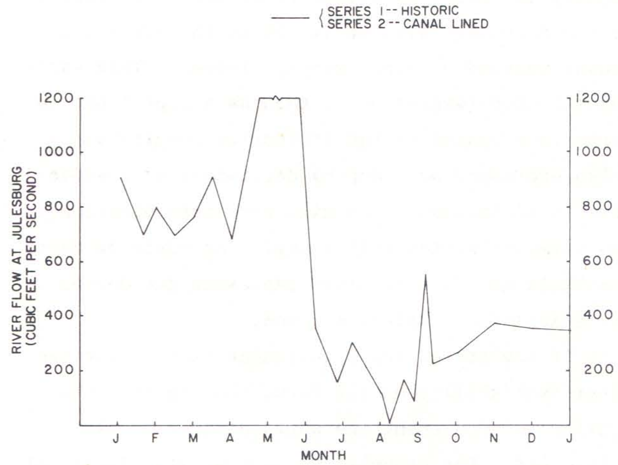
In the fourth run (Series 4 or Pumping *as needed* run) the system is the historical system (no lining, no improved farm efficiency, etc.) but the water allocation strategy for pumped water is fairly liberal. The surface water allocation strategy is the same as in Series 2 and 3. Pumping is allowed in excess of historical value but not to exceed the installed pumping capacity (as estimated from well records in 1973) and only enough to meet the crop water need not satisfied by the available surface water at the farm.

In the fifth run (Series 5 or Combination run) the same canals that were lined in Series 2 are lined, the farm efficiency is increased to the value of 75 percent as in Series 3, and the water allocation strategy for surface and ground waters is the same as in Series 4.

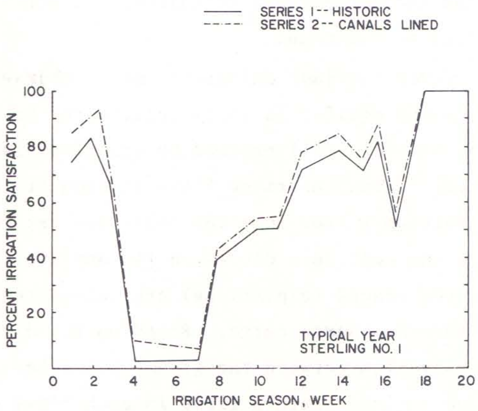
EVALUATION OF TESTED STRATEGIES

Merit of Lining Canals

The impact of this management strategy on the loss of water flowing out of state is negligible for the entire duration of the simulation period (1952-1961). It cannot be differentiated from the historical (Series 1) run. The reduction in annual volume of outflow was typically about three percent.

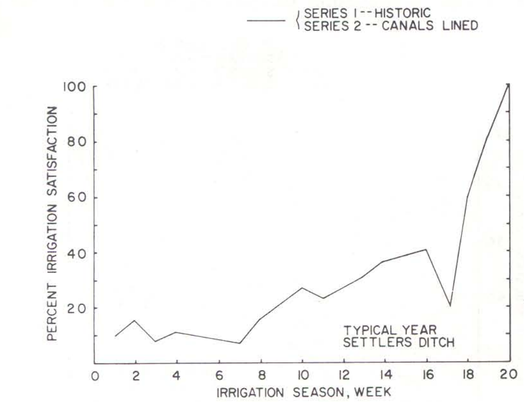


Water saved from canal seepage is applied to irrigated fields where it is partially consumed by crops and partially lost by percolation to the ground water. Lining raises the degree of satisfaction of irrigation water requirement by at most an absolute 10 percent which in dry years does not



provide much absolute relief. Farm irrigation efficiency tends to drop when water supply is increased so that canal seepage losses which are saved by lining and delivered to farms show up in part as ground water return flow to the river.

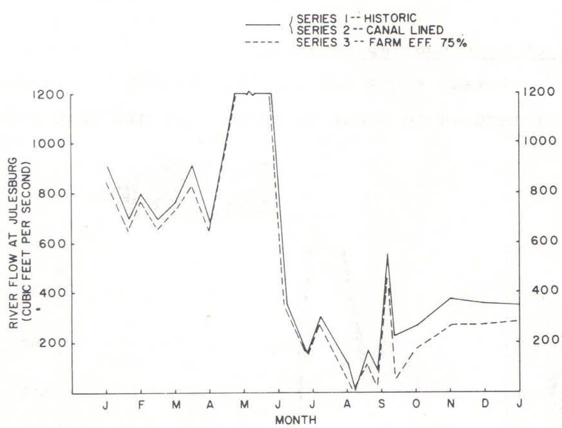
The water saved from lining the Sterling No. 1 area canal is used entirely by this senior water right and no relief is felt at all by the junior



downstream Settlers Ditch area. There is no detrimental effect of lining on junior surface rights in the river, however.

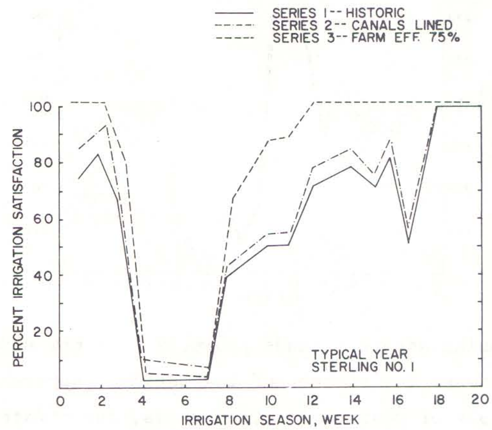
Merit of Increasing Farm Irrigation Efficiency

This management strategy reduces the downstream overflow noticeably late in the irrigation season and also after the irrigation season. As opposed to the Series 2 (lining of canals) result, there is now a

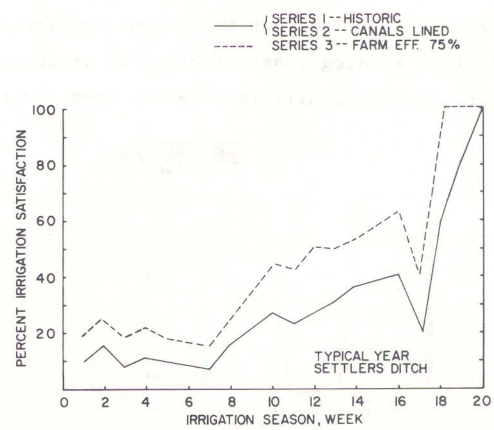


clear reduction in river flow out of state. The annual volume of outflow is now about 70 percent of historical. It is noteworthy that the position of the Series 1 line (Reference run) relative to the Series 3 line does not change much from year to year. This suggests that a new stream-aquifer equilibrium position has been found as a result of the new strategy and that the new equilibrium is reached within a couple of years. It was found that the reduction in volume of river flow out of state is precisely equal to the increased consumptive use of water on the farms.

The improvement in irrigation satisfaction in this case is at most 10 percent on the Sterling No. 1



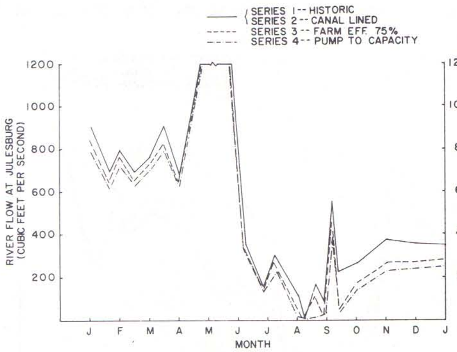
system and less on the Settlers Ditch system. When water is really scarce the strategy does not help much. Little water used efficiently is still little water. Generally some improvement in supply is realized on individual farms, but not when it is needed



most. Improved farm irrigation efficiency is therefore not a water-saving remedy for a severe water drought condition as experienced in 1952, 1954, 1955, 1957, etc.

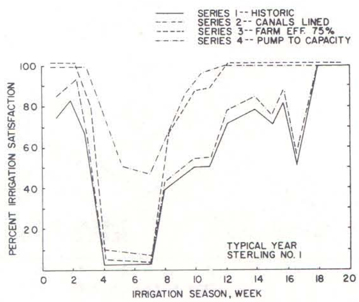
<u>Merit of Pumping *as needed*</u>

Under this strategy the river flow out of state is further reduced to around 50 percent of historical. The steady application, starting in 1952, of

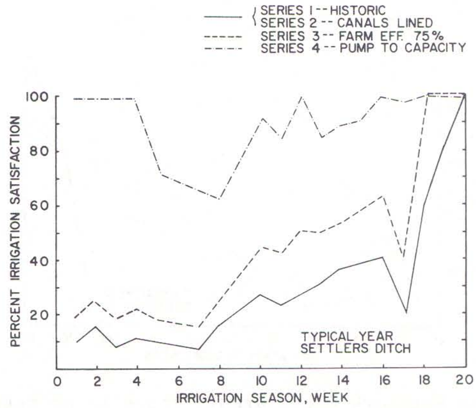


this pumping strategy leads promptly to a new equilibrium between the stream and the aquifer, apparently in a couple of years. In other words, the strategy does not result in a continued mining of the aquifer but rather in a new equilibrium. It is fortunate that a 10-year horizon was chosen for this study because the fears of a continuous decline in aquifer storage with time as a result of a pumping *as needed* strategy appear now unfounded. This is a very significant result with important management implications.

With this strategy, satisfaction of irrigation requirement is drastically improved as compared to



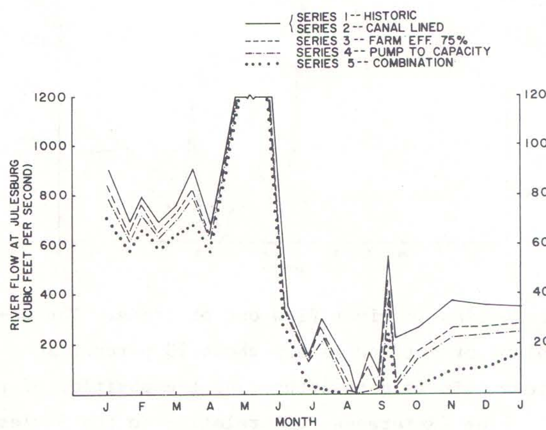
the previous strategies even during periods of severe drought. The irrigation water requirements were fully met through most of every irrigation season with with only a few exceptions occurring during periods



of very high evapotranspiration. Lining of canals and increased farm efficiency are only relative remedies because the extra amount of available water is proportional to surface supplies. If supply is small, the water saving is also small. A strategy of pumping *as needed* is an absolute remedy. Except for pump capacity limitation, water is made available as needed, where and when needed.

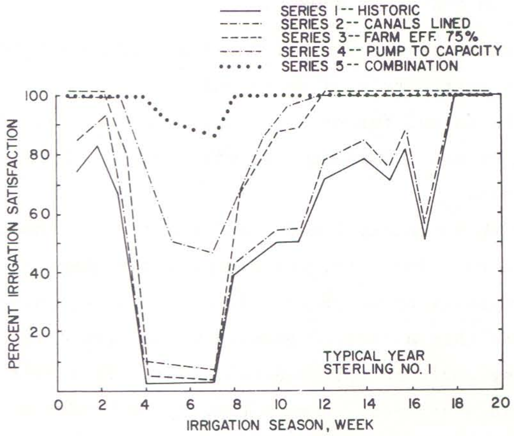
<u>Merit of Combined Improvements</u>

Downstream flows out of state in the river are further reduced to about 30 percent of historic and

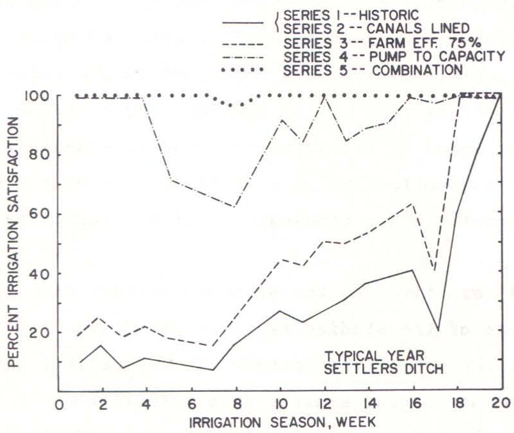


irrigation satisfaction is fully met with no exceptions throughout the season every year. Notice that the same result could have been achieved with increased pumping capacity.

In years when installed pumping capacity is limiting (to full irrigation satisfaction), improved



(75 percent) farm efficiency brings the system to perfect performance. Again, the same result could be achieved with more pumping capacity.



CONCLUSIONS

This study indicates that capital improvements to the irrigation system for lining of canals or on-farm improved efficiency are not very attractive and would not solve the Lower South Platte basin's water supply problems in times of drought. On the other hand, a liberal policy toward aquifer pumping in times of drought is very attractive. The study indicates that with 1973 installed pumping capacity (and the right to use it) irrigated agriculture in the South Platte would have ridden smoothly over the drought of the 50's. If any capital money is to be invested in the system, it appears that it should be invested in more wells rather than in lining canals.

The problem with lining the canals or increased farm water use efficiency is that the extra water made available to the crops for growth is proportional to the amount of surface water available for diversion in the first place. If that amount is small, the amount of saved water is also small. These measures may be attractive to certain individual farms but do little to increase overall water use efficiency in the basin because the same volume of water continues to be lost downstream out of the state.

Drawing supplemental water from the aquifer as needed, when and where needed, provides the best remedy to the water supply problem. The price of reducing water loss out of state is a modest lowering of the water table. However, if no more land is put into production, the system appears to reach a new equilibrium state in about two years. Thus with a pumping *as needed* strategy the South Platte irrigated agriculture could weather droughts as severe as that of the fifties and maintain its normal productivity.

The very distinct impacts of the various strategies show that the overall performance of the basin water system can be controlled effectively by improved management without much need for system physical and capital improvements. This is not to say that individual farm operations will not profit from such improvements.

Foremost the potential of use of the aquifer as storage must be fully recognized in any management scheme. This use has been advocated recently by Mr. W. D. Farr (Colorado Water Resources Research Institute, 1977, pp. 20-21), well-known agricultural and business leader in the South Platte basin. Said he, speaking about drought management:

> "Another suggestion is to better use our tremendous ground water resources. The present law is completely wrong as far as water conservation is concerned. The only thing it accomplishes is to try and keep old priority surface rights satisfied in a dry year. When the dry year occurs, the state engineer shuts down the wells or forces them to run other surface water down the river to augment the old priorities. This is certainly not a good total use of water resources.
>
> Our ground water is our greatest unused water resource. It should be thought of as a savings account, and it should be used on that basis. When snowpack is short and the runoff is minimal, every pump should be running and withdrawing our underground savings account when it is needed.
>
> To be a little more specific on this point, I firmly believe that when there is a good year with a sufficient stream flow of water, then I should not be allowed to use my wells. We should conserve and build up our ground water reserves in those years. On the contrary, when water supplies are short, I should be forced to use my wells. My ditch water and reservoir water should go to my neighbors who do not have an underground supply. If our water supplies were managed in this manner, I would guess that our total yearly supplies of water would be increased by almost one-third."

The current study has indeed confirmed and provided quantitative verification of the views based on experience expressed by Mr. Farr.

FUTURE RESEARCH

The study has shown the feasibility with the C.W.R.R.I. surface-ground water model to predict accurately and cost-effectively the behavior of the South Platte system with both a fine space (mile) and fine time (week) scale over many years. If as Mr. Farr said,

> "The problem is to best manage and utilize our total water supplies, not only on a day-to-day basis, but on a prudent plan for years ahead",

the current stream-aquifer model should be refined so that cost-effective runs could be made on a daily basis and for extended periods of years. Research on model improvements will proceed in this direction.

With the current model a few more runs should be made to illustrate, for example, the mixed strategy proposed by Mr. Farr. If a year is declared a wet year then a limited pumping water allocation strategy could be followed that year. If a year is declared a dry year, then a pumping *as needed* strategy would be followed that year. For example, the dry 1952-1959 years were followed by relatively wet years in 1960 and 1961. One could determine that with a limited-pumping strategy in the years 1960-1961 whether or not the system outflows bounce back in a year or two to the level experienced under historical conditions and thus confirm the relatively fast recovery time of the aquifer. Even at the current level of development of the stream-aquifer model (cost-effective on a weekly basis) many more runs testing other combinations of strategies can be made.

Alternatives to the proposed Narrows dam, just upstream of the studied reach of the South Platte river, could be investigated. It is possible that managed use of the aquifer as a reservoir could substitute to some extent for a surface reservoir. Or a smaller surface reservoir might serve a useful purpose for regulating stream flow to reduce losses out of state and also to maximize recharge into the aquifer from the stream. Furthermore, it might facilitate special diversions into canals for aquifer recharge. A conjunctive management operational study of the upstream Narrows surface reservoir and of the aquifer reservoir for different capacities of the upstream surface storage for the 1952-1961 dry period would shed a great deal of light on alternatives.

There is an urgent need in Colorado to be able to analyze alternatives in water resource management such as those mentioned above and many more, as prelude to changes in historic practice and policy. And changes seem inevitable,

> "...that Western States must go on the offensive and come up with a comprehensive western water policy or risk losing the initiative to the Federal Government.

witness the Federal water policy initiatives which have produced great turmoil within all western states. Practical tools for predicting effects of potential changes, such as the model described herein, should be immediately exploited to establish a rational basis for policy change decisions.

IMPACTS OF THREE POTENTIAL WATER MANAGEMENT OPTIONS
ON LOSS OF ADJUDICATED WATER

Downstream Out of State

(Result of Simulation for 1955-56 Water Year*)

Water Management Option / Impact	No Change (Reference)	Line Selected Canals	Increase Irr. Eff. to 75%	Allow Pumping to 1977 Installed Capacity**	All Three	Compact Requirement
River Outflow at State Line Acre Feet	151 964	147 909	104 424	70 616	43 500	47 100
Outflow as a Percent of Reference	100%	97%	69%	47%	29%	--

* Simulation shows hydrologic result if option had been employed during 1955-56.

** Assume pumps in place in 1977-78 had been in place during 1955-56.