EROSION AND SEDIMENTATION ON IRRIGATED LANDS

J. A. Bondurant*
Member ASAE

Abstract: Most erosion on irrigated land is caused by the irrigation itself. Surface irrigation--where water is applied directly to the surface as in furrow or border irrigation--can be very erosive. Data from southern Idaho show that large quantities of sediment may be generated within an irrigation system; however, less sediment may be returned to the river than is diverted with the water supply. Technology for reducing erosion from irrigated fields is available: irrigation systems may be modified or changed, fields may be leveled or profiled to nonerosive slopes, tillage operations can be reduced, vegetative filter strips and drain ditch elevation control will remove sediment, or sediment ponds may be used after runoff leaves the field.

Erosion and sedimentation are active processes on much of the irrigated land of the United States. Erosion may be caused by rainfall or wind, but the bulk of the erosion on irrigated land is caused by the irrigation itself.

EROSION SOURCES

Rainfall

A major part of the irrigated land of the United States lies in the arid West where rainfall erosion is seldom a problem. Where significant rain does fall during the irrigation season it must be considered in the system's design so that furrows will be large enough to conduct the resulting flow. Rain falling on an irrigated field may cause more runoff erosion than will the irrigation.

Wind Erosion

Wind erosion is a problem on some irrigated as well as nonirrigated lands and results generally from one of two situations. Noncohesive soils, such as sands and fine sandy loams, tend to erode easily. On cohesive soils, wind erosion results from improper tillage practices and is usually an indication that the soil has been worked too fine and left unprotected. For example, smoothing a field with a land plane breaks the soil down, and the high percentage of very fine particles left on the soil surface are then subject to wind erosion. This erosion can usually be controlled by tillage with a spike-tooth harrow immediately after the leveling operation.

Wind erosion on sandy soils is usually best controlled by use of cover crops planted during the off-crop season. Wheat, rye or a similar crop planted in the fall protects the land from blowing during the winter and spring. At planting time the cover crop is either disked under, selectively tilled for seeding rows, or killed by herbicides.

*Agricultural Engineer, Snake River Conservation Research Center, Agricultural Research Service, Kimberly, Idaho 83341.

Erosion from Sprinklers

Some water runs off under sprinkler irrigation, particularly at the outer end of large center pivot systems. Generally this occurs where the water application rate is much higher than the soil's infiltration rate. The application rate from a sprinkler system may be as high as 9 cm/hr (3½ in/hr) as the lateral passes over a given spot. This application rate (and sometimes the volume) may be equivalent to a 100-year rainfall event. However, since the area covered is small compared to that covered by a general storm, the total runoff is relatively small.

Erosion from Surface Irrigation Systems

Most erosion and sediment problems arising from irrigation or on irrigated lands originate with the practice of surface irrigation where the water is applied directly to the soil surface under gravity flow. Erosion of irrigated land has long been recognized as a serious problem. Israelson, et al. (1946) in Utah concluded that erosion would have to be controlled if permanent irrigated agriculture were to exist. Probably erosion has been a problem ever since irrigation has been practiced.

The extent of erosion and sediment problems in irrigated agriculture has been estimated for years. Recently, two large irrigated tracts in southern Idaho were studied to obtain a water and sediment balance (Brown, et al. 1974). On the 82,030-hectare Twin Falls tract 75,820 metric tons of sediment were diverted from the Snake River into the irrigation system and 113,610 tons were returned to the Snake River with the surface runoff water. An estimated 78,000 tons were removed mechanically during the year from the canal system. On the 65,350 hectare Northside Canal Company project, 57,250 metric tons of sediment were diverted from the Snake River into the irrigation system and 12,080 metric tons were returned to the river in the runoff water. The Northside Canal Company estimated that 295,000 metric tons of sediment are removed mechanically each year from their system. On the Northside tract the soil loss from the fields was about 4.0 metric tons/hectare/year as opposed to about 1.42 metric tons/hectare/year on the Twin Falls tract. More erosion occurs on the Northside Canal Company lands because the land is sandy and steeper; however, the canal system itself is generally flatter and the areas where the drains return to the Snake River are much flatter. Sediment ponds are used to catch the sediment on some return drains. On the Twin Falls tract the field slopes are less but the drain slopes are steeper so that sediment that does get to a drainage system usually returns to the river. Erosion varies over both of the areas. On the Twin Falls tract, 11.4 metric tons/hectare were measured leaving one 1400-hectare (3500-acre) subbasin.

CONTROL TECHNOLOGY

Erosion reduction and sediment control on irrigated lands may generally be improved by (1) modifying the present system and system management, (2) changing to a less erosive irrigation system, or (3) controlling the sediment after it leaves the field. Combinations of these techniques may be used on any particular field.

When comparing erosion losses from furrow, corrugation, and border and basin methods, the bulk of the erosion occurs with the furrow and corrugate types of irrigation. Efficient furrow irrigation can be obtained by using a nonerosive stream size and matching the stream size and length of run so that the stream will advance through the field in approximately one-fourth of the total time of irrigation. When runoff begins, the stream should be cut back to about equal the infiltration in the furrow. This reduces surface runoff and erosion. An approximate relationship for maximum nonerosive stream size and furrow irrigations has been given in USDA Handbook 82 (Criddle, et al.,

1956) as:

$$\text{Max. nonerosive stream, } \ell/\text{sec} = 0.63/\text{slope, } \% \left(\text{gpm} = \frac{10}{\text{slope}}\right).$$

Although these relationships and ideas have been known for many years, not all farmers accept them. Farmers do not like shortened run lengths because they require additional cross ditches which take up space, are hard to maintain, and increase the tillage time. There also is the problem of what to do with the rest of the water flow when the stream is cut back. And, not all streams advance through the field at the same rate. Usually streams will advance 1.5 to 2 times faster in furrows that have been travelled by the tractor wheel.

Much work has been done to develop modifications so that the concepts of limiting lengths of run and cutting back stream sizes can be made acceptable to the farmer. Automation of surface irrigation (Humpherys, 1975), by itself or combined with the multi-set technique of shortening lengths of run and using smaller stream sizes (Rasmussen, et al. 1973), and with buried laterals (Worstell, 1975) provides techniques for overcoming objections to short furrows and small streams. Automatic cutback is obtained with gated pipe systems by automatically irrigating one-half of the field until runoff starts, then irrigating the other half, and finally putting the entire flow over the whole field. When properly designed, this provides an automatic 50 percent cutback in stream size and greatly reduces runoff and erosion. The multi-set concept of using small streams and short lengths of run, when coupled with the automated buried lateral concept, leaves the entire field open for cultivation and tillage so that the farmer can essentially use unbroken fields and thereby obtain good tillage efficiency.

Another on-field modification that can be implemented with an existing furrow irrigation system is to relevel the field. In a geologic sense, ultimate land forms tend to be steep at the upper end of an area and continually flatten in grade until they are almost entirely level at the lower end (Meyer and Kramer, 1969). This concept is applied to an irrigated field by continually decreasing the slope on the entire field so that the lower end of the field is almost entirely flat. Sediment eroded at the upper end will be deposited on the lower end of the field, thus tending toward a more stable land form. This can be enhanced by using vegetative strips at the lower end of the field to filter the sediment and by structural control of runoff water elevations at the end of the field. Some fields may also be leveled on the ends by using sediment obtained from sediment ponds or soil obtained from other areas.

Major leveling changes may be used to improve erosion control on irrigated lands. The type of system may be changed, (i.e., furrow to border) or the same system improved by changing the slope. For a given stream size, erosion is a function of slope, so erosion can be decreased by decreasing the slope on the field. Fields with slopes of 0.1 to 0 percent may be irrigated by either border, basin, or furrow systems. Virtually all of the world's land that has been under irrigation for one to two thousand years is level, is flooded as a basin, and generally contributes no runoff or sediment. Very accurate leveling can be achieved relatively inexpensively with modern lazer-controlled leveling equipment. Much of the land developed for sprinkler irrigation in recent years could have been leveled for border, basin, or furrow systems with a much smaller operating energy requirement.

The number and type of tillage operations affect the amount of erosion on a given field. Tillage often leaves the soil loose and erosive. It also increases roughness, thereby requiring larger streams which tend to be more erosive. Reducing the number of tillage operations reduces soil compaction and saves energy.

Some control of runoff water and sediment from irrigated fields may be obtained at the end of the field using vegetative filter strips with no other modification of the system (Fitzsimmons, et al. 1977). The filter strips may be either a permanent grass or annual crops such as wheat or barley.

Mini-basins or small settling ponds may be used at the end of a field to combine the runoff from 4 to 6 furrows and provide enough settling area to remove most of the sediment. The water is then discharged across a small filter strip or a grassed ditch bank into a drain system. The mini-basins are made by cutting one or two blade widths with a tractor-mounted scraper (Fitzsimmons, et al. 1977).

Sprinkler irrigation systems may be substituted for furrow systems on lands that are too steep, or have intake rates too high for efficient surface irrigation. Wheel-move laterals, solid-set systems and hand lines usually have application rates low enough to eliminate most runoff. Big gun and center pivot systems have high application rates that may cause runoff.

Sediment ponds can reduce the amount of sediment returning to streams after the runoff water leaves the field. In southern Idaho, sediment ponds have been 65 to 90 percent efficient on an annual basis in removing sediment from irrigation return flow (Carter, et al. 1976). Much of the phosphorus is also removed because it is attached to the sediment. Sediment ponds can generally be designed to remove particles down through the silt size, but they will not remove clay size particles. These particles require a grass filter, some chemical flocculation, or other treatment.

Sediment ponds are designed using Stoke's Law for particle settling velocities and considering the forward velocity due to the stream size and pond cross-sectional area (Bondurant, et al. 1975). Ponds need to be designed so that all of the water moves. Short-circuiting channels should not be allowed to develop in the pond, as these transport sediment right on through the pond. Generally, sediment ponds should be rectangular, with the length at least 4 times the width. The flow should be piped into the pond at the center of the inlet section so that vortices form on either side, slowing down the forward velocity and distributing the flow. Where possible, full pond width exit sections should be used. This prevents an increase in velocity at the outlet end of the pond which could prevent particles from settling out. If a concentrating exit is used at the end of the pond, it may prevent 10 to 15 percent of the pond length from being effective for settling.

The sediment pond may be used effectively in conjunction with a return flow system whereby runoff water is pumped back to the head of the field and reused (Bondurant, 1969). This can be used to provide larger furrow stream sizes during advance time by pumping additional water from the pond. Pumping can be discontinued when the water reaches the ends of the furrows to reduce or cut back the stream sizes (Stringham and Hamad, 1975).

Soil collected in sediment ponds can be used to level the end of contributing fields as previously described. This makes these fields less erosive so that they do not contribute sediment and the water in the return system can be used without further treatment.

NEEDED TECHNOLOGY

Although the practices listed above are effective, useful and sometimes very economical, other control measures are still needed. Automated and multi-set irrigation systems need to be further perfected. Erosion and sedimentation are tied directly to irrigation efficiency which, in turn, can be greatly increased by automation. The use of mulch tillage has not been investigated as a means of erosion control under surface irrigation. Planting and irrigating in the furrow is also a means of using smaller, nonerosive streams (Rasmussen, 1976).

SUMMARY

Erosion and sedimentation on irrigated lands cause great losses of productive soil, tillage problems and degraded water quality downstream. Most of the sediment eroded from irrigated lands comes from furrow-irrigated systems. This may be changed by improved management, improved grade control, and improved water control through automation and using moveable or buried multi-set laterals. Extensive leveling is also one method of control and recently developed equipment has increased leveling accuracy and reduced its cost. Some surface irrigation systems may need to be converted to sprinkler irrigation and, similarly, some sprinkler irrigation systems should be converted to furrow or surface irrigation systems to conserve energy. Other on-field practices that reduce sediment in the runoff water are vegetative filter strips at the ends of the fields, mini-basins for sedimentation at the end of furrows, and sediment ponds. Sediment ponds may be used most effectively when combined with water return systems and when the sediment collected is used to reduce the grade on the end of the contributing fields. This makes the sediment pond system a self-correcting system and should, in time, greatly reduce sediment in the runoff water from the fields.

REFERENCES

1. Bondurant, J. A. 1969. Design of recirculating irrigation systems. TRANS. of the ASAE 12(2): 195-198, 201.

2. Bondurant, J. A., C. E. Brockway and M. J. Brown. 1975. Some aspects of sedimentation pond design. Proc. Natl. Symp. Urban Hydrol. and Sediment Control. Univ. of KY, pp. cc:117-121.

3. Brown, M. J., D. L. Carter and J. A. Bondurant. 1974. Sediment in irrigation and drainage waters and sediment inputs and outputs for two large tracts in southern Idaho. J. Envir. Qual. 3(4): 347-351.

4. Carter, D. L., M. J. Brown and J. A. Bondurant. 1976. Sediment-phosphorus relations in surface runoff from irrigated lands. Proc. 3rd Interagency Sedimentation Conference, Denver, CO pp. 3:41-52.

5. Criddle, W. D., S. Davis, C. H. Pair and D. Shockley. 1956. Method for evaluating irrigation systems. USDA-SCS, Agr. Hbk. No. 82.

6. Fitzsimmons, D. W., C. E. Brockway, J. R. Busch, G. C. Lewis, G. M. McMaster and C. W. Berg. 1977. On-farm methods for controlling sediment and nutrient losses. Proc. National Conference on Irrigation Return Flow Quality Management. pp. 183-192, Ft. Collins, CO.

7. Humpherys, A. S. 1975. Automatic valves for surface irrigation pipelines. ASCE IR2: 95-109.

8. Israelson, O. W., G. D. Clyde and C. W. Lauritzen. 1946. Soil erosion in small irrigation furrows. Utah Agr. Expt. Sta., Bull. No. 320.

9. Meyer, L. D. and L. A. Kramer. 1969. Erosion equations predict land slope development. Agr. Engr. 50(9): 522-523.

10. Rasmussen, W. W., J. A. Bondurant and R. D. Berg. 1973. Multiset surface irrigation systems. Intl. Comm. on Irrig. and Drain. Bull. 22: 48-52.

11. Rasmussen, W. W. 1976. New technique saves irrigation water. USDA Agr. Res. 24: 14.

12. Stringham, G. E. and S. N. Hamad. 1975. Irrigation runoff recovery in the design of constant flow furrow discharge systems. TRANS. of the ASAE 18: 79-84.

13. Worstell, R. V. 1976. An experimental buried multiset irrigation system. TRANS. of the ASAE 19: 1122-1128.