THE WHITTINGTON INTERCEPTOR DRAIN TRIAL

REPORT TO THE PUBLIC WORKS DEPARTMENT, WESTERN AUSTRALIA

from Professor J.W. Holmes

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jwh:nb:T/8

18th October, 1979

The Under Secretary for Works,
Public Works Department,
2 Havelock Street,
West Perth W.A. 6005

Dear Sir,

THE WHITTINGTON INTERCEPTOR DRAIN TRIAL

I have completed my review of the Whittington Interceptor Drain trial, according to the brief that I was given by your letter and enclosure of 24th April (PWWS 1292/77). My report is enclosed in this packet, one original typescript for off-printing and one copy.

I wish to thank you for the opportunity to contribute to the work of the PWD, about this difficult management problem posed by the dry-land salinity. I thank, too, the officers of the Department who were so helpful during my visit to Western Australia.

Yours sincerely,

J.W. Holmes

J.W. Holmes
Professor of Earth Sciences

THE WHITTINGTON INTERCEPTOR DRAIN TRIAL

REPORT TO THE PUBLIC WORKS DEPARTMENT, W.A.

from Professor J.W. Holmes

24th September, 1979

1. INTRODUCTION

As an independent consultant, my terms of reference were stated to be,

a) Review the Whittington Interceptor Drain Concept and advise on its potential to control land and stream salinity.

b) Having regard to the above, review the adequacy of the trial which is at present in course on Batalling Creek, and advise on whether it is considered satisfactory to adequately test the system.

c) To advise as to whether the present trial should be continued in its present form, modified, extended or abandoned and a new trial established.

d) If the trial is to be modified or extended, or a new trial established indicate the form that such a trial would take.

e) The estimated cost of undertaking the work recommended and the likely time before meaningful results will be obtained.

f) Provide a continuing review of any trial that proceeds.

The first four terms of reference imply that the consultant's work should include a description of the dryland salinity in Western Australia, in terms of the accepted theory of water flow through soils and underlying aquifers. This review, which draws its information principally from published works of many authors, is now given in Section 2.

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2. REVIEW OF DRYLAND SALTING IN W.A.

A. *Principles of groundwater flow in a valley.*

A perennial stream is fed by groundwater and base-flow, during dry weather, when there can be no surface run-off. A pictorial representation (Fig. 1) shows that the pathways for water flow underground can occupy the whole of the permeable zone, no matter how deep it may be. Fig. 1 is meant to be a vertical section taken parallel to the streamlines, and if there is a very flat grade down the drainage line of the valley, the section is almost at right angles to the valley stream itself. Otherwise it may make an angle somewhat less than 90^{o} with the direction of the stream.

The dimensions of Fig. 1 have been chosen to be relevant to the Batalling Ck. trial, so that calculations may indicate scales of time and discharge that are appropriate, although the main purpose of this review of principles is to show how the calculations can be done, and applied to any situation. The valley slope, of 10 metres in 145 metres is the slope of the valley side at Batalling Ck., at the location of the piezometer line. The vertical and horizontal scales of the figure are the same, in order to avoid a danger of lack of perspective which can misguide our understanding when the vertical scale is drawn longer than the horizontal, which is sometimes done for clarity in the pictorial representation.

The idealised soil and aquifer of Fig. 1 are uniform in their important hydrologic properties, hydraulic conductivity, K, and saturated water content, $\bar{\theta}_S$ (porosity). We may calculate the mean physical velocity of flow between equipotentials 0.8 m and 0.6 m. It is given, in magnitude, by

$$\bar{v}' = \frac{1}{\theta_S} * K * \frac{d\phi}{dx} , \qquad (1)$$

where θ_S is the saturated water content equal to 0.4 $m^3\ m^{-3}$, K is the saturated hydraulic conductivity equal to 10 mm day^{-1}, and $d\phi/dx$ is

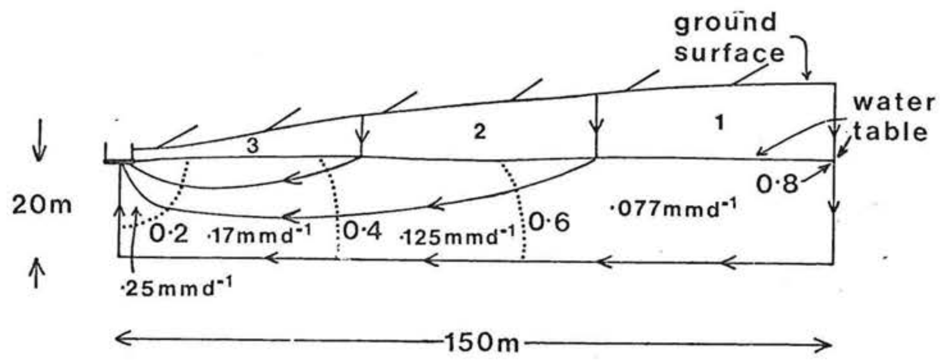

Fig. 1 - Schematic of groundwater flow in a direction almost at right angles to the direction of flow of surface water in a drainage line. The conducting zone is 20 m deep and it extends 150 m to the groundwater divide. The slope of the water table is too small to be visible, but the equipotential lines, labelled 0.2, 0.4 and 0.6 m give the height of the water table where they intersect it, relative to water in the drain of the valley, that is shown in stylised form as a rectangular section. The hydraulic conductivity is assumed to be 1 mm day^{-1}, in the saturated zone. The approximate physical velocity of the water flowing underground is shown by the insertions 0.077 mm day^{-1}, etc. There are three stream-tubes shown, numbered 1, 2 and 3.

the hydraulic head gradient equal to 0.2/65. The mean velocity is about 0.077 mm d^{-1} in this segment. It increases in the other segments as shown by the insertions in Fig. 1.

The actual discharge by underground flow, is again given by an application of Darcy's law, namely

$$v = -b\ K\ \frac{d\phi}{dx} \qquad (2)$$

where b is the thickness of the streamtube, or depth of the aquifer. Then it may be calculated that the discharge between equipotentials 0.6 and 0.4, in streamtube 1 is about 6.5 x 10^{-4} m^3 d^{-1}. This is gained from infiltration of rain through a ground surface area of 50 m^2. The water harvest is therefore 6.5 x 10^{-4} m^3 d^{-1} from 50 m^2, or 4.7 mm yr^{-1}. The sketch has been designed so that there is, in fact, a uniform infiltration rate over the whole of the ground from the stream to the groundwater divide. The rate of replacement of the water in the reservoir under the ground is given by

$$\frac{i}{\theta_S\ b}\ , \qquad (3)$$

where i is the infiltration rate (4.7 mm yr^{-1}) and b is here the thickness of the aquifer (20 m). The value adopted for the fractional rate of replacement is therefore 0.59 x 10^{-3} yr^{-1}, or the whole of the underground water storage would be replaced exactly once every 1/(0.59 x 10^{-3}) years, i.e. approximately, every 1,700 years.

If the rainwater has a salt content of 6 mg l^{-1}, and the annual rainfall is about 550 mm, the long-term equilibrium salt content of the groundwater by evaporative concentration would be

$$\frac{6 \times 550}{4\ 7}\ ,\ mg\ l^{-1}$$

i.e. 702 mg l^{-1}. Add about 300 mg l^{-1} for rock weathering production of salts, and root zone bicarbonates, and we have 1000 mg l^{-1}. This value could be taken as a guide to the expected TDS of the groundwater at equilibrium, when the annual runoff is about 5mm out of an annual rainfall of 550 mm. No influence of further, enhanced runoff, either by overland flow or interflow, is allowed for here, but I will treat these influences later on.

The actual salinity of groundwaters in the deep subsoil, and aquifers of the valleys, is often about 10,000 mg l^{-1}, in contrast to the hypothetical 1,000 mg l^{-1} postulated in the previous paragraph. Under a steady state salt budget this would imply an annual runoff of about 0.5 mm yr^{-1} when that land was supporting the evergreen and perennial tree and bush communities, before clearing.

The question of upward flow of water, through "impermeable" layers in the valley bottoms, was often discussed during my tour, and when I spoke with interested people. We can calculate some rates of flow to demonstrate the physical situation that is to be expected, and is observed in the field.

Suppose that Fig. 2 is a schematic of upwards flow in the valley bottoms.

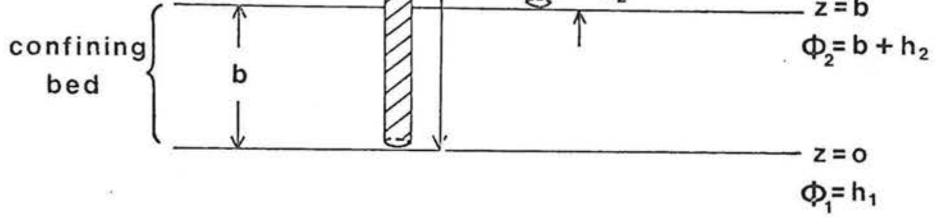

Fig. 2 - Schematic of seepage flow through a confining bed of thickness b, hydraulic conductivity K and hydraulic heads ϕ_1, at the lower boundary and ϕ_2 at the upper boundary.

The rate of upward flow ($m^3\ m^{-2}\ day^{-1}$) through the layer of thickness b is,

$$v = -K \frac{d\phi}{dz} . \qquad (4)$$

ϕ at $z = o$ is $\phi_1 = h_1$, and

ϕ at $z = b$ is $\phi_2 = b + h_2$.

Therefore $\frac{d\phi}{dz} = \frac{b + h_2 - h_1}{b}$,

$$\text{and } v = K\left(\frac{h_1 - h_2}{b}\right) - K . \qquad (5)$$

The term -K is the gravity term, and the term $K(h_1 - h_2)/b$ is the pressure gradient term.

If $(h_1 - h_2) = b$, the water is at rest, i.e. the level at which the water rests in piezometer 1, at h_1 is exactly the same as its level in piezometer 2.

Suppose $h_1 = 3$ m,

$h_2 = 1$ m,

$b = 1$ m, and

$K = 1$ mm d^{-1}, and is the hydraulic conductivity of the confining bed.

$v = 1 \times 10^{-3} \times (2 - 1)$, $m\ d^{-1}$

$= 10^{-3}\ m\ d^{-1}$, or

$365 \times 10^{-3}\ m\ yr^{-1}$,

$= 3650 \times 10^{-3}$ m in 10 years, or

$3.65\ m^3$ per m^2 in 10 years.

Suppose that all of this water should evaporate and that the salt that it transported during its flow to the sites of evaporation is distributed into the top 100 mm of the soil. If we assume that the salt concentration of the ground water was 10,000 mg l^{-1}, then 3.65 m^3 of water will have contained 36.5 kg of salt. If the bulk density of the soil is assumed to be 1,500 kg of soil per m^3, the salt concentration in the postulated 100 mm of the top soil would become

$$\frac{3.65 \times 10}{1 \times 10^{-1} \times 1500} \text{ kg kg}^{-1}$$

after 10 years, or 0.24 kg salt per kg of dry soil.

B. *Survey of the literature*

Teakle (1938) described the problem in the following words. "In developing a farm, clearing is usually first undertaken on the more productive soil types. These typically occur in the valleys and on lower slopes and cultivation is carried on more or less independently of the minor topographic features. The first manifestation of enhanced water movement is on the surface where development of gutters in the valleys may occur in the course of two or three years or more. Later, moist patches, indicative of sub-soil water movement, appear in these valleys and frequently salt accumulates as a surface crust, a residue the result of evaporation of water containing soluble salts. These salt patches may be limited to a few yards in extent or may extend over many acres in extreme cases". "The manifestion of the salt problem is most common in the valleys and along creeks but also occurs on the slopes where seepage of water brings the salt to the surface. The first appearance is generally noted within a few years of clearing and salt accumulation reaches a maximum in 10 to 20 years. Thereafter improvement is commonly observed. In the lower rainfall portions of this zone, and where heavy textured soils limit underground water movement, marked appearance of salt patches may be postponed for 15 to 20 years after clearing, the maximum is reached much later and recovery will be much slower".

Teakle refers to the Report of the Royal Commission on the mallee belt and Esperance lands (1917) and mentions that a 1912 report of P.V. O'Brien, the Engineer for Goldfields Water Supplies, was presented as evidence given before that Royal Commission. O'Brien's statement that, following clearing "natural vegetation no longer utilizes the larger proportion of the rainfall, which entering the ground dissolves more or less of the salts, and as it soaks through the soil and gradually flows down the hillside to the lower land, the water carries the salts with it" ... was endorsed by Teakle. Teakle himself, educated at the University of California, Berkeley (Ph.D.) during the period 1924-7 following his graduation from the University of Western Australia, must have had close working experience with the American soil scientists then addressing themselves to the problem of soil salinity and water-logging of the irrigated lands of the western States.

Teakle (1938) also endorsed the opinion, then widely held, that the soil salinity and salinity of seepage flows would eventually decrease. He suggested that ... "dilution of the saline water will occur and the percolating water will become less and less saline. Eventually the whole of the saline water will be removed and subsoil waters, where drainage is possible, will become fresh or non-saline".

Later in this same article, Teakle goes on to state "Certain action may be taken to assist nature in the removal of salt occurring under these circumstances. Flow in the creeks should be facilitated to accelerate drainage. Seepage patches occurring on slopes may be tapped by T drains. The top part of the T drain intercepts the percolating water and the stem removes it to the valley. Moisture absorbing plants of some salt tolerance may be established to utilise portion of the percolating water and provide feed for stock. Judicious cultivation and cropping will promote reclamation".

These quotations have been included in this review to show that all the elements of the present-day policy of the Department of Agriculture, for management and reclamation of the saline soils, were explicit in Teakle's work (and others too, including Burvill's and S.T. Smith's). Furthermore, the descriptive theory given by Teakle is accepted now. Peck and Hurle

(1973) estimated recovery times for a variety of subsurface conditions that influence the time scale, principally depth of weathered zone, its hydraulic conductivity and salt content. The lack of quantitative calculations in the work of the 1920 to 1950 period has been made good in recent years, and the descriptive theory has been substantiated. But there have been some errors.

The detailed study of the Belka Valley, by CSIRO scientists (Bettenay, Blackmore and Hingston, 1964) enabled relevant data to be seen in perspective, particularly for the salt budget aspects. Unfortunately these authors did not pursue their calculations far enough and reached the conclusion that the confined and continuous fine-textured aquifer, separated from upper horizons by an aquiclude, is not significantly influenced by waters in the upper horizon. I criticised this paper, in draft form during its preparation, because I thought that there was no evidence for this conclusion. Further work would be likely to verify the deduction from theory, using a possible value of vertical hydraulic conductivity, that the upper and lower waters were hydraulically continuous. Bettenay, et al. did, however, by implication, support the view that the salt present in the sediment of valley and near valley locations came there by very slow transport by water (solutions) in the whole depth of saturated aquifers.

Conacher (1975) used a rather tentative suggestion of Bettenay et al. (1964) with strong approval. He wrote that "vegetation clearing is considered to have increased the supply of water to valley bottoms by overland flow and stream flow 'thereby leading to higher soil water content, and a more spatially extensive wet zone above the aquifer. This in turn has resulted in greater upward movement of water and the accumulation of salts at the surface in areas previously salt-free'. This alternative to the rising groundwater table hypothesis does not appear to have received the recognition it deserves, possibly because the different mechanism suggested has been insufficiently stressed" (Conacher, 1975, p.35). Conacher's development of the theory of through flow led him to his statement of practical implications (p.63), that include,

(1) "Remedial measures aimed at lowering groundwater tables must be considered irrelevant.

(2) Establishment of salt-tolerant plants on salt-scalded areas may be successful but will not permit the land to be returned to the normal farm rotation pattern (i.e. full rehabilitation). Their establishment will not reduce the quantities of water and salts entering the scalded areas, nor will they sufficiently increase the amounts of water and salts leaving the system.

(3) Improved drainage of scalded areas is technically feasible. However the low gradients, and the low permeability of many scalded soil materials, would require the installation of closely spaced drains as in irrigated areas with similar problems. Further, the drained waters may only transfer the problem downvalley.

(4) Prevention of water from reaching the scalded areas, possibly allied with elements of measures (2) and (3) above, appears to be the logical solution."

These four summary statements, bearing with them implied rules for management are aligned with the statement of Whittington (1975, p.23) that "no evidence of a rising salt water table existed."

The purposes of my visit to Western Australia during August 1979 were aided by many discussions. The question whether a "rising water table" could actually occur when the confining, and indurated, layer appeared to have so small a conductivity for water, was often debated. There is a widely held opinion that there can be no significant upwards movement of water if the soil layers appear to be unsaturated and relatively dry above the confining bed. This opinion was committed to the scientific record by Conacher (1975, pp. 57-8), who wrote "In 1972 the Department of Agriculture drilled two holes in the approximate centre of the remaining bare portion of the Springhill scald as part of their continuing investigation into the rising groundwater table hypothesis (Negus, personal communication, 1972; and personal observation). The Gemco rotary drill penetrated the hardpan with extreme difficulty in the first hole, and encountered groundwater at a depth of 7 m. The water (salinity 6817 p.p.m.) was under considerable pressure, and rose up the piezometer tube to 61 cm above ground level. The second hole, located 2.7 m from the first, was drilled to a depth of 1.5 m into extremely hard, dry, hardpan materials, intersecting a perched soil-water zone 38 cm below the surface. The perched soil-water very gradually filled the piezometer tube to the same level (38 cm below ground surface) and had a salinity concentration twice that of the groundwater. This evidence, allied with the rehabilitation of the scald as a result of the interceptor bank programme, demonstrates that the perched waters responsible for the scalding are unconnected with the deeper, confined aquifer, as was also concluded from the Dalwallinu area."

The conclusion that Mr. Conacher reached from this and other experiments of the Department of Agriculture, and which was also communicated to me by many farmers, including Mr. Whittington does not necessarily follow from these observations. The conclusion is probably wrong. Certainly the waters in the deeper, confined aquifer could be seeping upwards at that site on "Springhill" and the observations could remain in accord with the accepted theory of water flow through soil layers that vary greatly in their hydraulic conductivities.

Suppose that Fig. 3 represents schematically the system of upwards flow through a confining layer, of thickness b_1 and hydraulic conductivity K_1. Let ϕ_1 be the height of the potentiometric surface of the water at

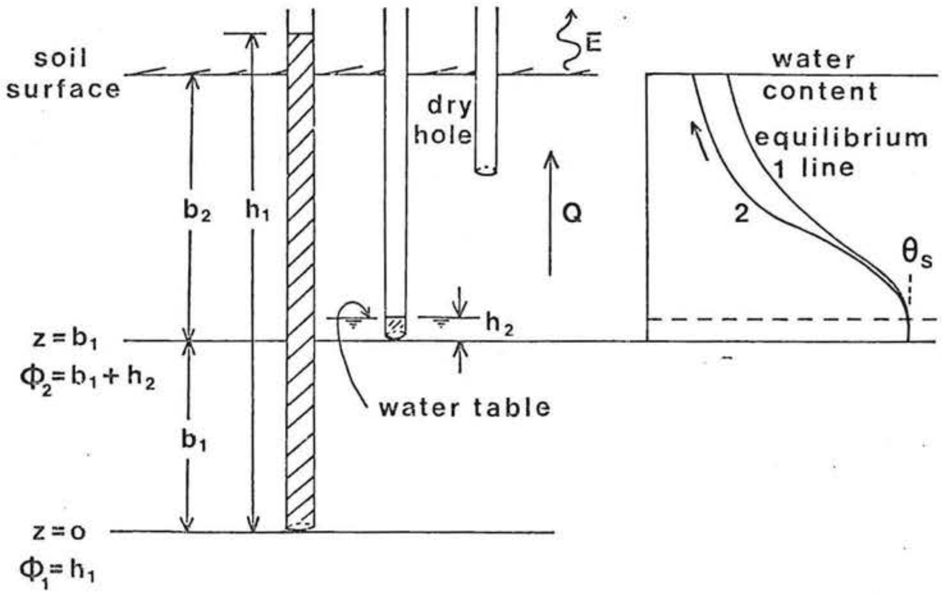

Fig. 3 - Schematic of upwards flow, with an example of the water content profile to be expected at equilibrium in the unsaturated zone. The confining bed is represented by b_1.

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the lower side of the confining bed (where z = o) and ϕ_2 the same at the upper surface (where $z = b_1$). Then the magnitude of the flow of water through the bed will be given by

$$v = K_1 \frac{\phi_1 - \phi_2}{b_1} \quad . \tag{6}$$

Using values of the hydraulic parameters suggested by recent measurements that I will refer to again later, namely $K_1 = 1$ mm day^{-1}, $b_1 = 1$ m and a value of $\phi_1 = 0.61$ m above the ground surface, observed by the Department of Agriculture experimenters at "Springhill" and quoted by Conacher (1975, p.58), the upwards flow, if the water table stood just at the soil surface would be $v = \frac{1 \times 0.61}{1}$ mm day^{-1} = 0.61 mm day^{-1}. This rate of upwards flow is less than the rate of evaporation at all seasons of the year. In particular, during summer when the potential evaporation rate is about 6mm day^{-1}, the water table could not remain at the soil surface but would retreat into the soil by drying of the uppermost parts of the soil.

Suppose that the water table were just at the upper surface of the confining bed as, in fact, shown in the figure, and that b_2 = 1 m. Then the rate of upwards flow would be given by $v = \frac{1 \times 1.61}{1} = 1.61$ mm day^{-1}. This is still considerably less than the potential evaporation rate at nearly all times during the year. If, per chance, the water table was truly at a stationary level at $z = b_1$, then flow of water through the unsaturated zone from $z = b_1$ to the surface would also be at the steady rate 1.61 mm day^{-1}. The water content profile would have a shape somewhat like curve 2, and the rate of flow through the confining bed would act as a throttle. The conditions in the overlying layer of thickness b_2 and saturated hydraulic conductivity $K_2 >> K_1$ would adjust themselves naturally to accommodate the flux by unsaturated flow. Nothingin this theory permits the statement that the waters in zones b_1 and b_2 are disconnected, unless $K_1 = o$ strictly. The presence of a dry zone in b_2 despite the potentiometric level at ϕ_1, much higher than the soil surface, is no evidence at all that upward flow cannot occur.

Similar application of theory is instructive about the downwards percolation of water through a layered soil or aquifer. Suppose that Fig. 4 represents the schematic of downwards flow of water through a layer of

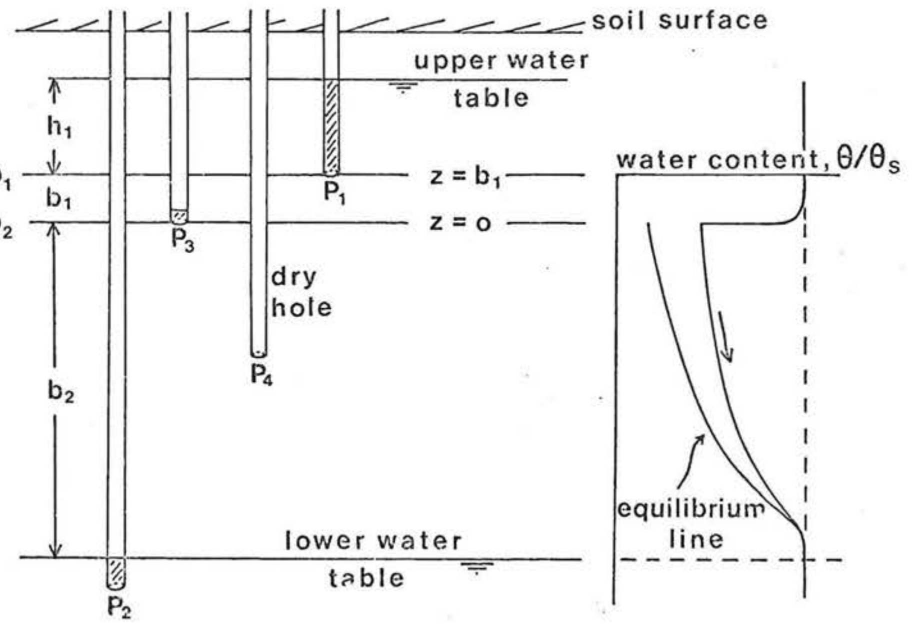

Fig. 4 - Schematic of downwards flow impeded by a layer of small conductivity b_1, in which $K_1 << K_2$, the hydraulic conductivity in b_2. The lower water table is maintained by unspecified outflow in layer b_2.

small conductivity K_1 ($<<$ K_2) to a deeper water table. There is a perched water table of height h_1 above the upper side of the confining bed. Then the rate of downwards flow can be given in magnitude by

$$v = K_1 \frac{\phi_1 - \phi_2}{b_1} \tag{7}$$

$$= K_1 \frac{b_1 + h_1 - \phi_2}{b_1}$$

$$= K_1 + K_1 \left(\frac{h_1 - \phi_2}{b_1}\right) . \tag{8}$$

Equation (8) tells us that the rate of downwards flow is the sum of the effect of the gravitational gradient, K_1, to which we may add or subtract a second term due to the pressure potential gradient. In zone b_2 the saturated hydraulic conductivity is much larger than in zone b_1, by assumption. Therefore the aquifer material in zone b_2 cannot remain saturated. Water drains out of it to the water table below until its unsaturated hydraulic conductivity K_2 (unsaturated) becomes adjusted to a value just appropriate to pass on the water flux entering zone b_2 from b_1.

At the boundary we must have continuity of pore water pressure and the effect of unsaturation in zone b_2 is to induce a small depth of unsaturation in zone b_1, extending upwards, but not far, from the lower side. The overall effect is therefore to increase the hydraulic head gradient through b_1 to a little more than it otherwise would be. In Fig. 4 I have drawn a representation of the water content profiles in zones b_1 and b_2 to show how they must meet at the zonal interface. The relative water content, θ/θ_S (i.e. water content normalised to 1 at saturation) must be unity at the lower water table. It is less than unity above the lower saturated zone. There is a region of rapid transition at the interface to another saturated zone within the less permeable horizon of thickness b_1. A hole augered through these layers would clearly encounter a dry intermediate zone.

If K_1 were very small relative to K_2 the unsaturated part near the top of zone b_2 could appear to be very dry indeed. Furthermore, piezometers whose open ends were located at points P_1 to P_4 shown on the figure would indicate the water levels as shown, and P_4 would be quite dry.

The frequent observations of apparently dry soil or aquifer material occurring in close proximity to zones of saturation through which water can be seen to seep, may be puzzling, not to say vexing. Nulsen (1978) described, and in his paper there are photographs of, water flowing out of channels, some possibly marking decayed root lines, in what appears to be otherwise dry soil. He says "... the very fine pores between the clay particles and between aggregates of clay particles transport very little water compared to the volume transported by the preferred pathway".

C. Conclusions from past and present work.

I have read many papers other than those quoted, that have contributed to the literature of dry land salinity in Western Australia, but for brevity it is not possible to refer to them all. Peck (1978) summarized much of the work, gave a list of numerous references and related the Western Australian situation to similar experience in other parts of the world. My reading and re-reading (I would like to emphasise that I have had a professional and working interest in this problem for more than 20 years) confirms my view that the research has been, and is, on a sound and correct basis, with one exception. Statements that there can be no significant input of water or salts to the valley bottoms by the mechanism of a "rising water table", must be regarded as false at this stage.

Those who hold to this view derive it from their direct observations that the ground surface can be separated by a manifestly dry zone from the saturated zone, often under pressure, at greater depth. That these observations are quite consistent with hydraulic continuity between layers is what I have tried to show above.

The undue prominence sometimes given to the process of "through-flow" is a result of the lack of appreciation of how much salt (and water) can be transported through very poorly permeable strata given sufficient time and a slowly varying (and increasing!) hydraulic head gradient. There must be many actual situations where the increase in salt content of the valley bottoms could not be ascribed solely to the translocation of the salt originally contained in the permeable surface horizon in which through-flow is accomodated. There would not be sufficient salt to make the equation balance.

3. THE CONSULTANT'S BRIEF, IN DETAILED EXAMINATION OF ITS PARTS

A. *Review of the Whittington Interceptor Drain concept, and its potential to control land and stream salinity.*

I understand the interceptor drain, as designed and constructed by Mr. Whittington and his associates, to be intended to drain a shallow zone of the soil near the ground surface. Its effects could be as follows.

i) On valley sides, the saturated zone (characteristically from the surface to 0.5 m) could drain more quickly if the water were led away. If it were not led away, there could be some promotion of deep percolation rather than a lessening of it.

ii) The drainage water entering the drain could be relatively fresh if the drain were high on the valley side. It could be relatively saline if the drain were near the valley bottom. The fresh water could be useful as a dilution flow, but the saline water could be troublesome as an enhanced salt flow.

iii) Along the drainage lines of valley floors the interceptor drains would become not interceptors but promoters of more effective drainage. Disposal of the water which, in nearly all cases would be very saline, would always present a problem. It would be a problem at a regional scale rather than at the farm scale.

The Interceptor Drain concept, I believe, should not be regarded as a general guide to alleviation or cure of the dryland salting. The concept has the following deficiencies.

a) It cannot lessen the hydraulic head gradients such as have been hydraulic demonstrated at Batalling Ck. and many other localities, because a shallow cut of up to 1m on a hillside cannot do much to reduce head differences up to 10 m, unless all infiltrating water can be intercepted. This, I believe, would be impossible to achieve.

b) On the valley floors the drains designed by Mr. Whittington are too shallow. They may take surface water away more effectively, but they are likely to be of no help in reducing soil salinity.

I have no enthusiasm for drainage of the kind advocated by Mr. Whittington and WISALTS. The capital investment that has gone into the construction of these kinds of drains would have been employed more effectively if their design had been guided by principles long established in the drainage industry. The first requirement in limiting the effect of saline groundwater is to lower the water table to about 2 m below the ground surface. Where the water is partially confined (the word partially is used advisedly) the potentiometric surface also must be reduced to 2 m below the surface. Many of the designers of the shallow drains in W.A. have not been guided by established drainage theory or practice.

It is a truism that every drainage situation must be treated on its merits. I would not presume to write general specifications for drainage when conditions could be found within the following range

- drainage water; saline to fresh
- disposal of drainage water; can/cannot be put into the natural drainage ways
- aquifer type; water table/highly confined
- hydraulic conductivity; very small (~ 1 mm day^{-1}) to moderate (10 m day^{-1})
- stability of bank batters; highly unstable sands to indurated/cemented rock.

All I can write at the conclusion of this section is that the salinity problem in Western Australia should be attacked with better technological skills than the present drainage schemes appear to possess. The books "Drainage for agriculture" (Agronomy 17, 1974) and "Drainage of agricultural lands" (Agronomy 7, 1957) contain accounts of theory and engineering practice that should not be ignored. In them will be found an extensive account of methods of field measurement of hydraulic conductivity and transmissivity for drainage design, together with the principles of design of ditch and tile-drainage. Because many of the drainage situations therein described occur in irrigated fields or in very wet climate zones, a rapid lowering of the water table is often the principal aim of the drainage system.

The amount of water to be dispersed from most of the salt affected slopes and valleys in Western Australia is much smaller than from typical irrigated or climatically-wet lands. The criteria for depth and spacing of drains that should apply to the land affected by dry-land salinity are therefore not necessarily those that are appropriate to the classical drainage needs. For example, the rate of lowering of the water table, or potentiometric surface in the valleys can be much slower. If well-engineered drainage works could lower the hydraulic head generally in a valley by (say) 2 m in a year, that would probably be an acceptable time scale. For protection against water logging in wetlands the same would have to be achieved in a few days. These matters could be determined by a drainage research programme, and in consultation with farmers to get their recommendations about how long they can wait for improvement.

The cost of tile-drainage in irrigated areas of Victoria could be used as a guide to expected costs in Western Australia, if an efficient drainage industry were to be established there.

B. *Review the adequacy of the trial which is at present in course on Batalling Creek, and advise if it can adequately test the system.*

The Progress Report of May 1979 (PWD Water Resources Information Note, 1979) supplies the data upon which I have to base my remarks in this section. The operation of the trial during the 1978 rainfall season, to which the results refer, appears to have been satisfactory. Table 4 (p. 23 of the Progress Report) sets out the measured water and chloride fluxes from the monitored hillside. The corresponding fluxes carried by the deep groundwater seepage, presumed to terminate in the valley bottom, were gained by calculation, which I have verified to be correct.

The results of 1978 observations can be summarised in the table below.

Water flux	Amount (appropriate to the area affected by the shallow drain)
Deep groundwater seepage	$1.02 \times 10^3\ m^3\ yr^{-1}$
Shallow subsurface seepage	$4.82 \times 10^3\ m^3\ yr^{-1}$
Total water flux to be associated with the hillslope that is influenced by the trial drain.	$5.84 \times 10^3\ m^3\ yr^{-1}$

Chloride flux	Amount
In the deep groundwater seepage	9.2×10^3 kg yr^{-1}
In the shallow subsurface seepage	0.475×10^3 kg yr^{-1}
Total chloride flux	9.675×10^3 kg yr^{-1}

The chloride concentration if the two waters were to be mixed, would be 1,660 mg l^{-1}, or about 3,200 mg l^{-1} TDS.

The error to be expected in these measurements or calculations was not assessed in the Progress Report. My estimate would be that the results for the shallow subsurface flow could be ±15%, and for the deep groundwater seepage ±50%. However, the correspondence between the actually measured chloride flux at the Batalling Ck. gauging station, and the scaled-up chloride flow calculated to be delivered by deep subsurface seepage from the whole of the catchment is good (Table 3a). The value of 40 mm day^{-1} for hydraulic conductivity of the deep aquifer, adopted for the calculation, is probably reliable to better than ±50%, as quoted above. I am satisfied that the Progress Report has no errors that could create doubt about the conclusions of the 1978 experiment.

The results shown in my table above include a calculation not done for the PWD Progress Report. If a shandy of the two water fluxes were to give the true quality of the stream flow leaving the Batalling Ck. catchment it would have a salinity of about 3,200 mg l^{-1} TDS (discharge-weighted mean), or 1,660 mg l^{-1} of chloride. This may be compared with 2,290 mg l^{-1} of chloride quoted in Table 6, and derived from the actually measured parameters at the Batalling Ck. gauging station.

The internal consistencies in the data allow me to give my opinion, with confidence, that the trial is well conducted and its design does indeed allow an adequate test of the system, so far as the system claims to be beneficial.

C. *Advise as to whether the present trial should be continued in its present form, modified, extended or abandoned and a new trial established.*

When I visited the site of the trial on Batalling Ck., on 21/8/79, I was able to discuss details about the trial, including the purpose for which it was conducted with Mr. Whittington, Mr. Loh, Mr. Webster and Mr. Craig, on whose farm the drains are located. The intention of the experiment seems to me to have been well summarised by Loh (1978) in a PWD Water Resources Information Note. Mr. Loh writes "The Department has recently commenced an investigation of a surface drainage scheme suggested by Mr. Whittington as a technique for rehabilitation of salt affected streams. Mr. Whittington has claimed considerable success with a similar (but not precisely the same) technique for rehabilitation of salt affected land on his property at Brookton. Interceptor channels have been constructed under Mr. Whittington's supervision upstream of a previous gauging station on Batalling Creek, a tributary of the Collie River East Branch. The concept is that the interceptor channels will intersect shallow fresh subsurface flow and pass it more directly to the stream system. That is, by harnessing this fresher water, seepage to the valley is reduced, evaporation is therefore reduced and salts do not concentrate in the soil surface in the valley. Mr. Whittington's scheme assumes that deep ground-water is not a major factor in the salinity problem".

The aim is clearly stated. It is the "rehabilitation of salt-affected streams" not pasture

The results of the 1978 experiment allow us to evaluate whether the shallow sub-surface drains were able to mitigate the stream salinity significantly during that year. The crudest measure would be the TDS of the shandied water as described in Section 3B above. A salinity of 3,200 mg l^{-1} is, of course, absolutely unacceptable for any water that could flow into Wellington Reservoir. That quality was attained by dilution of the available salt with the discharge from surface flow and shallow sub-surface flow. To attain an acceptable salinity of (let us say) 500 mg l^{-1} the dilution flow should be about 7 times what it actually was in 1978, allowing for the fact that the dilution flow itself must bear some salt. Therefore, to be effective we would have needed a run-off of about 7 x 47.8 = 335 mm in 1978. That is clearly an impossible fraction (0.57) of the rainfall.

We should now examine whether the argument that I have just used is valid in application to the actual constructions on Batalling Ck. The chloride concentration of water flowing through the main weir was 2,290 mg l^{-1} and of water contributing to that flow from the shallow sub-surface source it was, by assumption, the same as that actually measured in the samples from the interceptor drain, namely 98.6 mg l^{-1}. Could these two waters be kept from mixing?

The answer to that question could be given by consideration of the hydraulic head gradient for vertical flow at the site of Bores Nos. 041, 042 and 043, located on the valley bottom. The heads and vertical separations of these bores were as follows.

Bore No.	Water surface reduced level on 15/9/78	Vertical distances between depths of slotted casing.
041	76.961 m	
		3.8 m
042	77.768	
		4.2 m
043	78.580	

It may be calculated that the vertical, upwards flux of water through the aquifer at that site, on 15/9/78, was about 8.5 mm d^{-1} between 042 and 041, and 7.7 mm d^{-1} between 043 and 042, using a hydraulic conductivity of 40 mm d^{-1}. When I visited the site on 21/8/79 there did not appear to be enough water seeping to the surface to account for 8.5 mm d^{-1}. Nevertheless there was a glisten of water over much of the ground surface, which would be consistent with the upwards seepage having to supply a contemporary evaporation rate of about 2 mm d^{-1}. Perhaps the vertical hydraulic conductivity is about 10 mm d^{-1}.

The stream in the valley bottom of Batalling Ck. is clearly a gaining stream. Water that flows along its stream bed or in the various rivulets and distributaries on the valley bottom must inevitably receive further saline water by base flow. It would be possible to avoid contamination of the water already there only if the head gradient were to be reversed in direction. This could be done by retaining the surface stream in a canal constructed to be, in the case of Batalling Ck., about 2 m or more above the ground surface.

The present trial has served its purpose already. I expect that the 1979 results will confirm those of 1978. In descriptive terms these conclusions are as follows. On the Batalling Ck. catchment upstream from the main gauging station, the contribution of salt to the saline water run off is donated predominantly by deep seepage, the streamlines for which must occupy the whole of the weathered zone. The present head differential from valley side to valley bottom is too great to be affected significantly by shallow drains such as the Whittington interceptor drain.

Dilution flow of water taken out of the interceptor drain is too small to be significant in lessening the TDS of the runoff. The amount of dilution that would be required to lessen the salinity of the runoff water would be an impossibly large fraction of the annual rainfall.

I recommend that the trial on Batalling Ck. should now be terminated. It has served a useful purpose of demonstration, in a direct fashion, that the general theory held by PWD engineers, CSIRO scientists, Dept. of Agriculture soil physicists and agriculturists is correct.

D. *Indicate the form that a new trial should take.*

I do not believe that a new trial should be entered into.

E. *Estimate the cost of undertaking the work recommended.*

Not now applicable.

F. *Provide a continuing review of any trial that proceeds.*

Not immediately applicable.

4. CONCLUSIONS

A. *Reclamation of ground with saline soils.*

The reclamation of a soil in which deleterious amounts of salt are distributed through the upper part of the soil profile can be effected only by leaching out the salt. The invasion of more salt by a saline water influx must then be prevented. The installation of drains sufficiently deep and closely spaced to keep the water table at about 2 m below the soil surface is the method for the latter criterion.

Leaching of salt from the soil profile implies that rainfall, or good quality surface water, is available in sufficient quantity to fill and then be emptied from the total pore space of the soil at a faster rate than the accumulation of the salt. The hope that this can be done on the valley bottoms by spreading of surface water run quickly from valley slopes by shallow drains, is forlorn indeed. How can spread surface water, or rain, enter the soil against the hydraulic head? The only time of the year when water could enter the soil is when it has been dried by excessive evaporation. But the water that could then enter can only refill pore space that has been dried and retains the salt that has been left behind. The salt will remain almost stationary except for a very thin layer of soil near the soil surface from which salt will be cyclically displaced downwards a few centimetres and into which the salt will return by upwards flux during drying weather. Effective reclamation requires rainwater to be able to enter the soil at the surface and to be removed as a salt solution by the drains at a depth sufficient to ensure a good environment for the plant roots.

Drainage must have been considered as the method of improvement of salt-affected land almost from the beginning of recognition of the problem. We have some evidence from Teakle's article (Teakle, 1938) that I quoted above. That acceptance of the idea by farmers had to wait so long can only be attributed to a belief that the benefits could not meet the capital cost and subsequent maintenance. Farmers seem to be enthusiastic about drainage now. Yet I was not shown and have not read about one place where the shallow drains have been tested and proved to be effective according to standard principles of field experimentation. Any improvement attributed to those drains could have come just as probably from the natural cycle of slow approach to a new salt balance.

The enthusiasm, that appears to be widespread, for the shallow, interceptor type of drain should be encouraged towards a better concept of drainage. An effective lowering of the water table in salt affected locations is the only answer to the problem. The direct attack is therefore to install deep drains and to be able to dispose safely of the saline, drainage water. An indirect method of management could be to establish again a woodland community upon strategic landscape locations, and so to attempt to return the valley and slope hydrology to its pristine condition.

These two methods, in principle, should not be regarded as competitors, and it would be unfortunate if their respective protagonists conceived of themselves as competitors. Each can have its place, and the choice would probably depend upon whether reclamation of salt-affected land or protection of the quality of stream water is the predominating need. Decisions of this kind should ultimately rest upon the advice of the professional engineers and scientists. Those others who wish to enter this arena, bearing their motives of concern for the environment, or any other interest whatever it may be, should be willing to abide by professional standards of accountability. Bad advice, tendered for laudable motives, remains bad advice. Its translation into practice and its capture of men's ideas, for the time being, must emerge, sooner or later, as a bad service to a community that deserves better.

B. *The reduction of the salt concentration of water in streams.*

The improvement of stream water salinity and the improvement of salt-affected soils by drainage are naturally antagonistic processes, on a short time-scale. The only saving-grace of the saline waterways is that they could receive further saline drainage waters without objections being raised by any interested party, because the water resource is already unusable. But streams that are tributary to the reservoirs of Western Australia must clearly be protected against their further deterioration. If the era of countrywide drainage is upon us, then the whole operation must include as one of its parts the safe disposal of the saline water.

I can think of no alternative to the maintenance of fresh water in streams other than by design of the waterways to keep out the saline water. We must assume that the most saline water occurs underground of the valley bottoms, and that it seeps upwards and enters the creeks and rivers by base flow. In principle, then, the malady could be cured by a reversal of the head difference.

The sources of fresh water tend to be distributed upon the highest ground that was cleared the longest time ago. Furthermore, much of the landscape may contribute fresh water as runoff during and shortly after exceptionally wet weather. The sources of fresh water, wherever they are located, and the usable water that they supply, in the valley streams, need to be kept separate from subsequent saline water inflow. Canals, or drains, constructed at an elevation higher than the potentiometric head of water in the valley bottoms is the only way to do it. It would ensure that any stream in such a man-made canal could never become a gaining stream where its course had to traverse a salt-affected part of the valley.

The construction costs could be prohibitive, but an exercise in costing a scheme could be useful. It could put into perspective the costs and benefits associated with such an engineering solution, relative to the control that could be expected by selective afforestation of the catchments.

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