THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY

Report No. 15

REMOVAL OF RAINWATER FROM BRINE PONDS

by

R.T. Hattersley

Report to F. and R. Penny Pty. Ltd.
39 Manning Road, Double Bay, N.S.W.

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PREFACE

This report covers a preliminary investigation undertaken by the Water Research Laboratory of the University of New South Wales on behalf of P. and R. Penny Pty.Ltd. The investigation was commenced on 31st March and completed on 12th April 1960.

The hydrologic study (Appendix B) was made by Mr.C.G.Coulter, Project Engineer, the study of raindrop penetration (Appendix C) by Mr. D.T. Howell, Lecturer. The investigation of the motion of fresh and salt water systems (Appendix D) and the preparation of the final report were completed by Mr. R.T. Hattersley, Senior Lecturer.

H.R. Vallentine
Assoc. Professor of Civil Engineering
Officer-in-Charge of the Water Research Laboratory.

26th April 1960.

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SUMMARY

A commercial process for the production of salt by the solar evaporation of sea water entails the use of extensive evaporating ponds for the purpose of reduction of natural sea water to a brine of approximate specific gravity of 1.25. The brine is then drawn off to a concentrating area comprising a black heat absorbing surface in which crystallization is carried out to the point at which the salt crystals can be garnered and separated from the mother liquor.

A preliminary series of laboratory experiments have been carried out to establish principles for the design and operation of the evaporating ponds and to assess the effectiveness of protective and removal techniques for countering rainfall precipitation.

REMOVAL OF RAINWATER FROM BRINE PONDS

1. INTRODUCTION

1.1 Objects of Investigation

The development of a commercial process for solar evaporation of sea water to produce salt is dependent upon the control and removal of rainwater deposited on the evaporating areas. The evaporating areas comprise extensive artificial ponds fed with sea water to make up for water removed by natural evaporation from the pond surfaces. The residue remaining in the ponds comprises concentrated brine with an overlay of salt water. The average evaporation rate in the locality in which it is proposed to establish the industry is less than the rainfall. The success or otherwise of the process depends on the prevention, as far as is possible, of the mixing of rain water deposition with the surface layers of salt water and by efficient utilisation of natural density stratification within the pond to effect a removal of the fresh water to disposal drains.

On behalf of P. and R. Penny Pty.Ltd., an investigation has been carried out into aspects of flow behaviour with a view to establishing a basis of design for the fixed installations forming the ponds and to lay down the general principles of operation.

This investigation is not a full investigation of the problem, many aspects of which will require further research before complete quantitative evaluation of the principles and the techniques can be made. Actual operating experience will also be invaluable and essential to the improvement in the process and to bridge the inevitable gap between the extent of knowledge which can be gained by laboratory and theoretical investigation and that necessary in the commercial operation of the industry on a large scale.

In particular, the aspects which have been considered for the compilation of this report are as set down in P. and R. Penny's letter of 28th March 1960 (Appendix A) which may be summarised as follows:-

To investigate and report on:-

(i) The extent of penetration and mixing of raindrops on impact at the surface of a pond.

(ii) The feasibility of removal of rain deposition by drainage over marginal weirs including estimation of velocities attainable under storm run-off for storms of various intensities.

(iii) The possibility of restricting the movement of brine by means of baffles.

To obtain the information to answer the problems associated with this investigation, a series of laboratory tests and research were carried out under three main headings under articles 1.2, 1.3 and 1.4.

1.2 Hydrologic Study

This study comprises an evaluation of once-in-five year rainfalls in the area and the calculations of the water surface profiles and associated run-off rates from pond surfaces. Details of this study are contained in a subsidiary report by Mr. C.G. Coulter (Appendix B).

1.3 Laboratory Study of Raindrop Penetration and Mixing of Raindrops falling into Sea Water.

Tests were made by simulating rain drops of sizes corresponding to the largest raindrops likely to occur under storms of comparable intensity to those of Part 1.3 above. The results of these tests carried out by Mr. D.T. Howell are contained in a subsidiary report in Appendix "C".

1.4 Laboratory Investigation of the Motion of a Fresh Water - Salt Water System.

This series of tests was undertaken with the object of assessing the depths and movements of salt or fresh water streams moving relative to one another, the extent of mixing and other effects sufficient to establish an overall evaluation only. Details of the tests are contained in a subsidiary report by R.T. Hattersley (Appendix D).

THE EFFECT OF RAINFALL ON EVAPORATING PONDS

2.1 Natural Density Variation in Evaporating Ponds

No laboratory tests were carried out in connection with this report upon the mechanism of the movement of brine in the evaporating ponds during the periods of fine weather when evaporation is in progress. Welch, inter alia, (Ref.1) on the subject of limnology, has pointed out the form of stratification which takes place resulting in a stagnant layer of denser (and colder) water at the bottom of a lake. Above this bottom layer exists an intermediate layer called the thermocline above which circulation of water takes place under the combined action of wind and heat exchange. The liquid of surface layers falls to the thermocline and the layers immediately above the thermocline move continuously to the surface. In the case of the evaporating pond, it seems not unlikely that this process will also occur as it does in lakes with the added condition that brine concentrated by evaporation at the surface will ultimately, by reason of its density, find its way to the lower layer.

Recorded experimental or natural observation of this phenomenon in shallow pans is, however, lacking and it may be presumptive to assume that the conditions observed in deeper lakes also holds in all similarity in the shallow evaporating ponds. It is evident, however, that increased density produced by evaporation in the surface layers will result in turnover of the brine which, in the ponds of large surface area, may occur at local zones of circulation or points where local instability develops. However, under suitable conditions of prevailing winds and sub-division of the pond by artificial barriers, turnover could occur as a continuous circulation as is noted in lakes. Whichever way circulation does occur, it would seem not unreasonable to suppose that the denser brine will accumulate at the bottom and a density gradient will occur throughout the depth of the pond. The nature of the density distribution with depth in shallow evaporating ponds is unknown and further experiment on this aspect appears desirable.

As discussed later in this report, quantitative evaluation of the density-depth variation is relevant to the mode of operation of fresh water purging operations and the control of new sea water feed to the system.

As a model for design purposes in this investigation, it is therefore suggested that an average linear density gradient be assumed throughout the depth and that the relative density at the bottom of the pond be that at which the brine is suitable for draw-off to the concentrating area. This figure is stated by Bottomley and Atkins (Ref. 2) to be 1.25. The average density of the topmost layer will then be that of new sea water or slightly greater if the pond has been under evaporation for some time.

2.2 Penetration and Mixing of Raindrops

Experiments carried out by Mr.D.T. Howell, summarised in Appendix C, show that rain falling on the surface of the ponds mixes with the topmost layers by a process of turbulent diffusion. The extent of the penetration appears to depend upon the kinetic energy of the falling drops and is accordingly greater for larger size drops than small. The results of the experiments show that for large drops (approximately 3.3 mm dia.) the depth of contamination in sea water is about $2\frac{1}{2}$ inches and for smaller drops (2.4 mm dia.) about $1\frac{1}{3}$ inches. Owing to the effect of energy dissipation by turbulent diffusion, the upper region of salt water will suffer an average dilution in proportion to the total precipitation falling in a storm, assuming of course that the surface remains static and no run-off occurs during the period of rainfall.

2.3 Efficacy of Simple Drainage Processes

The hydrologic study by Mr. C.C. Coulter (Appendix B) indicates that, of the possible once-in-five year storms, that which lasts for 40 minutes with an average intensity of 2.4 inches per hour would produce the greatest outflow rate when flowing over a 200 ft. length of solid horizontal surface. The maximum velocity would be 0.6 ft/sec at the crest of the outflow sill. A short distance from the sill the velocities would be very much lower and, on the basis of the experiments in Appendix D, entrainment and mixing of underlying flow would be negligible under such conditions.

The effect of the rainfall-runoff process on mixing of the rainfall and brine would thus be predominantly that of raindrop penetration and consequent turbulent diffusion. Since this effect contaminates the brine to a depth of several inches, it is not feasible to base a rainfall removal process upon the assumption that rainfall will flow over the brine surface to simple drainage weirs as if falling upon and flowing over a solid surface.

RAINFALL REMOVAL BY DISPLACEMENT

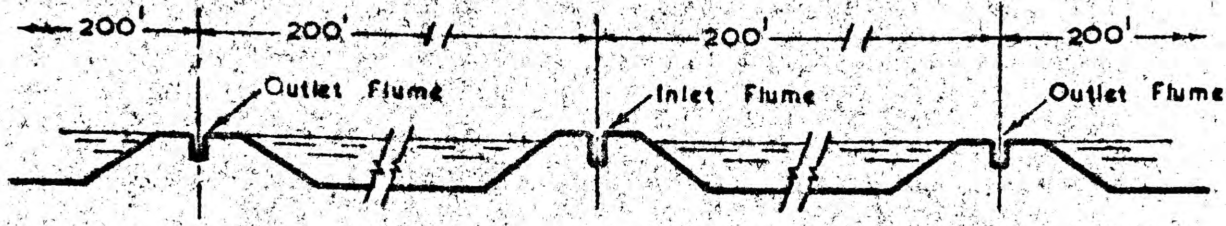
3.1 Displacement of Diluted Salt Water

The density of the upper layer of the brine, prior to rain, will be at least equal to that of fresh sea water, and at most times greater. It is clear that:-

1. attempted removal of contaminated top layers will only be justified if the average specific gravity of the contaminated layer falls below that of new sea water.

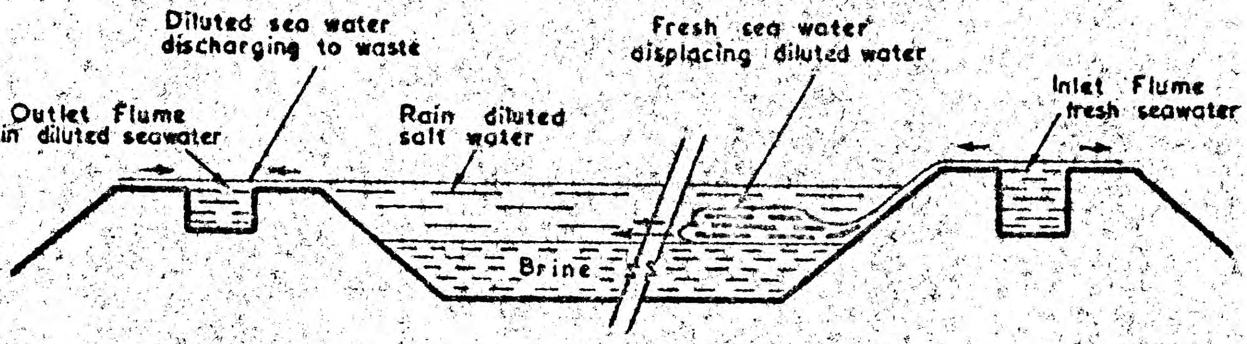
2. when heavy rain is imminent, the most effective form of protection may be to cover the pond area with a fresh layer of sea water of depth according to the estimated rainfall precipitation expected. This sea water, when contaminated, may then be removed by displacement with more sea water, which operation can be achieved at a cost approximately equal to the energy cost of pumping. (Reference Fig.1).

In cases where light rainfall occurs or rainfall occurs without adequate warning, the necessity of removal of the top layers would be determined by actual density measurements taken from samples at the surface of the ponds.



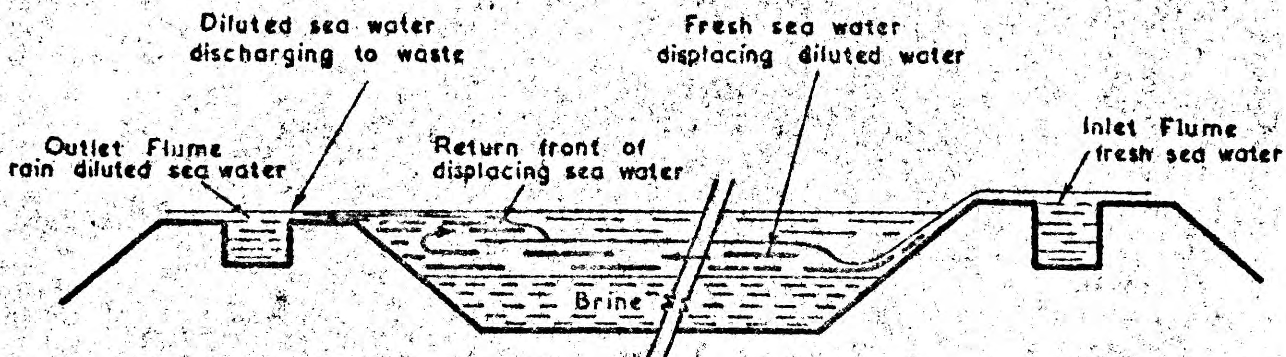
Cross-Section Through Evaporating Pond

FIG. 1a.



Initial Phase of Displacement Process

FIG. 1b.



Second Phase of Displacement Process

Process is complete when Return Front reaches the Vicinity of the Inlet Channel

FIG. 1c.

Not to Scale

FIGS. 1b. & 1c. ILLUSTRATE DISPLACEMENT PROCESS FOR REMOVING DILUTED BRINE

The quantity of contaminated water to be removed depends primarily on the drop size occurring with the rainfall. Laws and Parsons (Ref.3) have shown that raindrops range in size from 4 mm for storms 1 inch per hour or over down to drops 0.8 mm which occur in rainfall intensities of the order of 1/20 inch per hour. The average size of raindrops is about 1.5 mm and it is estimated that this is likely to produce a penetration of approximately one inch. Hence, the surface water of the evaporating pond will require removal to depths varying between 1" and 2-3/4" under ordinary conditions of operation.

The experiments described in Appendix "C" show that the differential movement of thin layers of fresh and salt water inevitably produces exchange of salt between the moving layers and for this reason the technique adopted for displacement of contaminated water should be such as to entail the least differential movement on any existing or newly created interface.

The spacing of feeding and outlet channels will therefore have to be designed with respect to the attainment of minimum velocities of displacement consistent with cost of provision of the channels.

Apart from the spacing of inlet and outlet channels, other factors will be of benefit in obtaining the maximum evaporative effect. The first of these is to ensure that the evaporating ponds are left with the minimum amount of disturbance during the fine weather periods. To accomplish this, it is desirable to slightly lower the surfaces in the evaporating ponds to ensure that wind action will not result in movement of brine over the marginal weirs with the consequent interference to the natural turnover processes. Loss of brine will also be prevented this way.

Removal of brine from the bottom of the evaporating pond is a means of lowering the surface levels without disturbance of the top layers.

Brine removal is required to feed the concentrating areas and the level lowering process may be achieved by drawing off brine for this purpose.

The drop in level in the evaporating ponds will then continue throughout the period of fine days. An examination of available records (Ref.4) of fine day sequences indicates that the mean number of rainless days per month is about 18 and it would appear that the interval between days in which consequential rainfall occurs lies anywhere between 3 or 4 days up to 30 days. This means that the evaporation in any rainless period would be between 3 to 4 inches down to ½ inch or less.

This range suggests that the best mode of operation is to refrain from adding new sea water unless the pond level falls below about three inches from the top of the ponds.

Upon receipt of a forecast of substantial or consequential rain the levels should then be adjusted by passing new sea water over the evaporating areas at surface velocities preferably not exceeding about 3 feet per minute until the depth of the new salt water reaches a depth depending on the estimate of the amount and intensity of the rain forecast; that is, if the threat is for cyclonic disturbance with heavy rain, to a depth of 3 inches. For lesser rain, e.g. light falls of ½ inch or less, 1½ inches would suffice.

Consideration should also be given to the possibility of draining brine from concentrating surfaces back through the collecting system to storage at the lower layers in the evaporating ponds. It would appear that such a system would entail little effective heat loss and would assist in adjustment of the levels in the evaporating areas.

In the event of rain, the pond surfaces should be within an inch or so of the weirs.

The effect of rainfall would then be to penetrate and contaminate the new salt water and if continued and heavy, finally to overtop the weirs. Field density tests made during the rainfall period or subsequent to the rainfall, together with experience gained in operating the ponds, would indicate the extent and time to add new sea water. Preferably, all sea water additions would be carried out at night or early morning hours when surface disturbance from the wind would be least and loss of evaporating time would be negligible. It is anticipated that removal of the contaminated surface by displacement with fresh sea water would commence before cessation of rainfall at a time when predictions are for a cessation of consequential rain within about 2 to 3 hours. The ponds would then be ready to commence useful evaporation as soon as fine weather becomes general.

3.2 Loss of Salt

In estimating unavoidable loss of salt from brine solutions, only those losses which are incurred from concentrations greater than sea water are accountable as loss.

Losses will occur in the following ways:-

(1) Loss of brine due to wind action causing waves and piling of the brine against marginal weirs.

(2) Loss of brine due to displacement operations for the removal of rain diluted top layers.

The first loss can be controlled by lowering top surface levels during evaporating periods.

The second form of loss will depend a great deal on the sequence of rainstorms encountered and their frequency and the skill exercised in forecasting their intensity. The skill exercised in timing and controlling the displacing flows of new salt water will also be vital to minimising the loss of brine. These skills will be developed in the practical operation of the processes.

Assuming the best conditions are realised, no significant loss of evaporated brine should result from the effects of moving a new layer of sea water over the brine surface. As shown in Tests 1, 2 and 3 of Appendix "C" the interface between the new sea water and the brine will be depressed and the new sea water will entrain some of the salt from the brine solution but the depth of penetration of brine into the new sea water is not likely to exceed one inch.

Loss of brine will, however, occur, if the initial overlay of new sea water is inadequate to prevent penetration of rainfall to the brine interface. Removal of diluted sea water will then entail removal of salt from the concentrated brine.

3.3 Sea Water Feeding and Drainage Systems

To meet the needs of the system proposed in the foregoing sections, the evaporating area is tentatively subdivided into areas not more than 200 feet in width for the full length of the pond. A cross section thrugh the evaporating pond as proposed would be as shown in Fig. I. Each divisional embankment made of earth would contain a flume. The flume in each alternate bank would be slightly higher than the flume in the neighbouring embankment. The elevated flumes would be used to feed new salt water to the ponds by allowing the water to flow laterally from the flume along its length to the pond surfaces.

The lower alternate flumes would be used to drain diluted sea water from the area after rainfall. Each of the flumes should be carefully set to grade by adjustment of levels during the initial stages of operation to obtain uniform depth spillage along the length of the flume. The orientation of the flume system should be arranged so that the direction of the prevailing winds in the locality lies approximately at right angles to the direction of the flumes.

3.4 Brine Handling.

The brine drainage and handling system could be generally along the lines suggested by Messrs. P. and R. Penny with the following exception.

It is suggested that the concentrating areas be elevated to approximately the evaporating pond surface level and that they be fed during normal working operations by pumping.

In the event of a threat of rain, brine from the concentrating areas may then be either

(1) pumped to temporary storage tanks,

(2) if advantageous after an extensive period of dry weather, drained back to the underside of the evaporating ponds to effect adjustment of levels as far as the capacity of the concentrating areas permits.

This system will have an added advantage that conservation of concentrated brine will still be possible in the event of failure of electricity supply at the critical period before the arrival of a storm.

4. CONCLUSIONS

The answers to the points raised in P. and R. Penny's letter of 28th March 1960 (Appendix A) taken in order are as follows:-

(1) Removal of rainwater from the surface of brine solution in an evaporating pond by simple drainage processes does not appear practicable.

(2) Vertical baffles are ineffective in the prevention of the mixing of brine and fresh water streams.

(3) Mixing of rain water and salt water occurs on impact of a raindrop upon a salt water surface, the depth of penetration depending on the drop size and the velocity of the drop.

(4) The design of a simple decanting system is apparently not feasible. On the other hand, a system of operation can be devised to effect removal of rainwater. The system described in Section 2 of this report depends upon the displacement of sea water diluted by rainwater with additional sea water pumped in at the termination of a rain storm.

The percentage of fresh water removed in this way in Test No.5 of Appendix "D" is 73 per cent. / ||

The test was conducted with the salt water in contact with a lower solid boundary. In the evaporation pond an interface will make the boundary between the new salt water and the brine and the question as to whether the percentage of 73 per cent for effective removal of rainfall, can be realised over the whole period in which rainfall occurs on the ponds will depend to a large extent on the manipulation of the protective sea water layers and the nature of the rainfall which actually occurs on the ponds. It is also likely that very light falls of rain will have to be tolerated without putting into effect protective measures at all.

To bridge the gap between the information to be gained from theoretical deduction and laboratory experiment, the construction of a pilot plant comprising an evaporating pond 200 feet wide by 200 feet long is recommended. Such a pilot plant could be sited so as to form part of the final installation. From the observations made on such a pond a fuller evaluation of the operating technique will be possible and the results would be available to effect modifications and adjustments to the essential design features before extensive capital commitments are made and the risks associated with investment in the enterprise would be thereby reduced to a minimum.

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3. The Relation of Raindrop Size to Rainfall Intensity . . . J.O. Laws and D.A. Parsons Transactions American Geophysical Union Hydrology Papers 1943 pp. 452 - 460.

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APPENDIX "A"

39 Manning Rd.,
DOUBLE BAY.

28th March 1960.

Prof. H.R. Vallentine,
Water Research Laboratory,
The University of New South Wales,
MANLY VALE.

Dear Sir,

Confirming our recent discussions with you and Mr. Hattersley, we would like you to carry out the following experiments on our behalf.

(1) Test the possibility of running water (rain) from the surface of a brine solution by weir effect.

(2) Test the possibility of holding the brine solution inert by means of baffles, so that the windage and wave effect is minimised.

(3) Obtain any information you may need from your Hydrographic Dept.

(4) On the findings from 1 and 2 what will be the pattern of the baffles ~~on an area 2000 ft. by 1000~~ ft. and what will be the maximum distance that the fresh water will slide over the boring in approximately two hours.

(5) Test the effect of rain by means of a sprinkler system to ascertain the depth of penetration of the rain drops and the extent of the mixing effect created by the velocity of the fall.

(6) From the conclusions of 1, 2, 3 and 4, is it possible to design a large scale de-canting arrangement to operate with an efficiency of approximately 75 per cent.

Yours faithfully,

P. AND R. PENNY PTY.LTD.

APPENDIX "B"

Hydrologic Study of Evaporation Ponds

Report by: C.G. Coulter
Date: 1.4.60

Synopsis

Once-in-five-year storms have been routed through 200 ft. length of horizontal strip one foot wide of an evaporation pan. Peak outflow discharge is estimated at 0.0075 cusecs when the depth at sill crest is 0.013 ft (slightly more than 1/8") and the velocity (crest) is 0.6 ft/sec. The storm producing the greatest outflow rate is of 40 minutes duration having an average intensity of 2.4"/hr.

Procedure of Investigation

The once-in-five-year rainfalls have been computed for the Port Stevens area by the data given in the First Report of the Stormwater Standards Committee of the Institution of Engineers, (Aust.) 1957.

Rainfall intensities are as shown in Table I and are shown on Fig. 2.

Table I

Duration	Intensity
½ hour	2.86"/hr
1 "	1.93"/hr
4 "	0.77"/hr

A strip of the pond 200 ft. long and 1 ft wide was considered and a backwater profile was calculated for the steady flow conditions under the half-hour storm. The depth of water at the sill was computed using the graph of C_d with K given in Rouse "Engineering Hydraulics" p.52[illegible]. The profile [illegible] was computed by a trial and error step by step procedure assuming that the flow was laminar throughout, (at the sill with peak outflow Reynolds Number, R = 770) that the interface between the salt and rainwater was a solid boundary, that surface tension had no effect and that there was no wind to upset flow gradients. The water slope was computed, neglecting velocity head terms, from the formula $S = \frac{3uV}{\gamma y^2}$

where S = surface slope
u = coefficient of viscosity
V = mean velocity
y = depth of flow
γ = specific weight of water

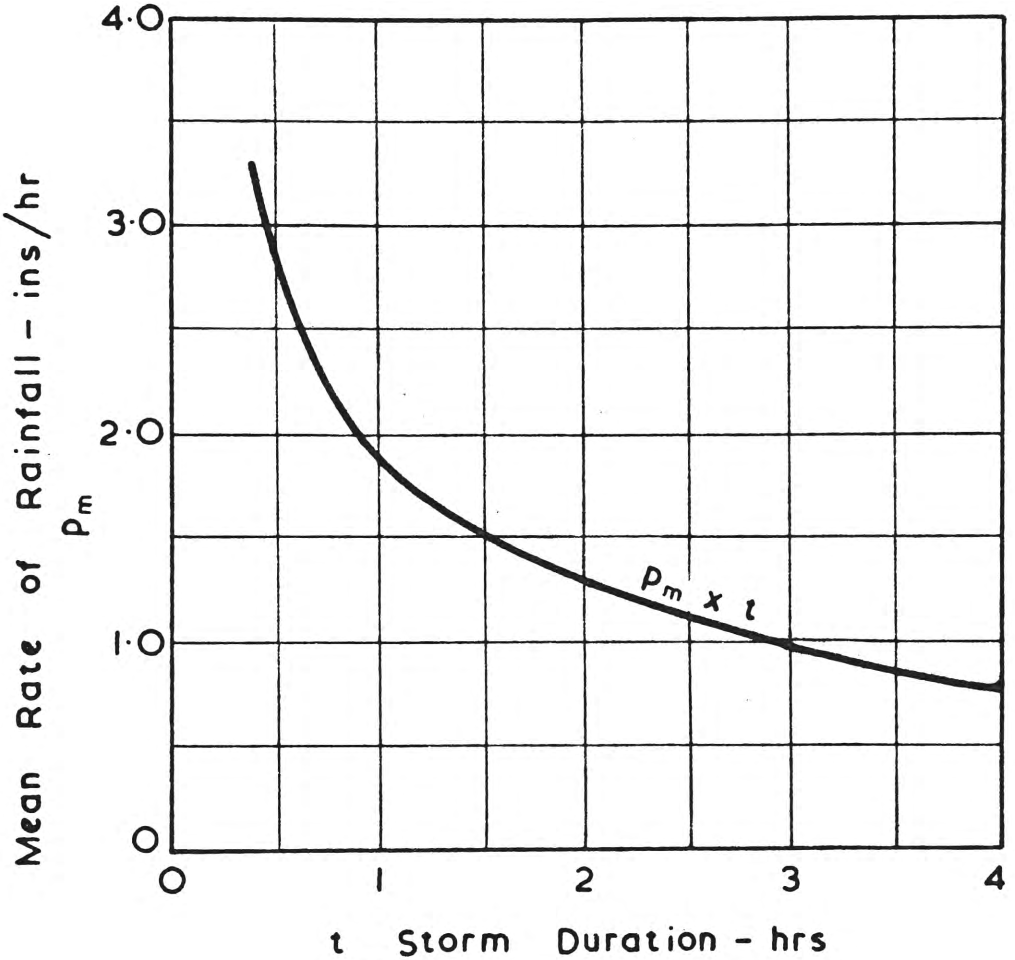
The lower discharge profiles were drawn in by eye from the computed profile and computation of the water depth at the sill. The relation between discharge and depth of water at the sill is given in Fig. 3.

The volume of water in storage for the different profiles was computed and the graph of routing function ($\frac{2S}{t}$ + O) against discharge (Fig. 2) prepared.

The ½-hour, 1-hour and 40 minutes duration storms were routed through the strip. The relation between storm duration and peak outflow is shown on Fig. 4, which indicates the greatest outflow is caused by a storm of 45 minutes duration when the peak outflow discharge is 0.0075 cusecs and the depth of water at the sill is 0.013 ft. (0.15 inches).

Discussion

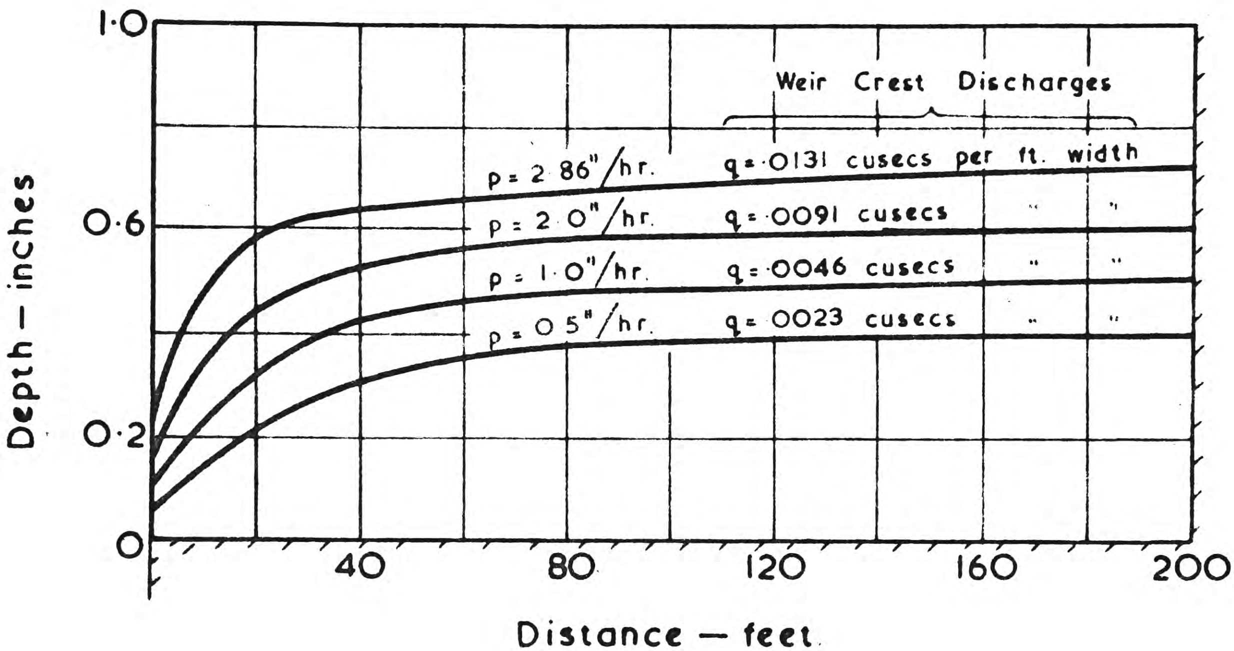
These results must be taken as approximate only. The effect of surface tension effects at the sill, non-level spillway, the effect of wind in blowing the water across the pan and the momentum of raindrops falling at an angle to the vertical, the assumption of a solid boundary at the interface, the application of discharge familiar to such small depths over the crest all introduce unknowns that cannot be evaluated.



RAINFALL INTENSITY DURATION CURVE
FOR 1 IN 5 YEAR STORM AT
PORT STEVENS

FIGURE No. 1.

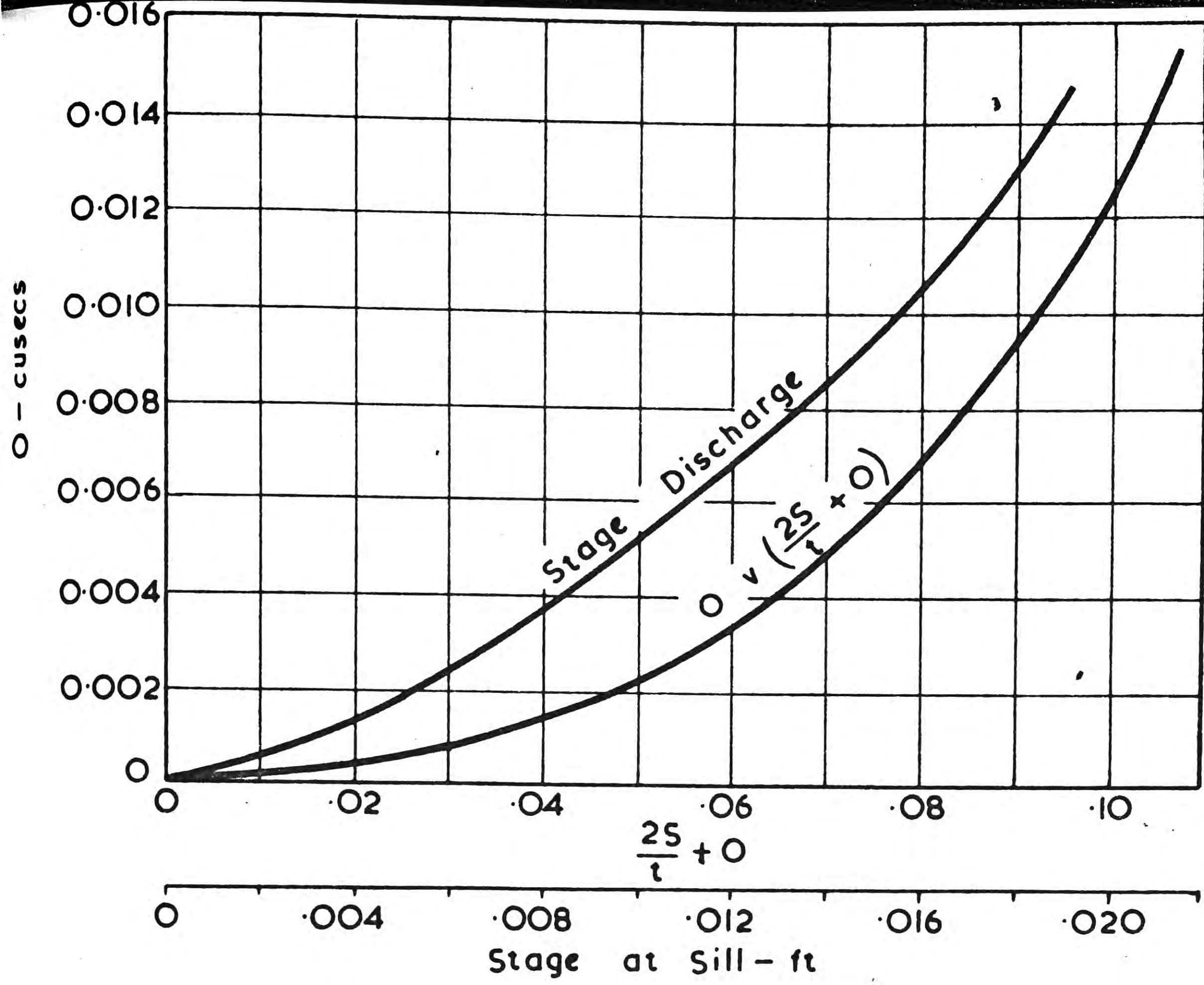
THE UNIVERSITY OF NEW SOUTH WALES WATER RESEARCH LABORATORY		
HYDROLOGIC STUDY OF EVAPORATION PONDS	Scale: Drawn: C.G. Coulter Traced: P.A.	Date: 17·5·60 CE-Q-1575



BACKWATER PROFILES

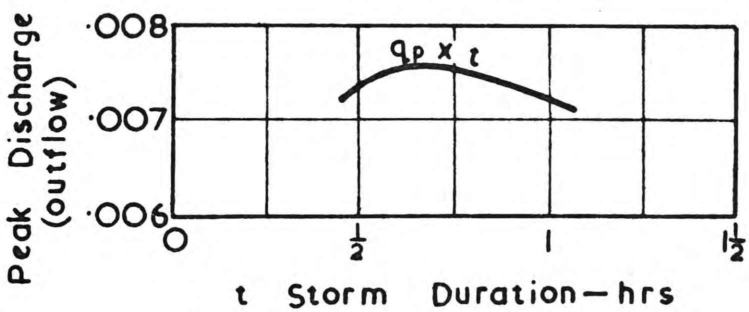
FIGURE No. 2

THE UNIVERSITY OF NEW SOUTH WALES WATER RESEARCH LABORATORY		
HYDROLOGIC STUDY OF EVAPORATION PONDS	Scale: Drawn: C. G. Coulter Traced: P. A.	Date: 17·5·60 CE-Q-1576



STORAGE/ELEVATION RELATION & FLOOD ROUTING PARAMETERS

FIGURE No. 3



PEAK OUTFLOW V. STORM DURATION

FIGURE No. 4

FIGURE Nos. 3 & 4

THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY

HYDROLOGIC STUDY OF EVAPORATION PONDS	Scale:	Date: 17.5.60
	Drawn: C.G.Coulter	CE-Q-1577
	Traced: P.M.A.	

APPENDIX "C"

Laboratory Investigation of the Depth of Penetration and Mixing of Raindrops Falling into Sea Water.

Report by: D. T. Howell
Date: 13th April 1960

1. Introduction

When raindrops fall into sea water, there is mixing between the sea water and the rain water to a depth which may be expected to depend in some way upon the size of the drops. Raindrop sizes vary in diameter between a little less than 1 millimetre to a little more than 4 millimetres. The larger drops fall with a much greater terminal velocity than the smaller drops.

Experiments were conducted to obtain some indication of the depth of penetration and mixing of raindrops of different sizes.

2. Method

Two experiments were conducted with drops of 4 mm and 2.6 mm diameter dropped from a height of 10 feet into a tank of sea water of specific gravity 1.023.

In both cases the drops were formed from fresh water dyed with red ink. The drops were produced under a small static head from a reservoir of dyed water through a drawn glass tube for the larger drops and a hypodermic needle for the smaller drops. In each case a jet was formed which broke up into drops of very nearly uniform size.

The drops of 4 mm diameter were obtained by visual comparison with the drops from an already calibrated infiltrometer nozzle operating under a pressure of 35 pounds per square inch. The unknown velocity of the drops from this nozzle prevented its direct use. The end of a tapered glass tube was cut until drops of the same size were obtained.

The size of the smaller drops (2.6 mm diameter) was obtained by weighing.

In each case a stream of drops was allowed to fall for 15 seconds from a 10 feet height into a perspex tank containing sea water. The penetration of the drops as indicated by the formation of a layer of dyed water was observed.

3. Experimental Results

The 4 mm drops were observed to form a layer of dyed water $2\frac{1}{2}$ inches thick. The 2.6 mm drops produced a layer $1\frac{1}{2}$ inches thick.

4. Calculations

In both these experiments the drops fell from a height which did not allow their full terminal velocity to be attained. Raindrops of the same kinetic energies as in the experiments will have smaller diameters.

When corrections are made it is found that the experimental drops are equivalent to raindrops of 3.3 mm and 2.4 mm.

5. Conclusions

The experiments showed that raindrops of 3.3 mm and 2.4 mm diameter falling vertically will have depths of mixing of ap reximately $1\frac{1}{2}$ inches and $2\frac{1}{2}$ inches respectively. The most commonly occurring raindrops size (approximately 1.5 mm) will then have a depth of mixing of approximately one inch.

APPENDIX "D"

A Study of Drainage and Displacement Techniques for the Removal of Rainwater from Brine Ponds.

Report by: R.T.Hattersley
Date: 13th April 1960.

Introduction

As part of a preliminary programme of research into the development of a commercial process for solar evaporation of sea water to produce salt, this study is designed to investigate the flow behaviour of a stream of fresh water or near fresh water over a layer of salt water and to establish the extent of intermixing of the salt solution with the fresh water with and without transverse baffles.

General Description of the Flow of Fresh and Salt Streams

The movement of fresh water over the top of sea water has been noted by previous observers and it is known that a defined line of demarcation between an overlying stream of fresh water will persist for a considerable time. It is also known that turbulence within the flow will assist an interchange of salt water across the boundary of the counterflowing streams but the extent of the interchange and the stability of the depth of the respective flows with variation in time apparently has not been published.

The movement of a fresh water stream over a salt water layer commonly occurs when the fresh water stream flows under the action of gravity to an outlet with free overfall as in the case of an overflow weir. Of particular interest in this instance, is the suggestion that rainfall deposition on the surface of an evaporating pond may be removed by gravity flow. It is then obvious that the movement of the water should be controlled if possible to minimise the mixing of the fresh water with the salt water and for this purpose it might be supposed that a system of baffles may assist in inhibiting the mixing operation by limiting the influence of the fresh water stream and by also confining the salt water between stationary barriers.

Experimental Procedure

To test the efficacy of such a process two vertical baffles were arranged three feet apart in a horizontal flume 2 feet wide fitted with an observation window. The total length of the flume, 20 feet, left room for an approach length and a downstream dispersal length each about 8 feet. The height of the baffles was arranged at 12" and the top edges were carefully levelled.

The space between the two baffles was filled initially to a depth of 12 inches with salt water and the approach and dispesal regions with fresh water.

A stream of fresh water was introduced at a steady rate into the approach length through a stilling baffle over the top of the central baffles and flowed at a controlled depth onto the surface of the salt water.

The time of commencement of the operation was noted and the position of the interface between the salt water and the fresh was observed at succeeding intervals of time.

Density changes in the depth of the water were made visible by the use of "Pycnosound" Floats identifiable by colour bands observed through the observation window. The Pycnosound Floats are calibrated to float at set values of liquid density and give by the relative position of the float heads the approximate density of the water immediately below the float head.

Movement of the water stream was traced by fluorescein dye injection.

Tabulated results of these observations are shown in attachments pages (D13-14) and referred to as Tests 1, 2, 3 and 4.

A further test was conducted with no baffles in the full length of flume commencing with a depth of salt water at 3.6 inches. The fresh water was fed into the flume in this instance down a smooth board sloped at 1 vertical to 4½ horizontal. This test is referred to as Test No.4.

In all four tests the surface velocities were observed by timing a Pycnosound Float (approximately 1 inch long) rated at relative density 1.000 as it moved over a length of 3 feet near the surface.

A fifth test was carried out without baffles to determine the movement of a stream of salt water beneath a layer of fresh water.

Test No.1 - Description of Flow Behaviour

An initial test run for the purpose of qualitative observation of the phenomena showed that a turbulent fresh water stream quickly extended in depth in the first few minutes of the flow. It continued to extend at a diminishing rate until the fresh water to salt water interface reached a relatively stable position. The flow of fresh water was then cut off and the water in the flume was left to stand for a period of 16 hours during which time the level was lowered by leakage about 3 inches. The interface remained relatively undisturbed. The extent of the interface was then photographed and is shown in Plate I in which the positions of the Pyenesound Floats are clearly indicated.

The floats range in calibration from relative density 1.025 to 1.005 in approximately equal steps. The black floats at the surface are rated at relative density 1.000. The initial density of the sea water used lay between 1.300 and 1.025. It will be seen that below the interface a considerable depth of sea water has remained undisturbed. Above the interface a layer of fresh water has accumulated many times the depth of the passing flow at the surface.

Following the initial test, tests numbered 2, 3 were conducted under steady flow conditions. Test No.2 was taken at low surface average velocity of 0.022 feet per second and Test No.3 at 0.19 feet per second. Flow in this case was turbulent.

Tests 2 and 3

The general pattern of relative movement of the liquids during Tests 2, 3 and 4 are shown in Fig.I. The relative positions of the interface during the tests are shown in Plates II and III.

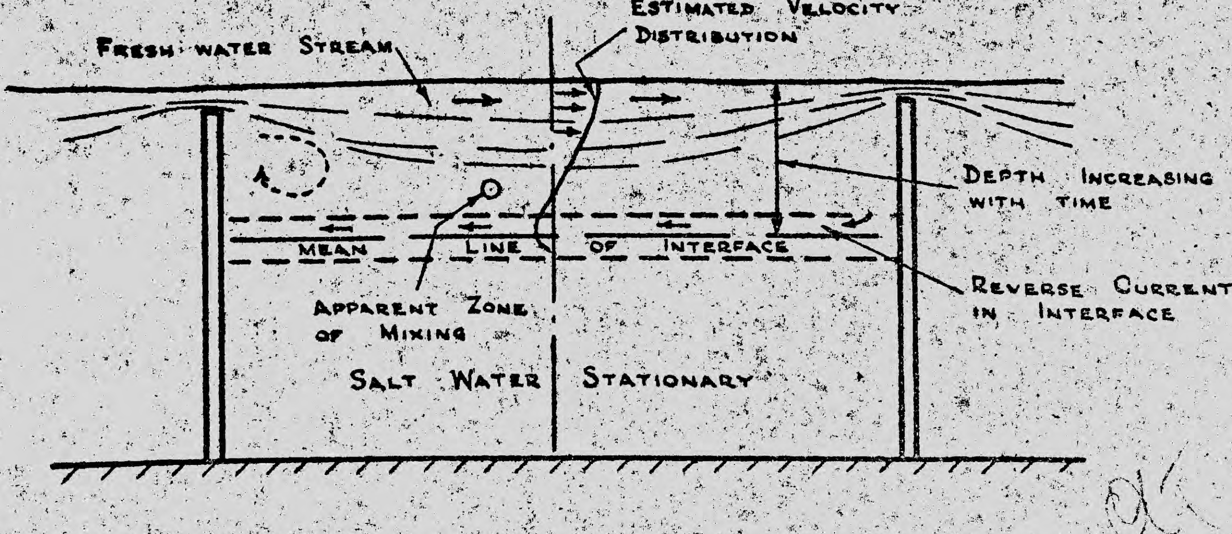
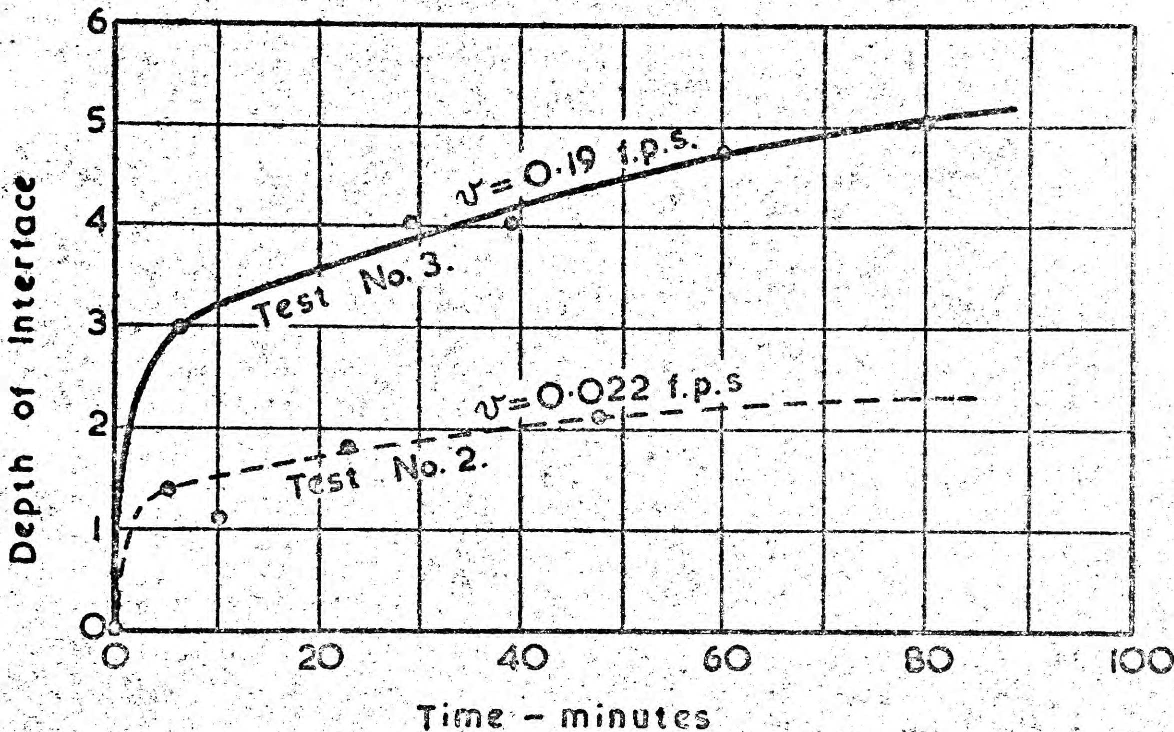


FIGURE No. I

FIGURE No. 2.



MOVEMENT OF SALT WATER INTERFACE

BENEATH A FRESH WATER STREAM

The surface mean velocity of the fresh water stream was found to be independent of the depth to the interface and remained constant in each test.

The interface was observed to have a slight gradient against the direction of fresh water flow and within the interface a reverse creeping current was noted (traced by sediment particles and dye) moving down the gradient. The surface of the interface readily deflected light rays incident beneath the face. Waves of wave length approximately four inches and of amplitude 1/4 inch to 3/8 inch were noted when the mean surface velocity was 0.19 feet per second.

The rate of increase in depth of the overlying fresh water is shown by curves in Figure 2 which also indicate that the depth of depression of the interface is related to the time of flow and to the mean surface velocity.

Salt water is apparently bled from the interface in a slow steady manner without marked disturbance of the density gradient in the interface and is carried upward against upstream baffle where it is carried away at low concentration in the surface flow. Plates 2 and 3 show the positions of Pycnosound Floats marking the interface boundaries after periods of 1/2 hour and 1 hour in Tests 2 and 3 respectively.

The rate of bleeding of the salt water from the interface appears to depend on the velocity gradient of the fresh water stream near the salt water interface. As the depth of fresh water increases, the velocity gradient in this region diminishes and the depth of fresh water overlying the salt tends towards a constant value.

The effect of the eddy formed in the zone of separation near the baffle also assists the mixing of the bled salt water with the fresh water passing overhead.

Conclusion

A distinct difference between the rate of increase in depth of the interface was shown to occur between the case for laminar flow and that for turbulent flow, the latter being the greater. This test showed that the use of vertical baffles to prevent the surface fresh water mixing with the underlying salt water was ineffective.

Test No.4 - Further Test of Mixing of Surface Flow with No Baffles

In an attempt to eliminate the effect of the vertical baffle in producing an eddy a further test was conducted with a sloping inlet ramp at 4½ horizontal to 1 vertical (See Fig. 3). The initial depth in the flume was 3.6 inches of salt water and the effective length of

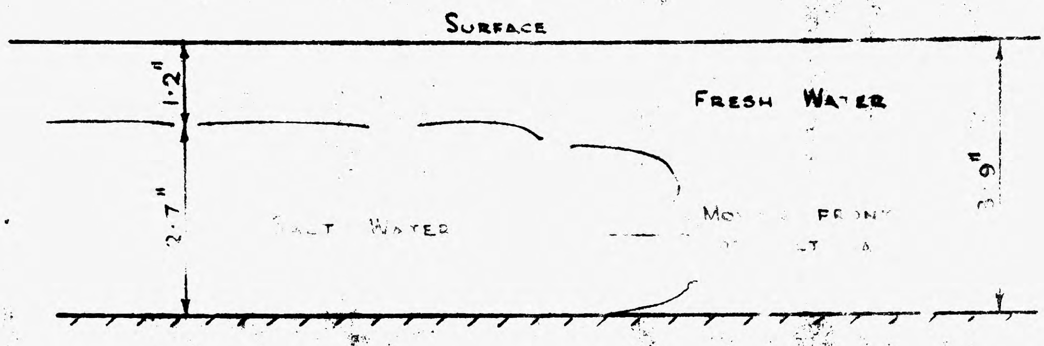


Fig. 5a.

Initial Movement of Salt Water Front to Overflow Weir

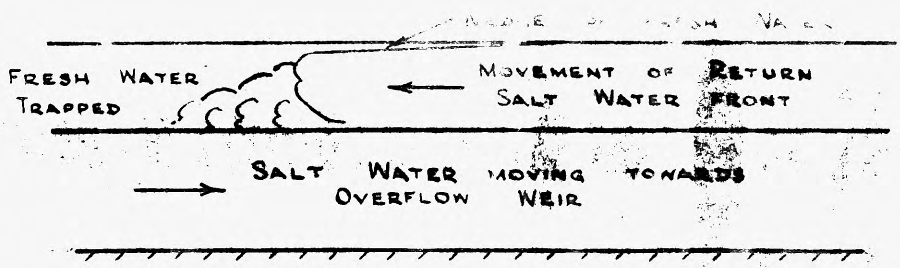


Fig. 5 b.

Movement of Salt Water Front on Reflection from Weir

FIGURE No. 5.

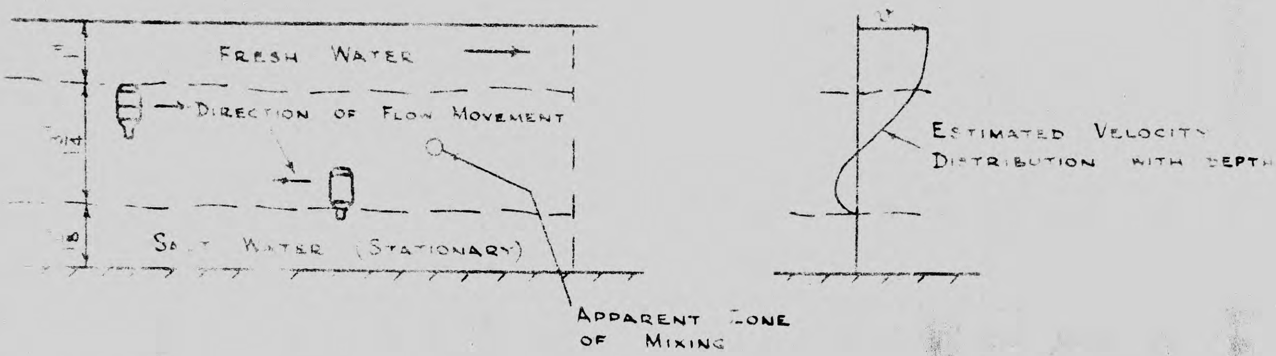


FIGURE No. 4.

[illegible] minutes after the commencement of the test the fresh water [illegible] depressed to two inches in depth.

At 13 minutes after the commencement of the test both red-blue and blue floats were in contact with the bottom of the flume and the [illegible] of stationary salt water had diminished to 1/4 inch depth. [illegible] of [illegible]

[illegible] overall [illegible] the duration of the test 3.6 inches in 13 minutes corresponded generally with that shown in Fig.2 for a surface velocity of 0.1[illegible] feet per second although the surface velocity in [illegible] only 0.103.

Conclusion

In this test the increased length in the channel extended the time taken to establish nearly steady conditions of flow and the depth in the apparent zone of mixing was greater than the case with baffles. The length of laboratory channel is much shorter than the length of run of the water from the furthest point of the evaporating pond to the weir overfall. On the other hand the rate at which the water moves from the surface of the evaporating pond will depend on the draw-down curve to the weir. The velocity remote from the weir in the evaporating pond will therefore be small increasing to a maximum near the [illegible] overfall. The surface velocities recorded in the test [illegible]

[illegible] run-off from the heaviest storms, at points close to the [illegible] flow weirs. As in the case of Tests 1, 2 and 3, the mixing of the fresh and salt water is shown in Test No.4 to depend on the rate of surface flow and the depth to which the interface is depressed below the surface. In both cases the fresh water to salt water interface was depressed more than 3 inches in a period of fifteen minutes. In the evaporating ponds, the amount of intermixing of fresh and salt water layers will be slight at the greatest distances from the weirs in the evaporating ponds but closer to the weirs attempted removal of surface layers of fresh water is likely to cause a serious concurrent loss of brine at depths upwards of 3 inches if the time of run-off is to exceed 15 minutes.

Test No.5 - Inflow of Sea Water Beneath a Layer of Fresh Water

From the conclusions of Tests 1 to 4, it is seen that removal of overlying fresh rain water by simple drainage processes is unlikely to be a very effective means of rehabilitating the evaporating pond surfaces.

Test No. 5 was conducted to evaluate the possibility of interposing a stream of sea water over evaporated brine thus displacing and lifting the fresh water. The fresh water could then be carried on the top of the sea water to the weir overfalls.

Concentrated brine was not used in the model. The boundary between the concentrated brine and fresh water was represented by/the solid bottom of the test flume and it was assumed that newly introduced sea water would form an interface between the sea water and the concentrated brine at a position corresponding to the solid bottom of the test flume.

The same channel as used for Test No.4 was filled with fresh water to a depth of 3.6 inches. Salt water of density 1.03 was introduced through a stilling box and dyed with fluorescein before flowing over the sloping weir into the fresh water. The salt water moved down the weir face and spread initially to a depth of 1 inch, but rose a few inches beyond the ramp to form a front approximately 2.7 inches high about 1 foot to downstream of the point of entry. The top surface layer of fresh water was displaced until the depth of fresh water from the surface was approximately 1.2 inches at the rear of the newly formed salt-fresh front as shown in Fig.5. Fresh water was displaced freely at the weir face until the salt front reached the weir whereupon the salt water front returned over the top of the lower stream tending to trap the fresh water in front of the new return front which spread slowly back towards the supply point. At this stage the flow over the outlet weir comprised mainly salt water. The fresh water trapped above the salt gradually diminished in volume as either admixture occurred on the interface or the fresh water was forced back to the supply weir where turbulence produced by the incoming flow of salt water tended to accelerate the mixing process.

Fifteen minutes after commencement of the test the inflow was cut off and the water in the channel was allowed to become still. At this stage all the fresh water had been either mixed or removed by displacement.

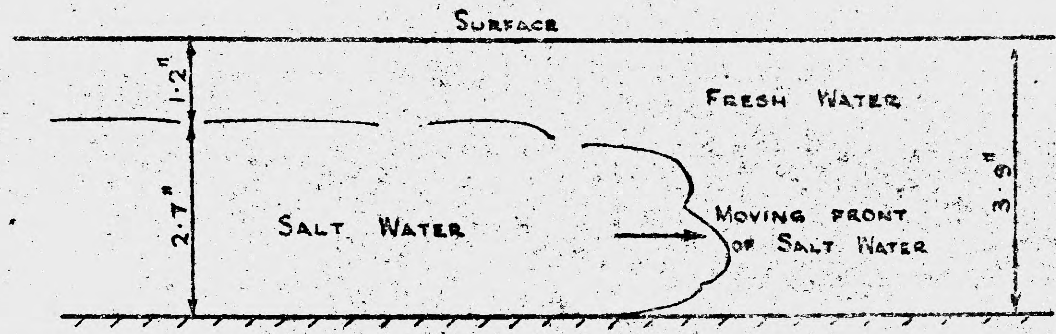


Fig. 5a.

Initial Movement of Salt Water Front to Overflow Weir

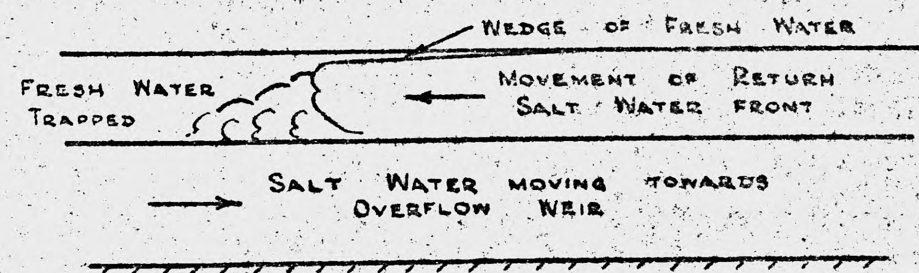


Fig. 5 b.

Movement of Salt Water Front on Reflection from Weir

FIGURE No. 5.

Density readings on the depth of still water were as follows:-

Depth from Surface inches	Mean Relative Density	
3.6	1.025	
2.0	1.0225	mean
1.12	1.020	= 1.022
0.00	1.0175	

Conclusion:

This test showed that removal of approximately 73.4 per cent of a volume of fresh water at a depth of approximately $3\frac{1}{2}$ inches is feasible by displacement with an equal volume of sea water fed in from a weir at the side of the pond. The sea water residual in the process was reduced in density by the admixture of 26.6 per cent of the fresh water with the sea water.

The test was carried out with a solid boundary on the lower face of the inflowing salt water. In an evaporating pond it is expected that an interface would develop between the incoming sea water and brine in the pond. In such an event the behaviour of the interface would be similar to the fresh water to salt water interface studied in tests 1, 2, 3 and 4.

Test No.1 Result

Description of Test

An initial test of a series of four to determine the behaviour of a surface flow of fresh water passing over a layer of salt water bounded by vertical baffles normal to the direction of motion of the fresh water stream.

Date of Test - 5th April 1960

Initial Depth of Salt Water - 12.3 inches

Depth of Fresh Water above edge of baffles - 1/4 inch

Water Temperature - Fresh Water 69°F. Sea Water 70°F

Times from commencement of Test - minutes	0	10	45
Depth of Fresh Water between baffles - inches	1/4	1-1/16	4"

Comment: Tank left to stand overnight 16 hours and observation of fresh water depth showed little change.

Refer Plate I

Negative 3/17/98.

PLATE I

Float Identification

BLACK
1·0000

CREAM
1·0050

RED / BLACK
1·0075

BLUE / BLACK
1·0125

CREAM / BLUE
1·0175

BLACK
1·0000

CREAM / RED
1·0150

BLACK / CREAM
1·0200

BLUE
1·0250

RED / BLUE
1·0225

Test No.2 Result

Description of Test

This is the second of a series of four to determine the behaviour of a surface flow of freshwater passing over a layer of salt water. The salt water was bounded by vertical baffles normal to the direction of motion of the fresh water stream. The surface flow was practically laminar.

Date of Test - 4th April 1960.

Initial Depth of Salt Water - 12.3 inches

Depth of Fresh Water over top edge of vertical baffle 0.07 in.

Length of salt water surface-3'0"

Temperature of Fresh Water - 69°F

Temperature of Salt Water - 70°F

Relative Density of Sea Water - 1.03

Time p.m.	2.22	2.37	2.45	2.54	3.00
Depth of Red/Blue Float measured from surface	-	1-3/8	1-3/4	-	2-1/8"
Time of travel of Black Float at surface - seconds. Length of travel 3'-0"	135½	-	138½	-	132½
Mean Velocity of Float feet per second	0.0221	-	0.0216	-	0.0226

Refer Plate II

négatisé 4/1798

PLATE II

TEST No. 2. Time of Run – 30 minutes

Surface Velocity – 0·02 feet per second

Float Identification

CREAM
BLUE
1·0175

RED
BLACK
1·0075

RED
1·0100

RED
BLUE
1·0225

BLACK
CREAM
1·0200

BLACK
1·0000

CREAM
1·0050

BLUE
BLACK
1·0125

BLUE
1·025

BLACK
RED
CREAM
1·0300

Test No. 3 Result

Description of Test

The third of a series of four to determine the behaviour of a surface flow of fresh water passing over a layer of salt water bounded by vertical baffles normal to the direction of motion of the fresh water stream. The surface flow was turbulent.

Date of Test - 6th April 1960

Initial Depth of Salt Water - 12.3 inches.

Depth of Fresh Water over top edge of vertical baffle - 0.80 inches.

Length of Salt Water surface - 3' 0".

Temperature of Salt Water - 70°F.

Relative Density of Sea Water - 1.03.

ime p.m.	3-22½	3-25	3-29	3-39	3-52	4-07	4-23	4-4(
epth of Red-lue Float easured from urface inches	Nil	3	3-1/4	3	4	4	4-7/8"	5"
ime of Travel f Black Float at surface-secs Length of travel 3'-0"	(13½ (17 (14 (18 (15½ (18	(16.6 (16.8				(15.5 (16.5	14.0	(16.5 (16.2
Mean of times of travel	16.1	16.7				16.0	14.0	16.4
Mean velocity of Float	0.186	0.180				0.187	0.228	0.183

Photograph taken at 4.25 p.m. Floats photographed cream, red, red/blue

Note: Position of red/blue float gives approximate position of interface

Refer Plate III

Negative V/ 1798

PLATE III

TEST No. 3. Time of Run — 1 Hour

Surface velocity — 0·19 feet per second

NOTE — Stagnant Dye Pattern in Salt Water below Interface

Float Identification

CREAM
1·0050

RED
1·0100

RED
BLUE
1·0225

Test No. 4

Description of Test

The fourth test of a series of four to determine the behaviour of a surface flow of fresh water passing over a layer of salt water. In this instance the fresh water was introduced on a sloping plane sloped at $4\frac{1}{2}$ horizontal to one vertical.

Date of Test – 12th April 1960.

Initial Depth of Salt Water – 3.6 inches
Length of Salt Water surface – 17'.8"
Temperature of Fresh Water – 70°F
Temperature of Salt Water – 70°F
Relative Density of Sea Water – 1.03
Total Depth of Flow – 3.9 inches.

Time p.m.	3–46	3–49	3–51	3–56	3–59
Depth of Red float Blue measured from surface	–	7/8"	1" water in 2 layers as density current reflects from outlet point	2"	3-5/8 (Float on bottom of channel)
Time of travel of Black Float at surface in seconds length of travel 3'0"	29	29.3	–	–	–
Mean velocity of float feet per sec.	0.103	0.102	–	–	–

Test No.5

Description of Test

A test to observe the behaviour of a flow of sea water beneath a layer of fresh water. The fresh water was contained in a flume 17'8" long and the salt water was introduced down a sloping board sloped at 4½ horizontal to one vertical.

Date of Test - 13th April 1960.

Initial Depth of fresh water 3.6 inches
Specific Gravity of sea water = 1.03
Temperature of Salt water 70° F
Temperature of Fresh Water 69°F

Time of commencement of test - 2.10 p.m.
Time of cessation of salt flow - 2.25 p.m.
Time of measurement of density distribution - 2.35 p.m.

Behaviour of Salt Stream

The salt stream after passing the initial disturbance at entry formed a front of depth 2½" approx. which progressed to the weir displacing fresh water ahead of it and over the weir. The front was then reflected at the weir and salt water commenced to discharge over the weir and the fresh flow appeared trapped behind the return wave but appeared to form a thin wedge tapering to an indecipherable depth over the advancing salt front.

Density measurements taken at 2.35 p.m. showed the following distribution.

Depth from Surface inches	Mean Relative Density	
3.6	1.025	
2.0	1.0225	(overall mean RD 1.022)
1.12	1.020	
0.00	1.0175	