RESEARCH BULLETIN 817 FEBRUARY,

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

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Sealing Farm Ponds in Missouri

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Missouri Agricultural Experiment Station and the United States Department of Agriculture Cooperating

(Publication authorized February 2, 1963)

COLUMBIA, MISSOURI

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Contribution from the Corn Belt Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, in cooperation with the Agricultural Engineering and Soils Departments of the Missouri Agricultural Experiment Station and with the Soil Conservation Service, USDA.

Fig. 1—An excellent pond in Texas County. A satisfactory runoff yield from the watershed and good storage volume without excavation into permeable subsoil layers are favorable features of this pond.

Sealing Farm Ponds in Missouri

V. C. JAMISON AND J. F. THORNTON[1]

INTRODUCTION

Many farm ponds in Missouri are more than 8 feet deep and have a satisfactory seal (Figure 1). But in certain areas of the state, excess seepage from ponds is a serious problem (Figure 2). Farm ponds in Dade County were surveyed in November, 1959, by Soil Conservation Service Soil Scientists. They found 75 to 80 seriously leaking or dry and estimated there were between 750 and 1000 in such condition in southwestern Missouri. Most of these ponds were excavated in soils derived from Mississippian limestones and shales. Failures occurred most frequently where ponds were excavated in soils classified as Newtonia, Baxter, Eldon, Eldorado, Craig, and Gasconade series. Most of the dry ponds were constructed according to current recommendations, which specify a depth of at least 8 feet. Thus, they were generally excavated deeper than the older reservoirs, which had fewer failures (Figure 3). The older, shallow structures were less apt to expose the highly aggregated red clay subsoil or cherty gravel layers in the deep subsoil. Also, many of the older ponds are not fenced and farm animals are allowed to trample in them. This may improve the sealing of the pond bottom.

A contributing factor to the failure of many farm ponds in the Ozark Region arises from the high permeability of the soils. The water yields from water-

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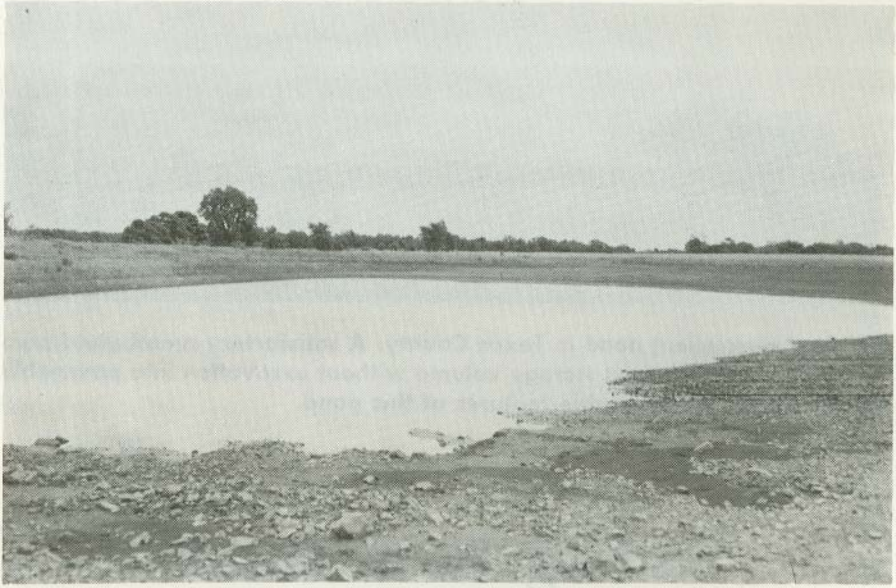

Fig. 2—A medium-sized pond in Dade County that leaks badly. It fills during high runoff periods, but is dry during dry periods. Note the cherty subsoil aggregate in the foreground.

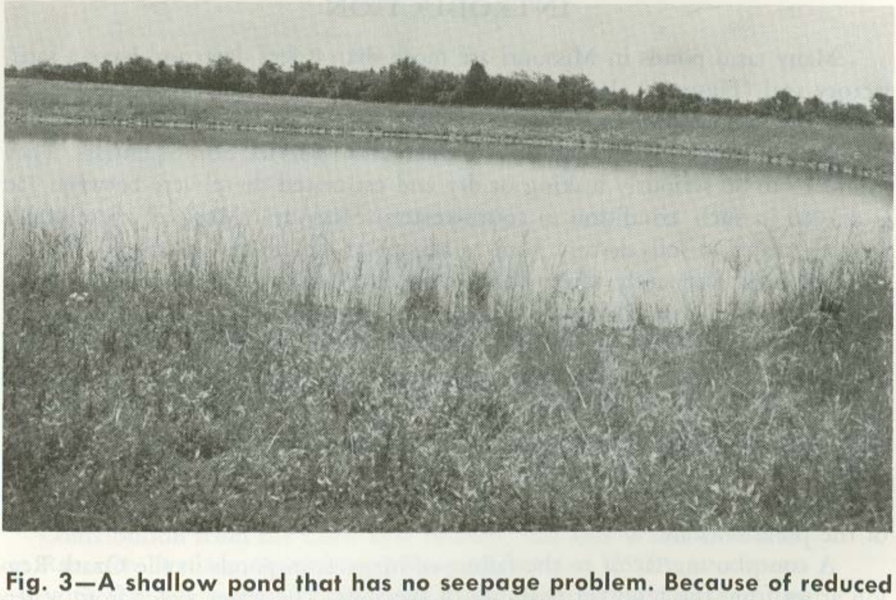

Fig. 3—A shallow pond that has no seepage problem. Because of reduced storage volume, shallow ponds may go dry due to evaporation during sustained periods of drouth. It may be necessary to increase the storage volume by increasing the area of the excavation and height of the dam, rather than cutting deeply into permeable cherty layers.

Fig. 4—Low water yields from the watershed areas above ponds contribute to the failure of ponds to fill. Runoff is low from highly permeable soils. When large areas are taken from cultivation and crop production, runoff yields are further reduced.

sheds in this region are somewhat lower than elsewhere. Also, when large areas are taken from cultivation and crop production and placed in the Soil Conservation Reserve, water yields are further reduced (Figures 4 and 5).

The problem of rapid pond seepage is not confined to the Ozark Region. There are also many ponds elsewhere in the State which are not sealed satisfactorily. Some leaking ponds have been excavated in the river-hill soils, such as Menfro, Winfield and Memphis, and a few may be found in the rolling uplands of northwestern Missouri in Shelby, Grundy, and Marshall soils.

Principles of Sealing Farm Ponds

Basic principles of pond construction and sealing have been presented by Holtan *(5)*.[2] If an impervious layer is beneath the bottom of the pond, a good seal may be achieved by packing an impervious core in the fill, or by spreading and compacting a surface blanket of impervious material on the face of the fill. The core or blanket of the fill must be keyed into the impervious layer to form a good seal.

Where no impervious layer is accessible or where such a layer is not continuous, a bag-type seal may be used. This consists of a compacted, impervious blanket covering the pond bottom, sides, and fill and extending above the high water level. To prevent excessive seepage or "blowout" failures, the sealing layer

[2]Italic numbers in parentheses refer to Literature Cited, pg. 28.

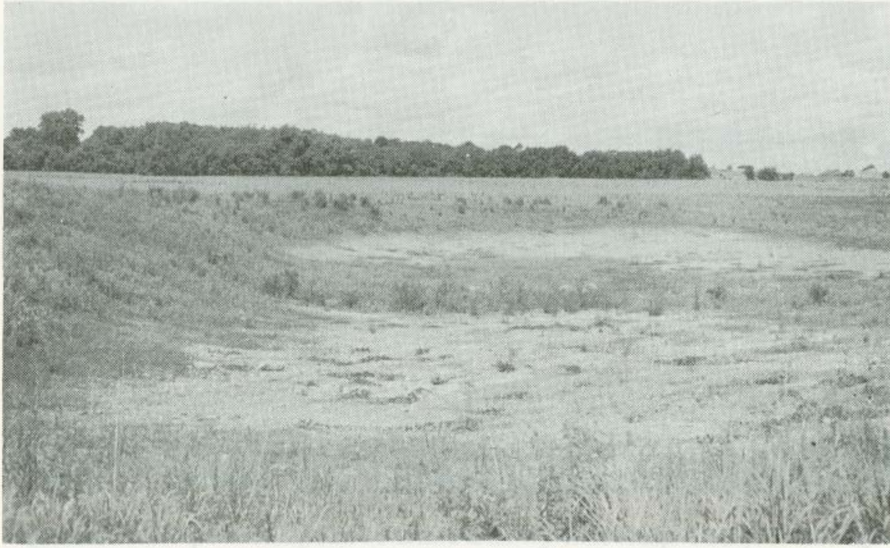

Fig. 5—A dry pond in Dade County. This pond is located near the shallow pond shown in Figure 3. The small amount of runoff draining into this pond from the Conservation Reserve watershed above it leaks out rapidly through the cherty red clay aggregate into which it was excavated.

must have beneath it or within its depth, sufficient strength to support the head of water above it as well as have low permeability.

Holtan's tests *(6)* in Virginia showed that compacted blankets of sandy loam soil materials should be most satisfactory. A good combination of strength and impermeability could be expected from about 1 foot of compacted sandy loam. He suggested that ideal material should have from 70 to as high as 95 percent of sharp sand and 5 to 30 percent of clay and silt as needed to improve the gradation of particle sizes. Compacting the material at optimum moisture content improved strength and seal. Puddling increased the seal but often reduced the strength of the material and increased the tendency for blowout failures. Addition of colloidal clay such as bentonite increased the seal of sands but excessive amounts reduced the soil strength. Also, bentonite acted as a dispersing agent in clays of the same electronic charge, thereby improving the seal but reducing the strength.

Clay and other additives have been tested for sealing farm ponds and canals *(1, 3,* and *4).* Some tests indicated treatment benefits, though the duration of the effects was uncertain. Where soil aggregation is responsible for high seepage, it may be possible to improve a pond seal by dispersing some of the aggregates so as to clog the soil voids in deeper-lying layers with dispersed clay. Observation indicates that the trampling of animals will reduce seepage, probably through puddling and dispersion as well as by compaction of the soil aggregates to form a sealed layer below the trampled zone.

Recent tests with tripolyphosphates *(1, 7)*, which have a dispersing effect on sesquioxide-bonded soil aggregates, indicate that these and similar chemicals may be used to improve pond sealing. Whatever method is used, it will be effective only if the pores are sufficiently fine beneath the disturbed or dispersed zone to entrap the fine particles and if the soil bed has sufficient depth and strength to provide resistance to blowout failures.

There are problems related to sealing ponds. With some chemical treatments, contamination of the water may make it unfit for irrigation or use by animals. Dispersed clay or other colloids in the water may reduce the value of the pond for stock consumption or recreational purposes. Dispersion, by trampling of animals or other means, may be expected to increase erosion of the soil at the water-line, unless this zone is protected by riprapping or other means.

SURVEY OF MISSOURI SOILS USED FOR POND CONSTRUCTION

Description of Soils

General descriptions of soils in Missouri's three problem areas for pond seepage will be given here. Profile descriptions of representative soils in each of these areas are given elsewhere *(8, 9)*.

The surface layer of the Ozark soils is usually silt loam in texture. As with other silt loam soils, Ozark surface soils can usually be compacted to high bulk densities; however, they are often "spongy" and fairly permeable after compaction. This may be due to the presence of clay aggregates. The subsoil layers are high in chert, which is intermixed with highly stable aggregated red clay (Figure 2).

The soils of the Ozark Region, composed of highly aggregated red clay and cherty limestone residuum, are classified in the Red-Yellow Podzolic group *(8)*. They are weathered from cherty, dolomitic limestone. In some instances, thick layers of chert-free red clay occur in the upper subsoil. This material is rapidly permeable, due to its well-developed structure and stable aggregation. Layers of fragmental, porous chert, relatively free of fine material, also occur. Exposure of either red clay or cherty material in the pond construction will result in rapid seepage loss. Soils in this general area which have permeable red clay subsoils or porous cherty subsoil layers are primarily Newtonia and Baxter. Other cherty soils or soils with clay subsoils occurring in this area but less likely to result in excess seepage are Clarksville, Bodine, Nixa and Eldon. The subsoil clay of these soils is less permeable. However, exposure of cherty layers may result in rapid seepage.

The surface layers of the river-hill soil are silt loams. The texture usually becomes finer with depth, grading to a silty clay loam. Materials similar to these may be compacted to high bulk densities at optimum moisture conditions *(6)*.

Soils in this area are classified in the Gray-Brown Podzolic group *(8)*. The parent material is deep loess over glacial till. Representative soils are Menfro, Winfield, and Weldon in the deeper loess, and soils like Union where the loess cap is thinner. Permeability of the subsoils varies from rapid to slow. Excess seepage of ponds in these soils arises from construction in coarse and porous loess and from the exposure of porous sandy or gravelly till, sandstone, fragmental limestone or shale strata.

The surface layer of the rolling upland soils of northwestern Missouri varies from silt loam to clay loam. The texture of the subsoil layers varies from silty clay loam to clay loam. Materials such as these may generally be compacted to fairly high bulk densities at optimum moisture conditions. The degree of maximum compaction to be expected is higher for the silt loams and lower for those of finer texture *(6)*.

Soils in this area are classified in the Brunizem and Humic Gley group *(8)* They are developed in varying depths of loess over glacial till of the Kansan and Nebraskan ages. Permeability of the subsoils varies from rapid in the deep loess to slow in the shallow loess over till. Representative soils are Marshall and Knox in the deeper loess, and Shelby and Gara where the loess over the till is essentially absent.

Excessive seepage results for ponds constructed in coarse, porous loess or where porous nonconforming subsoil material such as sandy or gravelly till is exposed in construction.

Test Procedures

Soil samples have been collected from 25 leaking or dry ponds in 12 counties of the state. These have been tested for hydraulic conductivity when compacted moist to about maximum bulk density feasible for each soil. The resulting density values varied from 1.50 to about 1.95 gm per cc. The lowest values were obtained with clay loams, intermediate ones with silt loams and the highest with sandy loams. Tests were made on one or more samples from the pond bottom or the waterline, and one or more from adjacent field areas. These latter field area samples were tested to determine whether it may be feasible to use the nearby surface soil as a blanket to seal the bottom of the pond.

Compaction is an important factor in producing a good seal. Preliminary tests showed that degree of compaction greatly affects the hydraulic conductivity or the seal obtained with the various soils. If we assume that the compacted layer in the upper 8 or 10 inches of a pond bottom largely determines the seepage rate, then for a 10-foot depth of water, the rate will be roughly 10 times the hydraulic conductivity. If a seepage loss of 0.1 inch or less per day is taken as an acceptable pond seal, then a hydraulic conductivity of .01 inch per day may be taken as a maximum allowable rate indicative of good sealing possibilities for the soil and treatment tested. Throughout the tables presented here, acceptable values are underscored with a solid line and marginal rates with a dashed line.

In Table 1, the effect of compaction on soil seal obtained is shown. The change in bulk density (D_b) from 1.60 to 1.75 with the Winfield soil from Lewis County changed the seal from poor to satisfactory.

TABLE 1-THE EFFECT OF COMPACTION ON SEAL OF SOIL MATERIALS

Location County	Soil Description Series	Layer	D_b Gm/cc	K[3] Inches/day
Lewis	Winfield	Silt loam surface	1.30	10.0
			1.60	0.43
			1.75	.0001
Marion	Menfro	Gravelly loam subsoil	1.30	.19
			1.70	.11
		Silt loam topsoil	1.20	10.0
			1.70	.0003
Ralls	Winfield	Sandy loam subsoil	1.30	10.0
			1.85	.006
Franklin	Memphis	Silt loam surface	1.30	10.0
			1.65	.0004
Franklin	Clarksville	Clay loam subsoil	1.30	10.0
			1.65	.55

[3]Hydraulic Conductivity or flow rate at unit pressure gradient. For a 10-foot head of water, the seepage rate may be about 10 times this amount. Conductivity equal to or less than .01 inch/day indicates good sealing possibilities.

The moisture content at which the soil is compacted is usually critical in determining the seal (Table 2). Actually, soil materials compacted a little on the dry side of "field capacity" moisture content will be a little more compact than if they were compacted at a higher moisture condition. However, a better seal is usually obtained where the soil is compacted at a moisture condition a little wetter than field capacity. In the tests made for the survey of the pond soils, the samples were compacted in the test cylinders at a moisture content equivalent to a suction of about 0.2 atmosphere. Farmers would consider this condition for most soils as "too wet to plow," although ideal for obtaining a good seal.

TABLE 2-EFFECT OF MOISTURE CONDITION ON COMPACTION SEAL OF SOIL MATERIALS

Location County	Soil Description Series	Layer	Packing condition[4]	K
				Inches/day
Nodaway	Grundy	Clay loam subsoil	Moist	0.080
		do	Wet	.002
Nodaway	Grundy	Clay loam subsoil	Moist	.23
		do	Wet	.023
McDonald	Bodine-Clarksville	Clay loam subsoil	Moist	.023
		do	Wet	.002
McDonald	Bodine-Clarksville	Clay loam subsoil	Moist	.032
		do	Wet	.008

[4]Packed at the maximum bulk density feasible for the given moisture condition. A "moist" condition is on the dry side and a "wet" condition on the wet side of ideal conditions for tillage.

Results of Survey

The results of the tests of the soil samples taken from pond sites are shown in Table 3. In general, the silt and sandy loams will seal satisfactorily if compacted to maximum density at optimum moisture conditions. The loessal soils of the river-hill areas usually seal better than the silt loam surface soils of the Ozark Region. A certain degree of sponginess seems to persist in the latter samples after compaction.

The best seals were obtained with the Grundy and Marshall silty clay loams. With some compacted samples, it was necessary to apply hydraulic pressures exceeding 100 feet of water to obtain measurable flow rates. This fact indicated that some leaking ponds that were excavated in these soils may be satisfactorily sealed by compacting the present bottoms. Possibly, the addition of a compacted blanket of sufficient depth may be necessary to avoid blowouts if porous subsurface soil or rock layers have been exposed. The compacted blankets should be at least 1 foot thick over such exposures. Elsewhere, over moderately permeable exposed subsoils, a dense blanket of about 4 to 6 inches should provide a satisfactory seal for these soil materials. For silt loam to silty clay loam soils, similar to the Marshall and Grundy samples studied, it should be possible to achieve

TABLE 3-SUMMARY OF RESULTS OF SURVEY OF LEAKING OR DRY MISSOURI FARM PONDS

Location	Pond	Observed	Samples			Test Results	
County	Size	Condition	Series	Location	Texture	D_b	K
	Acres					Gm/cc	In./day
Dade	11	dry	Baxter	Pond bottom	Brown, silty clay	1.65	0.017
Do	do	do		do	Dark red clay	1.55	.098
do	do	-----		Adjacent field	Silt loam	1.65	.002
do	1.5	dry	Baxter	Pond bottom	Red clay	1.55	2.10
do		-----		Adjacent field	Silt loam	1.65	.081
do		-----		do	do	1.65	.034
Marion	0.5	leaks badly	Menfro	Water line	Gravelly loam	1.70	.11
do	do	-----	do	Adjacent field	Silt loam	1.70	.001
Ralls	0.25	leaks badly	Menfro	Water line	Sandy loam	1.85	.006
do	do	-----	Winfield	Adjacent field	Silt loam	1.65	.0004
Ralls	0.25	leaks badly	do	Adjacent field	Silt loam	1.50	.0001
Marion	Test Sample		Menfro	Subsoil sample	Silt loam	1.65	.006
Lewis	0.25	leaks badly	Winfield	Pond edge	Sandy loam	1.95	.007
do	do	-----	do	Adjacent field	Silt loam	1.75	.0001
Franklin	0.9	leaks badly	Clarksville	Pond edge	Gravelly loam	1.70	.0001
Franklin	0.9	leaks badly	Clarksville	Adjacent field	Silt loam	1.60	.00003
do	1.0	leaks badly	Memphis	Adjacent field	Silt loam	1.65	.001
do	1.0	nearly dry	Clarksville	Pond bottom	Clay loam	1.65	.001
Nodaway	0.5	dam leakage	Shelby	Water's edge	Clay loam	1.65	.00002
do	-----	-----	do	Adjacent field	Silt loam	1.65	.00001
do	0.3	dam leakage	Grundy	Water's edge	Clay loam	1.65	.006
do	-----	-----	do	Adjacent field	Silt loam	1.65	.00003
do	0.7	leaks badly	Grundy	Water's edge	Clay loam	1.70	.023
Nodaway	-----	-----	Grundy s.l.	Adjacent field	Silt loam	1.65	.002
do	0.7	some leakage	Marshall	Water's edge	Silty clay loam	1.65	.00002
do	do	-----	do	Adjacent field	Silt loam	1.65	.00003

TABLE 3-CONTINUED

Location County	Pond Size	Observed Condition	Samples Series	Samples Location	Samples Texture	Test Results D_b	Test Results K
	Acres					Gm/cc	In./day
do	0.25	dry most of time	do	Pond bottom	Silty clay loam	1.65	.023
do	-----	-----	do	Adjacent field	Silty loam	1.65	.00004
do	0.3	leaks under dam	Grundy	Water's edge	Silty clay loam	1.65	.00006
do	-----	-----	do	Adjacent field	Silty clay loam	1.65	.00003
McDonald	0.5	leaks badly	Bodine-Clarksville	Pond edge	Silty clay loam	1.70	.002
McDonald	-----	-----	Bodine-Clarksville	Adjacent field	Silt loam	1.74	.034
do	0.5	leaks badly	do	Pond edge	Silty clay loam	1.72	.008
do	-----	-----	do	Adjacent field	Silt loam	1.80	.017
Newton	Not yet constructed		Bodine	Near dam site	Silt loam	1.75	.010
do	do		do	250 feet above dam, subsoil	Silt loam	1.90	.002
do	0.5	leaks badly	Bodine-Baxter	Water's edge	Silt loam	1.90	.008
do	-----	-----	do	Adjacent field	Silt loam	1.73	.010
Texas	1.0	Dry	Clarksville	Pond bottom	Clay loam	1.60	.96
do	-----	-----	do	Adjacent field	Silt loam	1.65	.023
do	1.0	Dry	do	Pond bottom	Clay loam	1.60	.037
do	-----	-----	do	Adjacent field	Silt loam	1.65	.070
do	1.0	leaks badly	do	Adjacent field	Silt loam	1.60	.035
Greene	5	leaks badly	Baxter	Pond edge, west side	Red clay loam	1.55	1.41
do	do	-----	Baxter	Adjacent field	Silt loam	1.65	.008
Jasper	1.0	Dry	Baxter	Pond bottom	Clay loam	1.68	.18
do	-----	-----	Dunning	River Bottom nearby	Silty clay loam	1.75	.00008

seals of sufficiently low conductivity that the seepage would be very small in comparison with pond surface evaporation losses.

In the Ozark Region, special treatments and precautions appear necessary to obtain good seals for most soils. Since only fair seals were indicated by the tests with the blanket materials available in the surface soils from nearby fields, treatments other than compaction were tried. In most cases, mixing from 50 to 90 percent of surface soil material with the red clay loam of the pond bottom achieved a better-compacted seal than either soil material alone (Table 4). This result indicated that the blanket material should be spread on the pond bottom and tilled or stirred into the underlying clay before being compacted.

TABLE 4–EFFECT OF MIXING TOPSOIL BLANKET WITH CLAY LOAM SUBSOIL BEFORE COMPACTING TO MAXIMUM BULK DENSITY

Location County	Mixing Ratio	K
	Topsoil:subsoil	Inches/day
Texas	Topsoil alone	0.023
Do	Subsoil alone	.96
do	1:1	.005
do	Topsoil alone	.070
do	Subsoil alone	.037
do	1:1	.083
McDonald	Topsoil alone	.034
do	Subsoil alone	.002
do	1:1	.007
do	Topsoil alone	.017
do	Subsoil alone	.008
do	1:1	.007
Dade	Topsoil alone	.017
do	Subsoil alone	.10
do	1:9	.0005
do	Topsoil alone	.034
do	Subsoil alone	2.10
do	1:9	.029

Tests with Barnyard Manure

Manure from farm animals was tested to see if it had a sealing effect in addition to whatever effect may be due to trampling by the animals. Barnyard manure was suspended in the water used to measure hydraulic conductivity with time (Table 5). The reduction obtained over a period of one or two weeks was profound. Further tests with ammonia in solution indicated that this constituent of the manure was not responsible. The sealing effect is probably due to some complex organic material. However, tests with organic gums and acrylic polymers gave disappointing results. Suspended clay or ground hay in the water improved sealing but to a somewhat lesser degree than manure.

TABLE 5-THE EFFECT OF MANURE SUSPENDED IN POND WATER ON SOIL SEAL

Soil Material		Treatment	Time After Treatment	K
Series	Description		days	Inches/day
Baxter	Red clay loam subsoil plus surface soil mixed 1:1	Manure suspended in water @ 3 tons of dry matter per acre-foot	0	0.14
			2	.004
			4	.001
Newtonia	Dark red clay Loam plus surface soil mixed 1:1	do	0	.23
		do	1	.16
			3	.09
			6	.06
			7	.05
			10	.04
Newtonia	Dark red clay subsoil	do	0	1.41
			1	.76
			3	.23
			6	.15
			8	.05
			10	.04
			13	.03
			16	.03

Tests with Polyphosphates and Silicates

Since soil puddling or a soil dispersing action may be largely responsible for the effect of the trampling of animals in reducing pond seepage, tests were made of chemical dispersants. The dispersants studied were hexametaphosphate and tripolyphosphates (condensed phosphates) as well as sodium silicate (Waterglass). Results with a soil from a Dade County pond are shown in Table 6. The effects of the hexametaphosphate are often spectacular. Those with tripolyphos-

TABLE 6-THE EFFECT OF CHEMICAL DISPERSANTS ON SEALING OF SOIL MATERIALS

Soil Material	Dispersant	Rate Applied	K
		Tons/acre-6"	Inches/day
Dark red clay loam subsoil	Sodium hexa-metaphosphate	None	1.10
	do	0.5	.021
	do	2	.0004
	do	10	.0004
	Sodium tripoly-phosphate	None	.64
	do	2	.001
	Waterglass	1	.37
	do	10	.023
Silty clay from pond bottom	Sodium hexa-metaphosphate	None	.017
	do	2	.003
	do	10	.002
Silt loam surface soil	Sodium hexa-metaphosphate	None	.002
	do	1	.0005
	Waterglass	10	.005
Silt loam - red clay loam mixture	Sodium tripoly-phosphate	0	.25
	do	2	.018

phate were not so profound and even less so with Waterglass. Treatments with soda lime and ammonia gave small decreases in conductivity. The dispersing effect of the condensed phosphates of sodium is due to the formation of soluble ion complexes with the multivalent cations in the soil (such as iron, aluminum, calcium and magnesium), which are responsible for binding clay particles in stable floccules and aggregates. The activity of the flocculating polyvalent cations is reduced and replaced by the monovalent cation sodium. Also, the condensed phosphate is strongly absorbed on the clay particules. The process virtually rips the clay mineral apart, due to the complexing of iron and aluminum.[5]

[5]Personal communication from R. R. Allmaras, Soil Scientist, Soil and Water Conservation Research Division, Morris, Minnesota.

At the same bulk density, a puddled mass of dispersed clay will be less permeable than a gravel-like body of aggregates before dispersion. Unfortunately, the condensed phosphates hydrolyze to ordinary orthophosphate so that flocculation and a reversion to the aggregation of the clay particules may be expected after several months.

Although chemical treatments are quite effective, they may be too expensive to be practical. The use of mechanical dispersion methods, either by machinery designed to tread or stir the soil beneath the pond water surface or simply by allowing animals to trample in the pond, may be more satisfactory, at least from the cost standpoint.

Tests with Emulsions

Some asphalt-water emulsions and a commercial emulsion were tested for the effect on soil sealing. The results with asphalt emulsions, either mixed in the soil or suspended in the water, were disappointing. The decreases obtained were little different than may be obtained by working and compacting the soil to the same extent in a slightly wet condition. Tests with the commercial emulsion indicated that it will reduce the flow rate about 60 or 70 percent. These results were consistent with the claims of the distributors of this material. However, for sealing farm ponds, a more effective method or material is needed.

LABORATORY MODEL STUDIES

It would be extremely difficult to determine the distribution of hydraulic pressures and flow characteristics in the soil under a pond. Yet, these relationships, especially in the top of the soil profile, would be helpful in predicting the effectiveness of a compacted layer in reducing seepage. These are not easy to study directly, but something can be learned about the principles involved by the use of laboratory models.

Procedure

The model consisted of a column of soil packed in a cylinder of clear, rigid plastic tubing (Figure 6). The base was sealed to a sheet of clear plastic with an outlet for drainage, and a coarse screen was placed in the bottom to conduct drainage to the outlet. In the first test, red clay subsoil from a Baxter profile was packed into the cylinder to a depth of 43 inches and a bulk density of about 1.0 gm/cc.

In the second test, the upper 4-inch layer of the soil was compacted to 1.20 gm/cc. In the final test of this series, the top was sealed with a 1-inch layer of fine silt loam (Knox subsoil). The column was capped with an aluminum plate which was clamped and sealed with a gasket to make it possible to increase the pressure on the water on the soil surface by using compressed air. The cap was fitted with an air inlet and also an inlet for water so that water could be introduced and kept on the soil surface by opening a valve to the water line. One re-

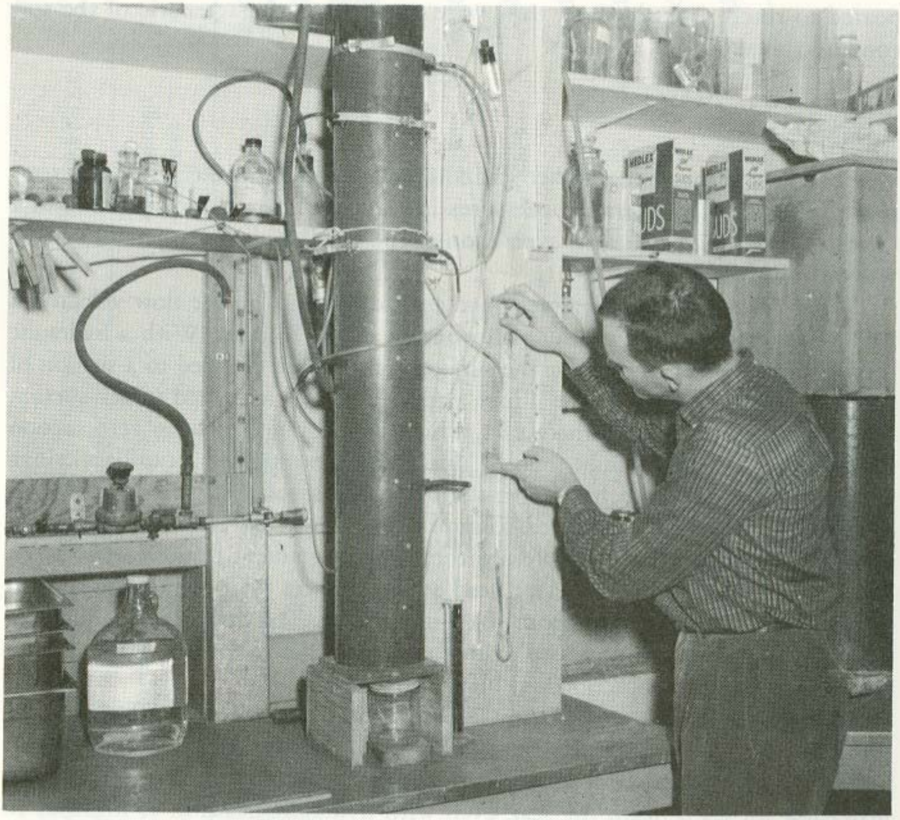

Fig. 6—Laboratory model of the soil beneath a farm pond. Tensiometers inserted through the plastic wall measured hydraulic pressure in the soil water. Screws turned loosely into threaded holes in the wall allow the air in the soil pores to adjust to the pressure of the atmosphere.

quirement was that the air pressure inside the chamber be less than the water line pressure. Manometers of the U-tube type were attached with tygon tubing to porous tensiometer cups that were inserted into the soil through the wall of the cylinder and sealed in place to measure pressure or suction at 4, 8, 16, 24 and 32 inches below the soil surface. Screws were turned into threaded holes at 4-inch intervals. Keeping these loosely fitted in the zone of negative hydraulic pressures reduced water vapor loss, yet allowed the soil air to adjust to atmospheric pressure. A screw would be tightened to prevent water loss only when positive pressure was registered at the nearest manometer. When the water was draining slowly from the outlet, it was assumed that, at the base of the soil, the pressure in the water was one atmosphere; that is, the differential pressure, or suction in the air-water interface was equal to zero. After flow and pressure appeared to reach a steady state, they were recorded as characteristic of the soil condition used.

Results

The flow through the Baxter soil column without a blanket seal was excessive (Table 7). The hydraulic pressures in the column remained positive to a depth of more than two feet, even though the head applied at the soil surface was only 35 inches.

The wet compaction treatment had a striking effect on the flow velocity as well as on the hydraulic pressure distribution in the column. With a hydraulic head of nearly 6 feet of water at the surface, the pressure dropped to a suction of about 9 inches of water at the 4-inch depth. The soil remained under suction throughout the column to the outlet, which was assumed to be at zero suction or pressure. The soil would then be unsaturated except for a capillary fringe zone extending a few inches above the base. The seepage loss was reduced to about 1% of that of the unsealed column. The compacted 1-inch silt loam seal further reduced seepage and increased the pressure gradient in the surface layer. Even with more than 15.5 feet of head at the surface, the pressure dropped to negative (suction) values at about the 5-inch depth. The hydraulic conductivity of the surface layer was decreased from about 10 inches to 0.002 inch per day by the combined wet compaction and blanket treatments.

The results of this model study indicate that even under a leaking pond the soil water may be at pressures below that of the atmosphere at a foot or two below the soil surface. Beneath a pond, the soil water is probably under suction just a few inches beneath the seal, even with hydraulic heads of as much as 10 feet of water above the seal. The suction effect will make a small contribution to the hydraulic gradient and, hence, the forces causing seepage. With a good seal, this effect will be negligible.

The observed drop from applied pressure to suction over the sealed interval has one further practical application. If sufficient supporting strength is provided beneath the seal, a coarse aggregate or gravelly zone below the sealed layer will contribute less to seepage than a moderately fine material, since water will not enter large pores until the suction force approaches zero or the pressure becomes positive. Water moving under a suction force of about 0.1 atmosphere or greater will flow faster at the same gradient through dispersed medium-to-fine textured soil particles than through sand, gravel, or loose aggregates.

The results of this test were used to test the reliability of using the conductivity of the least permeable layer in a soil as a measure of the permeability of the profile. According to Schwartzendruber *(10),* the flow velocity, or seepage rate, will depend upon the total pressure head over the soil profile and the sum of the resistivities of the soil layers; that is,

$$V = \frac{h + L_S + L_1 + L_2 \ldots + L_n}{L_S/K_S + L/K_1 + L_2/K_2 \ldots + L_n/K_n} \qquad (1)$$

TABLE 7-THE EFFECT OF A SURFACE SEAL BY COMPACTING WET, AND BY ADDING A COMPACTED SILT LOAM BLANKET ON SEEPAGE LOSS

	Unsealed[6]			Surface 4 inches Compacted wet			Compacted Blanket[7]		
Seepage, Inches/Day	43			0.41			.09		
Soil Depth	Hydraulic Pressure	Hydraulic Gradient	Hydraulic Conduc-tivity	Hydraulic Pressure	Hydraulic Gradient	Hydraulic Conduc-tivity	Hydraulic Pressure	Hydraulic Gradient	Hydraulic Conduc-tivity
Inches	Inches of water		Inches/ Day	Inches of water		Inches/ Day	Inches of water		Inches/ Day
0	35			57.1			186		
		4.1	10.2		17.7	.023		41.8	0.002
4	24			- 8.7			- 23.2		
		3.2	13.4		2.2	.19		.4	.25
8	14			-13.8			- 20.5		
		1.3	32		1.1	.37		1	.91
16	11			-14.6			- 20.5		
		2	20.9		1	.41		.5	.19
24	3.7			-14.6			- 16.3		
		1.7	25.2		.5	.83		.5	.20
32	- 2.1			-10.6			- 10.6		
		.8	51.2		.2	2.05		.2	.45
[8]43	0			0			0		

[6] Baxter subsoil aggregates at a bulk density of 1.0 or about that of its natural condition.

[7] Surface 4 inches, compacted wet with a 1-inch blanket of Knox silt loam compacted to 1.6 gm./cc.

[8] Base of the column where outflow occurred is assumed to be at zero differential pressure.

Where V is the flow velocity, h is the water depth on the soil, L is the depth of a layer and K is its permeability. The subscript S refers to the sealed layer and the subscript numerals to other profile layers down to the lowest layer n. Schwartzendruber pointed out that only when K_S is very small in comparison with that of the other layers may one take the measurement of the flow through this layer as representative of that of the profile. Only then will $V_L = V$ where V_L is the velocity measured through the "limiting layer" and the above equation will reduce to

$$V_L = \frac{K_S}{L_S}(h + L_S)$$

It has also been shown[9] that, under a sealed layer, the velocity will approach a critical value as the negative pressure (or suction) in the soil beneath the sealed layer approaches the degree of unsaturation where air enters a large portion of the pores and flow is restricted in the lower layers. When the critical pressure P_c is reached, V_c or the critical velocity may be taken as equal to V. The value of P_c varies for most soils from about -15 cm. of water for coarse-textured to about -45 cm. of water for soils of finer texture. Thus, the critical velocity will be

$$V_c = \frac{K_S}{L_S}(h + L_S - P_c)$$

In Table 8, the measured velocities and those calculated from the more precise equation of Schwartzendruber are compared with the approximate V_L and V_c values for the different degrees of seal used in the model. Only for small K_S/K ratios are the V_L and V_c values good estimates of the seepage rate to be expected.

The permeability of a sample isolated from a profile layer will represent the flow to be expected in the profile only if the value is small compared with that of the rest of the profile, or if conditions are such that the soil pores are largely air-filled (unsaturated) in the layers beneath the layer tested.

FIELD TESTS

Procedure

Sealing tests have been made on two ponds in southwestern Missouri. These were a 1.5-acre pond in Dade County and a 5-acre pond in Greene County. (See Table 3 for description.)

The Greene County pond leaked badly, evidently through the exposed red clay aggregate on both of the basin side walls near the fill. There was no evidence of seepage through or under the fill. Cattle were kept in the field which enclosed this pond. The feeders and salt boxes were kept on the east side so that trampling was not uniform around the pond. The Dade County pond was dry

[9]Personal Communication with Herman Bouwer, Research Hydraulic Engineer, U. S. Water Conservation Laboratory, Tempe, Arizona.

TABLE 8-THE COMPARISON OF MEASURED VELOCITIES WITH THOSE CALCULATED FROM PREDICTING EQUATIONS FOR THREE DEGREES OF SEAL IN THE SOIL MODEL

K_S/K	Unsealed	Compacted Wet	Compacted Blanket
	0.45	.051	.012
Velocities		cm./day	
V_L	280	0.91	0.215
V_c, P_c=15	324	1.00	.212
V_c, P_c=45	391	1.18	.224
V	106	1.04	.235
Measured	108	1.05	.230

most of the time. Any runoff that collected in it following rainfall was lost rapidly into the exposed cherty red clay aggregate in the pond basin.

The Greene County pond was treated on April 11, 1961 (Figure 7). The treatment consisted of spreading 1000 pounds of hexametaphosphate for about 30 feet above the water line on each side above the fill. The fill was not treated. The chemical was harrowed into the soil and then blanketed with 3 inches of silt loam topsoil from a field nearby. It was assumed that the trampling of the animals would pack or puddle the soil. It was suggested that the owner rotate the location of the feeders and salt boxes about the pond so as to distribute trampling more evenly.

The Dade County pond was treated June 12-15, 1961. At this time, there was a shallow pool of water less than 1 foot deep in the basin (Figure 8). Fif-

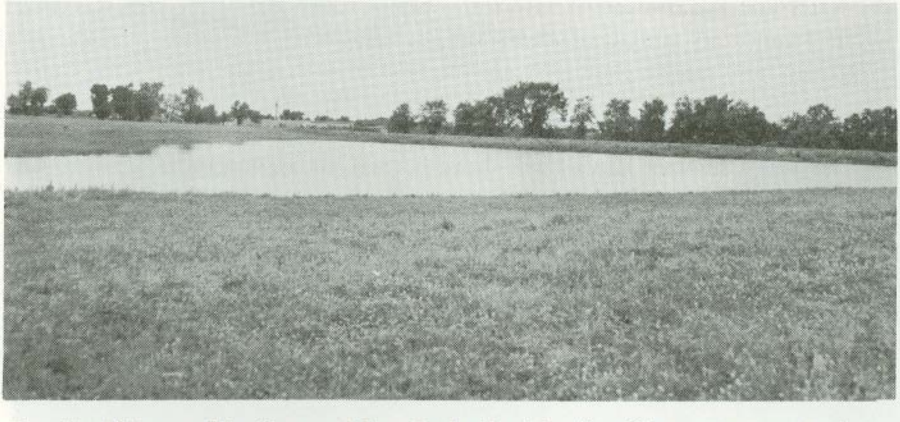

Fig. 7—This pond in Greene County leaked badly. Since treatment above the water line with hexametaphosphate and a silt loam blanket, the pond has remained filled to the treated level. Water that collects above this level during heavy runoff seeps away rapidly.

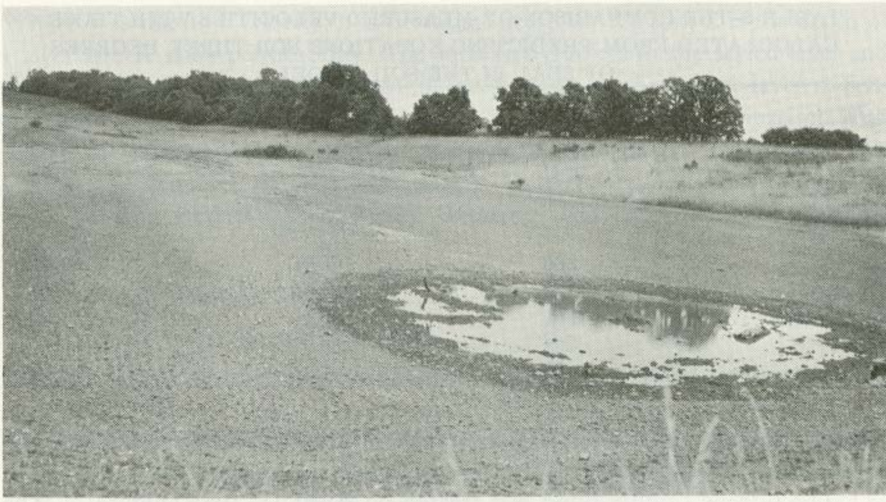

Fig. 8—The pond in Dade County one month after treatment. The size of the shallow pool in the basin has been increased with a small amount of runoff.

teen hundred pounds of hexametaphosphate were spread over the basin below the spillway level. The chemical was disked into the soil surface. Topsoil from the field area above the pond was spread by a road grader as a blanket over the total basin area to a depth of about 4 inches and mixed with some of the basin soil by disking. Topsoil was pushed into the shallow pool of water and spread by a bulldozer. The cleat-tracks thoroughly stirred and puddled the soil under the water and a short distance above the water line. The soil in the basin above the water line was compacted with a sheepsfoot roller. All of the area was rolled about 5 times. A rainfall of about 0.5 inch on June 14 moistened the soil to about the optimum moisture for maximum compaction.

Observations

Although summer rainfall was above normal for southwestern Missouri during 1961, the distribution was such that there were no large runoff-producing storms. Occasional observations showed the water levels in the two ponds were slowly rising.

In November, the level in the Greene County pond was about one foot higher than ever before. It was still between 4 and 5 feet below the spillway but well above the blanket-treated area. At this time, the pond in Dade County had more water in it than ever before, although it was less than half filled (Figure 9).

On February 20, 1962, this pond was filled to the 5-foot depth (Fig. 10, Table 9). According to the owner, it had been at this level for several weeks. The Greene County pond, at this time, was about the same level as in Novem-

Fig. 9—The Dade County pond in November 1961 (five months after treatment). The low summer runoff has increased the level to a depth of 3.5 feet.

Fig. 10—The Dade County pond eight months after treatment (February 20, 1962). The pond was filled to the 5-foot depth.

Fig. 11—The Dade County pond one year after treatment. At this time, it was filled to a depth of 7.4 feet—near the upper limit of the blanket-treated part of the basin.

TABLE 9-WATER LEVEL CHANGES OF THE POND IN DADE COUNTY AFTER SEALING TREATMENT, IN RELATION TO MONTHLY RAINFALL AMOUNTS

Water Level[10]		Rainfall[11]	
Date	Stage, Feet	Month	Amount, Inches
		1961	
		June	2.0
7/24	1.0	July	6.0
9/6	1.5	August	2.7
10/3	2.0	September	6.9
10/31	3.0	October	4.1
11/20	3.5	November	2.7
12/18	4.0	December	2.2
		1962	
1/3	4.5	January	1.3
2/20	5.0	February	2.1
3/27	5.0	March	2.9
4/30	6.0	April	4.2
5/14	7.0	May	3.9
6/4	7.0	June	5.5
6/15	7.7		
7/3	7.4	July	0.0

[10] Maximum depth to emergency spillway is 12 feet.

[11] From the records of the nearest U. S. Weather Bureau Station at Lockwood, Missouri.

ber. The cattle were still being kept on one side of the pond. If they had been moved to the other side as recommended, the seal would probably have been improved further. On July 3, 1962, the Dade County pond was filled to a depth of 7.4 feet (Figure 11). This was near the upper level of the treated area of the basin.

Future Field Testing

From observations in the laboratory of the effects of compaction and puddling and from the evidence that the trampling of animals will improve sealing, there is need for development of machinery to effectively treat the submerged soil surface. The action of such equipment in the soil beneath the water should probably be similar to that of animals or a sheepsfoot roller. It should have the advantage over animals in not being restricted to a zone near the water line but could be made to tread the total basin area. Efforts should be made to develop and test such equipment in the near future.

RECOMMENDATIONS

Field testing with leaking ponds in Missouri has proceeded far enough to make some recommendations. These are based on principles outlined from work elsewhere *(5, 6),* on the results of the laboratory and model studies, as well as the field observations. If these suggestions are followed, seals can be improved so that most leaking or dry ponds may be salvaged.

Ponds that leak badly only after they reach a certain level can be sealed by treatments around the water line zone. Unless the leak is through very porous materials or channels, puddling will improve the seal. This may be done with a harrow, disk or even a rotary hoe. Farm animals may be kept near the leaking region to trample the soil. For a leak through chert, gravel, or rock seams, it will be necessary to compact a blanket (one foot or more in thickness) over the faculty area when the pond is dry or the water has been drained below this level. A loamy material with no more than about 20 percent clay will be suitable for this.

The fill should be inspected for evidence of seepage. To repair serious leakage in a fill at and above the contact base, the basin side of the pond fill should be compacted and, if the material is composed of cherty aggregates, it will be necessary to compact a loam blanket over the basin face of the fill. This can be done during a drouth when the pond is dry or after it has been drained.

For a pond basin that is dry most of the time because the area is excavated in porous chert and aggregate—and the fill is also porous because it is composed of the same material—it will be necessary to compact a loam blanket over the whole basin area including that of the fill. For the more porous spots, 6 inches or more of sandy loam material should be applied and compacted. If sandy loam is not available, silt loam may be used. A blanket of silt loam should then be spread and compacted over the entire area. Compaction may be with a heavy sheepsfoot roller or a weighted disk. With a disk, the final passes should be with the disks set almost straight so as to compact rather than stir the surface.

Some owners feel that since deep excavation is responsible for the exposure of pockets or layers of aggregated clay, gravel or coarse sand pockets, or of porous rock ledges or other highly permeable materials, deep excavations should be avoided. Depth is essential to adequate storage volume. High evaporation losses during drouths will tend to nullify the value of a shallow pond, since it will hold water only when the need is not great. A shallow pond may be little more than a source of mosquito infestation during normal periods of rainfall and a dry basin during dry seasons when stored water is needed.

The current specifications for at least 8 feet of storage depth should be maintained. It may be desirable to achieve this with higher fills rather than deep cuts, particularly in some of the Ozark soils similar to the Baxter and Newtonia series *(2)*. Desirable storage volume may be provided by cutting the basin somewhat deeper farther from the fill but not so deep as to intercept porous layers in the basin near the fill. This procedure would be more costly than the usual method of deep cutting near the fill, but would be less apt to result in failure due to excessive seepage.

Ponds with a normal drainage should fill in a reasonable length of time after construction, probably no longer than one year of normal rainfall. Estimated seepage losses, after a reasonable correction is made for evaporation, should not exceed 2 inches per month. In Missouri, seepage plus evaporation should not exceed about 12 inches in a hot, dry summer month and should be no more than about 4 inches in a cool winter month.

Where possible, the soils with highly permeable or faulty conditions in the subsoil should be avoided.[12] If the owner has good reason to construct a pond in such soils, he should be sure suitable blanket material is available adjacent to the site. In such cases, it may also be desirable to get more of the necessary storage depth from the height of the fill rather than from the depth of the excava-

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[12]The estimated permeability to be expected for compacted soil of fill, blanket or basin bottom can be found by a simple test. Cut the top from a used quart oil can and perforate the bottom with nail holes. Pack moist soil in layers about one inch thick into the can, using the end of a hammer handle or similar implement to pack the soil as densely as possible. Leave about one inch of free space at the top. Place the can inside a small clear plastic bag and set it on small rods or blocks to keep the base free for drainage and place indoors out of the sun and where temperature fluctuations aren't extreme. Add water to the top of the soil and close the plastic bag loosely by tying with string or by folding. Add water as needed to keep the level near the top of the can. After two or three days or when water starts draining, the rate of water loss from the top should be observed. If the water level drops less than ¼ inch per week, one may expect a good seal from this material, if it is packed to maximum density at optimum moisture content.

tion. The fill should be keyed into an impervious layer or a compacted blanket should be spread as a bag seal over the basin, including the basin side of the fill. The seals in some ponds may be improved by a heavy application of barnyard manure. For moderate seepage rates, it is evident that manure will improve the seal when added to pond water. For such ponds, it is recommended that manure applications be tried. The use of manure may be objectionable from the standpoint of contamination. Laboratory tests and practical experience with sewage lagoons have demonstrated that such contamination in the water is short-lived, due to decomposition.

Manure treatment in ponds having high seepage rates may be disappointing. Laboratory tests with highly permeable soils indicate little effect from this treatment, though it is very effective for moderately permeable material. Perhaps the manure residues that tend to bond and plug medium and small pores are swept on through larger pores with the more rapid rates of flow.

The owner may not wish to keep cattle in a pond area to disperse and improve the seal in an aggregated clay pond basin. If he feels that the extra cost is justifiable, he may prefer to use chemical dispersants in lieu of or in conjunction with mechanical methods. The hexametaphosphate used in the tests in Missouri cost about $250 per ton delivered at Columbia. A satisfactory seal was obtained with about 2 tons/acre-6 inches with the Baxter red clay aggregates (Table 6). The tripolyphosphates are comparable in cost, though less effective. Chemicals such as the polyphosphates will greatly reduce the soil manipulation needed to produce a dispersion seal. One should keep in mind that dispersion reduces soil strength. Provision should be made for adequate support below the sealed layer to insure against blowout failures. A blanket of loam or a mixture of about equal parts of the clay aggregate material with silt loam about one foot in thickness should be spread over the faulty areas. The chemical should be stirred into the soil surface and the soil compacted with a weighted disk or a sheepsfoot roller.

Since it will usually take some time after soil treatment before there is enough runoff to fill a pond, precautions should be taken to protect the soil from drying and cracking. This may be done by spreading a mulch of straw manure, old hay, or straw on the surface before the final rolling or disking used to compact the blanket. The final passes of the roller or disk will pin the mulch into the soil to prevent its disturbance by wind and runoff.

The area above the high water line should be seeded with a suitable sod-forming grass like fescue. If a mature fescue hay is used as the mulch on this area, it will serve to seed it as well as to protect it from erosion.

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