Management Guidelines for Controlling Sediments, Nutrients, and Adsorbed Biocides in Irrigation Return Flows

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ABSTRACT

Sediments in irrigation return flows arise mostly from furrow erosion, and nearly all nutrients and biocides in surface irrigation return flows, except those applied directly to the water, are adsorbed to the sediments. Therefore, controlling erosion and sediment loss in these surface return flows also controls the nutrients and biocides. There are three general management approaches for controlling sediments in return flows. The first is to eliminate surface runoff by using irrigation methods that produce no runoff. These methods include properly designed and operated sprinkler systems, basin, trickle, and some border and level furrow methods. The second approach is to eliminate or reduce erosion by controlling the slope in the direction of irrigation, the furrow stream size, the run length, the irrigation frequency and duration, and tillage practices. The third is to remove sediments from surface return flows by controlling the tailwater and utilizing sediment retention basins. All three approaches are applicable and necessary for adequate control in most irrigated areas. Available technology needs to be integrated and applied to these approaches. Research to develop improved irrigation systems and methods, improved irrigation water distribution systems, and better field management practices, and research on design and operational criteria for sediment retention basins are needed.

INTRODUCTION

Surface irrigation return flow is that portion of the irrigation water applied to soil which passes over the soil surface and becomes runoff. It usually includes direct spill from canals and water that flows through farm ditches but is not applied to the land. Typically, 10 to 30 per cent of the water applied to furrow irrigated land becomes surface runoff. Surface irrigation return flow can also result from irrigation by wild flooding, some border systems and where sprinkle systems apply water more rapidly than the infiltration rate on sloping soils. Only a small portion of the total surface irrigation return flow results from these latter three irrigation methods. No surface runoff results when the water application rate is equal to or less than the infiltration rate. Such application rates can be achieved with properly designed sprinkle irrigation systems and with trickle systems, but the energy requirements of sprinkle systems and the expense of trickle systems limit their use. In contrast to sprinkle irrigation where the entire soil surface is the infiltrating area, only the furrows are the infiltrating area for furrow irrigated land. Furthermore, the furrows also serve as conveyance channels to supply water to the down slope portions of the field. Surface irrigation return flows do not occur with subsurface irrigation or with certain border and furrow methods that confine applied water to a given area, including pumpback systems.

Water passing over the soil surface has limited contact and exposure to the soil at the soil surface, and flow at the interface is into the soil. Therefore, the quantities of soluble salts, fertilizer nutrients and pesticides dissolved or washed off the soil into the water flowing over the soil surface are expected to be extremely small. This is particularly true where water is confined to furrows and contacts only a portion of the land surface. Such water does pick up debris, crop residue, applied manure residue, nematodes, plant pathogens and other foreign matter that tends to be floated away by water. When erosion occurs, the most important material picked up is soil and material attached to it. Soil picked up in the erosion process is usually referred to as suspended sediment or sediment.

Erosion of irrigated land has been recognized as a serious problem for many years. Isrealson, et al. (1946) stated that excessive erosion of irrigated lands was adverse to the perpetuation of permanent agriculture in arid regions. Gardner and Lauritzen (1946) reported that it was apparent to every farmer that serious damage resulted when attempting to irrigate steep slopes unless the stream was very small. They recognized that little erosion occurred on lands with gently slopes even with relatively large stream sizes. These observations led them to suggest the vital importance of finding a means to estimate the rate at which soil would erode with various stream sizes at various slopes.

Today, 30 years later, furrow irrigation on steep slopes with stream sizes that are too large, resulting in serious erosion is still commonly observed. Much technology has been developed to control erosion of irrigated land and to reduce sediment concentrations in surface irrigation return flows, but it has not been applied.

There is a need to apply available technology and to develop new technology for reducing erosion and sediment loss from irrigated lands. The purposes of this paper are to provide an overview and an assessment of the problems associated with sediment and adsorbed nutrients and biocides in surface irrigation return flows, to assess currently available technology for implementing control measures, and to suggest research and demonstration needs to develop and apply improved control technology.

Erosion on Irrigated Land

Whenever water flows over cultivated land, erosion may occur. Factors influencing the amount of erosion include: (1) the slope in the direction of irrigation; (2) the stream size; (3) the soil texture; (4) the condition of the soil surface; (5) the duration of the irrigation; and (6) the crop. Most erosion on irrigated land results from furrow irrigation, and basically is erosion of the furrows. Isrealson, et al. (1946) reported that furrows near the head ditches eroded 2.5 to 10 cm in sugarbeet fields. Mech (1959) reported soil losses of 50 metric tons/hectare during a 24-hour irrigation of corn on a fine sandy loam soil on a 7 per cent slope. He further stated that even on relatively flat fields with short runs, 30 cm of surface soil have sometimes been lost after about 10 years of cultivation and irrigation. Similar results have been reported in the 1970's on Portneuf silt loam planted to dry beans, sugarbeets, potatoes and corn.

Each furrow on furrow irrigated land functions as the absorbing surface and as a channel for conducting water to irrigate the remaining length of run (Mech and Smith, 1967). Therefore, the stream size at the head of the furrow must be sufficient to meet the infiltration requirements over the entire furrow length and to propagate the stream to the end of the furrow fast enough to give a reasonably uniform distribution throughout the length of run; ideally, it should not exceed that size. Obviously, larger streams are required to irrigate longer runs. But larger streams have greater energy to erode soils and transport sediment on sloping lands, and thereby cause more erosion. More erosion is expected near the heads of the furrows where runs are long because that is where the stream size is largest. Practically, short irrigation runs have not been used because cross ditches interfere with tillage, seeding, cultivating and harvesting operations. Also, shorter irrigation runs require more labor for irrigation. Also, it is difficult to control stream size so that just enough water is added to meet infiltration needs because the infiltration rate usually changes during irrigation. As a result of these practical factors, irrigation runs are usually longer and furrow stream sizes are larger than needed, and erosion results, particularly at the heads of the furrows.

Characteristics of flow and silt load along irrigation furrows in two closely controlled tests were reported by Smith and Mech (1967) (Table 1). The flow was carefully controlled into each furrow and the runoff and sediment loss was measured from the upper, middle and lower third of each furrow. The run length was 274 m and the slope was 2 per cent. The flow into each furrow was about 15 per cent greater in test 2 than in test 1. Results of these studies clearly illustrate that erosion was greatest where stream size was largest. Soil eroded from the upper third was deposited in the middle and lower thirds as the stream size, and thereby the energy to erode and the capacity to transport sediment, decreased because of infiltration. Results from these studies contrast to erosion resulting from rainfall which is usually more severe down slope where stream sizes are large enough to erode and where slopes are greatest.

The common practice on many furrow irrigated farms today is to place a large enough stream in each furrow so that the water reaches the lower end of the furrow in about 2 or 3 hours for a 12- or 24-hour set. This usually allows sufficient infiltration time to replenish water depleted by the crop without reducing the stream size or requiring labor during the set. With this practice, stream sizes are often large and 40 to 60 per cent of the applied water becomes runoff, and erosion is extensive.

Another serious erosion problem is associated with the common practice in some irrigated areas of keeping the drain ditch at the lower end of the field 10 to 20 cm deeper than the furrows and at a slope steep enough that the tailwater flows rapidly away. With this practice, the ends of the furrows erode rapidly, even with very small streams. This erosion moves up the slope because erosion increases the effective slope near the end of the furrows. As the process continues, the slope is increased on the lower 5 to 10 m of the field, making it difficult to control erosion and soil loss from this portion of the field, and to achieve adequate intake because of smaller wetted perimeters. The lower ends of fields may have to be reshaped every few years because of this practice. This type of erosion is easily controlled by proper tailwater management.

Many fields with steep slopes are irrigated, and usually in the direction of the steepest slope, even though it has been recognized for decades that serious erosion results from such practices. Isrealson, et at. (1946) demonstrated over 30 years ago that increasing the slope from 1.15 to 6.07 per cent increased the erosion 16 times. About that same time, Gardner, et al. (1946) and Gardner and Lauritzen (1946) presented relationships among furrow slope, stream size and erosion. Unfortunately, irrigation farmers gave little attention to these results.

Following the early work in Utah, the USDA-SCS Division of Irrigation conducted many tests throughout the western U. S. and developed the relationship:

Max. Non-Erosive Stream Size,

$$\text{l/sec} = \frac{0.63}{\text{Slope, \%}} \quad (1)$$

Evans and Jensen (1952) and Mech (1949) studied the effects of stream size, slope, and soil surface conditions on erosion. All of the work to date suggests that erosion may be expected on most row-cropped soils when slopes exceed 1 per cent. Erosion may be controlled reasonably well on slopes up to 2 per cent if the stream size is carefully controlled.

Public Law 92-500 has increased the interest among farmers and irrigation districts to control erosion and sediment in surface return flows. Many questions raised about erosion and sediment loss indicate that few irrigators and other personnel associated with irrigation have a good concept for visual determination of erosion in furrows. Carter and Bondurant (1976) presented a simple equation to estimate soil erosion:

$$\text{Soil erosion, } \frac{t}{ha} = \frac{1.2 \times \text{eroded area, cm}^2}{\text{furrow spacing, m}} \quad (2)$$

Equation (2) assumes a soil bulk density of 1.2 g/cm^3 or t/m^3. They also presented a nomogram for estimating erosion losses in English or metric units.

Sediment in Surface Irrigation Return Flows

Sediment concentrations in surface irrigation return flows vary widely. Brown, et al. (1974) reported concentrations ranging from 20 to 15,000 ppm from studies of two large irrigated tracts in southern Idaho (Table 2). Sediment concentration in the canal waters are given for comparison. The sediment concentrations in most surface drains exceed those in the irrigation water several fold. an exception is the W drain, which functions as a sediment retention basin with a long retention time. The sediment loss from a field or an irrigation tract is determined by the volume of surface runoff and the sediment concentration. Brown, et al. (1974) reported a net sediment inflow for the 65,350-ha Northside tract and a net sediment outflow for the 80,030-ha Twin Falls tract. There was erosion on both tracts, but most of the sediment settled in drains on the Northside tract, whereas, much of the sediment reaching drains on the Twin Falls tract was carried to the river because flow velocities in the drains were greater and sediments did not settle and deposit in the drains.

Nutrients in Surface Irrigation Return Flows

Nutrients in surface irrigation return flows are in dissolved forms, or they are attached to sediments eroded from the land. Bondurant (1971) showed mathematically that little soluble nutrient pickup could be expected to result from nutrient diffusion out of the soil into water passing over the soil surface, and he presented field data to verify his contention. Carter, et al. (1971) found that soluble nutrient and salt concentrations in surface irrigation return flows were essentially the same as those in the applied irrigation water. Edwards, et al. (1972) stated that once nitrate enters the soil surface, it does not re-enter surface runoff. Fitzsimmons, et al. (1972), Naylor and Busch (1973) and Carlile)1972) reported that nitrate and ammonium nitrogen concentrations were about the same in surface runoff as in the irrigation water. Naylor, et al. (1972) illustrated that nitrogen concentrations in surface irrigation return flows from fields can be markedly increased when liquid nitrogen is added to the irrigation water for fertilizing the crop. Fertilizer losses in the surface runoff from this practice were proportional to the fraction of the applied water that became surface runoff during the fertilizer application. In these studies, the soluble nitrogen was added directly to the water, increasing the soluble nitrogen concentration in the irrigation water. The concentration did not change as the water passed over the soil surface.

Phosphorus is tightly held by soil, and essentially all phosphorus in surface irrigation return flow is associated with sediment. Carter, et al. (1974) and Carter, et al. (1976) have extensively studied phosphorus-sediment relationships in irrigation return flows, and their results show that total phosphorus and sediment concentrations in surface runoff are closely related, but that no such relationship exists between soluble orthophosphate and sediment concentrations. They developed a regression equation relating total phosphorus concentration to sediment concentration over a wide range of conditions. Fitzsimmons, et al. (1972) and Naylor and Busch (1973) attributed greater total phosphorus concentrations in surface irrigation return flow than in irrigation water to the greater sediment concentration in the runoff water. Data reported by Carlile (1972) also illustrate the close relationship between sediment and total phosphorus concentration.

Results from many investigations show conclusively that increases in nutrient concentrations from the irrigation to the surface runoff water are closely associated to erosion and subsequent increase in the sediment concentration in the surface runoff water. Therefore, controlling the sediment in surface irrigation return flows will also control most of the nutrients.

Biocides in Surface Irrigation Return Flows

There is little published information on biocide concentrations in surface irrigation return flows. There is considerable information available on biocide concentrations in surface runoff from nonirrigated lands. A review of the literature indicates that except where biocides are applied to the water, or where they are washed off plant material in soluble forms by rain or by sprinkle irrigation, the biocides in surface runoff water are adsorbed to sediments (Evans and Duseja, 1973). Unpublished data from analyses of surface drainage waters and sediments from the Northside and Twin Falls tracts show that essentially all of the biocides are adsorbed to sediments (Carter, 1975). The available information indicates that controlling sediments in surface irrigation return flows will also control most of the biocides.

Controlling Sediments and Associated Nutrients and Biocides in Surface Irrigation Return Flows

There are three broad general ways to control sediments and associated nutrients and biocides in surface irrigation return flows. One is to eliminate or reduce surface irrigation return flow. The second is to reduce or eliminate soil erosion so that there will be little or no sediment in surface runoff from irrigation. The third is to remove sediments and associated materials from surface irrigation runoff before these waters enter natural streams. If runoff can be eliminated, obviously there would be no need for the second and third general ways of control. Any farmer or irrigation district making sufficient progress on the first two ways, so that sediment and associated material concentrations are reduced below problem levels, will no longer need to consider the third way. Such progress should be the aim of irrigated agriculture, with the recognition that many years may be required to achieve this goal. However, much immediate progress could be made if presently available technology were applied (Carter, 1972).

Eliminating or Reducing Surface Irrigation Return Flows

There are irrigation methods that produce no surface runoff. These include properly designed and operated sprinkle sytstems, basin, trickle, some border irrigation and level furrow systems. These methods all have limitations. Basin, border and level furrow methods are limited to nearly level land. Capital investment is high for center pivot, side roll and solid set sprinkle systems and even higher for trickle systems. Furthermore, energy requirements for sprinkle system operation are high and energy is limited. Batty, et al. (1975) compared energy inputs involved in the installation and operation of various sprinkle and surface irrigation systems and found that on a total annual energy basis, surface systems required only 10 to 22 per cent as much energy as sprinkle or trickle systems where some pumping was required for surface systems (Table 3). Energy requirements for gravity surface systems would be less than for those requiring pumping energy.

Sprinkle irrigation is an efficient means of applying water and can be used on lands too steep for surface irrigation and lands with undulating topography. The land area under sprinkle irrigation is rapidly increasing, but energy restraints may limit development in some areas. Certainly, utilizing sprinkler systems where practical can eliminate or reduce surface return flows. However, larger center pivot systems apply water at high rates and may cause serious runoff problems (Pair, 1968)).

The recirculating or pump-back system described by Bondurant (1969) and others (Davis, 1964 and Pope and Barefoot, 1973) is a useful method for eliminating, or greatly reducing, surface irrigation return flows from farms. This method uses a basin or pond at the lower end of the field to catch surface runoff. A pump returns the water to the upper end of the field or to another field for reuse as irrigation water. Erosion is not eliminated and sediments deposited in the basins must be removed mechanically, but sediment is prevented from leaving farms and entering natural streams.

Carter and Bondurant (1976) have summarized and discussed irrigation methods with little or no surface runoff in more detail. They point out that eliminating or greatly reducing surface irrigation return flows may cause other problems in the irrigated West. Many farmers depend wholly or in part upon surface return flows from upstream irrigated farms or tracts for their irrigation water supply. Many surface irrigated tracts operate on a reuse principle so that the only water entering streams is surface runoff from the farms at lowest elevation in these tracts.

Eliminating or greatly reducing surface runoff is a means to control sediments and associated materials in surface irrigation return flows in some areas, but changing to irrigation practices with no runoff would, in many instances, cause other problems and require costly changes in system design and operation. Where changes are practical, they should be implemented.

Reducing or Eliminating Erosion

Controlling Slope

Land slope greatly influences erosion. Results of many investigations have shown that erosion may be expected on most row cropped soils where slopes are 1 per cent or more (Mech, 1959; Mech and Smith, 1967; Swanson, 1960; Swanson and Dedrick, 1967; Harris and Watson, 1971). Erosion may be controlled reasonably well up to slopes of 2 per cent, but fields with slopes greater than 2 per cent should be examined carefully to see if they can be irrigated by different methods. Changing the direction of irrigation to one of lower slope, contour irrigation and land grading to reduce the slope near the lower ends of the fields to decrease flow velocity are possible ways of controlling slope. These changes are not without problems. Farmers resist contour farming because usually short rows result, thereby adding difficulty to farming operations with large equipment.Grading to decrease the slope and flow velocity usually causes furrows to fill with sediment and flooding or lateral flow between furrows results. Nevertheless, where slopes can be reduced to 1 per cent or less, the amount of erosion and sediment loss can be reduced.

Controlling the Furrow Stream Size

Excessive stream sizes cause serious erosion on sloping land (Mech, 1959; Mech and Smith, 1967). Devices that positively control the amount of water from the pipeline, flume or ditch into each furrow are essential to effective erosion control and efficient irrigation. Most valves, gates, siphon tubes, and other flow control devices permit small flow adjustments that remain unchanged until reset. This equipment is available, but is often not used or used incorrectly.

A greater initial flow is often desired to get the water to the end of the furrow and allow a uniform intake time. Once the water reaches the end, the flow should be reduced or cutback to decrease erosion and runoff. However, when the stream size is reduced for a given water set, the excess water from the set after cutback must be used elsewhere or wasted in most systems with open ditches. Applying it to other sections of the farm would require that irrigation sets be made several times each day, and this conflicts with other farming operations. Humpherys (1971) developed several systems for reducing flows in furrows after water has reached the ends. One system splits the set, applying all the water alternately to half the set until water reaches the ends of the furrows, then applies the water to the entire set so that flow in each furrow is one half the amount initially.

Much can be done with present technology to reduce erosion by controlling stream size. Further development and application of automated systems with proper stream size control would bring about a marked reduction in erosion and sediment loss from furrow irrigated land.

The Run Length

The run length and furrow stream size are closed related. Short runs can be irrigated with small streams with very little erosion and sediment loss, but cross ditches interfere with farming practices. The multiset systems developed by Rasmussen, et al. (1973) provide an alternative to cross ditches for shortening the run length. Aluminum or plastic pipe distributes water at several points along the furrows so that small streams are used and erosion and runoff is essentially eliminated. Pipes are moved for tillage, seeding and harvesting operations.

Worstell (1975) field tested an adaptation of the multi-set systems with buried laterals so farming operations could be carried out without moving pipe. The system is fully automated and can be programmed to apply water daily according to ET depletion, or less often if desired. Initial results are promising, but further testing is needed. These kinds of systems have great potential for controlling stream size or length of run. With such systems, erosion and sediment loss can be essentially eliminated and irrigation efficiency can be greatly increased.

Controlling Irrigation Frequency and Duration

Erosion and sediment loss are highest during the early part of an irrigation after soils have been disturbed by cultivation. Mech (1959) reported a soil loss of 39.9 t/ha from a recently cultivated corn field during the first 32 minutes runoff. The total soil loss for a 24-hour irrigation was 50.9 t/ha, and it occurred during the first 4 hours even though runoff increased after that because of decreasing intake. Less erosion would occur with less frequent irrigations, particularly when irrigations follow cultivations.

Alternate furrow irrigation is another practice to reduce erosion. Only half as much soil surface is contacted by water and erosion is less. However, the success of alternate furrow irrigation depends upon soil conditions. Some soils do not permit adequate lateral water movement, or deep percolation losses may be too great during the increased time required for lateral movement.

Removing Sediment and Associated Nutrients and Biocides From Surface Irrigation Return Flows

Controlling tailwater

The most important factor in controlling tailwater is to limit the amount of runoff. The smallest stream that will irrigate to the end of the furrow will add nearly as much water to the soil as a larger stream, and the amount of runoff water will be much less and more easily controlled. Practices that will assure more uniform intake rates of individual furrows need to be developed and utilized for better runoff control.

The drain ditch at the lower end of the field should be shallow and at a low slope, or checked so that water moves slowly and sediments settle out before the water leaves the field. Checking the drain ditch forms miniature sediment basins. Brockway, et al. (1976) found that mini-basins receiving runoff from a few furrows each, effectively controlled sediment losses.

Passing tailwater through grass or other close growing crops efficiently filters sediments from water. Grass buffer strips, heavy seeded fall grain strips, or alfalfa at the ends of row cropped fields, can greatly reduce sediment losses. Another alternative is to utilize runoff from row crops to irrigate alfalfa, pasture or other close growing crops.

Utilizing Sediment Retention Basins

Much of the sediment in surface irrigation return flows can be removed in sediment retention basins. The need to remove sediments from surface irrigation return flow will continue for many years even though much can be done to reduce erosion and sediment loss from irrigated fields. Basins are a partial cure to the sediment problem, not a prevention. Their construction and periodic cleaning are relatively expensive.

The effectiveness of simple sediment retention basins is illustrated by a 0.45-ha basin removing 2390 t of sediment during two irrigation seasons from part of the runoff water from a 117-ha tract. The erosion loss was 20.5 t/ha. The sediment removal efficiency exceeded 80 per cent when the sediment concentration exceeded 0.1 per cent and it was never less than 65 per cent (Robbins and Carter, 1975).

The trapping efficiency of sediment basins is directly related to the forward velocity, settling depth and particle size of the sediment. Basins can be designed to remove given particle sizes if the flow volume is known so that velocity relationships can be established. The trapping efficiency of one district basin designed to remove at least 50 per cent of the incoming sediment has not been less than 65 per cent over 5 years (Brown, 1977). More information on design criteria is needed and some is being developed and tested currently (Bondurant, et al. 1976).

Particle size segregation takes place as sediments settle in basins. Sediments remaining in suspension are mostly in the clay size fraction, although much clay settles in aggregates because dispersion is not complete. Dispersion is greater in waters with very low salt concentration, and more clay remains suspended. The clay size fraction is richer in phosphorus, so passing surface runoff through a sediment retention basin can give an apparent phosphorus enrichment when phosphorus is measured per unit of suspended material. However, sediment retention basins conserve phosphorus because most of the sediment is removed by the basins (Carter, et al. 1974).

The use of sediment retention basins can be discontinued for any field, farm or district where implementation of erosion control practices have eliminated excessive sediment concentrations in the surface irrigation return flow. Also, use of basins may not be needed every season, depending upon the crops grown. Non use during one or more seasons when close growing crops are grown would allow the collected sediment to dry and time for cleaning.

CONCLUSIONS

The quantity of sediment and associated nutrients and biocides in surface irrigation return flows could be reduced significantly by applying presently available control technology. There are restraints to direct application of some practices such as the energy limitation for converting to sprinkle irrigation, and the dependence of some farmers on the surface runoff from upstream farms or tracts for their supply or irrigation water. The development of irrigation methods with precise flow controls that distribute water over the entire field with little or no runoff and with low energy requirements should receive top priority. The buried lateral multiset system is an example of systems that might be developed and improved. The basic relationships among stream size, flow velocity, erosion, sedimentation, run length and

TABLE 1

Water Flow and Soil Loss along Irrigation Furrows (Mech and Smith, 1967).

Distance from upper end		Flow per furrow per minute		Soil loss per furrow		Runoff	Travel Time: From point of application	Travel Time: For 91-m (300-ft) distance
m	ft	liters	gal	kg	lb	%	min	min
				Test no. 1				
0	0	26.6	7.03	0	0		0	
91	300	17.0	4.49	43.3	116	61	48	48
183	600	7.3	1.94	4.8	13	21	244	163
274	900	2.5	0.67	0.4	1	2	632	471
				Test no. 2				
0	0	30.6	8.08	0	0		0	
91	300	20.7	5.46	51.1	137	65	24	24
183	600	11.9	3.14	14.2	38	35	98	74
274	900	5.4	1.42	0.7	2	8	436	339

sediment settling velocity need to be integrated into new technology that will permit modification of various control parameters. New ideas are needed, and new and better water control systems need to be developed.

TABLE 2

Sediment Concentrations in Irrigation and Drainage Waters For Two Large Tracts During the 1971 Irrigation Season.

Drain	*Sampling Date*												
	Northside Canal Company, 65,350												
	4/20	5/3	5/17	5/28	6/7	6/15	6/29	7/13	7/26	8/10	8/24	9/8	9/28
	Sediment Concentrations in parts per million												
K	240	190	270	140	200	160	110	120	90	90	90	40	40
N-32	380	100	150	120	170	90	70	30	180	20	20	60	50
J-8	1,580	1,430	2,610	510	660	680	300	80	170	110	70	100	110
S	320	350	110	140	100	200	440	110	130	90	60	130	140
W-26	160	80	100	60	100	130	100	60	160	100	40	50	50
W	160	50	60	30	30	40	20	20	30	20	20	10	40
	Twin Falls Canal Company, 82,030 ha												
				5/25	6/2	6/15	6/29	7/13	7/26	8/10	8/24	9/8	9/28
	Sediment Concentrations in parts per million												
Rock Creek	—	—	—	540	300	140	190	310	320	390	200	120	150
Cedar Draw	—	—	—	200	210	100	120	220	550	520	330	150	200
Filer Drain	—	—	—	710	400	210	710	2,250	2,120	110	820	270	290
Mud Creek	—	—	—	260	180	140	130	120	200	190	250	260	130
Deep Creek	—	—	—	200	110	70	80	60	70	110	10	100	90
			4/20	5/14	5/26	6/23	7/6	7/20	8/3	8/17	9/2	9/16	10/5
Hansen Drain	—	—	—	1,550	380	510	3,180	14,500	4,970	290	3,160	280	—
Kimberly Drain	—	—	4,180	1,080	360	610	2,860	1,420	4,960	180	150	70	40

Canal Water, Monthly Average Concentrations

	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
Northside	63	63	29	37	33	26	26	26	—
Twin Falls	74	40	52	85	55	29	29	29	29

TABLE 3

Total Annual Energy Inputs, in Thousands of Kilocalories (or Gallons of Diesel Fuel) Per Acre Irrigated for Nine Irrigation Systems, Based on 36-in. (915-mm) Net Irrigation Requirement and Zero Pumping Lift (Batty, et al., 1975).

Irrigation system	*Installation energy*[a]	*Pumping energy*	*Installation per pumping energy ratio*	*Labor energy*	*Total energy*
Surface without Irrigated Runoff Recovery System	103.2	35.2	2.93	0.50	138.9 (15.0)
Surface with Irrigated Runoff Recovery System	179.9	48.0	3.75	0.30	228.2 (24.6)
Solid-set sprinkle	614.1	770.0	0.80	0.40	1,384.0 (149.5)
Permanent sprinkle	493.6	770.0	0.64	0.10	1,263.7 (136.5)
Hand-moved sprinkle	159.7	804.0	0.20	4.80	968.5 (104.6)
Side-roll sprinkle	200.3	804.0	0.25	2.40	1,007.1 (108.8)
Center-pivot sprinkle	383.5	864.0	0.45	0.10	1,252.6 (135.3)
Traveler sprinkle	288.9	1,569.0	0.18	0.40	1,858.0 (200.7)
Trickle	530.5	468.0	1.13	0.10	998.6 (107.8)

[a]These figures were obtained by dividing the installation energy by the system life and by the net acres irrigated and multiplying by 1.03 to include annual maintenance energy for all systems except for solid set where 1.01 was used.

Conversion factors: 1 kcal = 4.19 kJ; 1 kcal = 0.000108 gal of diesel.

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