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Chemical sealing of small earth dams using sodium tripolyphosphate

Summary

By: R. G. Pepper
Editor: D. A. W. Johnston

A method of sealing leaking small earth dams of the excavated tank type was investigated. A new technique was developed by dissolving the soil dispersant, sodium tripolyphosphate (STPP) in the dam water.

Using tensiometers installed in the dam batters below water level, it was shown that seepage was governed by a relatively thin (0.4 m) layer of soil of low hydraulic conductivity bounding the excavation.

As the seepage rate of 3.1 mm/d was considered too high, STPP was dissolved in the dam water in an attempt to disperse the clay and reduce the hydraulic conductivity. Application of STPP altered the original sealing layer at first and, as seepage progressed, a new seal started to form at a depth of 0.8 m below the batter. The seepage rate was reduced to 0.39 mm/d and the hydraulic conductivity of this new seal was 2.0 x 10^{-9} m/s.

Studies of pore size distribution of soil cores obtained after treatment indicated that the soil in the top layers of the batter had collapsed to a more dense material as evidenced by the lower porosities and lesser volume of pores of all sizes.

Rates of hydrolysis of STPP were studied and it was found that hydrolysis was nearly complete 18 d after application.

The rates of STPP used, up to 0.5 kg/m^3, did not cause toxicity problems in sheep and cattle and did not promote algal blooms.

Brief descriptions of 14 case studies are appended.

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Introduction

Excessive seepage from earth dams (excavated tanks) occurs when the soil has a high hydraulic conductivity, due either to it being well structured or to sand or gravel seams intercepting the excavation.

There are several ways in which dams can be sealed. They are:

- Puddling and compaction by livestock
- Compaction by machine
- Clay blankets of local or imported clay such as bentonite.
- Chemical dispersing agents
- Additions of straw or manure (gleization)
- Membranes such as plastic, rubber, asphalt or concrete

One method of dam sealing involves dispersion of the soil aggregates into primary particles. A dispersed, puddled or remoulded soil reduces hydraulic conductvity by reorganising clay particles into a soil mass which is more compact and has less pore space. Soil dispersion can be accomplished by mechanical or chemical means. Where sand or gravel seams are causing seepage, clay blankets or artificial membranes can be used to seal the dam.

In all cases where seepage is restricted, water movement is limited by a relatively thin layer of soil, membrane liner or concrete. Flow through the thin layer into the underlying soil can be described using Darcy's Law

$$u = -K \Delta \phi$$

where:

u is the flow velocity through the sealing layer per unit time

K is the hydraulic conductivity of the sealing layer

$\Delta \phi$ is the total hydraulic potential across the sealing layer.

In sealing dams, the desired seepage rate given by u (usually no more than 2 mm/d) is used to find the thickness of the sealing layer required, given the hydraulic conductivity and total hydraulic potential across the sealing layer.

Sodium tripolyphosphate (STPP) has been used as a soil dispersant in many instances to reduce excessive seepage from small earth dams and ponds, (Fonner 1958, Decker 1963, Nakayama 1966, Sewell 1969). These workers incorporated STPP into the dry batters of the dams. However, in Western Australia most farm dams are of the excavated tank type. These dams are usually prismoidal in shape with a rectangular plan and hold most, if not all, of the water below original ground level.

Seepage is through the *in situ* soil bounding the excavation. The steep batters (1 in 3) of these dams exclude the use of conventional farm machinery. The placement of STPP in the dry dam, mixing and compaction, requires the use of tracked machinery.

In this paper an easy method of application of STPP to a leaking dam is discussed. The paper is in two sections. The first examines the effect of STPP on the soil structure when the chemical is dissolved in the water of a leaking dam. The second discusses the stability (hydrolysis) of STPP in the dam water and soil.

The chemistry of STPP—its hydrolysis and adsorption on clay surfaces.

Sodium tripolyphosphate is a linear molecule, composed of linked phosphorous-oxygen tetrahedra, with the formula $Na_5P_30_{10}{\cdot}6H_20$. In aqueous solution, it ionises to yield an extended anionic chain, surrounded by sodium ions.

STPP undergoes hydrolysis to orthophosphate in water, the reactions being:

$$P_3O_{10}^{5-} + H_2O = P_2O_7^{4-} + PO_4^{3-} + 2H^+$$
$$(P_2O_7^{4-} = \text{Pyrophosphate})$$

$$P_2O_7^{4-} + H_2O = 2PO_4^{3-} + 2H^+$$
$$(PO_4^{3-} = \text{Orthophosphate})$$

The above two hydrolysis reactions can be expressed as:

$$P_3O_{10}^{5-} + 2H_2O = 3PO_4^{3-} + 4H^+$$

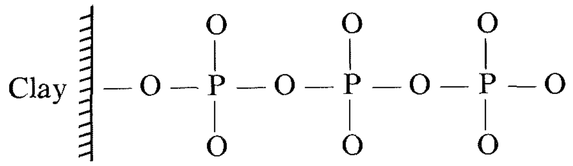
Rates of hydrolysis depend on the pH of the medium, initial concentrations of TPP and the presence or absence of other ions. Usually water insoluble hydroxides of many metals, particularly aluminium, greatly accelerate hydrolysis. Michaels (1958) reports that STPP at 0.25 g/L in suspensions of kaolinite at 100 g/L, undergoes complete hydrolysis in 6 h, whereas in the absence of kaolinite, hydrolysis of STPP was not detectable after 6 h. However, results obtained by Shannon and Lee (1966) showed that total hydrolysis would be completed after 7 h in distilled water. Their initial concentrations were very low at 2.7 mg/L and could account for the rapid complete hydrolysis.

Using columns packed with a fine sandy clay loam, to which 380 g/m² of ammonium tripolyphosphate had been added to the surface, Hashimoto and Lehr (1973) found that after 28 d, 93% of the water soluble phosphate had been hydrolysed. The initial pH value of the soil was 5.8.

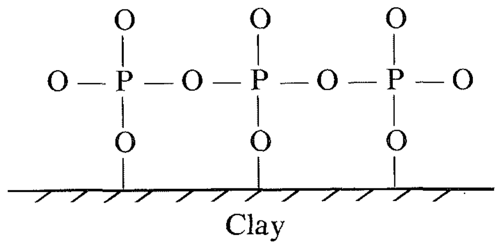
Working with ammonium pyrophosphate $[(NH_4)_3HP_2O_7.H_2O]$, Gilliam and Sample (1968) indicated that over half of the pyrophosphate had hydrolyzed within 10 d in clay soils when the pH value of the soil was 4.8. When the pH value was raised to 7.2 over half the pyrophosphate was still present after 120 d. However, in solutions, Lake and MacIntyre (1977) found that hydrolysis was doubled by an increase in pH values from 6 to 8.

The adsorption of polyphosphates by clay surfaces is governed by factors such as pH, initial concentration and temperature.

If the tripolyphosphate (TPP) molecule remains intact on the clay mineral, the bonding of TPP could be either:



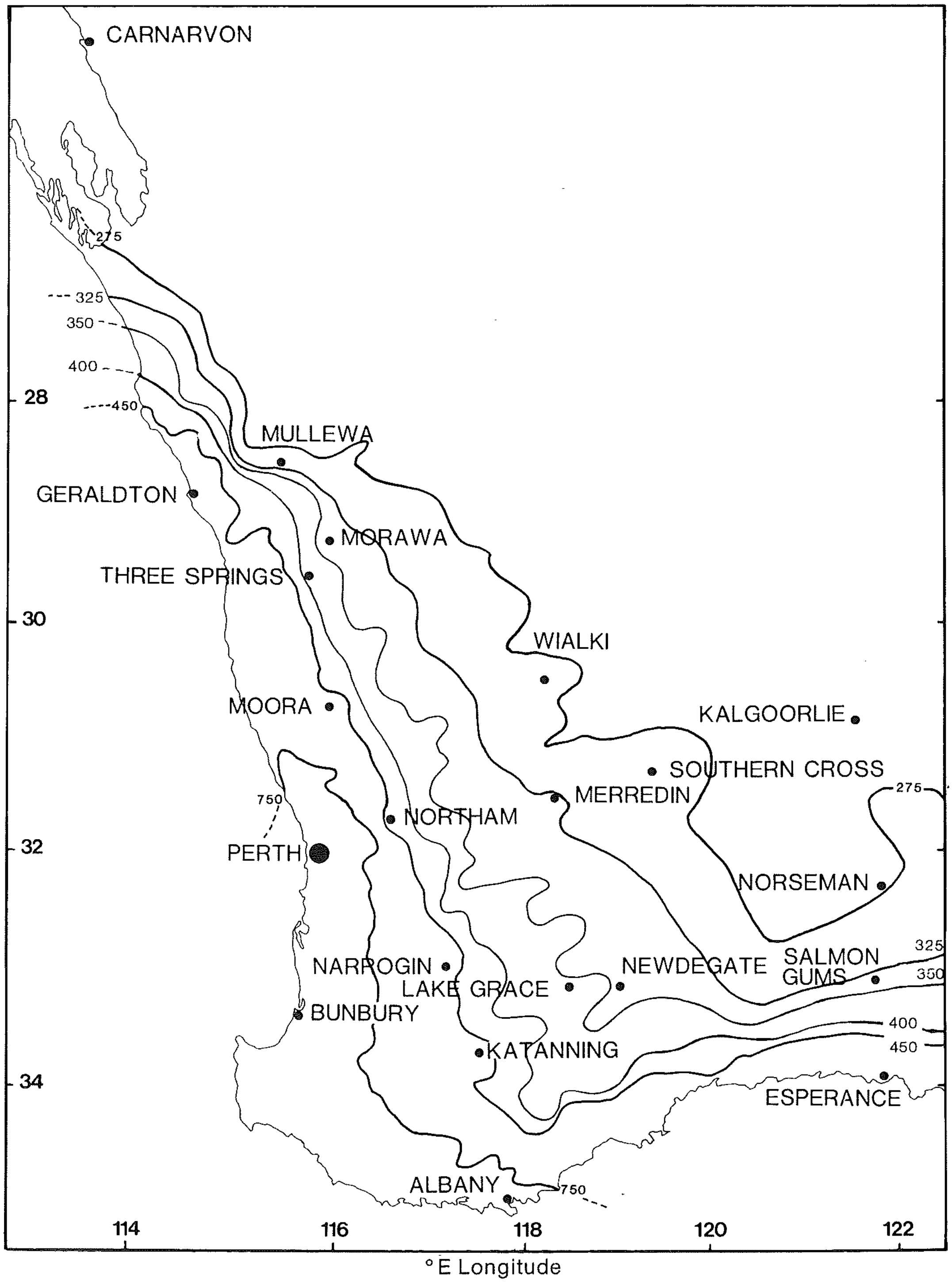
or



Lake and MacIntyre (1977) indicated that the first type of bonding does occur. They concluded that more research was needed before a distinction could be made between the two types of bonding of tripolyphosphate and between adsorption with and without surface hydrolysis.

The physico-chemical factors influencing the stability of aqueous colloidal dispersions have been discussed by Overbeek (1952) and Weiser (1949). The ability of certain compounds to disperse a flocculated aqueous system into primary particles is due primarily to an increase in electrokinetic potential of the particles. This increase in potential may arise from replacement of polyvalent cations by monovalent cations, such as Na, in the diffuse double layer that surrounds the clay particle; or from selective adsorption on the clay surface of an ionised component, such as STPP, with a consequent increase in charge density.

The South-West Province of Western Australia.
Area of predominantly winter rainfall above 275 mm per year showing selected rainfall isohyets.



Because electrokinetic potentials can be developed only in solutions of low ionic strength, dispersing agents are only effective in systems low in dissolved salts and maximum dispersion occurs at relatively low concentrations of the dispersing agent.

Treatment of kaolinite with STPP increases the cation exchange capacity and then with sodium ions present, the diffuse double layer expands causing a repulsion of clay plates so that dispersion of the clay occurs (Michaels, 1958).

The ability of polyphosphates to disperse kaolinite usually increases with molecular weight. The dimer (pyrophosphate) is relatively ineffective, the trimer (tripolyphosphate) considerably better, and the tetramer (tetrapolyphosphate) still more active. Beyond the tetramer, there is little increase in effectiveness with chain length (Michaels, 1958).

EFFECTS ON SOIL STRUCTURE

Materials and methods

A leaking dam, situated just below a gravel hill or breakaway (Mulcahy 1960) was selected at Badgingarra, Western Australia, 30°24'S, 115°50'E.

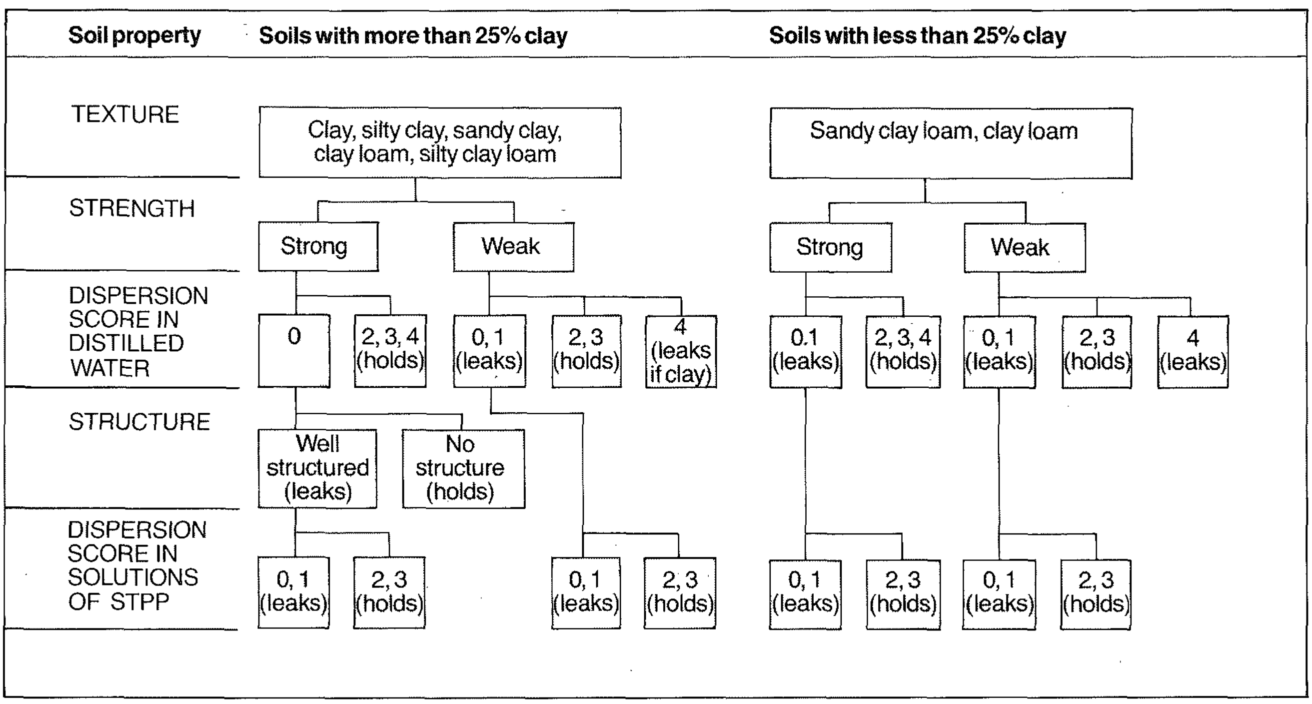
Ten soil samples were taken from the dam batters below original ground level. Similarity in texture and colour were used as criteria for bulking individual samples within each soil horizon from the dam.

Tensiometers were installed in the dam to measure matric potentials in the soil beneath the water, at depths of 0.11; 0.23; 0.38; 0.65; 0.79, and 1.33 m below the soil water interface. A water balance was carried out on the dam before and after treatment. Seepage or net fall per day (NFD) for the dam was calculated, where NFD = drop in dam water level/day minus evaporation/day (Pepper 1977).

Dispersion tests were carried out on air dried aggregates in solutions of varying concentrations of STPP to determine the amount of STPP to dissolve in the dam water. Concentrations of STPP used to test dispersion, were 0.05; 0.1; 0.2; 0.3 and 0.4 g/L. The air dried aggregates were placed in these solutions and rated after 20 h. A score of 0 to 4 was used (Loveday, 1974) to rate the degree of dispersion. To seal a dam there must be sufficient dispersion, that is, moderate dispersion or at least half the aggregate dispersed (score 2, 3). If the aggregates completely disperse (score 4) piping failure could result if that concentration of STPP is used in the dam. A key for testing soils is given in fig. 1.

The highest solution concentration that gave a score of 2-3 was selected. The highest concentration that scored 2-3 must be used because when STPP is dissolved in muddy dam water, it is specifically adsorbed onto the suspended clay and there is insufficient available for dispersing the clay in the dam

Figure 1. Extended key to test soils for dam sites and to assess the response of soils to STPP.



batters. This has been overcome by selecting the highest concentration of STPP that gives a dispersion score 2-3 and not the lowest.

The STPP was dissolved in the dam water at the rate of 0.4 kg/m^3 by circulating the water through a 200 L tank in which there was a sieve and baffle (figure 2 and plate 1). The water returned by gravity to the dam. The water was circulated by means of a high volume, low head pump, consisting of a boat propellor mounted in a 225 mm diameter steel tube, driven by a 6 Kw motor. Water discharge from this pump was 250 m^3/h. The pump and outlet from the tank were so positioned at the waters edge of the dam that thorough mixing of the dam water occurred (plate 2).

STPP was added to the inlet side of the sieve at a rate of 30 kg/h. When all the STPP had been added, the total volume of water in the dam was then circulated through the pump, changing the outlet at least once during this operation to ensure thorough mixing. The STPP after this time should have been thoroughly mixed in the dam, giving a uniform concentration throughout the volume of the dam water. Water samples were taken 1 m below the surface for analysis before and after the addition of STPP.

After STPP had been added to the dam water, soil cores were obtained from the batter to determine changes in pore size distribution with depth. Coring took place when the dam had dried out. Cores were obtained by driving a 46 mm internal diameter stainless steel tube (2 mm wall thickness) into the soil to a depth of 150 mm. The tube was withdrawn from the soil and the core removed. The tube was then re-inserted into the same hole to obtain another 150 mm length of core. This procedure gave minimum disturbance to the soil cores and was repeated until about 1.6 m of soil profile was sampled. Pore volumes at particular suctions were determined on ceramic plates and pressure membrane apparatus and drying curves were obtained.

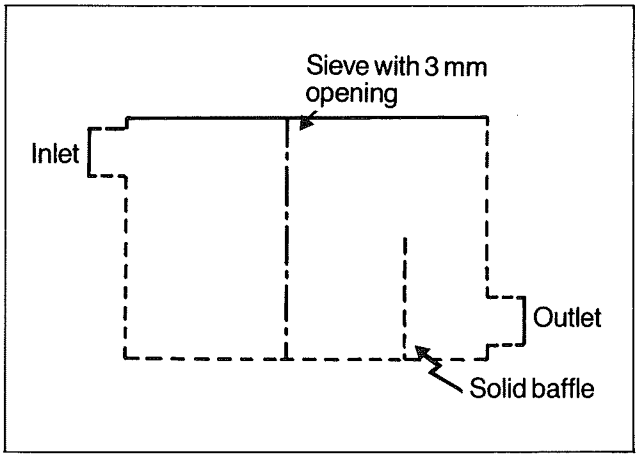


Figure 2. Cross section of dissolving tank showing sieve and baffle. STPP added to inlet side of sieve.

Results and discussion

Soil properties from the dam are listed in table 1. The soil was intermediate between a sandy clay loam and a sandy clay. The cation exchange capacity (CEC) was very low with Mg being the dominant exchangeable cation. Loveday's (1974) dispersion index and Emerson's (1967) classification of aggregates are also given in table 1.

The dominant clay minerals were kaolinite 95%, and goethite, 5%.

Changes in seepage rates with time after treatment are shown in fig. 3 together with the depths of water above the tensiometers. It is seen that 5 d after treatment, seepage increased to 5.2 mm/d. Seepage then decreased linearly over the next 38 d to 0.4 mm and then stayed constant till there was insufficient water in the dam to carry out a water balance. It had previously been recorded that the seepage rate of the dam before treatment was 3.0 mm/d when 0.29 m of water was above the tensiometers. This indicates that the reduction in seepage rate shown in fig. 3 was due to the effect of STPP and not to the lower head of water in the dam.

Table 1—Properties of two bulked soil samples from the dam

Coarse sand	Fine sand (% by wt)	Silt	Clay	CEC* (meq/100 g)	%Exchangeable cations				pH	Aggregate class (Emerson)	Dispersion index (Loveday)
					Ca	Mg	K	Na			
53	20	5	22	1.4	14	32	2	2	4.8	6	0
41	19	4	36	2.1	23	32	2	2	4.7	3	2

* CEC = cation exchange capacity.

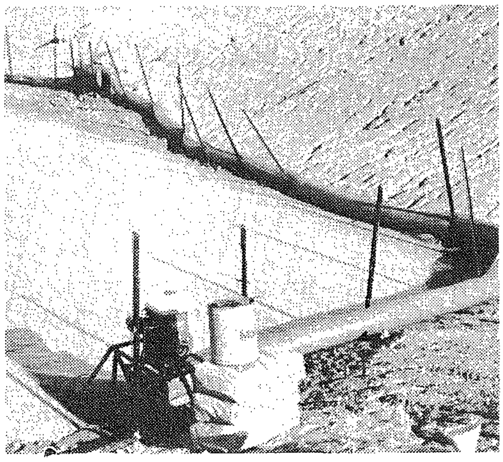


Plate 1. Tank, showing sieve, in which STPP is dissolved.

Plate 2. Pump and tank, at waters edge, dissolving STPP in water.

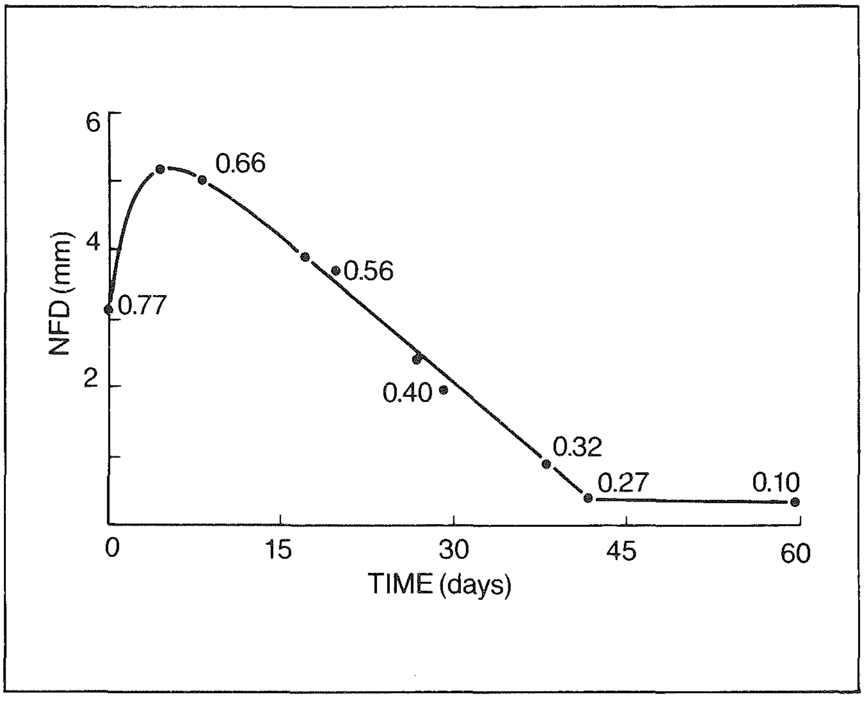


Figure 3. Seepage rate from the dam after treatment. Depth of water in metres shown by numbers.

Table 2 shows the chemical analysis of the dam water before and after the addition of STPP. Suspended clay in the water, sodium ion concentration and sodium absorption ratio (SAR) increased.

Tensiometer readings before the addition of STPP indicated that the matric potentials (Ψ), 0.4 m or more beneath the batter, were between -1.2 and -1.1 m H_2O. Above 0.4 m, Ψ values of -0.76 and -0.52 m H_2O were recorded. Matric potentials are plotted in fig. 4, reaching positive values because of the pressure of the water above. From these data the total potential ($\emptyset$) defined as Ψ-Z (where Z is the vertical co-ordinate, origin at water surface and positive downwards), can be calculated. If $\emptyset$ is defined as zero at the air-water interface, it will also be zero at the water-soil interface. Therefore, from the Ψ values, $\emptyset$ can be calculated (fig. 4).

This figure shows that there was a large drop in potential of 2.24 m H_2O across the first 0.4 m of the soil (the potential gradient being 5.6). At this time there was 0.76 m of water above the tensiometers. In the soil beneath 0.4 m, the potential gradient was 1.0. Since water had been in the dam for at least 5 months and because the seepage rate was 3.1 mm/d, seepage would have reached a steady state.

Using Darcy's law, the vector flow velocity (u) is equal in both the top 0.4 m of soil and the unsaturated soil beneath

$$u = -K_a \Delta \emptyset_1 \ldots\ldots\ a$$

$$u = -K(\Theta) \Delta \emptyset_2 \ldots\ldots\ b$$

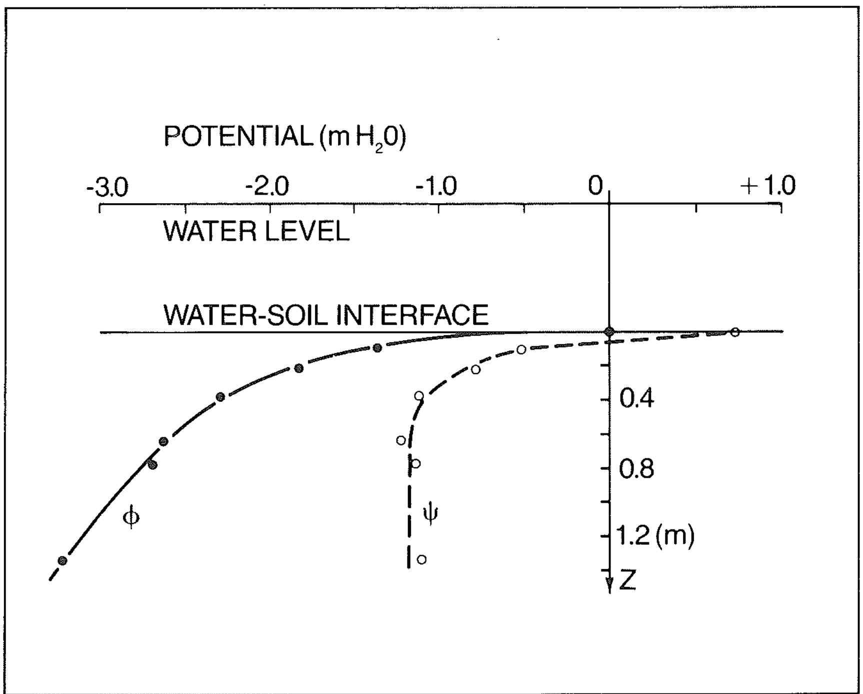
where K_a and $K(\Theta)$ are the hydraulic conductivities of the top 0.4 m and the

Table 2—Chemical analysis of the dam water before and after the addition of STPP

	Before	After
Soluble cations	mg/L	mg/L
Ca	5.7	8.0
Mg	3.0	3.7
K	12.9	12.5
Na	12.3	118.0
	g/L	g/L
Suspended clay	0.99	1.72
SAR*	1.0	8.7
pH	6.9	7.7

* Sodium absorption ratio

Figure 4. Matric potential Ψ and the total potential $\emptyset$ beneath the dam batter before treatment. (Depth of water, 0.76 m; NFD, 3.1 mm.)



unsaturated soil respectively, and $\Delta \phi_1$, and $\Delta \phi_2$ are the hydraulic potential gradients in the respective soil zones.

Equating equations a and b, and given that $\Delta \phi_2 = 1$

$$-K_a \Delta \phi_1 = -K(\Theta)$$

$$\therefore K_a = \frac{K(\Theta)}{\Delta \phi_1}$$

but from fig. 4, $\Delta \phi_1 = \frac{2.24}{0.4}$

$$= 5.6$$

$$\therefore K_a = \frac{K(\Theta)}{5.6}$$

The hydraulic conductivity, K_a of the top 0.4 m of the batters is 0.18 that of $K(\Theta)$ for the underlying soil.

The drop in potential of 2.24 m H_2O across the first 0.4 m of soil indicates that this zone limited seepage from the dam. Using Darcy's law the hydraulic conductivity of the limiting zone can be calculated to be 6.1×10^{-9} m/s (Pepper, 1977).

The increase in seepage rate after treatment (fig. 3) was due to the STPP dispersing the soil in the batters as evidenced by the increase in suspended clay (table 2) in the water and tensiometer readings. Matric and total potentials after treatment are plotted in fig. 5. Seepage at that time was still 3.7 mm/d when the depth of water over the tensiometers was 0.53 m. From fig. 5 it can be seen that Ψ was positive down to 0.8 m below the batter indicating that STPP caused a collapse of the soil aggregates and positive pore pressure. This in turn caused the rise in seepage rate shown in fig. 3.

Figure 5. indicates that down to the depth of 0.65 m the potential gradient was less than 1, between 0.65-0.8 m the gradient was 7.7, and below 0.8 m the gradient was 1.0. This showed that a new seal had started to form at the 0.65-0.8 m depth, since the soil was saturated above this depth and at a gradient of one beneath this zone. The hydraulic conductivity of this new sealing layer was 3.9×10^{-9} m/s.

Bridge and Collis-George (1973) obtained similar changes in potential gradients as shown in fig. 5 when they studied infiltration into structurally unstable soils. They found that soil aggregates in the top of the soil columns slaked, and the potential gradient was less than 1 in this zone. Beneath the visibly slaked layer, potential gradients reached 5.9 and below this the gradient was 1.0.

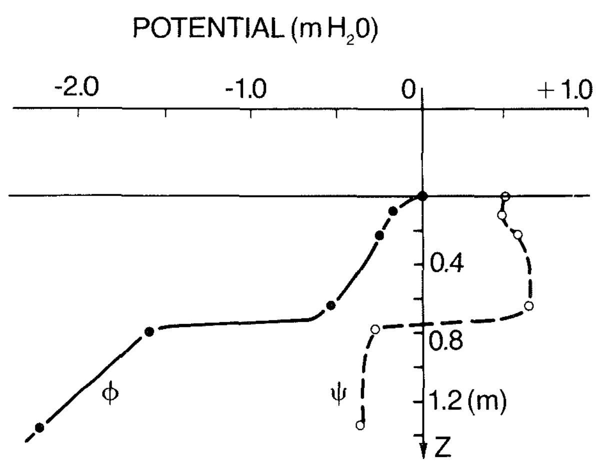


Figure 5. Matric potential Ψ and total potential ϕ beneath the dam batter after treatment, showing new sealing layer forming at 0.65-0.80 m.

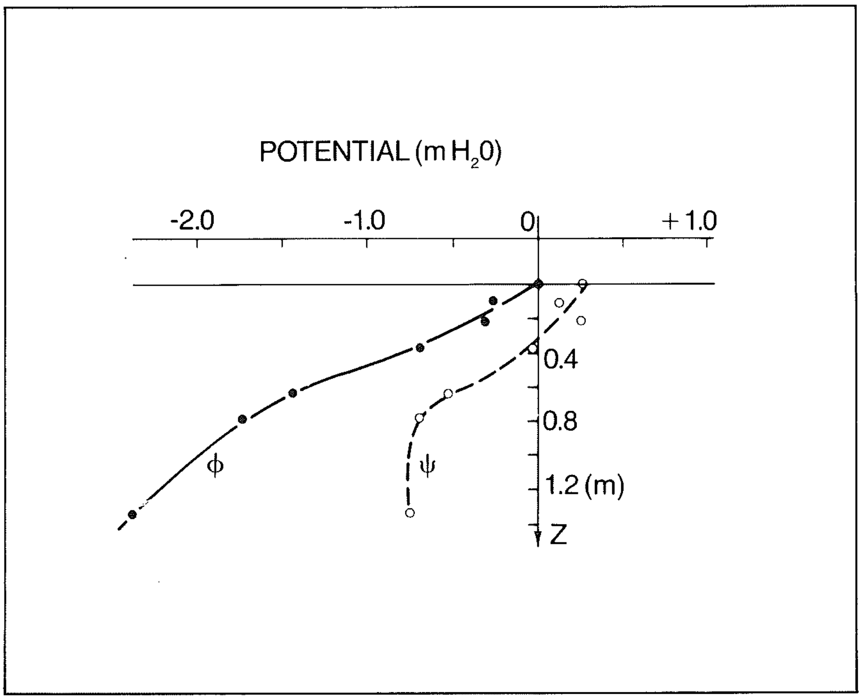


Figure 6. Matric potential Ψ and total potential Ø, 43 days after treatment.

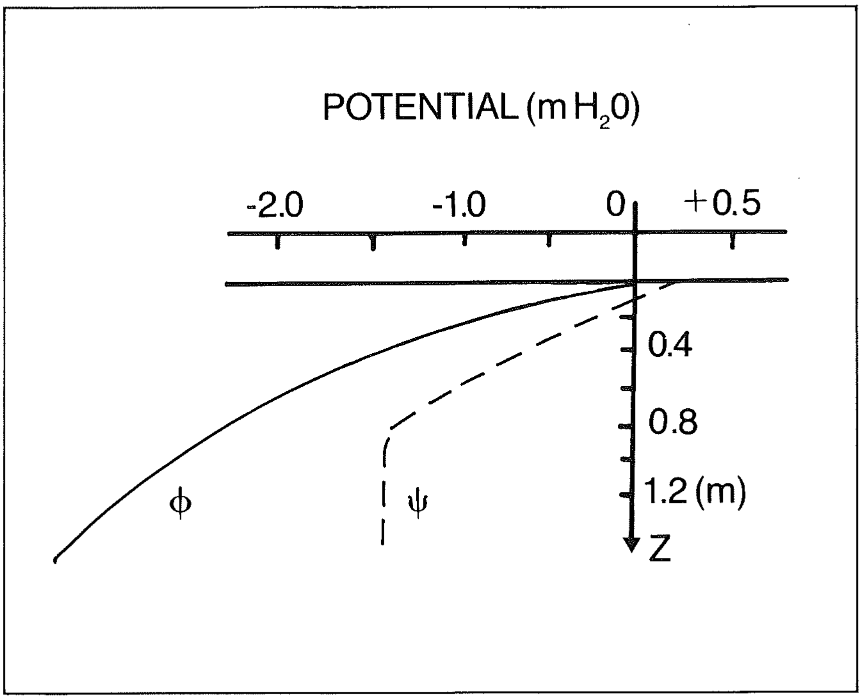


Figure 7. Matric potential Ψ and total potential Ø, two years after treatment.

Forty three days after treatment the seepage rate had dropped to 0.39 mm/d and matric potentials had started to become more negative. Comparison of figs. 5 and 6 indicated that the soil was starting to dry out as shown by the shift in Ψ to more negative values. The potential gradient from the surface to 0.65 m was then greater than unity. The average gradient from the surface to 0.8 m was 2.16 and below 0.8 m was still at unity.

It appears that as seepage progressed, suspended clay in the water partially blocked the pores and formed a new seal from the 0.8 m depth to the surface (fig. 7). Comparison of the matric potentials in figs. 4 and 7 show that the soil beneath the dam had dried out after treatment. The matric potential was -300 mm H_2O less. The hydraulic conductivity of this new seal was 2.0 x 10^{-9} m/s.

Changes in pore size distribution in the soil profile beneath the dam water after treatment are shown in fig. 8. From this figure it is seen that at the shallower depths in the soil, there is a smaller volume of pores of any particular size conducting water, and a lower porosity. The lesser volume of pores in the shallower soil, 0.8 m upwards, indicates that the soil structure

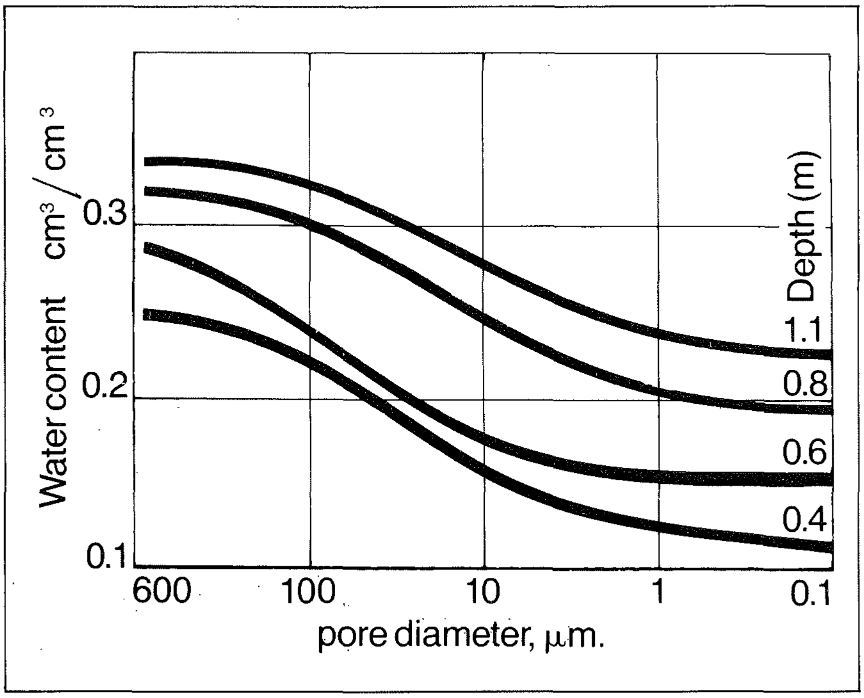


Figure 8. Pore size distribution curves at different depths below the dam batter.

has collapsed reducing porosity and that suspended clay has been carried with the seepage water and clogged pores of all sizes.

From the pore size distribution for the different depths below the dam batter (fig. 8) and the matric potentials (fig. 7) unsaturated hydraulic conductivities K(Θ) can be determined. The method developed by Marshall (1958) was used.

K(Θ) values are given in table 3, together with the largest pore conducting water at a particular depth. Since the flow velocity, u, should be constant down the profile, using $\Delta\phi$ values calculated from fig. 7, u can be determined. These values are shown in table 3.

The K(Θ) values calculated down the profile are about one order of magnitude greater than those measured in the field. This could be due to fissures occurring in the cores during sampling and handling in the laboratory.

The flow velocity calculated from these K(Θ) values and $\Delta\phi$ at the particular depth all show good agreement with one another when the errors of the measurement of K(Θ) are considered.

Table 3 K(Θ) values at different depths below dam batter

Depth metres	Largest pore, µm conducting water	$\Delta\phi$	K(Θ)	u
			m/s	m/s
0.4	43	2.6	3.4×10^{-8}	9.6×10^{-8}
0.6	28	2	3.9×10^{-8}	7.8×10^{-8}
0.8	22	1.7	5.6×10^{-8}	9.5×10^{-8}
1.1	21	1	7.9×10^{-8}	7.9×10^{-8}

HYDROLYSIS OF SODIUM TRIPOLYPHOSPHATE

Materials and methods

STPP was added to a leaking dam constructed in a white pallid zone sandy clay loam at Margaret River, 34° S, 115° 4′ E. The rate of STPP dissolved was 0.1 kg/m^3.

Water samples were taken every 2 to 3 d. Since only orthophosphate responds to the colorimetric tests and polyphosphates do not, the water samples were analysed for phosphate before and after acid hydrolysis. The difference in measured phosphate was attributed to the presence of polyphosphates in solution.

The method described by Murphy and Riley (1962) was used to determine orthophosphate. Hydrolysis of polyphosphates was carried out by gently boiling with a sulphuric-nitric acid mixture as described in APHA (1975), cooled, neutralised and orthophosphate determined.

Total phosphate content of the waters were determined after digestion with nitric-perchloric acids (APHA, 1975). This measurement includes all of the soluble and insoluble orthophosphate and polyphosphates.

Total phosphorus was determined on soil samples taken from the dam by grinding and digestion with perchloric acid (Olsen and Dean, 1965). Dispersion tests were carried out on 1-2 mm air dried aggregates obtained from these soils. The air dried aggregates were placed in distilled water and the degree of dispersion rated after 20 h. The degree of dispersion was judged visually and a score of 0-4 was assigned (Loveday, 1974).

Results and discussion

Values of polyphosphate, orthophosphate and total phosphate are plotted in figure 9 with time in days after treatment. It is seen that the polyphosphate concentration decreases linearly and the reaction is nearly complete 18 d after addition. Orthophosphate levels increase to a maximum at about day 10 and then decrease. The decrease in orthophosphate would be due to the phosphate being adsorbed on clay and sesquioxides in the soil. Total phosphorus also decreased with time.

This rate of hydrolysis in solution is much slower than reported by Michaels (1958), and could be because the suspended clay (kaolin) concentration was very low at 100 mg/L, whereas Michaels used 100 g/L of kaolinite in suspension.

Since hydrolysis of STPP was nearly complete after 18 d (fig. 9), it should not be effective in dispersing the soil.

However, the STPP molecules could have been adsorbed onto the clay and still cause dispersion. Hashimoto and Lehr (1973) found that after 28 d, 93% of water soluble phosphate in soil had been hydrolysed. Therefore, it is unlikely that STPP was still active as a dispersing agent 28 d after application, at the pH (5.3) of this soil.

Soil samples of the batters, which had been under water when the treatment was carried out, were obtained 9 months later when the dam was dry.

Total phosphate values (mg P/100 g soil) down the profile are plotted in fig. 10.

Only the top soil sample from 0-0.2 m with a P level of 37.5 mg/100 g soil, showed dispersion in distilled water (score 1). When the P level

Figure 9. Concentration of the different forms of phosphate in dam water as a function of time.

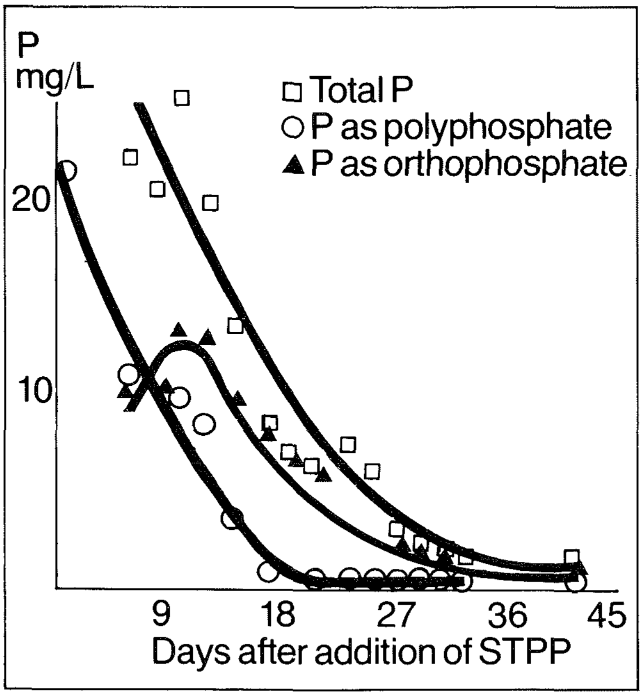
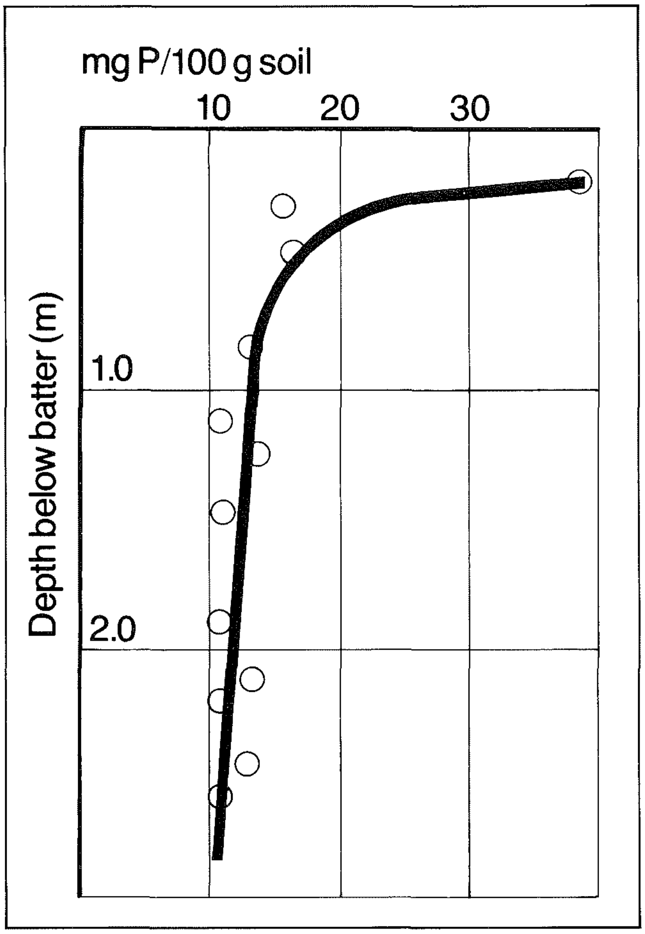


Figure 10. Distribution of P beneath the dam batter.



was 10 to 14 mg/100 g soil, there is either not enough STPP present to cause dispersion or it has hydrolysed to orthophosphate. The soil showed no dispersion due to hydrolysis. Additions of STPP to the soil showed that only 6 mg P/100 g soil as STPP was enough to cause dispersion (score 2-3). It appears that the 10 mg P/100 g soil at depth (fig. 10) must be present as orthophosphate, and negligible STPP, 9 months after treatment.

The movement of STPP down the profile beneath the batter could not be traced, because of the high levels of P (fig. 10). Only 30 kg P as STPP was added to this dam, but four times this amount occurred in the top 0.4 m. The high levels of P in this dam as compared with native P (2.5 mg P/100 g soil) could be due to P coming from sheep manure (800 mg P/100 g, Bowden, 1983, personal communication) being washed into the dam.

Conclusions

It has been shown that by dissolving the soil dispersant, sodium tripolyphosphate in the water of a leaking dam, soil structure collapsed so forming a dense material with less pore volume. A reduction in pore volume over all the pore sizes studied was affected by the addition of STPP. This method of application to seal small earth dams overcomes the problem of hydrolysis of the STPP which effects the soil within 5 d after application, produces a dense soil and so reduces seepage from the dam within 42 d.

The rates of STPP used, up to 0.5 kg/m^3 (95 mg P/L) would not affect sheep and cattle drinking the water. Snook (1955) indicated that only when phosphorus levels were 1 000 mg/L did the water become unpalatable to stock. It was thought that the addition of phosphate to the dam water would cause an algal bloom, since blooms can be expected when the concentrations of inorganic phosphorus and nitrogen equal or exceed 0.01 mg/L and 0.30 mg/L respectively (Sawyer, 1952).

After 42 d (fig. 9) there was still sufficient P in the water to cause an algal bloom, but no blooms occurred in dams treated with STPP. After the addition of STPP, the concentration of suspended clay in the water increased (table 2) and sunlight was unable to penetrate the water and cause algal growth. Nitrogen concentrations could also limit growth. Most treatments took place in July-August, when water levels in the dam were at their highest, and temperatures could be too low to cause rapid growth of algae.

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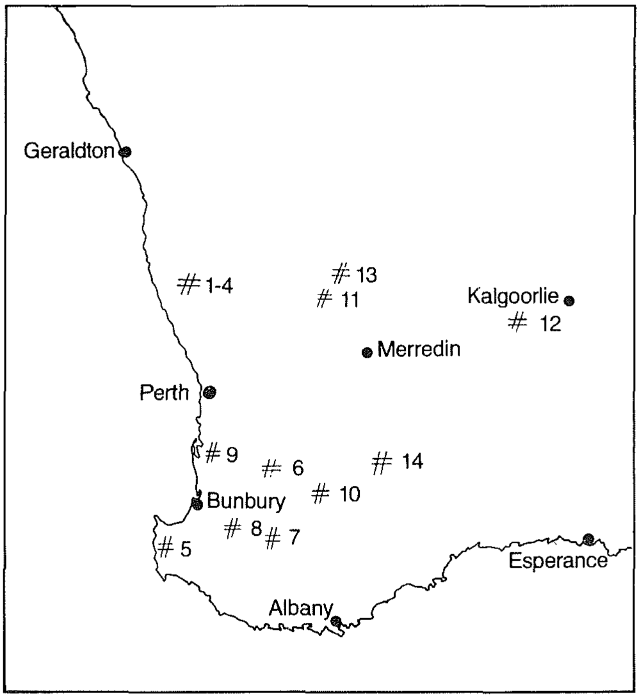
Figure 11. Location of dams to which STPP has been added.



Appendix 1

Case studies of dams to which STPP has been added.

Soil and seepage data from dams in which STPP has been dissolved in the water are discussed below.

While some of this work has been experimental, most was done as part of an advisory service. In some instances farmers were willing to try the technique because of its low cost even though STPP did not give sufficient dispersion of aggregates in the laboratory.

The location of the following dams in the South-West Province of Western Australia are shown in fig. 11.

Dam 1—Badgingarra

STPP was dissolved in the water of this dam in 1974, at the rate of 0.8 kg/m^3. Soil properties from dams 1 to 4 are given in table A1.1. Seepage data and its standard deviation (in parenthesis) and depth of water in the dam when the measurements were taken are given in table A1.2 below.

It can be seen that, since treatment, the dam has had a seepage rate of less than 2.1 mm/d.

Table A1.1
Soil properties of dams from Badgingarra treated with STPP

Dam	Coarse sand %	Fine sand %	Silt %	Clay %	CEC* meq/100 g	Plasticity index
1	41	18	4	37	2.2	13
2	24	41	6	29	2.0	11
3	47	20	4	29	1.7	12
4	20	41	8	31	2.2	12

* CEC—cation exchange capacity

Table A1.2—Seepage data determined before and after treatment with STPP at Badgingarra. Data collected using burettes and immersed class A pans (Pepper 1977). Reading errors ± 0.3 mm.

Dam	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
					Year Seepage mm/d					
1	3.93 0.37* 1.52†	3.00A 1.84* 1.78†	0.75 0.51* 1.65†	0.42 0.38* 0.82†	0.96 1.04* 1.27†	0.73 0.76* 1.50†	N	2.00 1.13* 1.50†	2.10 0.58* 1.20†	0.61 0.29* 1.20†
2	6.48 0.56* 1.27†	NA	5.4	2.80 0.74* 0.67†	0.68 0.60* 1.21†	2.78 1.60* 1.20†	N	2.57 1.18* 1.50†	2.68 0.50* 1.20†	N
3	2.83 0.70* 1.02†	1.45 0.83* 0.75†	0.61A 0.17* 1.14†	0.44 0.12* 0.98†	2.11 1.20* 0.96†	0.79 0.47* 0.74†	N	3.04 1.28* 0.60†	2.74+ 1.50* 0.52†	2.00+ 1.87* 0.60†
4	4.94 0.63* 0.51†	N	N	6.20 2.88* 0.68†	NA	1.36 0.84* 0.60†	N	2.00 1.22* 0.90†	2.28 1.30* 0.60†	1.45+ 0.07* 0.52†

A Indicates when STPP added.
N No water balance calculated.

* Standard deviation.
† Average depth of water (metres) in dam when water balance calculated.
\+ Water balance carried out using depth boards. Reading errors, ± 2.5 mm.

Dam 2—Badgingarra

STPP was dissolved in the water of this dam in 1974 at a rate of 1.2 kg/m³. The dam emptied in 5 d. The high rate of application used caused piping failure in the bottom of the dam. At that time the crumb dispersion test to calculate rates had not been developed. Over 50 vertical pipes into the *in situ* soil were present (Aitchison and Wood, 1965) ranging in diameter from 10-20 mm, with one up to 400 mm in diameter. The larger pipes were back filled with a moist sandy clay and thoroughly compacted by hand. The floor and batters were cultivated and mixed with a rotary hoe to a depth of 150 mm and compacted with a rubber tyred agricultural tractor. The results are tabulated in table A1.2.

Dam 3—Badgingarra

Details of the application of STPP to this dam in 1975, and its soil properties, are described in the first section of this paper.

Dam 4—Badgingarra

STPP was dissolved in this dam at the rate of 0.3 kg/m³ in November 1977. Seepage declined from 4.94 mm/d to 2.28 mm/d following treatment.

Dam 5—Margaret River

Dam excavated into the pallid zone of the laterite profile. The soil was a sandy clay loam. When first constructed, this dam leaked at a rate of 98 mm/d. Dispersion tests indicated that 0.2 kg/m^3 STPP had to be dissolved in this dam. Since the initial seepage rate was high, it was thought that the dissolving of the full quantity of STPP in the water could lead to piping failure through the embankment. To avoid this, two half applications of STPP (0.1 kg/m^3) about 8 weeks apart were added to the dam. After the first application, seepage was reduced to 35 mm/d and after the second application seepage was reduced to 4.5 mm/d.

Dam 6—Narrogin; Forests Department

Dam constructed into a yellow soil developed directly from gneiss. Soil textures of samples taken down the front batter, together with dispersion scores, are shown in table A1.3.

All the samples dispersed to some extent (score 1), but none of the samples below 2.9 m scored more than 2. The deepest sample scored 1 in both distilled water and 0.4 g/L STPP. The soil from this depth was a sandy loam which contained between 10-15% clay which is probably sufficient to form a seal with dispersion. It was decided to attempt to seal this dam by dissolving 0.2 kg/m^3 STPP in the water. Before treatment the dam was leaking at a rate of 11 mm/d. Sixteen months after treatment seepage had been reduced to 2.2 mm/d.

Table A1.3

Soil profile description and dispersion data for the Forests Department dam, Narrogin

Depth below ground level metres			Dispersion score g/L STPP			
			0	0.1	0.2	0.4
0.9	Sandy clay		0	2	3	2
1.7	Sandy clay loam	Micaceous	0	2	2-3	2-3
2.9	Sandy clay loam	Micaceous	2	2-3	2-3	2
3.4	Sandy loam	Micaceous	1	2	2	2
4.4	Sandy loam	Micaceous	2	2	2	2
5.2	Sandy loam	Micaceous	1	1	1	1

Dam 7—Jingalup via Kojonup

Dam constructed just below a gravel hill in a mottled, sandy clay loam. The soil was very micaceous, indicating that the bottom of the excavation was close to the parent material. All samples contained 20-25% clay and scored 2 to 3 when dispersed in 0.1 g/L STPP solutions. The dam leaked at 8 mm/d before treatment. After the addition of 0.1 kg/m^3 the dam still leaked at 7 mm/d. As it was known that the STPP had caused dispersion of the clay, the original treatment rate of STPP must have been too low. A repeat application of 0.3 kg/m^3 STPP was added to this dam 7 months later. Seepage was reduced to 1 mm/d.

Dam 8—Boyup Brook

Dam constructed into mottled sandy clay and leaked at a rate of 26 mm/d. STPP was dissolved in the water at a rate of 0.5 kg/m^3. The dam now holds and has a seepage rate of less than 0.5 mm/d.

Dam 9—Dwellingup

Dam constructed into a sandy clay loam typical of the pallid zone and showed dispersion in solutions of 0.1 g/L STPP although dispersion did not increase with increasing concentrations of STPP. Seepage from the dam was reduced from 43 mm to 13 mm/d by dissolving STPP in the dam at the rate of 0.1 kg/m^3.

Dam 10—Nyabing

Dam constructed into a mottled sandy clay loam leaked at the rate of 10.6 mm/d. STPP was dissolved in this dam at the rate of 0.4 kg/m^3. Seepage is now 0.5 mm/d.

There are instances where dams leak due to a hard cemented pallid zone being encountered in the excavation. Usually overlying these hard cemented materials are very plastic sandy clays that are non-dispersive and would hold water if the dam had not been excavated deeper than these plastic materials. If enough clay could be dispersed and suspended in the dam water and carried with the seepage water, it may block the pores in the hard cemented materials and so seal the dam. The following four dams are built in such situations and the action of STPP on these materials are described.

Dam 11—Cleary

A dam 5 m deep, was excavated into a pallid zone sandy clay loam which was known to leak. The top 3 m of the profile was a brown, sandy clay overlying the pallid zone. Two metres of the pallid zone was exposed in the excavation.

This dam leaked at a rate of 56 mm/d. Dispersion tests carried out on the soil were:

	Dispersion score in STPP g/L		
	0	0.1	0.2
3.0 m sandy clay	1	2	3-4
4.5 m sandy clay loam	1	1	1
5.0 m hard pallid zone	0	0	0

This data suggests that a concentration of 0.2 g/L of STPP should disperse the sandy clay, but not the soils of the hard pallid zone. After treatment the seepage rate of the dam increased to 130 mm/d, but did not subsequently decrease as with the other dams. Inspection of the dam when empty revealed severe piping in the batters and bottom of the dam. Pits dug into the bottom of the dam revealed the heterogeneous nature of the pallid zone. Many seams of grey sandy clay ramified through the hard white pallid zone and close inspection showed channels, some 0.1-0.6 mm in diameter, in these seams. The soil from these seams had a dispersion score of 3 in distilled water, and so piped with solutions of STPP.

Dam 12—Wooliba via Kalgoorlie

A hard cemented pallid zone was encountered in this dam at a depth of 3.5 m. The dam was 6 m deep and 0.2 kg/m^3 of STPP was dissolved in the water. The seepage rate was reduced from 35 mm to 14 mm/d.

Dam 13—Beacon-Bonnie Rock

This dam is 5.3 m deep, the bottom 0.6 m being excavated into a hard cemented pallid zone. STPP at 0.05 g/L was dissolved in the water. Seepage increased from 30 mm to 65 mm/d 10 d after treatment, but 14 d after treatment the seepage rate had returned to 30 mm/d.

Seepage rate from this dam is now 20 mm/d.

Dam 14-Buniche

This dam, about 33 km east of Lake Grace, was constructed into white pallid zone sandy clay loam. In one bottom corner of the dam a very hard cemented pallid zone was encountered. The dam leaked at 7 mm/d. STPP at the rate of 0.05 kg/m^3 caused dispersion of the soft white pallid zone material, but not the hard cemented pallid zone. Fourteen months after the addition of STPP the seepage rate was less than 0.5 mm/d.

Appendix 2

Adoption of technique by farmers

The technique of dissolving STPP in dam water to seal dams has been recommended to farmers since 1979 and a soil testing service is available for assessing STPP application rates. However, the low rate of adoption of the technique prompted a mail survey to find out why it had not been widely used.

Most requests for advice on how to seal farm dams came via Department of Agriculture District Offices. A questionnaire (table A2.1) was sent to the officer at the District Office who initially requested the advice on rates of STPP. This officer then contacted the farmer from whom the enquiry was received.

Results

Advice was given on 55 farmers' dams of which four used the technique. Three farmers reported that their dams subsequently held water.

Reasons by farmers for not using the technique on the other 51 dams are reported below. The number of dams concerned appear in parenthesis.

- Stock (4). Stock entering the dam pug and compact the soil, which in turn can reduce seepage.
- Insufficient water (6). The technique requires that water be present in the dam to dissolve the STPP. When the farmer wanted to seal the dam it contained insufficient water.
- Has not got around to it (20). This could be due to the farmers being unfamiliar with the new technique, or they were not sure that it would work.
- Dam site moved (3). This was advice given on potential dam sites. Instead of risking building a dam at that site, the three farmers concerned chose different sites.
- New owners (3). The farms concerned had changed ownership.
- Finance (4). No funds available.
- Interest only (1). A farmer wanted advice only for interest.
- Alternative water supply was developed (2). Either a well, bore or another dam.
- Clay liner (1). A clay liner was placed in the dam to form a seal.
- Not sure of technique (1).
- Other reasons (6). The Forest Department wished to seal some stilling weirs on 6 gauging stations, but after the advice was given, decided to carry out phosphate analysis on the water coming from this catchment. The technique could not then be used.

Table A2.1

Questionnaire sent to District Offices to ascertain rates of adoption of STPP

Survey of sodium tripolyphosphate treatment of dams

District Office
Officer

Farmer
Address

Date advice
given

Dam identification

Rate of STPP
recommended

Date STPP added

Seepage before
treatment

Seepage after treatment

Seepage now

Is it considered
a success?

Problems in
adding chemical

If not added,
why?

Comments

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