Fate of Suspended Sediment during Basin Recharge

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Suspended sediment in water used for recharge was tagged with the radioisotope ^{134}Cs to determine the extent of its movement into materials underlying recharge basins and to aid in evaluating the effect of its accumulation on infiltration rates and the basin life. When openings of naturally occurring large pores were allowed to remain at the basin surface, 50% of the sediment suspended in the recharge water was moved deeper than 18 inches. However, when large-pore openings at the surface were destroyed by cultivation, over 90% of the suspended sediment was filtered in the upper 1 inch. Most of this sediment could easily be removed at frequent intervals. The suspended sediment that moved deeper than about 0.15 inch, the depth removed at the end of each recharge cycle, has not noticeably reduced infiltration rates of a 0.1-acre experimental basin.

Recharging groundwater reservoirs from surface basins or by water spreading has been practiced in many areas [*Todd,* 1964; *Hall,* 1955; *Thomas,* 1968; *Bliss and Johnson,* 1952; *Schiff,* 1950, 1953; *Clyma,* 1963]. Most successful systems have recharged clear or low-turbidity water; however, *Aronovici et al.* [1970, 1972] have recharged runoff water containing up to 250 ppm of suspended sediment through excavated basins. Continuous recharge with these turbid waters was not possible owing to the suspended sediment plugging the basin surface. After plugging, the basins were successfully reclaimed by removing the thin coating of sediment. In recharge experiments at the USDA Southwestern Great Plains Research Center, Bushland, Texas, more than 219 vertical feet of turbid runoff water have been recharged through a 0.1-acre basin at an average rate of 1.5 ft/day. This recharging was accomplished during seven separate recharge periods or cycles. The sediment deposited on the surface was removed at the end of each recharge cycle before the next cycle began.

Curry [1966], *Curry et al.* [1965], *Stanley* [1955], and *Rausch and Curry* [1963] have used porous columns as filters for colloidal suspensions. They showed that, although much of the suspended material is filtered at the surface, some colloidal material moved into the porous media. Consequently, information was needed regarding the extent that sediment suspended in the infiltration water moves into the material underlying recharge basins and its effect on permeability. If clogging results at significant depths beneath the surface, the long-term use of such basins will be seriously affected. If clogging occurs near the surface, removal of the surface few inches of material will renovate the basins.

Measurements of small amounts of sediment movement can be made most accurately by radiotracer techniques. Numerous workers have proposed using or used radiotracers in following soil movement during erosion and sedimentation or in tracing movement of suspended material through columns of porous media [*Wool-*

dridge, 1965; *McHenry and McDowell,* 1962; *McHenry,* 1968; *Frere and Roberts,* 1963; *Ritchie et al.,* 1970; *Curry,* 1966; *Stanley,* 1955].

Experiments on cesium sorption showed that microquantities of cesium are readily fixed by clay and are essentially nonexchangeable [*Sawhney,* 1972]. The order of cesium fixation on clays is vermiculite > chlorite > illite > montmorillonite > kaolinite [*Jacobs,* 1962; *Sawhney,* 1967; *Coleman et al.,* 1963*a*]. It has also been shown that calcium does not compete strongly with small amounts of cesium in adsorption [*Coleman et al.,* 1963*b*; *Sawhney,* 1964; *Sawhney and Frink,* 1964]. The turbid recharge water and soils of concern to this study contain mostly montmorillonite, illite, and kaolinite [*Allen et al.,* 1972]. In addition, calcium is the dominant cation in the recharge and percolation water owing to the calcareous sediments of the area. These facts indicate that ^{134}Cs would move with the suspended sediment and that the depth and amount of suspended sediment movement occurring during recharge could be determined by analyzing core increments for ^{134}Cs. Therefore ^{134}Cs was selected for this experiment, since it has a convenient half-life of 2.3 years.

PROCEDURE

Basins and underlying materials. The recharge basins were constructed by removing the slowly permeable surface of the Pullman clay loam or one of the associated soils [*Aronovici et al.,* 1972]. These soils and the underlying sedimentary materials have been described in detail by *Mathers et al.* [1963]. The underlying calcareous unconsolidated sedimentary materials were clay loam in texture and contained many continuous relatively large pores ranging from 0.1 to 1.0 mm in diameter. Measurement of the distribution of these pores in field cores indicated that approximately 20% of the total pore volume could be accounted for by the large pores.

Experiment 1. A 40-inch-diameter shaft was drilled to a depth of 6 feet to expose the calcareous underlying sediments. A 36-inch-diameter steel infiltration ring was placed in the shaft, and the space between the shaft wall and the infiltration ring was backfilled and packed. The basin floor was cleaned of all loose debris to expose the naturally occurring large-pore openings for rapid infiltration. A 265-gal. tank, placed adjacent to the infiltration ring, was used as a reservoir for the water being fed to the infiltration ring. Water containing the suspended sediment was pumped to the mixing tank as it was needed and mixed with a 0.79-μc/ml solution of ^{134}Cs. The ^{134}Cs concentration of the infiltrating water was maintained at 0.001 μc/ml. A water level in the infiltration ring of 2.25 feet was established during the first day and maintained by a float valve.

Experiment 2. A second 36-inch-diameter infiltration ring was pressed to a depth of 8 inches in the floor of a 0.1-acre infiltration basin. The 0.1-acre basin was an established recharge basin that had recharged approximately 230 vertical feet of turbid water during five cycles with no significant reduction of the initial infiltration rate. This experiment was conducted in an established recharge basin to determine sediment movement under actual conditions of recharge. The surface of this basin was disturbed by tillage after construction. The tillage destroyed the naturally occurring large-pore openings at the surface. The water level of the 0.1-acre basin and the infiltration ring was maintained at 2.25 feet after the 6th day. Freezing weather on the 2nd–5th day hampered filling the basins. Experiment 2 was conducted in the same way as experiment 1 from this point in time.

Coring. After termination of infiltration the water was removed from the infiltration rings, and the material below the basin floor was allowed to drain. The underlying material was cored, and the cores were separated into appropriate increments for ^{134}Cs analyses. In both experiments, two sets of cores were taken from within the basins. In experiment 1, two additional cores were taken 6 inches outside the perimeter of the basin.

Cesium 134 determination. The samples for ^{134}Cs analyses were dried and ground to pass a 2-mm sieve. Analyses for ^{134}Cs were made by using a 2-inch × 2-inch well-type crystal of sodium iodide with a Hamner single-channel analyzer. Three 1-min counts of 8-gram samples were obtained. The counts were averaged, corrected for background, and converted to equivalent amounts of tagged sediment by comparison to a standard curve. To prepare the standard curve, known amounts of ^{134}Cs tagged sediment from the recharge water were mixed with surrounding untagged material and counted in the same way as the core increments.

Adsorption of ^{134}*Cs*. Samples of the recharge water were filtered through a 0.1-μm filter, and the filtrate was analyzed for ^{134}Cs content. This analysis indicated that 2.76% of the ^{134}Cs added to the sediment suspended in the water passed through the 0.1-μm filter. Some turbidity was evident in the filtrate, so that it could not be determined if this was ^{134}Cs in solution or adsorbed on clay particles smaller than those collected on the filter. The filtrate was mixed with some of the sedimentary material underlying the basins and centrifuged. The centrifugate did not contain ^{134}Cs. Thus it was concluded that, if any ^{134}Cs was unadsorbed, it would immediately be adsorbed by the sedimentary materials underlying the basin.

Sediment from the basin surface crust was separated into four size fractions by centrifugation. The size fractions were >6, 6–1, 1–0.08, and <0.08 μm. The total sample contained 3.86 μc/g of ^{134}Cs. The >6-μm fraction contained 1.93 μc/g of ^{134}Cs, the 6- to 1-μm fraction contained 4.82 μc/g of ^{134}Cs, and the 1- to 0.08-μm and the <0.08-μm fractions contained 5.78 and 5.40 μc/g of ^{134}Cs. These data indicated that most of the ^{134}Cs was adsorbed by the clay and fine silt fraction and that the various clay fractions adsorbed ^{134}Cs at approximately the same rate.

Bulk density. Additional cores were obtained in the experiment 1 basin to a depth of 24 inches for bulk density analysis. The bulk density of the material below this depth was assumed to be the same as that of an adjacent basin. Bulk densities of the material underlying the basin in experiment 2 were assumed to be the same as those taken in the larger surrounding basin. Core bulk densities are presented in Tables 1 and 2 for experiments 1 and 2, respectively. Bulk densities of the surface sediment crust and two natural layers beneath the surface crust of both experiments were calculated. Small pieces of the material were measured with a measuring hand magnifier and weighed. The bulk density of the dried surface crust averaged 2.33 g/cm³ from 43 measurements. This high bulk density was probably due to the plate-shaped clay particles settling out parallel to each other and allowing for maximum compaction.

TABLE 1. Sediment Concentration with Depth and Cumulative Accumulation of Sediment with Depth for Experiment 1

					Average for Cores 1A and 1B	
	Bulk	Tagged Clay, %				
Depth, inches	Density, g/cm³	Core 1A	Core 1B	Average	Tagged Sediment, mg/cm³	Cumulative Sediment Added, %
0.00–0.05	2.33	31.855	35.524	33.690	784.98	18.46
0.05–0.50	1.94	1.543	1.930	1.737	33.70	25.59
0.50–1.00	1.62	0.183	1.122	0.653	10.58	28.08
1.00–2.00	1.54	0.089	0.780	0.435	6.70	31.23
2.00–3.00	1.52	0.072	0.371	0.222	3.37	32.82
3.00–6.00	1.52	0.095	0.136	0.116	1.76	35.30
6.00–9.00	1.52	0.059	0.149	0.104	1.58	37.53
9.00–12.00	1.49	0.109	0.231	0.170	2.53	41.10
12.00–18.00	1.59	0.114	0.285	0.200	3.78	50.08
18.00–24.00	1.59	0.208	0.260	0.234	3.12	60.58
24.00–30.00	1.52	0.106	0.162	0.134	2.04	66.34
30.00–36.00	1.52	0.070	0.068	0.069	1.05	69.30
36.00–48.00	1.52	0.071	0.054	0.063	0.96	74.72
48.00–60.00	1.52	0.038	0.028	0.033	0.50	77.54
60.00–72.00	1.52	0.048	0.036	0.042	0.64	81.15
72.00–84.00	1.52	0.055	0.039	0.047	0.71	85.16
84.00–96.00	1.52	0.047	0.009	0.028	0.43	87.59
96.00–108.00	1.52	0.006	0.005	0.006	88.09	88.10

TABLE 2. Sediment Concentration with Depth and Cumulative Accumulation of Sediment with Depth for Experiment 2

					Average for Cores 2A and 2B	
Depth, inches	Bulk Density, g/cm³	Tagged Clay, % Core 2A	Core 2B	Average	Tagged Sediment, mg/cm³	Cumulative Sediment Added, %
0.00–0.03	2.33	41.800	34.570	38.190	889.83	37.44
0.03–0.50	1.75	1.160	9.330	2.270	39.73	63.64
0.50–1.00	1.75	0.160	4.689	2.270	39.73	91.51
1.00–2.00	1.75	0.090	0.047	0.068	1.19	93.18
2.00–3.00	1.75	0.058	0.070	0.060	1.05	94.65
3.00–6.00	1.70	0.021	0.053	0.038	0.65	97.39
6.00–9.00	1.70	0.011	0.010	0.011	0.19	98.19
9.00–12.00	1.70	0.007	0.008	0.007	0.12	98.70
12.00–18.00	1.75	0.003	0.003	0.003	0.05	99.12
18.00–24.00	1.75	0.001	0.001	0.001	0.02	99.29
24.00–30.00	1.76	0.001	0.002	0.001	0.02	99.42

RESULTS AND DISCUSSION

Experiment 1. Infiltration data are presented in Table 3. The infiltration rates over the 26-day recharge period ranged from an initial 8.6 ft/day to a final 0.44 ft/day. A total of 72.5 ft³ of water containing 1.11 lb of sediment was applied per square foot of basin. The maximum infiltration rates during the recharge period were considerably greater than the 3.8 ft/day maximum normally recorded in similar basins using turbid water [*Aronovici et al.*, 1972]. This greater maximum rate was expected, since the basin surface was cleaned of all loose debris to provide maximum exposure of the large-pore openings.

Sediment movement data for core 1A and core 1B are presented in Table 1. The percent of tagged sediment in core 1B was considerably higher than that in core 1A at depths from 0.5 to 18 inches. These differences were possibly due to variation in pore size distribution or sampling procedures. There were no cracks in the surface of the basin that would allow the sediment to move deeper in certain spots than in others. Regardless of the discrepancies of the values obtained for the two cores, they both indicate that sediment movement occurred to considerable depths. The average percent of tagged sediment for each horizon was used to calculate the total sediment accumulated at each sampling depth. These amounts were summed through the profile and divided by the total amount of sediment added to determine the percent added that had accumulated above any depth. The last two columns of Table 1 show the total sediment accumulated at each sampling depth and the cumulated percent of sediment accumulated above that depth. Only 88.1% of the added tagged sediment could be accounted for to a depth of 9 feet. Cores from greater depths did not show any evidence of tagged sediment. The cores taken outside the basin were used to calculate the amount of sediment accumulated in an 8-inch ring around the basin. The sediment accumulated in this ring accounted for 5.8%, bringing the total tagged sediment accounted for to 93.9%. The remaining 6.1% unaccounted for could be due to errors in measuring the average thickness or bulk density of the thin sediment crust at the surface, lateral movement, or sampling procedures. Figure 1 shows that more than 68% of the sediment added to the basin moved to a depth of >2 inches, and nearly 50% moved deeper than 18 inches. Some tagged sediment was detected to a depth of 9 feet. These results show that considerable sediment movement did occur in experiment 1. Therefore significant plugging may be expected to occur over a period of time, and the life of the basin will be shortened.

Experiment 2. Infiltration data during the 44-day recharge period in an established basin are presented in Table 4. The maximum infiltration rate was 2.69 ft/day on the 16th and 19th days, and the minimum infiltration rate was 0.27 ft/day on the last day. A total of 52.20 ft³

TABLE 3. Daily Quantity and Quality Values for Infiltrating Water and Cumulative Water and Sediment Added to the Basin in Experiment 1

Day	Infiltration Rate, feet/day	Average Daily Turbidity of Infiltration Water, ppm	Cumulative Water Flowing to Infiltration Ring, ft^3/ft^2*	Cumulative Sediment Flowing to Infiltration Ring, lb/ft^2*
1†	8.62	256	7.33	0.117
2	7.29	243	14.62	0.228
3	8.23	189	22.85	0.325
4	8.42	217	31.27	0.439
5	6.07	284	37.34	0.547
6	5.21	263	42.55	0.633
7	4.80	250	47.35	0.708
8	4.45	241	51.80	0.775
9	3.87	244	55.67	0.834
10	3.01	237	58.68	0.879
11	2.44	237	61.12	0.915
12	2.11	247	62.23	0.948
13	1.80	269	65.03	0.978
14	1.59	277	66.62	1.005
15	1.30	294	67.92	1.029
16	1.14	280	69.06	1.049
17	0.89	256	69.95	1.063
18	0.78	256	70.73	1.075
19	0.63	256	71.36	1.085
20	0.54	256	71.90	1.094
21	0.59	256	72.49	1.103
22	0.56	197	73.05	1.110
23	0.48	128	73.53	1.114
24	0.49	128	74.02	1.118
25	0.47	128	74.49	1.122
26†	0.44	128	74.67	1.123

* The total quantity of material infiltrated is 72.54 ft^3/ft^2 of water and 1.106 lb/ft^2 of sediment. These figures are less than the figures for the last day, since 2.13 ft^3/ft^2 of water containing 128 ppm of suspended sediment was pumped from the infiltration ring.

† Less than 24 hours.

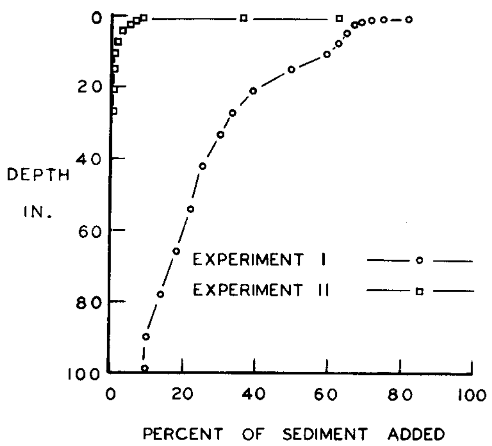

Fig. 1. Percent of the total sediment added to the basins that moved deeper than the indicated depth for experiments 1 and 2.

of water containing 0.54 lb of sediment was applied per square foot of basin.

Sediment movement data for cores 2A and 2B are presented in Table 4. During the experiment the basin floor cracked, and thus sediment accumulated in these cracks. The cracks covered 3% of the basin floor and averaged about 1 inch deep. Core 2B was taken over one of these cracks. The data in Table 2 show that the 0.03- to 1.00-inch depth had considerably more tagged sediment than the corresponding depth for core 2A. To obtain the average percent of tagged sediment, the cores were equally weighted except for the 0.03- to 1.00-inch depth. The average percent of tagged sediment for this depth was calculated by assuming that the sediment in the cracks, 3% of the depth increment, had an average tagged sediment content

TABLE 4. Daily Quantity and Quality Values for Infiltrating Water and Cumulative Water and Sediment Added to the Basins in Experiment 2

Day	Infiltration Rate, feet/day	Average Daily Turbidity of Infiltration Water, ppm	Cumulative Water Flowing to Infiltration Ring, ft^3/ft^2*	Cumulative Sediment Flowing to Infiltration Ring, lb/ft^2*
1†	2.73	263	1.14	0.019
2	1.72‡	253	2.86	0.046
3	1.64‡	207	4.50	0.067
4	0.22‡	207	4.72	0.070
5	0.70‡	207	5.42	0.079
6	1.18	219	6.60	0.095
7	1.35	221	7.95	0.114
8	1.44	214	9.39	0.133
9	1.56	201	10.95	0.153
10	1.64	194	12.59	0.173
11	1.76	177	14.35	0.192
12	1.99	166	16.34	0.213
13	2.13	137	18.47	0.231
14	1.98	134	20.45	0.248
15	2.45	120	22.90	0.265
16	2.69	125	25.59	0.287
17	2.55	114	28.14	0.305
18	2.57	85	30.71	0.319
19	2.69	56	33.40	0.328
20	2.67	45	36.07	0.336
21	2.55	63	38.62	0.346
22	2.21	75	40.83	0.356
23	1.64	72	42.47	0.363
24§	1.49	70	43.96	0.370
25	1.15	79	45.10	0.376
26	0.91	184	46.01	0.386
27	0.89	248	46.90	0.400
28	0.77	281	47.67	0.414
29	0.70	318	48.37	0.428
30	0.66	318	49.03	0.441
31	0.61	318	49.64	0.453
32	0.54	311	50.18	0.463
33	0.54	344	50.72	0.475
34	0.52	354	51.24	0.486
35	0.53	360	51.77	0.498
36	0.48	360	52.25	0.509
37	0.45	360	52.70	0.519
38	0.43	360	53.13	0.529
39	0.36	360	53.49	0.537
40	0.34	355	53.83	0.545
41	0.34	346	54.17	0.552
42	0.30	348	54.47	0.559
43	0.29	323	54.76	0.565
44†	0.27	312	54.94	0.568

* The total quantity of material infiltrated is 52.20 ft^3/ft^2 of water and 0.538 lb/ft^2 of sediment. These figures are less than the figures for the last day, since 2.74 ft^3/ft^2 of water containing 0.028 lb/ft^3 of sediment was pumped from the infiltration ring.

† Less than 24 hours.

‡ The head was not at maximum owing to the freezing of the float valves.

§ Infiltrated last part of ^{134}Cs-tagged clay.

equal to the thin surface crust, 38.19%, and the remaining material, 97%, had an average tagged sediment content of 1.16%. The last two columns of Table 2 show the total sediment accumulated at each depth and the cumulated percent of that added. The sediment accounted for was 99.42% of that added. Figure 1 shows the percent of sediment added that passed a given depth. Over 37% of the total sediment was contained in the 0.03-inch surface crust, and 91% of the total sediment could be accounted for in the upper 1.0 inch. Over 97% of the sediment was filtered above a depth of 6 inches, and there was no evidence of sediment movement beyond a depth of 30 inches. These results show that significant suspended sediment movement did not occur in experiment 2. These findings are probably representative because experiment 2 was conducted within an established recharge basin.

Conclusions

Results of these studies show that appreciable movement of suspended sediment occurred in experiment 1 but not in experiment 2. Sediment movement in experiment 1 was enhanced by the fact that the large pores were open to the surface of the basin. Tillage of the basin surface in experiment 2 apparently produced an effective filter for the suspended sediment that limited its depth of movement. Therefore the depth that the sediment is moved can be reduced by destroying the openings of large pores at the surface.

Experiment 2 had some sediment moved to a depth of 6 inches. The normal procedure for reclaiming the basins after surface plugging is to remove the dried surface crust that has never been more than 0.06 inches thick. This is accomplished by sweeping, air blasting, or washing the dried crust from the basin surface. Such practices remove slightly more than the thin surface crust but still allow for a gradual accumulation of sediment in the upper 6 inches. This gradual accumulation of sediment apparently does not appreciably affect the permeability of the basin. This fact is evidenced by examining the recharge rates of the 0.1-acre basin in which experiment 2 was conducted (Figure 2). Through seven recharge cycles the 1st and 5th days and the maximum infiltration rates showed no downward trend. The day on which the maximum rate occurred varied depending on the suspended sediment concentration of the infiltrating water.

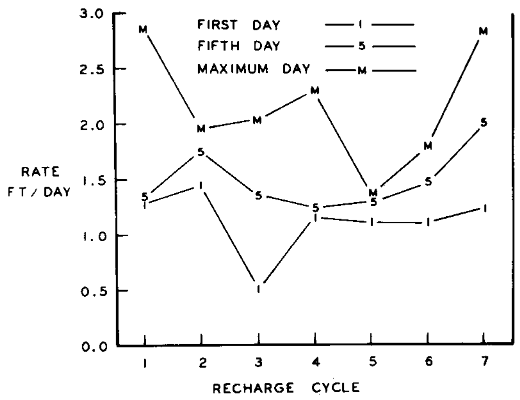

Fig. 2. Infiltration rates in feet per day for the first, fifth, and maximum day of recharge during seven recharge cycles in the 0.1-acre basin.

The results of this investigation show that the downward movement of sediment suspended in recharge water can be limited. Thus plugging with depth should not be a major factor in determining the feasibility of excavated basins as a method of artificially recharging turbid water.

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