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GROUND WATER RECHARGE THROUGH EXCAVATED BASINS

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ABSTRACT

Excavated basins were used to bypass slowly permeable soils in the Southern High Plains and artificially recharge the Ogallala aquifer. Recharge rates with turbid playa water were as rapid as 1.0 m/d, and average long-term rates were as rapid as 0.4 m/d. When suspended sediments in the recharge water were tagged with radioactive cesium, over 90% of the sediments were filtered within 25 mm of the basin surface. As a result, the basin surfaces could be renovated to maintain high recharge rates. An organic filter and high-head flooding treatments doubled the recharge rate in comparison to normal flooding depths without a filter material. A recharge system was developed in which erosion from high-intensity storms cleaned the corrugated basin surface at the same time water for recharge became available. Average recharge rates of 0.4 m/d were maintained during a 7-y field test without basin renovation.

INTRODUCTION

The soils of the Southern High Plains are slowly permeable; thus, water spreading is not a feasible method of artificial ground water recharge. Basins excavated into more permeable material are an alternative to surface water spreading, however. Slowly permeable soil can be removed to expose more permeable soil or sediments for vertical percolation of water.

High percolation rates are required to justify the cost of excavated basins. Even a shallow soil usually requires 0.5 m^3 or more of soil removal for every square meter of percolation area. In addition, more costly excavation with a backhoe is desirable to prevent compaction of the exposed soil. Low percolation rates that are acceptable with surface water spreading may not

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be acceptable with excavated basins. Because of high excavation costs, treatments to increase percolation rates are more easily justified.

This paper presents experimental data from excavated recharge basins in the Southern High Plains of the U.S.A. The research was conducted by the USDA Agricultural Research Service at or near their Laboratory at Bushland, TX (near Amarillo, TX). The experimental basins were used to recharge the Ogallala aquifer, which underlies most of the area. In this aquifer, water table declines from pumping exceed 30 m in many areas; and in some locations, the original saturated thickness has been reduced 50% or more (Gutentag et al., 1984). Storm runoff collecting in approximately 17,000 playas (shallow natural depressions) is the only major water source for artificial ground water recharge. This water contains high concentrations of suspended solids and organic matter, but the chemical quality is excellent. Soils throughout large areas of the Southern High Plains have steady state infiltration rates as low as 35 mm/d. Rapid evaporation rates in the area would cause prohibitive water losses from large spreading areas. Thus, rapid infiltration techniques are needed for successful ground water recharge.

RESEARCH WITH EXCAVATED BASINS

Recharge basins were excavated into two types of geologic profiles around a 40-ha playa located 24 km west of Amarillo, TX. The first basin excavated in alluvial playa sediments had a steady state recharge rate of only 37 mm/d. Other basins excavated in pluvial sediments had quasi-steady state recharge rates as rapid as 2.1 m/d.

Basin Excavated in Playa Sediments

After extensive hydrogeologic investigation of the 40-ha playa, Signor and Hauser (1968) excavated a basin in alluvial playa sediments at the southeast margin of the playa. A very fine sand stratum about 1 m thick occurred about 1.2 m below the playa surface. The sand stratum was underlain by about 6 m of fine-textured sediments ranging from clay loam to very fine sand. Separating this material from the Ogallala formation was about 6 m of fine to medium sand and a 0.5-m layer of indurated calcium carbonate called "the caprock" by local well drillers. Signor and Hauser (1968) excavated the upper 1.2 m of fine-textured soil to form a 36.5-m x 73-m basin.

The recharge potential of the basin was determined with a 19-d test with clear well water. During initial filling, the recharge rate started at 600 mm/d but declined steadily to about 240 mm/d. After filling, the recharge rate continued to decline to a quasi-steady rate of about 37 mm/d. The recharge rate was not limited by the basin surface but by the slowly permeable sediments from the 2- to 8-m depths. Although the final recharge rate was nine times as large as the evaporation rate, it was too low to justify tests with turbid playa water.

Basins Excavated in Pluvial Sediments

Aronovici et al. (1970, 1972) excavated three recharge basins along the northwest margin of the 40-ha playa. The excavation exposed pluvial Pleistocene-age sediments that had not been reworked by erosion. The pluvial Pleistocene, which occurs over much of the Southern High Plains, is highly calcareous, with small fragments of soft calcium carbonate and well rounded quartz grains similar to those in the Ogallala formation. Typically, it contains many fossil root casts and worm cavities; but where it has been exposed to the surface or reworked by water action, it is quite dense and has a blocky structure. The pluvial sediments are highly permeable only where they retain the original structure. Figure 1 illustrates a geologic section from the soil surface to the underlying aquifer.

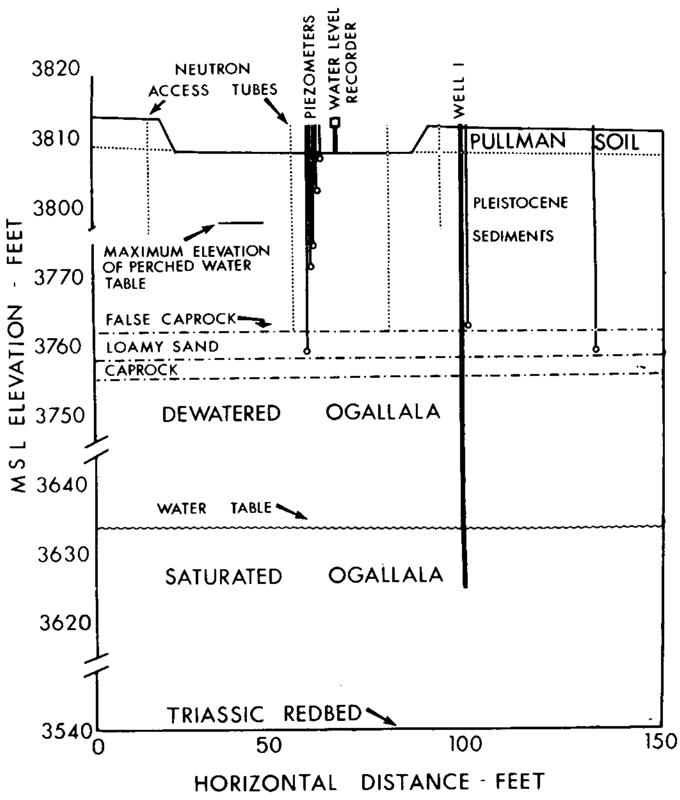

Fig. 1. Cross section of Basin A through N-S line of piezometers and neutron access tubes (from Aronovici et al., 1972) (1 foot = 0.305 meters).

Aronovici et al. (1970, 1972) removed the entire 1.3-m Pullman soil profile to expose the highly permeable calcium carbonate and Pleistocene sediments. The first two basins, designated as Basins A and B, were square with a 0.04-ha surface area. Initially, one of the basins was tested with clear well water and the other with turbid playa water. Basin C, a 0.4-ha area basin excavated nearer the playa, was tested initially with clear well water and later with playa water.

Recharge rates through the 0.04-ha basins were many times greater than those through the alluvial playa sediments (Fig. 2). The percolation rates were initially between 0.5 and 0.6 m/d and then gradually increased to about 1.2 m/d on the 26th day. After that, the suspended solids in the playa water began to seal Basin A, but the recharge rate of Basin B increased to more than 2.1 m/d before beginning to level off on the 42nd day. The 0.4-ha basin was excavated in less permeable sediments, and the initial recharge rate was only half that of the two smaller basins (Fig. 2); however, the rate increased in a similar manner. The cause of the increase in recharge rates was not determined, but Aronovici et al. (1972) suggested that it was due to the release of trapped air in the sediments and development and enlargement of macroflow channels. Although a perched water table formed on the caprock, it did not rise high enough to limit percolation from the basins. Initial tests showed that surface sealing would be the major problem in recharging turbid playa water through the excavated basins. Tests were then conducted to measure the depth of sediment penetration into the basin bottoms and to determine the feasibility of renovating a basin after sealing by suspended solids.

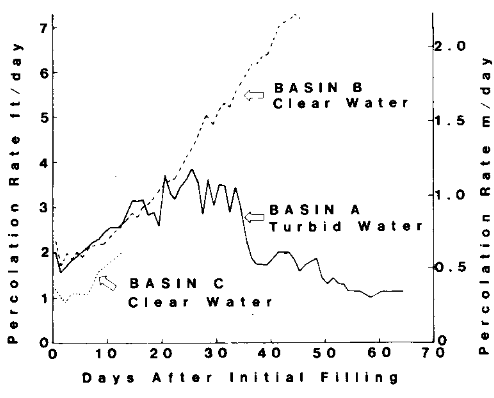

Fig. 2. Percolation rate of three basins during the first interval of flooding (from Aronovici et al., 1972).

Sediment Penetration and Basin Renovation

Most of the sediment penetration and basin renovation research was conducted in Basin A, one of the 0.04-ha basins. Eleven recharge tests were conducted with turbid playa water (Table 1), and the basin bottom was renovated several times by scraping or sweeping. During one of the tests, suspended sediment in the recharge water was tagged with the radioisotope ^{134}Cs to determine the extent of its movement into materials underlying the recharge basin. In addition, the movement and accumulation of the suspended sediment in the basin bottom were determined by microscopic examination of thin sections from this material.

Penetration of sediment into the bottom of the 0.04-ha basin is illustrated in Fig. 3. The curves show the percent of sediment added to the basin that moved deeper than the indicated depth for both the ^{134}Cs study and the thin-section study (Goss et al., 1973a, 1973b; Goss and Jones, 1973). The ^{134}Cs measurements indicated that over 90% of the suspended sediment was filtered within 25 mm of the basin surface. The thin section study showed that the average pore volume lost between the 25- and 50-mm depths was 1.5%; and below 50 mm, it was less than 1%. Both studies clearly showed that most sediment was filtered at or near the basin surface. Before any recharging began, the bottom of the 0.04-ha basin was chisel-tilled; and this destroyed the large, continuous soil pores. When the large pores were deliberately exposed, only 50% of the suspended sediment accumulated within the upper 0.46 m of the pluvial sediments. Thus, the large, continuous pores must be destroyed to prevent deep sediment penetration.

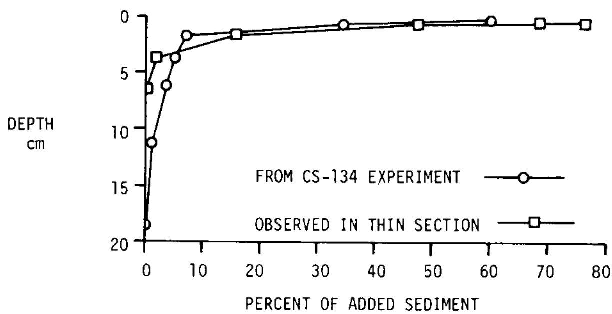

Fig. 3. Percent of sediment added to basin that moved deeper than indicated depth for thin section study and ^{134}Cs study (from Goss and Jones, 1973).

Table 1. Summary of recharge through three excavated basins on the Southern High Plains, 1969-1978.

Basin	Test no.	Year	Length of flooding, days	Total recharge, m	Average recharge rate, m/d	Range in rates, m/d	Average daily turbidity, mg/L	Range in turbidity, mg/L	Total suspended solids, kg/m^2
0.04 ha	1	1969	65	44.9	0.69	0.30-1.16	190	100-300	8.63
(Basin A)	1A	1970	6	2.8	0.47	0.18-0.55	Clear water		0
	2	1970	32	11.2	0.35	0.15-0.85	165	37-900	1.81
	3	1971	21	7.0	0.34	0.09-0.61	182	100-280	1.18
	4	1971	23	6.6	0.29	0.12-0.64	326	230-470	2.11
	5	1972	43	18.5	0.43	0.15-0.70	182	20-370	2.99
	6	1972	15	4.0	0.27	0.09-0.40	293	190-470	1.23
	7	1972	20	6.2	0.31	0.09-0.55	93	60-140	0.54
	8	1972	26	13.5	0.52	0.09-1.07	77	10-340	0.44
	9	1973	29	11.7	0.40	0.12-0.79	384	360-490	4.61
	10	1973	15	3.5	0.23	0.12-0.58	209	130-270	0.78
	11	1973	15	4.6	0.30	0.15-0.64	108	90-130	0.49
Total*			304	131.7					24.81
0.2 ha	1	1971	31	11.1	0.36	0.09-0.70	150	120-210	1.66
	2	1971	11	2.6	0.24	0.18-0.37	231	160-280	0.60
	3	1971	4	1.0	0.25	0.15-0.27	200	130-140	0.20
	4	1974	29	9.7	0.33	0.20-0.58	408	140-630	3.96
	5	1974	24	6.4	0.27	0.16-0.35	73	40-130	0.47
	6	1978	18	4.8	0.27	0.13-0.54	638	500-980	3.06
	7	1978	35	14.7	0.42	0.11-0.71	152	70-230	2.23
	8	1978	35	19.4	0.55	0.15-0.80	262	190-430	5.08
Total			187	69.7					17.26

* Clear water test data were excluded.

The basin surfaces were usually renovated by removing accumulated suspended solids before the next test. The 0.04-ha basin was renovated by sweeping or air blasting, and the 0.4-ha basin was renovated by scraping with a motor grader. Basin A was successfully renovated during 11 recharge tests in which the average suspended solids applied to the basin was 2.25 kg/m^2 per test. Total recharge during the tests was 132 m, and the average rate over 304 days of flooding was 0.433 m/d.

Cracking of the basin surfaces while the basins were flooded caused considerable variability between recharge cycles. The cracks were up to 10 mm wide and as deep as 100 mm and resembled dessication cracks in clay soil. When cracking occurred, recharge rates increased, and the total amount of suspended solids required to reduce recharge rates to 0.15 m/d, the minimum acceptable rate, increased. Most recharge after cracking began probably occurred through the vertical walls of the cracks where clay accumulation was less than on the horizontal surfaces. In the 0.04-ha basin, cracking occurred during Tests 1, 5, 8, and 9.

Basin Management Techniques

Basin management techniques were investigated in six 0.008-ha, square basins adjacent to the original 0.04-ha basins (Jones et al., 1981). A check treatment was managed the same as the basins reported by Aronovici et al. (1972). Additional treatments were: (1) organic filter of cotton gin trash incorporated into the basin surface; (2) coagulation with a polyelectrolyte flocculent within the basin; (3) high-head flooding of 1.2 m; (4) 0.6-m flooding depth followed by 1.2-m depth after the recharge rate dropped to 0.3 m/d; and (5) 0.4-m wide by 0.14-m high corrugations (ridges and furrows) in the basin bottom.

The basin management treatments were evaluated during four recharge tests over a 4-y interval (Table 2). In a pretest, recharge rates in the six basins were essentially equal; thus, any large differences in subsequent tests were due to the management treatments. The high-head treatment was most effective, with a 130% increase in total recharge over the check. The organic filter was also highly effective, with an increase of 98% over the check treatment. The flocculent treatment was effective in Test 2 with average suspended solids of 460 mg/L; however, it was ineffective in Test 4 with suspended solids averaging 151 mg/L. The variable-head treatment increased total recharge by 56% over the check, but it was not as effective as maintaining a continuous high-head. Although the corrugated basin surface increased total recharge only 19% over the check, the corrugated bottom could be renovated by washing away deposited sediment with a sprinkler irrigation system. This type of renovation proved to be highly effective in a prototype basin being tested at the same time.

Table 2. Summary of infiltration, days of flooding, and average playa water suspended solids concentration (from Jones et al., 1981).

Test no.	Test length	Check	Organic filter	Flocculent	High head	Variable head	Corr.
	days	m					
Pretest	9	7.19	7.01	7.61	7.76	7.60	6.27
1	10	2.98	7.06	3.08	8.41	5.89	5.06
2	36	7.76	14.17	17.21*	20.20	12.78	7.77
3	17	6.12	15.37	9.11	13.10	7.80	8.57
4	42	17.94	32.25	14.64*	38.50	27.84	20.06
Total**	105	34.80	68.85	44.04	80.21	54.31	41.46
		% increase					
		0.0	98.0	27.0	130.0	56.0	19.0

* Basin treatments were applied after pretest except for the flocculent basin, which received flocculent only during Tests 2 and 4.

** Total of Tests 1 through 4.

Prototype Basin

The prototype basin was excavated along the north margin of a 16-ha playa located 48 km west and 10 km south of Amarillo, TX (Schneider and Jones, 1983). The basin was 100 m long, 20 m wide, and approximately 1.2 m deep. The soil and geology were similar to that described by Aronovici et al. (1972) except that the Ogallala was overlain by a slightly thicker section of Pleistocene sediments. Initially, the basin surface was corrugated along the contour with 1-m wide ridges and furrows. After the third recharge test, the basin surface was recorrugated with similar corrugations running up and down the 3.5% slope. At that time, a basin drain was installed which removed runoff during storms and permitted emptying the basin after tests.

Eight recharge tests were conducted in the basin when playa water was available over a 7-y period. Results of the tests are listed in Table 1, where the basin is identified as the 0.2-ha basin. During 187 d of flooding, total recharge was 69.7 m, and the average rate was 0.373 m/d. The first three tests were conducted with a constant flooding depth of 0.76 m. During subsequent tests, the basin was filled daily, and the water level was allowed to drop over a 24-h period. Flooding depth was initially 0.8 m; but during Tests 7 and 8, it was increased to 1.4 and 1.5 m, respectively.

The corrugations up and down the slope, combined with the drain, tended to make the basin self-renovating. High-intensity storms that caused runoff to the playa also eroded deposited sediments from the basin surface. The sediment laden water flowed down the corrugations and out of the drain, thus cleaning the basin surface as recharge water became available. Corrugations were the only preparation or renovation to the basin surface during the 7-y test. Since the sediment laden water from the basin flowed into sediment laden water in the playa, no water quality degredation occurred.

DISCUSSION AND CONCLUSIONS

Careful site selection is essential to the success of excavated recharge basins. The pluvial Pleistocene sediments were largely silt, which would normally be less permeable than the very fine sand of the alluvial playa sediments. Because of the open structure of the pluvial sediments, however, the quasi-steady state recharge rate was 60 times greater than for the playa sediments. Where the pluvial sediments have been exposed to the surface or reworked by water action, the permeability is much lower, however. In site selection, soil coring with a tractor or pickup mounted sampler quickly provides data over a large area. Exploration pits are most desirable, however, for final site selection, which needs to include infiltration tests of the water to be recharged.

Good management techniques are essential for maintaining high basin recharge rates over a period of years. Where a basin surface must be renovated, intervals of flooding and drying need to be optimized. Then, techniques such as scraping or sweeping need to be developed to remove suspended solids filtered at the basin surface. If suitable organic material is available, organic mats offer potential for increased recharge rates and reduced renovation. Where the basin surface limits percolation, dikes will increase the depth of flooding and the recharge rates. Finally, the self-renovating system developed with the prototype basin offers considerable potential. Continued use of a recharge basin over a period of years without renovation greatly improves the feasibility of artificial ground water recharge.

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