IMPACT OF IRRIGATION EFFICIENCY IMPROVEMENTS ON WATER AVAILABILITY IN THE SOUTH PLATTE RIVER BASIN

by

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Colorado Water
Resources Research Institute

Technical Report No. 13

Colorado State University

FINAL REPORT

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ON WATER AVAILABILITY
IN THE SOUTH PLATTE RIVER BASIN

submitted to

State Drought Coordinator
Office of the Governor
State of Colorado

Work done under Contract No. 7-07-70-X0009
with the
U.S. Bureau of Reclamation
Emergency Drought Act of 1977

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January 1979

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P R E F A C E

EFFICIENCY OF WATER USE--AN OVERVIEW

By Norman A. Evans

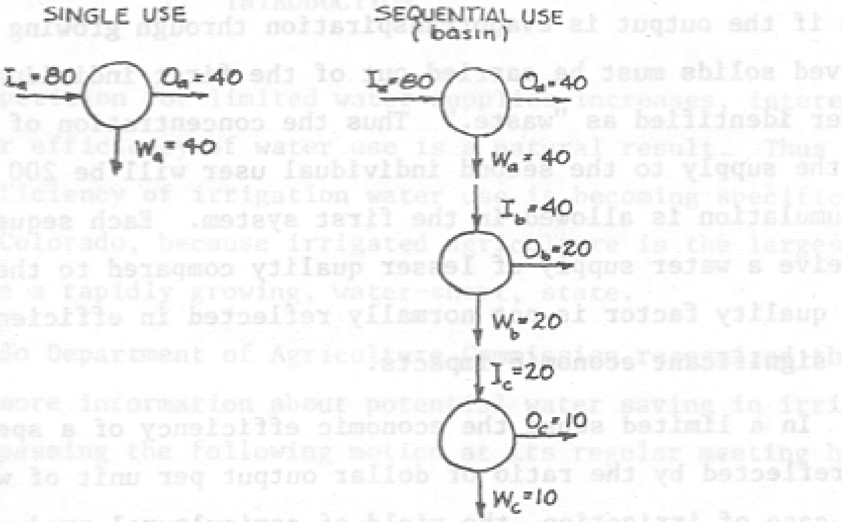
Water-use efficiency is used to describe how well the resource is conserved or utilized. Higher efficiencies in particular uses are assumed to have the effect of releasing unneeded resources for use by others. The purpose of this study is to examine that question as it applies to water in the South Platte River Basin.

Efficiency is evaluated by dividing the quantity of output from some given system by the quantity of input. A high efficiency implies that there is little waste involved in the system. In the case of water systems, if a high proportion of the water withdrawn from supply for a particular use is utilized in that use, the efficiency is said to be high. Although this concept is useful, its indiscriminate use can be deceiving.

For example, a high proportion of waste through deep percolation and surface runoff from an irrigated farm would result in a low irrigation water-use efficiency. This waste may be a real one to the individual farm, but the water is still contained within a larger hydrologic system of which the farm is merely a part. The water is not lost to the larger system; it is merely routed differently through the system. High seepage losses in conveyance or through deep percolation and surface runoff are not critical in terms of reducing the total water supply for a basin. It is true that its rerouting affects water distribution with time through the basin; this may be a benefit. There may be a loss of quality, however.

Extrapolation of efficiencies from a single user to regional or basin-wide efficiency would give misleading indications of new water supplies that could be available through adoption of efficiency measures. This is because one user's waste may be another user's supply.

The following diagram compares the efficiency concept applied to a single use for that of a larger system where several single uses are tied together in sequence, as is the case in a river basin. It is quite evident when the net output is compared to the net input for the basin, the calculated efficiency is quite different from that for an individual use by itself.



$$\text{Efficiency} = \frac{O_a}{I_a} = \frac{40}{80} = 50\% \qquad \text{Efficiency} = \frac{O_a + O_b + O_c}{I_a} = \frac{70}{80} = 87.5\%$$

While aggregated systems are much more complex than indicated in the diagram, such sequential uses are the common pattern in western river basins. The South Platte Basin is often described as the most complex sequential or reuse system in the entire western region. The important point to recognize is that an efficiency measurement is associated with a very specific boundary. Its implications must be viewed likewise in terms of the same boundary. High efficiency may be very meaningful to the single user in terms of volumes of water to be handled (because of associated costs - treatment, delivery), while from the viewpoint of the entire basin it may be insignificant.

In discussing water uses, it should be emphasized that all uses are not consumptive. Legitimate and beneficial uses range from "contact" and "in-stream" uses (boating, swimming, fishing); to withdrawals which do not consume (hydro-power); to withdrawals which consume (irrigation, municipal, industrial). The efficiency criteria can not be applied with the same meaning to all these different uses.

Efficiency criteria as applied to water use has not incorporated quality considerations. Yet quality is a key element today in water management. Referring again to the diagram of single and sequential uses, if the first withdrawal contains water having 100 ppm of dissolved solids, and if the output is evapotranspiration through growing crops, the dissolved solids must be carried out of the first individual system by the water identified as "waste." Thus the concentration of dissolved solids in the supply to the second individual user will be 200 ppm unless salt accumulation is allowed in the first system. Each sequential user will receive a water supply of lesser quality compared to the preceding user. The quality factor is not normally reflected in efficiency terms, yet it has significant economic impacts.

In a limited sense the economic efficiency of a specific water use is reflected by the ratio of dollar output per unit of water input. In the case of irrigation, the yield of agricultural product per acre-foot of water withdrawn from supply would represent the economic efficiency relative to water use. In this connotation the most efficient use would be that which adds the greatest value to the general economy.

Institutional and legal circumstances have an important influence on how well a given water supply can be made to accommodate all legitimate uses. If these elements are flexible and up-to-date, they can facilitate improvement in efficiencies of water use. If not, they can be a serious deterrent to improvements even though technical and managerial options may be available.

IMPACT OF IRRIGATION EFFICIENCY CHANGES ON WATER AVAILABILITY IN THE SOUTH PLATTE RIVER BASIN

I. INTRODUCTION

As the competition for limited water supplies increases, interest in achieving higher efficiency of water use is a natural result. Thus it is natural that efficiency of irrigation water use is becoming specifically of interest in Colorado, because irrigated agriculture is the largest user of water in a rapidly growing, water-short, state.

The Colorado Department of Agriculture Commission recognized the need to obtain more information about potential water saving in irrigated agriculture by passing the following motion at its regular meeting held May 20, 1977:

> To seek available information regarding the efficiency of the present delivery system for irrigated agriculture, to determine those system improvements, technological advancements and changes in irrigating practices which could be applicable to the present system, to evaluate the water consumption efficiencies to be gained, and to recommend actions, federal programs, legislative initiatives, and education programs deemed appropriate as a result of this investigation.

The motion led to a study funded by the U. S. Bureau of Reclamation pursuant to the Emergency Drought Act of 1977. The Bureau of Reclamation made the funds available to the State Drought Coordinator, Office of the Governor, who in turn contracted with the Colorado Water Resources Research Institute (WRRI) to conduct the study.

Purpose and Objectives

As stated in the agreement between the Colorado WRRI and the State Drought Coordinator, the purpose of the study is to:

> . . . provide the State with information on hydrologic and economic impacts of applying efficiency criteria to the irrigation conveyance, distribution and application system of the South Platte River Basin.

Specific objectives of the study are:

1. To adapt and expand the current CSU computer model for conjunctive management of a surface-ground water supply to the assessment of hydrologic impacts of improved irrigation water-use efficiency in the South Platte River Basin, and

2. To operate the conjunctive model with a range of assumed "efficiency" improvements in delivery, distribution and application systems and in irrigation water management practices so as to evaluate the basin-wise hydrologic impacts and costs.

Method of Approach

Many complex interacting factors must be considered in order to properly evaluate the benefits of increasing efficiency in irrigation. The larger the area considered the more this statement is true. The loss of water from one field or farm is often a part of the water supply historically used on other farms. Likewise, all seepage losses from ditches and reservoirs are not necessarily losses to a river reach or a basin.

In order to adequately take into consideration even the major interactions in an area of any size it is necessary to be able to compute the effects of the many interactions in both space and time. This requires development of a mathematical model which must be solved on a large computer because of the mass of data and the complexity of the calculations. For this study, a mathematical approach developed by Dr. Morel-Seytoux was chosen to be used. This model approach is described in general in a later section of this report along with references to more detailed descriptions.

A specific study area and base time period were selected for use in the model. These choices, described in detail below, were made principally because of availability of data. No inference should be drawn that the efficiency of irrigation and irrigation systems in the study area is better or worse than any other portion of the South Platte River Basin.

II. IRRIGATION WATER-USE EFFICIENCY

Irrigation water-use efficiency can be discussed and defined from several standpoints. From the standpoint of an individual farmer, the efficiency of use once he has taken delivery of the water from the irrigation company canal (and/or a well) is the only part of the entire system over which he has some direct control. These on-farm efficiency considerations, field irrigation efficiency and farm irrigation efficiency, are discussed in following sections.

From the standpoint of the canal and reservoir companies, the efficiency with which the water they are entitled to can be diverted, conveyed and delivered to the farm headgates is of interest. This is discussed below under the heading "Canal and Reservoir System Efficiency."

From a broader standpoint, one needs to be also concerned about efficiencies of water use on a larger scale, such as for an entire river reach or river basin. These concepts are discussed below under the headings "River Reach Efficiency" and "River Basin Efficiency."

Water Use in Crop Production

Water from the soil is absorbed by the plant root system and a very high proportion of it is transferred through the plant to the leaf surfaces where it is evaporated and lost to the atmosphere as water vapor. This process is universally referred to as transpiration. Although most of the absorbed water is ultimately transpired, a small but very important amount is used in metabolism and growth by the plant. Plant growth is a result of many complex processes within the various tissues, and the rate of these processes, and thus the growth rate, is determined by genetic and environmental factors. One of the most important environmental factors is the internal water balance within the plant cells. This water balance is a result of the relative rates of water uptake by the root system and the loss of transpired water from the leaf surfaces. As soon as absorption from the soil lags only slightly behind transpiration, a water deficit in the plant occurs and a decrease in the quantity or quality of growth results.

Thus, the production of high yielding crops requires a continued supply of readily available moisture in the soil root zone so that, even when the evaporative demand is high, water deficits in the plant are minimum. The principle purpose of irrigation is to maintain the soil-moisture level at sufficiently high values to meet the plant uptake requirements for maximum transpiration.

In addition to transpiration of water through the plants, some water is consumed in crop production by direct evaporation from the soil surface. To some extent this evaporation reduces transpiration because the relative humidity of the air within the crop canopy is increased. Consequently it has become customary to refer to the consumptive water use by crops as the sum of evaporation from the soil and of transpiration from the leaves (evapotranspiration). Evapotranspiration (ET) is dependent almost exclusively on meteorological conditions throughout the crop growing season if soil moisture does not become a limiting factor to water uptake by the root system. When soil moisture is reduced to such a degree that root absorption cannot meet the ET demand, a plant water deficit develops, leaf stomates partially close, and transpiration is restricted to the rate of root absorption. Plant growth and subsequent yield of the crop is reduced somewhat proportionally to the degree of plant water stress.

The amount of water used in the production of a crop may be expressed in many ways. The water actually consumed is simply that evaporated into vapor (from plant stomata or the soil) or converted into plant tissue. However, it is usually more meaningful to include water having other fates, such as runoff from the field or deep percolation through the soil to points below the root zone. In irrigation water management it is usually of great concern to determine the efficiency with which the water supply is used in crop production.

In the following sections various aspects of irrigation-water efficiency are discussed.

Field Irrigation Efficiency

Field irrigation efficiency has been defined for this study as:

$$\text{Field irrig. eff.} = \frac{\text{Volume of crop evapotranspiration}}{\text{Volume of water delivered to field}}$$

Several factors which affect field irrigation efficiency are discussed in the following paragraphs. Some of these can be altered by management and others can not. Two specific types of losses which decrease the field efficiency and which may be altered by management are those of deep percolation below the root zone and surface runoff from the field.

Soil type

Perhaps the most influential factor affecting the field irrigation efficiency, and which is generally only slightly alterable by management, is the soil type. Two very important soil properities are involved.

Soil water-holding capacity. The ability of the soil to hold water available for plant uptake is determined by the texture and the soil depth. In general, sandy soils have low, loam soils high, and clay soils intermediate available water-holding capacities. Typical values expressed as inches of available water per foot of soil are given in Figure 1. When the soil has a low capacity for holding water, due either to texture or depth, there is a much greater potential for loss of water by deep percolation. The irrigation application requirement must necessarily be low, and the ability of the irrigator to apply the correct amount without excessive leaching is considerably more difficult regardless of the application method used. Essentially nothing can be done to alter the water-holding capacity of a soil.

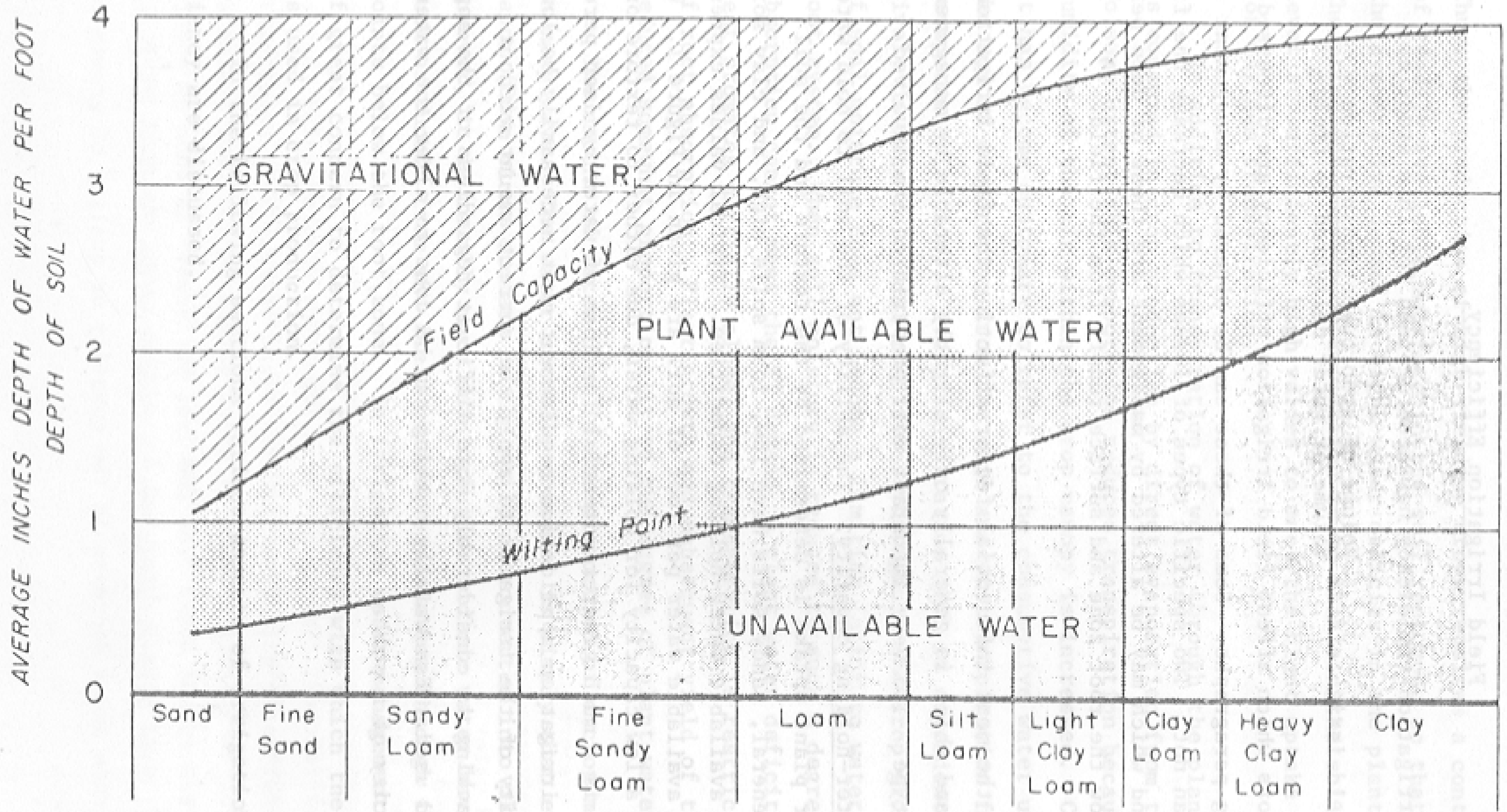


Figure I-1. --Typical water characteristics of different-textured soils.

Soil intake rate. The water intake rate of the soil influences, to a great extent, water losses from the field due to both runoff and deep percolation. If the intake rate is excessively low, it is difficult to irrigate without "tail water" running off the lower end of the field. The time that water must cover the soil in order to apply the required amount to recharge the root zone is increased by low intake rates, and, unless very special precautions are taken, this cannot be accomplished without runoff using surface irrigation methods. If the intake rate is excessively fast, it is difficult to uniformly recharge the soil moisture from one end of the field to the other without excessive application, and resultant leaching, at the upper end of the field. The use of sprinkler irrigation is usually the best procedure for preventing low field irrigation efficiencies when intake rates are very high. Intake rates are influenced to a great extent by surface soil texture but also by other factors influencing soil structure, compaction, aggregate dispersion and soil cracking. Management practices can be used to control, within limits, the intake rate of soils, but it is impossible to prevent some change in this property throughout the irrigation season as well as between years when different crops are grown and different tillage practices are required.

Surface contour and slope

Deep percolation and field runoff of irrigation water are both influenced by land topography. If the land is nearly level, as may be the case on alluvial soils near the river, it is difficult, with the small water-flow rates usually available in the lower South Platte Valley, to apply sufficiently large streams in furrows or border strips to cover the "set" before excessive penetration takes place at the head ditch end of the field. On the other hand, if the slope is steep, runoff at the lower end is essentially impossible to avoid before adequate water has been applied. Non-uniform slopes and land with high spots or swales make attainment of high field efficiencies difficult unless sprinkler or trickle irrigation is used or the land is reformed for efficient surface irrigation. This latter approach can be quite beneficial.

Type of crop

The influence of type of crop on field irrigation efficiency is chiefly one of dictating the method of irrigation water application. Row crops, such as corn, sugar beets, beans, sorghum, etc., are irrigated by the furrow method. Close-growing crops, such as pasture, alfalfa and small grains, are flood irrigated. Any crop may be sprinkler irrigated providing the sprinkler system used conforms satisfactorily to the height of the crop.

The type of crop also influences the frequency of irrigation and the depth of water required at each application. Alfalfa, a perennial crop that can establish a very deep root system, is ordinarily irrigated less frequently. Potatoes must have a relatively wet soil during the entire growing season if good quality tubers are to be produced, and thus they require frequent, light applications. (Light applications are often associated with low field irrigation efficiencies.) Corn develops a deep root system capable of removing water from the lower subsoil depths. It can thus, although to a lesser extent than alfalfa, utilize large, infrequent irrigations. Field beans, on the other hand, have a comparatively shallow root zone and require small depths of water applied at frequent intervals. Although field efficiencies may not be greatly affected when proper precautions are taken, depth of application is a real consideration.

Method of irrigation

Three general methods of irrigation are employed in the production of crops in Colorado: furrow, flood and sprinkler. Each of these are used with variations depending upon crop type, land slope and the personal desires of the farmer. Characteristically, sprinkler applications are associated with the highest field irrigation efficiencies, and flood methods with the lowest. However, in most cases, the attention and care exercised by the irrigator can cause far greater variation in irrigation efficiency than will that of the method employed.

When the land surface slope is variable, with high spots and steep slopes, a wild flooding application is frequently used. Large deliveries are usually required to force the water to the higher elevations and field runoff commonly results. With proper design and location of field ditches the tail water may be picked up and redistributed to maintain relatively good efficiency. When fields are of moderate and uniform slope in one direction, the border dike method of flood irrigation can be utilized to provide very high field efficiencies. Again, however, the result is largely governed by how well the irrigator controls the stream size, by the width and length of the border strips and by the time of set.

Application efficiency when using furrow irrigation may also vary appreciably. If the furrows are directed down steep slopes it is difficult to prevent field runoff. Contour furrows, running in general across slope, greatly increase the potential for uniform application of the desired water depth. Close attention to water control and proper field layout are essential.

Sprinkler irrigation provides the best method for water control and uniform application, especially on lands of variable topography and soil characteristics. Caution is required, however, to prevent application rates in excess of soil intake rates. If this occurs, runoff results and attained efficiencies may be considerably below attainable efficiencies. Thus, the sprinkler systems which are common to Eastern Colorado (i.e., center-pivot systems), with their inherent high application rates, are limited to the coarser textured soils which have high infiltration rates.

Whatever method of irrigation water application is employed, certain precautions and design techniques may be used to improve efficiency. Proper farm ditch locations, field design, stream size and cut-back techniques can be specified by trained irrigation technicians. Collection of runoff water into ditches for subsequent redistribution or into tail-water reuse pits, where it can be pumped back to the upper end of the field or directed to another field, is becoming increasingly popular with concerned irrigators.

Limits to field irrigation efficiency

It is important to recognize that the upper limit of irrigation application efficiency, even under the most ideal field conditions, is limited by the natural variability found in soil conditions. Soil intake rates vary from one place to another so it is impossible to apply the desired amount at one location without applying more than is needed at another location. Some drainage below the root zone necessarily results. Under furrow irrigation, tractor or implement wheels compact some furrows resulting in greatly decreased intake rates. It is practically impossible to have the intake time the same at all points along the length of the field. Thus, it cannot be expected that irrigation efficiencies should be above 70 to 75 percent if the entire irrigation requirement is met.

Soil salinity control under irrigated agriculture is an important management factor. The only satisfactory control measure is to periodically leach the soil salts below the crop root zone by the application of excessive irrigation water. By the above definition this decreases the field irrigation efficiency, but it is a necessary requirement for obtaining profitable yields.

Under many geological conditions in irrigated areas the "loss" of water to deep percolation is not a total loss. The ground water may flow to streams where it is again available for public use, or it may be pumped for reuse at the surface. In fact, the storage of ground water resulting from over-irrigation, and its rate of controlled release for reuse, may be an important factor in water management of an irrigated basin.

Farm Irrigation System Efficiency

Farm irrigation system efficiency includes in its definition the losses in the delivery system from the farm turnout on the canal system to the irrigated fields. All other components are the same as for field irrigation efficiency. Thus,

$$\text{Farm irrigation system efficiency} = \frac{\text{Volume of crop evapotranspiration}}{\text{Volume of water delivered to farm turnout}}$$