Ponding Surface Drainage Water for Sediment and Phosphorus Removal

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ABSTRACT

SEDIMENT and phosphorus (P) removal efficencies of a sediment-retention pond with a capacity of about 3400 m^3 receiving surface water runoff from 4050 ha of irrigated land, were measured for five years. Average daily flow through the pond, during the irrigation runoff period, was 347 L/s, with a pond retention time of 2.7 h. The pond removed 65 to 76 percent of the sediment, and 25 to 33 percent of the total P entering the pond. Sediment and phosphorus removal efficiencies depended upon the flow rate and the sediment concentration of surface return flow entering the pond. Sediment and phosphorus were most efficiently removed when the stream flow was 340 to 453 L/s and the sediment concentration was in the range of 20 to 750 mg/L. Sediment removed from the pond was used to cover protruding basalt to improve and expand a golf course.

INTRODUCTION

Sediment, an end product of soil erosion, is the largest single pollutant of surface drainage water in southern Idaho. It hampers irrigation, pollutes rivers, and constitutes an economic loss to the farmer and the nation.

Research is needed to develop technology to reduce or eliminate sediments and adsorbed nutrients from surface irrigation return flows. Robbins and Carter (1975) reported that many small ponds have been constructed for removing sediment. Many of these ponds had no specific design, but were built to trap sediment for filling low areas, leveling land, and combining small fields into larger, more economical units. They found that 60 to 95 percent of the suspended sediments were removed from surface drainage water by these ponds.

Soil erosion not only damages the area from which the soil is eroded, but it can also damage areas where sediment is deposited. Large amounts of sediment may be carried from irrigated fields. Brown et al. (1974) reported that sediment concentrations in surface irrigation return flows ranged from 20 to 15 000 mg/L.

Carter et al. (1974) found that phosphorus (P) can be conserved by removing sediment from return flow streams. They found that the smaller particles and aggregates contained higher P concentrations than did the larger ones. The P concentrations increased as the particle or aggregate size decreased. For example, 550, 1150, and 1285 mg/L total P were attached to the sand, silt, and clay fraction, respectively, in the K-lateral drainage stream.

Under present irrigation management systems, streams and rivers are continually being loaded with sediment from irrigation drainage streams. Therefore, an efficient, economical means of controlling sediment in irrigation return flow is needed.

During irrigation, the surface runoff carries various amounts of sediment into the combination drainage and delivery system. The eroded sediment from individual fields often moves only a short distance and settles in a feed ditch or in the drainage channel as the energy to erode and the capacity to transport sediment decreases. Later, if the flow velocity increases, some of the deposited sediments are resuspended and may be transported downstream. Therefore, deposition and scouring are continual processes in the drainage system and eventually, if sediment is not removed somewhere in the system, some will reach the river.

The pond in this study was designed specifically to remove at least 50 percent of the total sediment input. Study objectives were to determine the value and effectiveness of ponding surface drainage water for controlling sediment and removing P, as well as to provide data for developing and evaluating design criteria for designing and constructing other test ponds. To achieve these objectives, data were used from one large pond constructed on a stream for which several years of streamflow and sediment data (Carter et al., 1974) had been collected.

MATERIALS AND METHODS

The Northside Canal Company diverts water at Milner Dam on the Snake River in southern Idaho into one large North Main Canal. The water is then distributed through a series of smaller canals to irrigate about 63 350 ha (Fig. 1). Brown et al. (1974) described this study area. Irrigation water is usually diverted into the canal system beginning in April, and stopped at the end of the irrigation season, usually in October or November, depending upon the climatic conditions.

A kidney-shaped pond, 153.4-m × 18.3-m × 1.22-m deep, was constructed on the K-lateral near its confluence with the Snake River (Fig. 1) by the Northside Canal Company to conform to existing topography with

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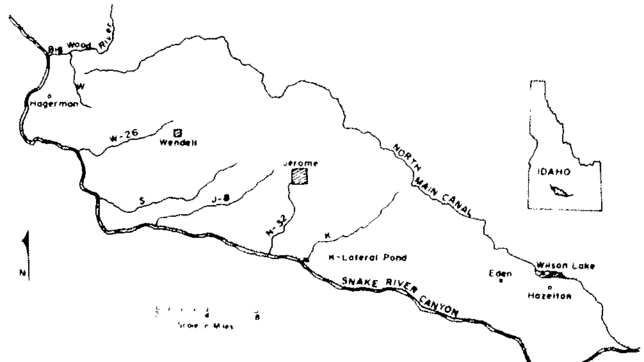

FIG. 1 The Northside irrigation tract showing the main canal, surface drains, and pond location.

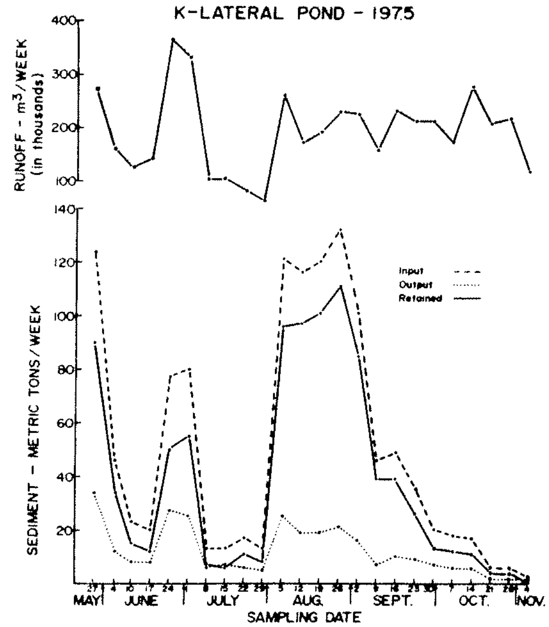

FIG. 2 Surface water runoff and sediment entering, retained, and leaving the sediment pond during the 1975 irrigation season.

minimal rock excavation. Probable removal efficiency for the pond was estimated using particle-size distributions, previously measured sediment concentrations, and an average discharge of 283 L/s. (Bondurant et al., 1975). Based on ideal settling basin assumptions of uniform inflow and outflow distribution, rectangular pond configuration and uniform horizontal velocity throughout the pond, a sediment-removal (trap) efficiency* of 54 percent was estimated. For the estimated flow and pond capacity of 3400 m³, this corresponds to an expected minimum particle-size removal of 5 μm assuming the requirements for applicability of Stokes' law were met.

Irrigation water is delivered to individual farm headgates at a constant rate of 0.87 L/s-ha continuous flow throughout the crop growing season. Water delivery may be decreased during August when water requirements for some crops decrease and when crops are nearing harvest.

Pond construction, including a 2.44 m (8.0 ft) wide suppressed weir for water measurement, was completed and studies began in 1972. The K-lateral pond was estimated to have adequate storage for two or three years' sediment with minor effects on the trap efficiency for the stream flow rates and volumes which occurred in this lateral. The pond was cleaned on alternate years, when the canal company removed sediment from the pond with a dragline in April 1973 and May 1975.

During the 5-yr study, to assure that the samples were representative of the stream and its sediment load, flow samples were collected at least weekly at a turbulent zone as the water entered the pond and at the measuring structure as it left the pond. Two samples were collected at each site. One was an unfiltered 200-mL sample, and the second was an unfiltered 10-L sample used to measure sediment concentration. Biological activity was inhibited in all samples by adding 40 mg $HgCl_2$/L. The 200-mL samples were refrigerated at 4 °C until analyzed. The total P concentration was determined in the 200-mL unfiltered sample (A.P.H.A., 1971; U.S.E.P.A., 1974; Watanabe and Olsen, 1965). Carter et al. (1974) have shown that virtually all soluble P passes directly through sediment ponds. The 10-L samples were allowed to settle for 1 week or longer in the laboratory, and then the clear, supernatant solution was siphoned off. The 1-week settling time was about three times longer than necessary, according to Stokes' law, for 1.0-μm diameter particles to settle 22 cm, the depth of the containers. The sediment remaining was suspended in a small amount of water and transferred into 600-mL beakers, dried at 105 °C, and weighed for sediment yield calculations.

The inflow sediment and the sediment retained were used to calculate the sediment removal efficiency.

RESULTS AND DISCUSSION

Runoff volume and sediment concentration entering the K-lateral pond in 1975 (Fig. 2) is representative of the 5 yrs studied. Runoff decreased during the first 3 weeks of June and the last 3 weeks of July 1975. The low runoff rate in June was due to preplant irrigation of corn and beans, as well as irrigating small grains and alfalfa. The first irrigation of row crops yields less runoff and sediment than later irrigations. During the low runoff in July, plant water requirements were high and some crops were being cultivated. Because most of the soil being irrigated was loose and friable and runoff rates were small, sediment eroded from the fields was probably deposited in farm drainage channels before reaching the pond. This was attributed to low stream velocity in relatively flat drainage channels. Only small quantities of sediment entered the pond during these low runoff periods.

Runoff peaked the last week of June and the first week of July when alfalfa was being harvested and when most other fields had been preplant irrigated for planting corn and beans. At these times many farmers do not use their water but let it flow through the farm and into drains or lower lying laterals. Runoff peaked again during hay harvest, the first week of August, after the 4-week low runoff period in July. During these peak runoff periods, the increased water velocity carried the channel-deposited sediments into the pond.

The flow rate affected both the sediment concentration entering and leaving the pond (Fig. 3). Bondurant et al. (1975) reported that removal efficiencies were higher at higher flow rates for the same pond during the 1972-1974 irrigation seasons. This was true for the 1975 and 1976 seasons. However, frequency analysis of the daily flow

*Sediment removal efficiency, expressed in percent, is the proportion of the inflowing sediment that was retained in the pond.

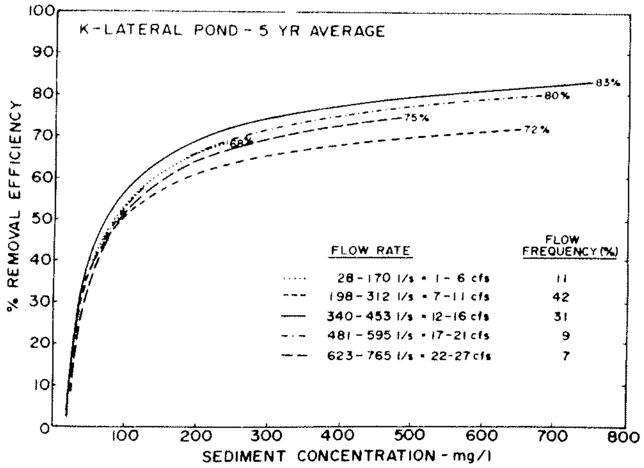

FIG. 3 The effect of sediment concentration and flow rate on the sediment removal efficiency.

rate and sediment concentration data entering the pond at each sampling date for the 5-yr study period indicated that this was true only for flows between 170 L/s and 453 L/s (Fig. 3). When the flow was 28 to 170 L/s, the sediment concentration entering the pond was never greater than 240 mg/L, and the peak sediment removal efficiency was 68 percent or less. At these flow rates most of the suspended sediment is smaller than 5 μm and will not settle out in this pond. The sediment removal efficiency increased to 83 percent as the flow increased from 340 to 453 L/s. However, when the flow increased to 623 to 765 L/s the sediment removal efficiency decreased to 75 percent because of the higher flow velocity. The retention time in the pond was decreased by almost 1 h at this flow rate, allowing more sediment to pass through the pond. The data showed the K-lateral pond removed sediment most efficiently when streamflow was 340 to 453 L/s and when the sediment concentration ranged from 240 mg/L up to the highest concentration measured, 750 mg/L.

The minimum and maximum retention times for the daily flows during the 5-yr study period ranged from 1.1 to 12.8 h (Table 1). The daily average retention time ranged from 2.1 to 3.4 h when the average daily flows ranged from 456 to 278 L/s, respectively. As the average retention time increased (Table 1), the sediment removal efficiency increased (Table 2) for each year studied, except 1973. The pond capacity decreased as sediment settled in the pond, decreasing the pond retention time. As sediment settled at the inlet to form a delta, the full length of the pond was no longer effective in removing sediment. Sediment was mechanically removed from the pond every other year during this study.

During 1973 (a year the pond was cleaned), the average retention time was the highest, yet the sediment removal efficiency was the lowest as compared with the other years studied. During 1973, only about one-half as much sediment entered the pond as compared with the other 4 years as shown in Table 2. Also, 37 percent of the time during 1973, the average daily flow was less than 200 L/s and sediment concentration was less than 400 mg/L. Thus, a large percentage of sediment eroded from fields could have been deposited in the K-lateral drainage channel during 1973, only to be subsequently removed mechanically, having never gotten to the pond. About 4.5 metric tons of sediment per hectare of irrigated area in the whole Northside Canal system is mechanically removed annually from laterals and drains. For the 5-yr study period, average retention time was lowest during 1976, when the flow rate exceeded 481 L/s 43 percent of the time. Also, only during 1976 was stream flow greater than 800 L/s, which occurred 8 percent of the time. As a result, a higher percentage of eroded sediment was carried through the retention pond with a resulting lower sediment removal efficiency. The annual sediment removal efficiency ranged from a low of 65 percent in 1973 to a high of 76 percent in 1975. The daily average flow rate frequently ranged from 340 to 453 L/s

TABLE 1. THE DAILY MINIMUM, MAXIMUM, AND AVERAGE WATER FLOW AND RETENTION TIME, ALONG WITH THE ANNUAL WATER FLOW THROUGH THE K-LATERAL SEDIMENT POND OVER A FIVE-YR PERIOD.

	Water flow and retention time						
Year	Min. flow, L/s	Ret. time, h	Max. flow, L/s	Ret. time, h	Avg. flow, L/s	Daily avg. ret. time, h	Inflow, m^{3}x10^3
1972	159	5.9	674	1.4	360	2.6	5371
1973	74	12.8	637	1.5	278	3.4	4205
1974	147	6.4	552	1.7	326	2.9	5350
1975	108	8.7	600	1.6	317	3.0	4606
1976	201	4.7	844	1.1	456	2.1	7171
Avg.	138	6.8	661	1.4	347	2.7	5340

TABLE 2. METRIC TONS OF SEDIMENT REMOVED ANNUALLY AND PRECENT SEDIMENT REMOVAL EFFICIENCY OF THE K-LATERAL SEDIMENT POND OVER A 5-YEAR PERIOD.

	Total sediment				Removal efficiency,
	Inflow	Outflow	Retained	Daily Av.	
Year	metric tons				%
1972	1245	401	844	4.9	68
1973	629	221	408	2.4	65
1974	1143	294	849	4.4	74
1975	1216	288	928	5.5	76
1976	1899	614	1285	7.1	68
Avg.	1226	364	863	4.9	70

TABLE 3. TOTAL P REMOVED ANNUALLY AND PERCENT REMOVAL EFFICIENCY OF THE K-LATERAL SEDIMENT POND OVER A 5-YR PERIOD.

	Total P				Removal efficiency,
Year	Inflow	Outflow kg/yr	Retained	Daily av. retained kg/day	%
1972	1707	1234	473	3.5	28
1973	1375	1027	348	2.2	25
1974	1357	924	433	2.9	32
1975	1463	978	485	3.1	33
1976	2373	1726	647	3.5	27
Avg.	1655	1178	477	3.0	29

during 1975, which had the highest sediment concentration and the highest removal efficiency as compared with that for the other 4 years.

The total P removal efficiency ranged from 25 to 33 percent, with the low and high efficiency years in 1973 and 1975, respectively (Table 3). Carter et al. (1974) found that removing sediment from return flow streams also removes P because most of the P is attached to sediment. However, the P removal efficiency never equals or exceeds the sediment removal efficiencies for several reasons. First, some soluble P will always pass through the pond, even with 100 percent sediment removal. Also, when the flow rate exceeds the most efficient sediment removal value, a greater amount of small sediment particles with attached P pass through the pond. When the flow rate is lower than the most efficient sediment removal value, less sediment enters the pond and the finer clay particles with attached P still pass through the pond.

The K-lateral pond was constructed at canal company expense at our specifications on undeveloped land owned by the Jerome Country Club adjacent to a 9-hole golf course constructed on soil underlain with basalt. During this 5-yr study, sediment removed from the K-lateral pond was placed over areas of protruding basalt and grass was planted to improve the golf course. In other instances, sediment trapped in ponds has been used to fill low areas in fields and to reduce the slope on some fields, thus making them less subject to erosion.

CONCLUSIONS

A five year study of the sediment and phosphorus trapping efficiency of a sediment pond carrying irrigation runoff water showed that P retention is directly correlated with sediment retention. Seasonal sediment retention efficiencies of 65 to 76 percent resulted in P retention efficiencies of 25 to 33 percent. Phosphorus passing through the sediment pond was either in soluble form or was attached to soil particles which were too small to settle out in this pond.

The flow rate into this pond was equal to or greater than the design flow for all 5 yr of the study. Sediment (and associated P) trap efficiency was also greater than the predicted design efficiency for all 5 yr. Efficiency generally increased with increasing flow rate. Relatively high flow rates overloaded the pond resulting in increased velocities in the pond to the point where even silt size particles may not settle. Relatively low flows result in a suspended solids load comprised mainly of clay sized particles which cannot be trapped in ponds this size without flocculation aid.

References

1 American Public Health Association. 1971. Standard methods for examination of water and wastewater, 13th Ed., New York, pp. 518-534.

2 Bondurant, J. A., C. E. Brockway, and M. J. Brown. 1975. Some aspects of sedimentation pond design, pp. 117-121. In: Proc. Natl. Symp. Urban Hydrology and Sediment Control, Univ. Kentucky, Lexington, July 28-31. UKY-BU 109.

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. Environ. Qual. 3(4):347-351.

4 Carter, D. L., M. J. Brown, C. W. Robbins, and J. A. Bondurant. 1974. Phosphorus associated with sediments in irrigation and drainage waters for two large tracts in southern Idaho. J. Envir. Qual. 3(3):287-291.

5 Robbins, C. W., and D. L. Carter. 1975. Conservation of sediment in irrigation runoff. J. Soil Water Conserv. 30(3):134-135.

6 U. S. Environmental Protection Agency. 1974. Methods for chemical analyses of water and wastes, pp. 249-255. U. S. Environ. Prot. Agency, Washington, DC.

7 Watanabe, F. S., and S. R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Am. Proc. 29:677-678.

Humidity and Thermal Radiation Terms

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326 W/m². Starting with an initial guess of T_w^0 of 20 °C, successive iterations of equation [16] give $T_w^1 = 12.15$, $T_w^2 = 10.79$, $T_w^3 = 10.76$, and $T_w^4 = 10.76$ °C. Thus, convergence to within 0.01 °C was achieved in only four iterations. Substitution of $T_w = 10.76$ °C in equations [2], [3], and [4] gives R = 353.7, H = −203.4, and E = 175.7 W/m², respectively. Their sum is 326.0 W/m², the value of R_a, which confirms the energy balance of equation [1].

References

1 ASHRAE. 1972. ASHRAE Handbook of Fundamentals. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. NY. 688 p.

2 Idso, S. B. 1981. A set of equations for full spectrum and 8-14 μm and 10.5-12.5 μm thermal radiation from cloudless skies. Water Resources Research 17:295-304.

3 Kimball, B. A., S. B. Idso, and J. K. Aase. 1981. A model of thermal radiation from cloudly skies. (Submitted to J. of Geophys. Res.)

4 Kreyszig, E. 1962. Advanced Engineering Mathematics. John Wiley & Sons, Inc. NY. 856 p.

5 List, R. J. 1958. Smithsonian Meteorological Tables. Smithsonian Institution. Washington, DC. 527 p.

6 Lowe, P. R. 1977. An approximating polynomial for the computation of saturation vapor pressure. J. Appl. Meteorol. 16:100-103.

7 Murray, F. W. 1967. On the computation of saturation vapor pressure. J. Appl. Meteorol. 6:203-204.

8 Rasmussen, L. A. 1978. On the approximation of saturation vapor pressure. J. Appl. Meteorol. 17:1564-1565.

9 Weiss, A. 1977. Algorithms for the calculations of moist air properties on a hand calculator. TRANSACTIONS of the ASAE (6):1133-1136.