The losses along the farm conveyance system are of several kinds, but perhaps the greatest is seepage from ditches. Although seepage can be reduced by lining or surface treatment, it is not usually done because of high initial costs of lining material and the labor for installation.

Another loss, that of overtopping (spillage), can occur if ditch banks are not properly maintained. These losses can cause bank erosion and eventual bank failure with an associated loss. The problem is exacerbated if weeds are allowed to grow in the ditch, thus causing higher resistance to flow resulting in an increased flow for a constant depth for a given discharge.

Weeds outside the ditch cause an additional loss--that due to phreatophytic water use. Their removal of seepage water can increase the hydraulic gradient between the canal and the surrounding soil and thus increase seepage losses. They also prevent seep water from reaching the ground water for later pumping or return to the river.

Because one turnout may serve more than one field, additional losses may occur if there are leaks at farm gates. A neighbor may receive leakage water, or the farmer may have some of his water delivered where it is not needed or can not be used effectively.

A most important factor is the timing of water delivery to the farm. If sprinklers are used, economics dictate a relatively constant delivery rate during the irrigation season. If surface irrigation is used, it is necessary to have high flow rates, but unless the farm is quite large, only periodic deliveries are needed or can be used. If surface deliveries occur when water is not needed, such as after a substantial rain or during periods of low crop demand, that water which is not used by the system is wasted whether by diversion down a drain gulch or through application and subsequent deep seepage or runoff. Thus, it behooves the farmer to select cropping patterns with requirements which will in some way match his expected water delivery schedule.

The above comments pertain principally to farms and fields irrigated with surface water from mutual canal and reservoir systems. Some of the factors causing reduced efficiencies are overcome on farms and fields irrigated from wells because of shorter delivery canals and the capability of applying water on demand according to crop needs.

Canal and Reservoir System Efficiency

Canal and reservoir system efficiency can be defined as the percentage of water diverted from the river that is delivered to farm headgates or turnouts on the system. The principal factors that influence canal and reservoir system efficiency are (1) evaporation, (2) transpiration, (3) seepage and (4) operational losses.

Evaporation

Evaporation is defined as the process by which water is changed from the liquid into the gaseous state through the transfer of heat energy. At every free water surface, whether in a reservoir or a canal, there is a continuous interchange of water molecules across the free water surface. When the net sum of the interchange of the water molecules represents a loss from the water, there is evaporation. The evaporation rate is expressed in depth of water measured as liquid water removed from the free water surface per unit of time. The average annual evaporation rate from open water surfaces for the Balzac-to-Julesburg reach has been estimated to be about 50 inches per year.

Evaporation rates from free water surfaces have been established for specific areas using a "standard" circular pan, which is installed on the ground as a land pan or in the water as a floating pan. The U. S. Weather Bureau Class A pan is 4 feet in diameter and 10 inches deep. Theoretical approaches to the prediction of evaporation from free water surfaces involve equations representing mass transfer processes and energy transfer. Evaporation rate has been directly related to air and water temperature and wind speed.

Evaporation from open water surfaces is extremely high in the warmer regions of the United States. Values on the order of 90 inches per year and 80 inches per year have been recorded for southern California and southwestern Texas, respectively. A great deal of research has been conducted during the past several years on different methods for retarding evaporation from free water surfaces. Some reduction in evaporation has been accomplished by using thin films of chemicals spread over the water surface. Evaporation retardant processes are fairly expensive and are not being used extensively at this time. Operation of the water conveyance and storage systems, however, can be operated with the concept in mind that large, relatively shallow open water areas are susceptible to relatively large evaporation losses, particularly during the warmer seasons.

Transpiration

Transpiration is defined as the process whereby the water absorbed by the root system of plants is discharged to the atmosphere as a vapor from the plant leaves and other surfaces. Most of the water absorbed through the roots is discharged from the plants in this process. Only about one percent of the absorbed moisture is retained in the plant tissue. The annual transpiration rate for a given vegetative type is expressed in depth of water for the given area of a specific vegetative cover. The transpiration rate varies directly with the density of plant growth, the amount of sunshine, plant vigor and available moisture supply. Transpiration is essentially nonexistent below 40 degrees Fahrenheit.

Where there is sufficient soil moisture, growth and transpiration are determined mainly by temperature. Trees and other vegetation along canals and around reservoirs are generally blessed with adequate soil moisture during the growing season. The water used by plants in the transpiration process may be supplied directly from open bodies of water in reservoirs or canals (in the case of aquatic plants) or from water that has seeped from these facilities. The latter use can increase the seepage rate by increasing the hydraulic gradient.

Seepage

Seepage is defined as the slow movement, or percolation, of water through the pore structure and interstices of the soil around the wetted perimeter of a canal or reservoir. The seepage rate may be expressed as a flow volume per unit of time, and/or as a percentage of the flow rate occurring at a particular canal cross section. The rate of seepage from unlined canals and reservoirs is affected chiefly by the depth of water, permeability of the confining soil and the location of the ground-water table. Low seepage rates are generally associated with soils having fine particle size such as clay, loams and silts. Higher seepage rates occur in sands, gravels and decomposed granite. An estimated 2 million acre-feet of irrigation water is lost through seepage processes in Colorado each year. Seepage from canals and reservoirs not only reduces the availability of water to the operating company, but also (1) adds to the salt buildup in the soil profile and ground-water reservoirs, (2) sustains high-water-table areas and encourages the growth of phreatophytic vegetation and (3) reduces the area of land for agricultural use. On the other hand, seepage may be beneficial in that it recharges the underlying ground-water reservoir.

Depending on the cost and effort analyses of lining a specific canal or reservoir, various materials may be incorporated. Linings currently utilized in Colorado include (1) bentonite (or clay); (2) compacted earth; (3) both reinforced and unreinforced concrete; (4) asphalt, rubber and plastic membranes; and (5) chemical treatments.

Operational losses

Operational losses are defined as that water loss resulting from the manner in which the reservoir and/or canal system is operated. This loss includes overflow or breakage of canal banks, waste at the end of the main canal or lateral system, leakage past gates and other control structures, and direct dumpage back to the river system. In order to supply the most downstream lateral along a given canal, some overflow at the downstream end is often required. Direct dump back to the river system may be necessary during periods of unusually high precipitation or unanticipated canceling of a headgate diversion. In some instances such operational losses may be required to flush out excessive sediment loads or to satisfy downstream calls on the river.

It should be mentioned that seepage losses and operational losses which tend to reduce the efficiency of one canal and reservoir system may contribute to the water supply and thereby bolster the efficiency of one or more lower canal systems.

River Reach Efficiency

As discussed above, water losses from irrigated fields include water which percolates below the crop root zone and water which runs off the surface. Also, some of the "losses" in conveyance are made up of water which seeps downward, and upon occasion there are also operational spills into natural waterways.

In the cases of deep percolation and seepage, the water becomes part of the ground-water system. Fortunately, in many areas of the South Platte, the irrigated areas overlie permeable alluvium which serves as a natural drainage facility. Water in the alluvium, mostly put there from the irrigation activities, slowly moves back to the river to become available for diversion again (either by wells or by downstream ditches). This "return flow" is an important factor in the efficiency of water use in a reach or an entire basin.

The over-land flow of tail water from irrigated fields, as well as operational spills from ditches, also flow back towards the river. In the case of these surface flows, however, the water is often intercepted and used again by other irrigators either directly or through a lower canal system. This reuse is also an important factor in the overall water-use efficiency of a river reach or an entire basin.

Factors which influence reach efficiency include:

(1) The losses to nonbeneficial evaporation and transpiration which deplete both the ground-water and the surface-water return flow between the irrigation facilities and the river. Losses from the ground-water system occur in areas where the water table is near the land surface, resulting in direct evaporation as well as providing water for non-crop vegetation. The most severe area of high water table generally occurs in the immediate vicinity of the river. Typically, such an area supports a growth of phreatophytic vegetation capable of drawing water directly from the ground-water system.

(2) The opportunities for re-diversion of the return-flow water (and therefore an increase in reach efficiency) depends somewhat upon relative locations of water rights in the reach. For instance, if a senior water right for a large amount of water is located at the upper end of a particular reach, the downstream appropriators in the reach have an opportunity to redivert return flow generated by the senior right, even though their priorities are inferior. On the other hand, if, in a particular reach, the large senior right is located at the lower end of the reach, the water-use efficiency could be quite low. During times of shortages the upstream junior rights would be required to curtail diversions so as to allow water to flow to the senior right.

(3) Conveyance losses in the stream itself during low-flow conditions can be significant. A broad streambed and a low flow results in a large amount of surface area exposed to evaporation.

(4) Timing of return flows coming back into the stream is of importance, especially for direct-flow rights. If most of the return flow generated from irrigation in June does not get back to the stream during the irrigation season,it is not available to downstream direct-flow rights. If the reach under study does not have facilities to store the return flow accumulating during the nonirrigation season, that water is lost to the reach.

River Basin Efficiency

As the size of the area under consideration increases, so does the opportunity for reuse of water. This is particularly true in a basin such as the South Platte where the principal source of water is in the upper reaches and the major uses occur in the lower reaches. The efficiency of irrigation water use in the South Platte Basin as a whole is considerably higher than the average field or farm irrigation efficiency (or even the efficiencies within individual reaches) because of return flow and reuse.

As discussed above for a river reach, the distribution of water-right priorities can also have an influence on the overall basin water-use efficiency. For example, if most of the senior water rights are located at the lower end of the basin, these rights would be able to call out the upstream junior rights during periods of shortage. Under such a distribution of rights, it would be important that the water use under those senior rights be efficient such that the amount of call is no greater than necessary and the return flow from the seniors' use is held to a minimum.

On the other hand, if the most senior rights tend to be located in the upper reaches of the water-use area, the downstream junior rights have an opportunity to make reuse of the return flow and accomplish a high overall basin efficiency.

Assuming that in any basin water uses can be separated into "beneficial" and "nonbeneficial," the only opportunities for improving river basin water-use efficiency lie in <u>increasing</u> beneficial uses by <u>decreasing</u> nonbeneficial uses and/or by managing water diversions for direct use and storage (including groundwater storage) in the basin which will <u>decrease</u> the outflow at the lower end of the basin.

III. APPLICATION TO LOWER SOUTH PLATTE RIVER

For purposes of this study, a reach approximately 90 miles long at the lower end of the South Platte River in Colorado was chosen to be modeled. The reach is essentially that formerly known as Water District 64.

General Description of Reach

The study reach begins a few miles upstream from the gaging station at Balzac and ends at the Colorado-Nebraska State line (Julesburg gaging station). The reach contains about 120,000 acres of irrigated lands served by 30 ditch systems and 3 major reservoirs. In addition, there are about 750 irrigation wells, some of which serve the same land and are supplemental to the ditch-water supplies. An estimated 25,000 additional acres are irrigated from ground water only.

Stream-aquifer system

The water supply for the study reach comes from an hydraulically connected surface-water and ground-water system--generally referred to simply as a stream-aquifer system. The principal aquifer involved is the alluvium of the South Platte River from which most of the 750 irrigation wells withdraw their supplies. The alluvium varies from 2-1/2 to 7-1/2 miles in width, averaging about 4.3 miles. The saturated thickness exceeds 100 feet under about 76,000 acres between the North Sterling Canal headgate and the State line. The alluvium contains an estimated 3.5 million acre-feet of ground water under about 388 square miles.

The principal source of recharge to the alluvial aquifer is the deep percolation of irrigation water from canals, reservoirs and irrigated fields overlying the aquifer. In addition, other investigators have estimated that approximately 75,000 acre-feet of water a year flows into this reach of the South Platte alluvium from the High Plains ground-water system south of the river (Waltz and Sunada, 1972).

The water added to the ground-water system in the study reach is generally sufficient to maintain a water-table level higher than the streambed level, thus creating ground-water flow toward the stream and causing a gaining or effluent stream condition. During dry periods when the draft upon the ground water is high (from both wells and phreatophyte growth) this situation is probably reversed in portions of the reach, causing a losing or influent stream condition.

Selection of study period

A 15-year study period for the model analysis was chosen to begin January 1947 and run through December 1961. This time period was chosen principally for two reasons:

(1) Data for the study period, such as estimates of amount of ground water pumped under each ditch system, were previously assembled by the U. S. Bureau of Reclamation studies made in connection with the Narrows Reservoir project.

(2) The time period includes the major drought period of 1954 through 1956.

Water budget

The annual irrigation water supply for the study reach is highly dependent upon the return-flow phenomena discussed earlier. Except for the heavy mountain snowmelt runoff times in May and June, and the occasional flood runoff due to summer thunderstorms, the water used in the study reach is return flow from irrigation activities upstream. This is not only true for the direct-flow rights but also for the storage rights in that the stream flow during the fall, winter, and early spring months is essentially all derived from irrigation return flow.

Tables 1 and 2 show the estimated average water budget for the stream and the stream-aquifer system for the 15-year study period of 1947 through 1961. The importance of ground-water return flow and deep percolation of irrigation water can be seen in these budgets.

Table III-1

Average Annual Stream Water Budget for Study Area, 1947-61, Inclusive

Inflows	1000's of acre-feet
Streamflow[1/]	399.6
Prewitt Reservoir releases to stream[2/]	10.4
Tributary inflow[2/]	14.5
Ground-water return flow[3/]	225.2
Total	649.7
Outflows	
Streamflow[4/]	314.5
Canal diversions[2/]	332.4
Net evaporation from stream[5/]	2.8
Total	649.7

[1/] Measured streamflow at Balzac gaging station plus diversions by North Sterling, Prewitt, Johnson & Edwards, and Tetsel canals.

[2/] From U. S. Bureau of Reclamation (1965).

[3/] Calculated as remainder in balance equation.

[4/] Measured streamflow at Julesburg gaging station.

[5/] Estimated (1100 acres @ 2.5 ac-ft/ac).

Table III-2

Average Annual Combined Stream-Aquifer System Water Budget for Study Area, 1947-61, Inclusive

Inflows	1000's of acre-feet
Streamflow	399.6[1]
Ground-water flow in South Platte alluvium at North Sterling headgate	13.4[2]
Ground-water inflow from High Plains	75.0[3]
Deep percolation of irrigation water and precipitation to aquifer	221.0[4]
Tributary inflow (surface)	14.5[5]
Reservoir releases to stream	10.4[5]
Total	733.9

Outflows	
Streamflow	314.5[6]
Ground-water flow in South Platte alluvium at Julesburg	8.0[2]
Canal diversions	322.4[5]
Ground water pumped	22.8[5]
Phreatophyte and other ET from high water table areas	53.4[7]
Net evaporation from stream	2.8[8]
Total	733.9

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[1] Measured streamflow at Balzac gaging station plus diversions by North Sterling, Prewitt, Johnson & Edwards, and Tetsel canals.

[2] Calculated from data presented by Hurr et al. (1972).

[3] From Waltz and Sunada (1972).

[4] Calculated as remainder in balance equation assuming no change in storage.

[5] From U. S. Bureau of Reclamation (1965).

[6] Measured streamflow at Julesburg gaging station.

[7] Estimated (20,000 acres @ 2.67 ac-ft/ac).

[8] Estimated (1,100 acres @ 2.5 ac-ft/ac).

Irrigation water requirement

The amount of irrigation water required for optimum crop growth and production depends upon many factors including type of crop, stage of crop growth and climatic factors. Several methods are available for estimating irrigation water requirements. The method used in this study is commonly referred to as the Modified Blaney-Criddle Method as published by the USDA Soil Conservation Service (1967). This method is based upon correlations of field research on crop-water use with temperature, length of day, stage of crop growth and effective precipitation. Using these data and the coefficients recommended by the Soil Conservation Service, calculations of irrigation water requirements for each major crop grown in the study reach were made by weeks over the 15-year study period.

Colorado agricultural statistics for Logan and Sedgwick counties were used to estimate the percentage of each crop grown during each year of the 1947 through 1961 study period. These percentages were then used along with the Modified Blaney-Criddle analysis to estimate the total irrigation water requirements in the reach on a weekly basis. It should be emphasized that these figures represent an optimum or desirable amount of water each week and do not necessarily represent the amount of water actually received. A summary of the calculated annual irrigation water requirements per acre, using the appropriate crop mix for each year and measured climatological data at Fort Morgan, Sterling and Julesburg, is presented in Table 3.

Table III-3

Calculated Annual Irrigation Water Requirement per Irrigated Acre of Study Reach

Year	Ac-ft/ac
1947	1.46
1948	1.59
1949	1.58
1950	1.64
1951	1.30
1952	1.83
1953	1.69
1954	1.86
1955	1.64
1956	1.53
1957	1.49
1958	1.45
1959	1.76
1960	1.86
1961	1.34
Ave.	1.53

Water rights

Water rights in the study reach carry appropriation dates beginning with May 1, 1872, and extending to nearly the present time. Except for times of flood on the South Platte River, only the earliest of these water rights are in priority. The amount and distribution of direct-flow rights diverted between the Balzac and Julesburg gages which have appropriation dates senior to 1897 are given in Table 4. This table is arranged with the point-of-diversion locations in order from upstream to downstream along the top and priorities arranged from senior to junior along the left side; therefore, the resulting display of amounts of the rights provides a picture or graph of rights by location and priorities. It is readily apparent from the table that the most senior rights tend to be at the upper end of the reach, and the most junior rights at the lower end. As discussed earlier, such an arrangement is conducive to good reach efficiency in that the junior rights are able to take advantage of the return flows from the upstream senior diversions. For instance, the Liddle Ditch has very junior rights of 10 and 12 cubic feet per second, but is often able to divert all or most of this amount even when many of the upstream senior

TABLE III-4

Distribution of Direct-Flow Water Rights on South Platte River, Water District 64

Canals: / Approp. Dates (1800's)	South Platte (171.4 miles)1/	Farmers Pawnee (180.0 miles)	Davis Bros. (180.8 miles)	Schneider (185.6 miles)	Springdale (188.9 miles)	Sutton (190.9 miles)	Sterling No. 1 (191.9 miles)	Sterling No. 2 (195.3 miles)	Henderson & Smith (196.5 miles)	Lowline (198.8 miles)	Bravo (201.4 miles)	Farmers (Peoples) (202.5 miles)	Iliff & Platte V. (203.5 miles)	Lone Tree (204.9 miles)	Powell (213.0 miles)	Harmony No. 2 (214.4 miles)	Ramsey (218.4 miles)	Chambers (218.4 miles)	Harmony No. 1 (220.2 miles)	Harmony No. 3 (220.4 miles)	Tamarack (224.6 miles)	Settlers (228.3 miles)	Long Island (230.3 miles)	Hemmingway (231.7 miles)	Peterson (240.4 miles)	South Reservation (246.0 miles)	Liddle (248.2 miles)	Carlson (249.6 miles)	Colo.-Nebr. Compact Julesburg Gage (257.6 miles)	Total (cfs)	Accumulated Total (cfs)
3/01/72	22.50																													22.50	22.50
4/10/73				11.00 2/																										11.00	33.50
7/15/73							113.90																							113.90	147.40
9/17/73		14.40																												14.40	161.80
4/10/74			2.00 2/																											2.00	163.80
7/15/75			6.90	18.10																										25.00	188.80
3/15/76	7.50																													7.50	196.30
10/20/80			6.07	15.93																										22.00	218.30
11/30/80									12.50																					12.50	230.80
4/22/81		126.00																												126.00	356.80
10/14/82										39.90																				39.90	396.70
4/21/83	20.00																													20.00	416.70
10/01/83													150.00																	150.00	566.70
6/07/84								50.00																						50.00	616.70
7/19/86					62.50																									62.50	679.20
5/01/90	37.50																													37.50	716.70
12/01/90			3.00																											3.00	719.70
9/16/92																										25.00				25.00	744.70
2/21/93											40.00																			40.00	784.70
8/03/94																	12.00													12.00	796.70
9/17/94														10.00																10.00	806.70
9/20/94			20.00																											20.00	826.70
2/19/95															40.00															40.00	866.70
4/20/95																			252.00											252.00	1118.70
5/04/95																		30.00												30.00	1148.70
7/11/95												16.00																		16.00	1164.70
7/15/95														82.00																82.00	1246.70
4/01/96	50.00																													50.00	1296.70
3/01/97																50.00														50.00	1346.70
10/22/95 3/																											12.00			12.00	1358.70
10/21/95 3/																											10.00			10.00	1368.70
3/01/95 3/																									184.00					184.00	1552.70
8/14/97																													120.00	120.00	1672.70
Total (cfs)	137.50	140.40	37.97	45.03	62.50	--	113.90	50.00	12.50	39.90	40.00	16.00	150.00	92.00	40.00	50.00	12.00	30.00	252.00	--	--	--	--	--	184.00	25.00	22.00	--	120.00		
Accum. Total (cfs)	137.50	277.90	315.87	360.90	423.40	423.40	537.30	587.30	599.80	639.70	679.70	695.70	845.70	937.70	977.70	1027.70	1039.70	1069.70	1321.70	1321.70	1321.70	1321.70	1321.70	1321.70	1505.70	1530.70	1552.70	1552.70	1672.70		

1/ Figured from the South Platte River gaging station at Littleton, Colo.

2/ Meadow rights, limited to use from April 10 to July 10.

3/ Rights administered in order shown because of later adjudications.

rights do not have sufficient water physically available. Even though there are 1347 cubic feet per second of senior water rights upstream from the Liddle Ditch, because of the return-flow phenomena that ditch may be able to divert even when at times only 100 cubic feet per second is flowing by the Balzac gage.

The most junior appropriation date shown on Table 4 (June 14, 1897) has specific importance because of the compact between Colorado and Nebraska on the South Platte River. According to terms of the compact, if during the period between April 1 and October 15 of each year the flow at the Julesburg gage falls below 120 cubic feet per second, the compact puts a "call" on rights which are junior to that date within the Balzac to Julesburg reach in Colorado. As can be seen from the table, some 1550 cubic feet per second of direct-flow rights in this reach are senior to the compact date; so, in general, the rights junior to the compact are usually out of priority when the streamflow at Julesburg drops below 120 cubic feet per second. About six ditches in the lower 30 miles of this reach are the principal ones influenced by the compact terms.

Existing Efficiencies

Field and farm irrigation efficiencies

The field irrigation efficiencies and farm system irrigation efficiencies are most accurately determined for an area by actual field measurements. In an attempt to find what data were available and what efficiencies might be expected for the area, the following people were contacted.

(1) Mr. Floyd Brown, Colorado State University, retired. Mr. Brown was Extension Irrigation Specialist and worked for many years in the study area.

(2) Mr. Brice Boesch, Soil Conservation Service. Mr. Boesch is Irrigation Engineer for the study area and works out of the Denver office. He has had extensive experience on the Welton-Mohawk project (Arizona) on studies which are related to irrigation efficiencies and irrigation efficiency improvement.

(3) Mr. Don Brosz, Agricultural Technology Company. Mr. Brosz heads up the farm management services offered by this company out of their McCook, Nebraska, office. These services include recommendations for irrigation amount and timing.

(4) Mr. Rich Drew, Toups Corporation, Loveland. Mr. Drew, Project Engineer, is working on a related drought program, Conjunctive Surface Water/Ground Water Management Plan for Drought Relief in the South Platte River Basin.

(5) Dr. Dale Heermann, Agricultural Research Service, Fort Collins. Dr. Heermann has been working for several years on the management of center-pivot irrigation systems.

(6) Mr. Earl Hess, Soil Conservation Service, Denver. Mr. Hess is using the SCS Irrigation Methods Analysis (IRMA) computer program, the analysis and design of irrigation systems in the study area and other areas of Colorado.

(7) Mr. Keith Keppler, Toups Corporation, Loveland. Mr. Keppler has been working on a water management study near Loveland and has obtained field data on efficiencies.

(8) Dr. Eugene Maxwell, Colorado State University. Dr. Maxwell, Associate Professor of Earth Resources, has used satellite data in studies of the use of center-pivot irrigation systems in the study area.

(9) Mr. Charles Mitchell, Soil Conservation Service, retired. Mr. Mitchell was irrigation engineer for the South Platte River valley and had many years of field experience with irrigation.

(10) Mr. Earl Phipps, Northern Colorado Water Conservancy District. Mr. Phipps, Director, is familiar with the ditch systems in the study area.

(11) Mr. Elwin Ross, Soil Conservation Service, Greeley. Mr. Ross is Area Engineer for the study area.

(12) Mr. LeRoy Salazar, Colorado State University. Mr. Salazar is a master's candidate in the Department of Agricultural and Chemical Engineering. He directed a comprehensive study on farm irrigation efficiencies which was conducted on a farm near Lucerne (north of Greeley) during the summer of 1977.

(13) Mr. Walter Trimmer, University of Nebraska, Scottsbluff. Mr. Trimmer is District Extension Irrigation Engineer and is largely responsible for the irrigation scheduling portion of the AGNET system which is available to Nebraska farmers.

In the course of interviews with the above, it was recommended that we also interview Kenneth Ververs (SCS, Loveland), William Kipper (SCS, Julesburg) and Joseph Krib (SCS, Sterling). However, it was not possible to coordinate our schedules and theirs, so these interviews did not take place.

The interviewers arrived at several conclusions as a result of these interviews. It is clear that there is no definitive literature on irrigation efficiencies in the study area. Many investigations have been made in the past, and as a result of these some general trends are known. A few recent studies were completed which included measurements of runoff as well as deep seepage (through soil-moisture sampling). These were limited in scope, however, and give only isolated data points. However, as a result of these conversations, the following conclusions were reached by the writers.[1]

(1) The range of field irrigation efficiencies for the study area varied from an average low of 20 to 40 percent to an average high of 75 to 80 percent (surface irrigation).

(2) Field efficiencies will be higher when water availability is low (i.e., ratio of requirement to delivery is high).

(3) Field efficiencies will be affected by soils, topography and irrigation application depth in a manner which is generally known (see efficiency calculations below).

(4) Farm ditch losses may vary greatly depending upon length, soil and frequency of use.

(5) Field irrigation efficiencies for center-pivot systems in the study area can range from an average low of 63 percent to an average high of 83 percent, depending upon the level of management used (i.e., irrigation scheduling).

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[1] The conclusions drawn are those of the writers, based upon their interpretation of interviewee remarks. They are not necessarily the conclusions of the interviewees.

Establishing field input conditions. Soil associations were transferred to the computer model grid system from soil survey maps of Sedgwick and Logan counties (USDA, 1969; USDA, 1977). The soil series making up these associations were determined and evaluated as to texture and slope. Each grid point associated with an irrigation area (i.e., ditch) was identified by the appropriate soil association. The number of grid points of each soil association was tabulated for each irrigation area. The Soil Conservation Service intake family (USDA, 1974) was determined for each soil association, based upon its surface texture, using Figure 2. These intake families are the water intake rate of the soil in inches per hour at extended times. The soil series information gave information on land slopes. The average soil association properties for the study reach are summarized in Table 5.

Table III-5

Soil Association Average Properties
Lower Platte River Valley Irrigated Land, Colorado

Soil association	Plant available water (in.)	Slope (%)	Surface texture	Intake family (in./hr.)	Field irrig. eff.
2 L	8.4	1 - 3	loam	0.9	0.45
3 L	11.6	0 - 1	si. c. loam	0.6	0.55
4 L	5.3	5 +	l. sand	2.0	0.45
5 L	5.7	5 +	l. sand	2.0	0.45
7 L	5.4	5 +	f. s. loam	1.5	0.45
9 L	5.7	3 - 5	loam	0.9	0.45
11 L	10.7	5 +	loam	0.9	0.30
14 L	11.7	5 +	loam	0.9	0.30
2 S	11.0	1 - 3	loam	0.9	0.45
3 S	8.4	1 - 3	loam	0.9	0.45
4 S	4.4	5 +	f. sand	3.4	0.30
5 S	6.0	5 +	gravelly sa loam	2.0	0.45

Determination of initial values of farm irrigation system efficiencies. As indicated earlier, there is no information on farm irrigation system efficiencies which relate this parameter to slope, requirement and intake. However, it is recognized that the parameter is indeed dependent upon these

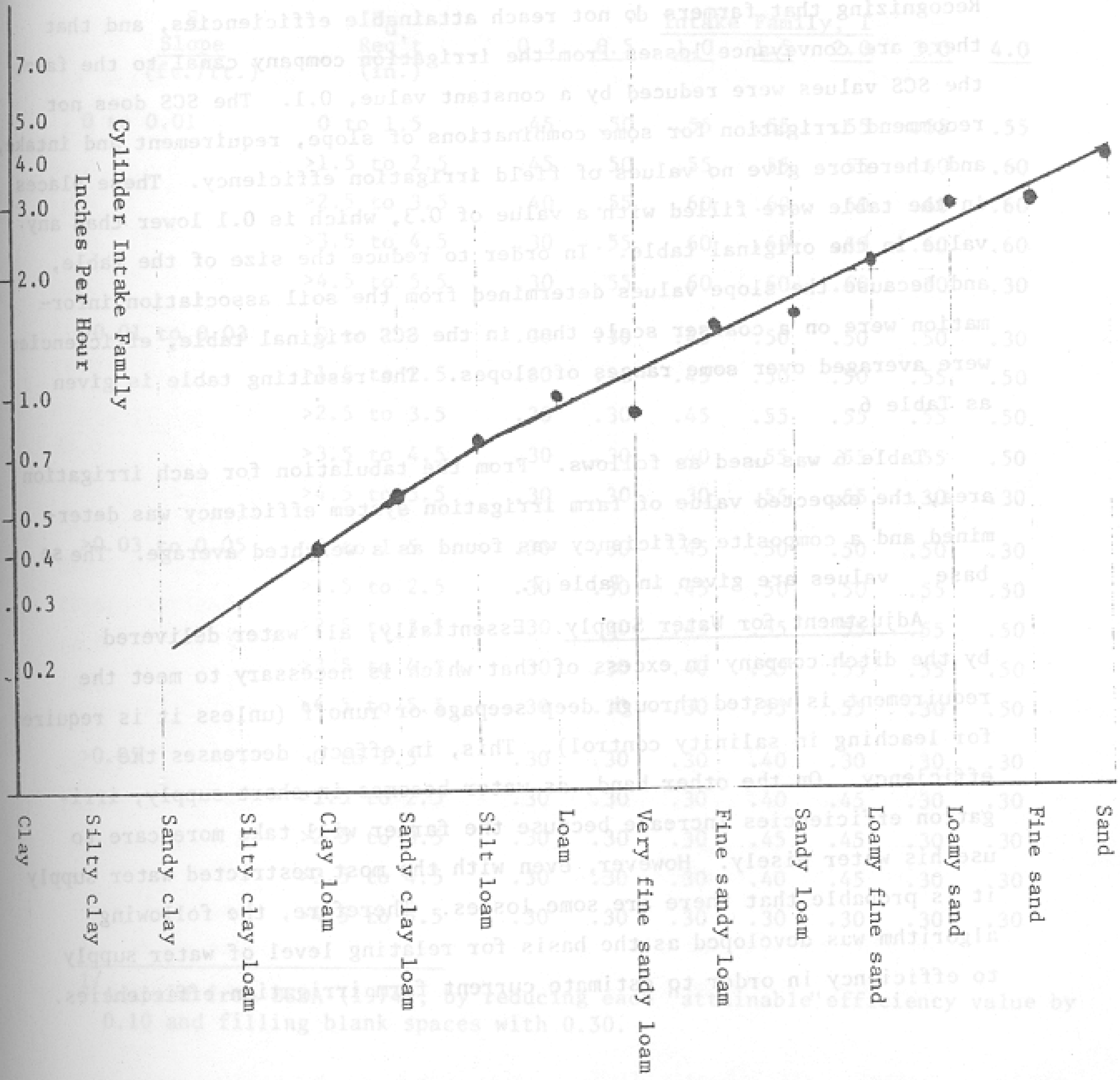

Figure III-2 Soil intake rates for various surface soil textures. (Adopted from Soil Conservation Service Engineering Handbook, USDA, 1974.)

factors. In order to arrive at a rational method of determining efficiency variations, the SCS recommendations for attainable field irrigation efficiencies under border irrigation were used as a base point (USDA, 1974). Recognizing that farmers do not reach attainable efficiencies, and that there are conveyance losses from the irrigation company canal to the farm, the SCS values were reduced by a constant value, 0.1. The SCS does not recommend irrigation for some combinations of slope, requirement and intake, and therefore give no values of field irrigation efficiency. These places in the table were filled with a value of 0.3, which is 0.1 lower than any value in the original table. In order to reduce the size of the table, and because the slope values determined from the soil association information were on a coarser scale than in the SCS original table, efficiencies were averaged over some ranges of slopes. The resulting table is given as Table 6.

Table 6 was used as follows. From the tabulation for each irrigation area, the expected value of farm irrigation system efficiency was determined and a composite efficiency was found as a weighted average. These base values are given in Table 7.

Adjustment for Water Supply. Essentially, all water delivered by the ditch company in excess of that which is necessary to meet the requirement is wasted through deep seepage or runoff (unless it is required for leaching in salinity control). This, in effect, decreases the efficiency. On the other hand, as water becomes in short supply, irrigation efficiencies increase because the farmer will take more care to use his water wisely. However, even with the most restricted water supply it is probable that there are some losses. Therefore, the following algorithm was developed as the basis for relating level of water supply to efficiency in order to estimate current farm irrigation efficiencies.