ENVIRONMENTAL MANAGEMENT

RICE GROWING CONTROLS

(A DISCUSSION PAPER)

October, 1988

RESOURCE ASSESSMENT GROUP

MURRUMBIDGEE REGION

Water Resources

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FOREWORD

This discussion report was collated by the author following the initiation of a review of rice administration procedures within the Department of Water Resources. It was decided that it was necessary to re-examine the need for administrative controls on rice growing. The reasons are to do with factors in the irrigated environment. This report is a technical review of these factors, the studies that have been carried out over the last 20 years into the relationship between these factors and the various types of administrative controls that may be adopted. The report should stimulate discussion about the subject.

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ENVIRONMENTAL MANAGEMENT - RICE GROWING CONTROLS

CONTENTS

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1. INTRODUCTION.

Rice growing practices involve the ponding of water for considerable periods of time. Where the soil is not completely impermeable, and this is usually the case, some water may percolate to a groundwater body. As a consequence pressure levels may rise, watertables may approach the surface and problems of waterlogging and salinity may develop, particularly where salts from the soil have become dissolved in the groundwater. The growing of rice therefore can have undesirable environmental consequences.

The consequences vary depending on the properties of the soil on which rice is grown and also on the underlying hydrogeological conditions. Whilst the principles of groundwater movement and the salinisation processes are now reasonably well understood, variations in the critical factors operating in the system have to date prevented the adoption of effective measures to manage the environment.

The perceived environmental consequences of rice growing have resulted over the years in a series of strategies to restrict rice growing to so-called suitable land. As time passed, each of these strategies proved to have problems in their application.

The Department of Water Resources, (1988) recognises seven key performance areas, to do with:

1. Serving the Government and customers.
2. Sharing water amongst users.
3. Supplying water.
4. Managing the environment and the catchment areas.
5. Water quality.
6. Organisational efficiency.
7. Managing assets.

Key Performance Area 4.2 states:

"Promote the integrated management of the natural resources within catchment areas".

The water supply for rice irrigation (k.p.a.3) is clearly linked with the responsibility to ensure that minimal harm will occur to natural resources such as land and vegetation (k.p.a.4). Rice growing control policies thus accord with this responsibility.

This document reviews the possible environmental consequences of rice growing, the objectives of rice growing control policies, and the possible mechanisms by which such policies might be implemented. The actual administrative procedures used are not discussed, as they can be finalised following agreement on the principles underlying the controls.

2. OBJECTIVES OF RICE GROWING CONTROLS.

If a direct link between rice growing and the environmental consequences could be established then policy objectives would aim to minimise the effects or eliminate them altogether. In an agricultural environment a trade-off may be desirable between maximised rice production on the one hand and minimised damage to the environment on the other. The question arises where the line should be drawn. The answer will require a fairly accurate prediction of the consequences of various intensities of rice growing or other sources of groundwater accessions.

Evidence is necessary regarding the link between rice growing and undesirable consequences. Land salting may occur also under other forms of irrigated agriculture, so the assessment should be in terms of additional impact rather than the total impact.

Where land salinisation and waterlogging develop the effects might be to reduce the potential yields of crops other than rice on the same farm; the potential yield of the rice crop itself might be affected, land on another farm might be affected, as might be the natural environment of a region, or in the long term, the community of the region as a whole.

The percolation process in some areas may create groundwater mounds which by lateral transfer through deep underlying aquifer systems might increase pressure levels in the rest of the Riverine Plain and in the Mallee country to the west. Potentially this could result in salt accumulation over thousands of square kilometres over time, the re-activation of evaporative depressions and gypsum swamps in the Western Division of New South Wales and potentially increased groundwater and salt discharges to the Murray River system [1]. Prevention of the build-up of groundwater mounds therefore could be environmentally advantageous, the alternatives being relatively expensive groundwater pumping schemes (where possible) to intercept the groundwater flow, or continued degradation of the system.

It is suggested that the following policy objectives are appropriate for a control system that will allow irrigation to remain viable in the long term without causing severe environmental impacts:

OBJECTIVE 1: TO MINIMISE OR ELIMINATE THE IMPACT OF RICE GROWING IN TERMS OF SALINITY AND WATERLOGGING.

OBJECTIVE 2: TO MAINTAIN VIABLE CROP PRODUCTION OF A RANGE OF IRRIGATED CROPS, INCLUDING RICE, ON AS LARGE A PROPORTION OF THE LANDSCAPE AS POSSIBLE.

OBJECTIVE 3: TO MAINTAIN CONDITIONS NECESSARY FOR THE NATURAL ENVIRONMENT WITHIN THE IRRIGATION AREAS TO BE IN A HEALTHY STATE.

OBJECTIVE 4: TO MINIMISE THE LONG TERM CONSEQUENCES ON THE COMMUNITY AS A WHOLE.

OBJECTIVE 5: TO PREVENT, IF FEASIBLE, EXCESSIVE LATERAL GROUNDWATER MOVEMENT TO DISCHARGE AREAS IN THE WESTERN PARTS IN THE RIVERINE PLAIN AND THE MALLEE.

3. FACTORS INFLUENCING THE EFFECT OF RICE GROWING ON THE ENVIRONMENT.

3.1 PHYSICAL FACTORS.

3.1.1. Topography.

Elevation is an indicator of the relative hazard of salting processes. Depressed sites are likely to become waterlogged and saline, while elevated areas are likely to be intake areas for groundwater accessions.

3.1.2. Soil Permeability.

The permeability of soils affects percolation rates. Soil permeability is a function of soil type, soil texture, relative compaction, the chemistry of the soil and the salinity of the percolating water. Different horizons in the soil have different permeabilities. The B-horizons of some duplex floodplain clay soils have the lowest permeability, in the order of a fraction of a millimetre per day. Sandy soils and self-mulching cracking clays have higher permeability, up to several centimetres per day for soils on which rice has been grown in the past [2].

Soil permeability also affects lateral groundwater movement through shallow soil horizons to adjacent land. The resulting seepage may cause salting adjacent to the ponded area. This is often found in the non-sand bed areas of the Murrumbidgee Irrigation Areas, and the Benerembah and Wah Wah Irrigation Districts.

3.1.3. Soil Texture.

In the Riverine Plain, soils of heavy texture are usually of low permeability, soils in most areas usually being sodic with dispersive properties. There are exceptions however. The horticultural soils around Griffith and Leeton have a property called sub-plasticity, which causes the soil to be more permeable [3]. Further, self-mulching cracking clay soils are non-sodic and are less dispersive, the reason being that calcium is the predominant cation on the clay complex.

Reliance on a policy which assumes a linear relationship between soil texture and permeability therefore is valid for many parts of the Riverine Plain, particularly the Southern Riverina Districts, but does not always produce good results in the other areas. This was experienced in the northern part of the Coleambally Irrigation Area where self-mulching clays occur.

3.1.4. Transmissivity.

The transmissivity of an underlying aquifer, where present, is an important factor in the rate of groundwater movement away from sources of accessions. The actual rate of movement is a direct function of transmissivity and hydraulic gradient.

The transmissivity is determined from pump testing or assessment from bore log information. It represents the transmissive properties (hydraulic conductivity times thickness) of an aquifer. There are several aquifers in the depositional sequence of the Riverine Plain, separated by strata of low permeability (aquitards) which allow slow leakage between aquifers.

3.1.5. Hydraulic Gradient.

The hydraulic gradient induced in the uppermost aquifer by percolation from a rice field may cause lateral flow to an adjacent field or to a deeper aquifer. Alternatively, a gradient may exist to a depression or creek line, where groundwater discharge in the form of evaporation could take place, causing salting. Or the gradient may be related to the general slope in the landscape, such as the gradient from east to west of about 0.4 m/km in the eastern parts of the Riverine Plain.

Where deeper aquifers are of high transmissivity they may dissipate percolating groundwater at a relatively high rate to western parts of the Plain. The result will be downward movement from shallow to deep aquifers in the eastern part of the plain (Coleambally, Berriquin, the Murrumbidgee Irrigation Areas) and upward movement from deep to shallow aquifers in the west (Balranald, Wakool, Kerang).

Where rice is grown and watertables are well down, the percolation rate is nearly the same as the hydraulic conductivity of the soil. The hydraulic gradient is near unity. When the watertables approach the surface the hydraulic gradient becomes the ratio of depth to watertable divided by the thickness of the restrictive layer. The percolation rate then drops to only a small fraction of the value applying for deep watertables.

3.1.6. Irrigation Water Salinity.

Where the irrigation water is of low salinity the naturally sodic soils of the Riverine Plain tend to disperse, creating low values for the hydraulic conductivity of the surface soil and B-horizon. Percolation rates are often less than 1 mm/day. However, when the salinity of the irrigation water is higher, this process does not occur and the hydraulic conductivity may actually increase, increasing the percolation rate.

Experiments at Whitton have demonstrated that the permeability of the soil may increase 3-5 fold to about 5 mm/day when water of salinity of 2-3 ds/m is used for rice growing [4]. As a result of this high percolation rate, salts from the irrigation water did not built up in the soil and the yield of rice was not affected by the higher irrigation water salinity.

3.1.7 Capillary Rise.

Capillary rise occurs when the watertable is sufficiently close to the surface, which in effect means less than 2 metres depth. It is one of the mechanisms by which groundwater accessions eventually dissipate, the other two being water uptake by the roots of vegetation, and groundwater seepage to depressions and natural streams. The rate of capillary rise increases as the watertable approaches the surface. An equilibrium is likely to develop between accessions in the recharge area and capillary rise in the discharge area (and hence the depth to the watertable).

Capillary rise involves the transport of salts from the groundwater to the rootzone and, if conditions are suitable, to the soil surface. Variations in capillary rise may cause uneven patterns of soil salinity (patchy salting). To avoid excessive rates of soil salting the capillary rise should be kept low, which in effect means that the groundwater accessions should be controlled.

More detailed discussion on capillary rise is included in Section 4.3.

3.1.8. Other Factors.

Other factors affecting percolation from rice fields are the bulk density of the soil, which may be affected by compaction; hard pans such as calcrete or silicrete; and cemented layers. Each of these can affect one or more of the factors mentioned previously, but they are not important on a large scale and are not discussed in detail.

The presence of natural vegetation in discharge areas helps keep the watertable down, thereby reducing the amount of capillary rise and salt accumulation near the soil surface.

Climatic factors such as rainfall and evaporation affect groundwater accessions and watertable levels in the non rice areas.

3.2 MANAGEMENT FACTORS.

3.2.1. Regional

Proportion of Land Under Rice.

As the proportion of land sown to rice increases the potential area from which percolation can occur increases proportionally. When in the 1970's the allowable rice area per farm was increased from 24 ha to 79 ha in the Coleambally Irrigation Area, the rate of watertable rise increased about three fold, as evidenced by long term hydrographs of piezometers [5].

The proportion of land under rice reflects the type of irrigated agriculture and the intensity of water application overall. A higher proportion in the Riverine Plain Districts usually means larger water availability (allocation) and the growing of fewer alternative crops such as wheat,pastures and summer crops.

Since rice has been and is one of the easier and more profitable crops to grow, the cost/price squeeze in agriculture induces the tendency to continually increase the areas of rice. Over the last 30 years there has been a gradual increase in the water diverted to individual farms, and in the overall water application rate (in ML/ha). Most of the increased water consumption has been for rice growing.

The term "hydraulic loading" is used to describe the rate of water application per unit area. The higher the loading the higher are the potential accessions, whilst at the same time the area in which these accessions can dissipate decreases. The result is higher watertable levels overall.

Land Classification Systems.

If rice growing is restricted to the least permeable parts of the floodplain the potential amount of groundwater accessions may be reduced, hopefully to acceptable levels. This has been the basis for most of the land classification systems used to date.

Rice growing on more elevated parts of the landscape will result in higher hydraulic gradients and hence, for the same soil properties , the rate of lateral flow will be higher for these situations. Rice growing classifications should include aspects of elevation.

Rice land classification systems should incorporate as many as possible of the factors that affect rice percolation and groundwater movement to environmentally sensitive area. A questionnaire to allow systematic examination of a particular case is discussed in detail in Section 6.4.

3.2.2. On-Farm Management Factors.

Rotations of Rice with Other Irrigated Crops.

If there is no percolation from rice fields, the effect of dissipation of groundwater accessions in other land does not have to be considered. If there is percolation then theoretically the area under rice experiences leaching and parts of other land salt accumulation.

If rice is grown in rotation with other crops then the groundwater movement may be partially reversed. Land which was previously subject to salt accumulation may now experience leaching and vice versa.

However, due to the gradients in the landscape the above principle can never be fully effective. If the rotation was completely systematic then a net salt accumulation over time would still be expected in the lower parts of the landscape, because the salt accumulation process in a non-rice growing year will be greater than the leaching process in the rice growing year.

Maximum Rice Area.

A landholder may reduce his rice area and thereby reduce accessions (assuming he has land in an area where percolation would be expected). This would probably have the effect of lowering watertables on his farm, enabling other irrigated cropping to be practised with a reduced hazard of waterlogging.

Unfortunately, aquifer systems have little regard for fences and if adjacent landholders do not respond by also reducing their rice areas then the farm with less rice is likely to become the discharge area for the higher intensity rice farms. Although average watertable levels may be deeper, the salinity risk may have increased.

Reduction of rice areas in areas where percolation is a potential problem should be a community-adopted policy rather than an individual decision.

Perimeter Reduction.

The volume of seepage from rice fields is related to the perimeter of the fields. Hence it is advantageous from the viewpoint of reducing seepage to grow all the rice of a farm in one block, and also to join up with the rice lands on adjacent farms. Many farmers in the Griffith area are already adopting this practice.

Landforming and Soil Amelioration.

Where landforming cuts are deep the least permeable part of the upper B-horizon is often removed and hence the average hydraulic conductivity of the profile increased. Percolation may increase as a result.

Similar arguments apply for deep ripping, deep ripping with gypsum, broadly spread gypsum applications and the so called slotting plus gypsum techniques. All methods to improve the subsoil conditions may also result in increased percolation rates.

No information is at hand as to whether the practice of stubble incorporation results in increased permeability of the subsoil.

Recirculation and Drainage

Drainage recirculation in Irrigation Districts without surface drainage schemes reduces the groundwater accessions from those areas where water would otherwise accumulate. As such it reduces the combined impact of percolation from rice lands and drainage depressions.

Water from Bores.

Although not legal at present there is potential to use water from bores for rice growing. These bores include spearpoints such as are used in the Berriquin Irrigation District and the deep production bores in the Darlington Point Area.

The salinity of water from bores is usually higher than river water, although still quite suitable for irrigation. Under ponded conditions however, it has been found that the percolation rate may increase. It has been estimated that the rice water consumption may increase by 2 ML/ha for every 0.5 dS/m that the salinity increases, although on a longer term basis the increase could be less as bicarbonates in the water may have a dispersive effect on the soil [6].

Trees, Vegetation and Swamps.

The planting of trees, maintenance of vegetative cover rather than clean cultivation, and maintaining the natural vegetation in swamps in a healthy condition, all have a potential ameliorating effect where a salinity hazard exists. These are not directly related to rice growing but rather to management of the environmental consequences that may follow from rice growing.

3.3 RECLAMATION.

If land reclamation measures such as tubewell drainage and tile drainage could be adopted wherever needed, the undesirable environmental effects of unrestricted rice growing could be counter-balanced. It then becomes a matter of economics whether the costs of the reclamation measures exceed the benefits gained by increased rice growing.

Unfortunately the disposal of effluent is not feasible in many situations, the groundwater salinity being usually high and safe disposal sites not being readily available. The reclamation option adopted for the Wakool/Tullakool District is not likely to be repeated elsewhere until current problems have been overcome and the economics of the scheme have been proven to be sound.

Where land is salt affected and subsurface drainage is implemented, the hydraulic gradient for downward percolation increases leaching increases and soil salinity decreases. The water consumption of rice in this situation would increase by a small proportion, say 1-2 ML/ha.

4. ASSESSING GROUNDWATER MOVEMENT - OVERVIEW OF STUDIES.

4.1 PERCOLATION.

Percolation studies were carried out in the period 1970 to 1976 using infiltrometer rings in at least 100 locations in rice fields, covering the main soil categories occurring in the MIA. The resulting percolation rates varied between 30mm to 2000 mm over a rice season as shown in Figure 1 [7]. Differences between the main soil categories were found, the main unexpected feature being the high rate of percolation in many of the self-mulching, cracking clay soils.

Attempts were made also to assess percolation rates on four farms over two years using inflow/outflow measurements of individual rice fields. It was found however that the accuracy was insufficient for meaningful conclusions, especially where percolation rates were low. Nevertheless, these investigations gave good data on the rate of evapotranspiration, which were subsequently used to assess percolation on an area basis [8].

Management factors affect rice water consumption, but over many years and many farms these factors balance out. Comparisons with areas where percolation is known to be low, such as the North Murrami, Bilbul, Widgelli and Yenda districts indicate where deep percolation may be excessive. Analyses of 9 years of data for the Coleambally Irrigation Area resulted in Figure 2 and indicated that up to 96000 ML of percolation occurred in this Area during the late 1970's. This was about 20% of all water diverted to the Area and represents about 4 ML/ha on average for all the rice lands [9].

In areas with shallow watertables the percolation is only a fraction of the rates recorded in deep watertable areas (usually less than 1 ML/ha of rice). Many parts of the sandbed areas in the Yanco and Mirrool Irrigation Areas during the 1940s and 1950s recorded rice water consumptions as high or higher than are now recorded in the Coleambally Irrigation Area, but consumption has dropped because shallow watertables have developed.

The fact that previously the rice water consumption was high indicates that the soil is relatively permeable, with percolation being reduced because of the shallower hydraulic gradients.

The question arises whether rice growing has a specific impact on the westerly movement of groundwater through the Calivil and Renmark Formations. The evidence is that restrictive layers occur between the surface aquifer of the Shepparton Formation and the Calivil Formation, usually to 60 m depth. These restrictive layers "throttle" the downward movement. In Coleambally the volume of accessions to the shallowest aquifer during the late 1970s was estimated to be almost 100,000 ML/year, but only about 40,000 ML/year of this appears to have reached the Calivil Aquifer [10]. If other crops than rice were used a similar result might have been expected, provided the recharge to the shallowest aquifer was above 40,000 ML.

When the percolation to deeper aquifers is "throttled" the total volume of percolation becomes a function of the total area irrigated rather than the area of rice, assuming reasonably high irrigation applications and hence accessions from alternative crops. The real impact of alternative irrigation practices cannot be assessed without detailed studies, but it appears unrealistic to attribute all deep percolation to rice growing. When only the additional impact of rice is considered, rather than the absolute impact, then the conclusion may be that rice growing has only limited impact on the deep aquifer environment.

4.2 LATERAL FLOW.

Although direct measurement of lateral flow in high watertable situations is possible using tracer techniques, it is more practical to use pump tests to assess transmissivity and piezometer readings to determine the hydraulic gradient. The effect of ponding on land can then be assessed using analytical models.

A typical cross section used for analytical assessment is shown in Figure 4. The equations are discussed in Reference 11. The main factors are the resistance to vertical flow through the clay layer, which is the inverse of the hydraulic conductivity multiplied by its thickness, the transmissivity of the aquifer and the hydraulic gradient.

Knowing the lateral flow component in a given situation is helpful in assessing salt transport and the volumes of groundwater that are transferred to the areas between rice fields for dissipation by capillary rise and evaporation. The actual field data of rice areas, watertable measurements and soil and stratigraphical conditions can be used to assess how these factors inter-relate to get a feel for the environmental risk in the landscape. Sections 4.7 and 4.8 contain further discussion of this topic.

4.3 CAPILLARY RISE.

The rate of capillary rise above the watertable is a function of soil pore size, watertable depth and the soil moisture potential gradient. As the topsoil dries out the gradient increases but since the unsaturated hydraulic conductivity below a certain moisture level drops faster than the increase in hydraulic gradient the capillary rise becomes less for very dry soil, just as it is very low for a wet soil without a soil moisture potential gradient.

Figure 3 shows two curves of capillary rise, both of which represent a maximum rate for a certain soil type. These maximum rates are reduced according to the soil moisture conditions as also shown on Figure 3.

It is evident that the capillary rise is much greater under shallow watertable conditions than under deep watertable conditions. The soil salting hazard is increased accordingly.

With increased rice areas watertable levels rise until a new equilibrium becomes established in which the increased accessions to the watertable due to seepage are balanced by increased losses due to capillary rise in the non-rise areas. From Figure 3 and other work, it is concluded that, for most Riverine Plains soils, the depth of the watertable at which safe salinity levels are maintained is about 1.2m.

Investigations at the C.S.I.R.O. Griffith have shown that, for non-self-mulching clay soils, rates of capillary rise varied between 0.1 and 1.0 mm/day, whilst for self- mulching clay soils rates of up to 3 mm/day were recorded with a watertable at 0.6 m depth [13].

4.4 LEACHING MOVEMENT.

Before rice is sown for the first time the soil profile usually contains quite high levels of salt throughout the profile. Irrigation of crops such as pastures and wheat tend to leach these salt gradually, but with rice the leaching is usually more dramatic, as evidenced by soil salinity sampling.

The results of soil salinity sampling, before and after a rice season, were combined with infiltration measurements and measurements of other factors such as bulk density and the salinity of the water in the rice bay, to develop a numerical model of percolation. This work for soils in the Wah Wah Irrigation District allowed simulation of leaching over the 120 days of ponding. Percolation rates of 0.5 - 5 mm/day were indicated in various leaching situations [14].

Other work at Whitton confirmed increasing percolation and leaching of salts where the salinity of the applied water was increased.

In some environments leaching is very small or only temporary e.g. in the non sandbed areas where there are no aquifers.

4.5 THE EFFECTS OF WATER SALINITY.

This matter has been addressed in Sections 3.1.6. and 4.4. For reference to investigations on this aspect in rice situations see sections 3.1.6. and 3.2.2.

The effects of water salinity on permeability and leaching in pasture soils have been investigated at the Tatura and Kyabram Research Institutes in Victoria (e.g. Mehanni and Rengasami).

4.6 PERCOLATION UNDER OTHER CROPS.

If is often alleged that percolation from irrigated crops other than rice may cause accessions to the groundwater system of a similar magnitute to those from ricefields. This is only true where these crops are grown on sandy, permeable soils under flood irrigation, e.g. the irrigated dairy pastures on the prior stream soils of the Berriquin Irrigation District. There is no evidence to suggest that it applies for other crops on floodplain clay soils.

Annual pastures are irrigated in spring and autumn. Following the autumn wetting of the profile by irrigation, winter rainfall may then create ponding in parts of the landscape, resulting in accessions to the watertable. Particularly wet years such as 1973/74 cause significant accessions which show up in watertable hydrographs. During many other years the accessions are much lower. In Victoria accessions are estimated to be in the order of 100 mm/year for prior stream soils and 30 mm/year for floodplain clay soils.

Wheat allows only very limited accessions. Where the watertable is high and non-saline, the wheat plants may actually lower the watertable or increase the rate of upward movement [15] to the root zone. In the peak growing season (September/October) the water supply to the plant tends to be too low, resulting in desiccation of the subsoil. On the other hand, during the pre-watering irrigation and also early winter, a small amount of percolation is possible depending on the soil and rainfall conditions.

Vegetable crops and other furrow irrigated summer crops may allow some percolation if irrigated frequently. Ponded conditions, however, occur only over a small proportion of the surface area and for only limited periods. Redistribution of soil moisture after irrigation may also cause some percolation. This would be less for crops which develop deep rooting systems such as sunflower, safflower and sorghum, and more so for vegetable crops and soybeans. Overall the percolation per unit area would be substantially less than for rice.

4.7 WATERTABLE/RICE RELATIONSHIPS.

The relationship between rice growing and watertable depth in a shallow watertable area depends on all the factors discussed in Section 3 as well as climatic data.

An area of 1100ha to the south-west of Hanwood was selected as a representative rice growing area to develop these type of relationships, and particularly to investigate the effects of a greater than normal proportion of the landscape under rice [16].

Pressure levels over 13 years were analysed to calculate averages for March and September for each of 40 piezometers in the area. As would be expected these averages were found to be topography-dependent, with piezometers in low-lying areas registering shallower levels.

Subsequently photographs taken in the three years 1966/67, 1974/75 and 1979/80 were analysed to obtain information on: the distances from the piezometers to rice fields, areas of rice, and perimeters of rice fields. Levels in piezometers in March and September, transmissivity of aquifer, resistance to vertical flow through superficial layers, and monthly rainfall prior to piezometer readings were also determined. All this information was statistically analysed and interpreted using the principles of the lateral flow models discussed in Section 4.2.

The data generally fitted the analytical models in that watertable depths increased with distance from rice fields. Although significant variability of watertable depth with distance was found, due to variations in topography, transmissivity etc., nevertheless the relationship was significant. Comparison between September and March readings for the study area indicated that over summer (the rice season) the water level generally rises within 300 m from a rice field but drops at greater distances. Apparently the seepage from rice beyond 300 m is less than the groundwater discharge in terms of capillary rise and evaporation.

During 1966/67 17% of the land was under rice, during 1974/78 24% and during 1979/80 it was 36%. The consequent rise in the overall watertable level is shown by Table 1.

Table 1. Water Table Distribution in Hanwood Area.

	36% rice %	24% rice %	17% rice %
March			
Within 1 m	48	38	20
Within 0.8 m	31	25	10
Within 0.6 m	20	15	5
September			
Within 1 m	34	15.6	6.4
Within 0.8 m	22	7.2	2.8
Within 0.6 m	12	3.2	1.1

In September the watertable level at any point is a function of winter rainfall, the proportion of land under rice during the previous season, and topographical factors. Thus it is possible to calculate the proportion of land under rice which would effectively give an average watertable depth in September of 1.2 m. For the Hanwood area this proportion was found to be 28%.

To achieve a 1.2 m watertable depth in March requires a lower proportion than 28%. The 1.2 m criterion was adopted not because it is considered a safe level but because capillary rise from this depth is usually low (Section 4.3). In such a situation soil salt accumulation becomes more manageable and the risk of waterlogging of other crops is also reduced.

The proportion will be different in other areas depending on the governing factors, but they have not yet been determined.

4.8 GROUNDWATER MODELS.

Groundwater models can be developed to analyse the impact of ponding on the groundwater regime and on salinity transport from some parts of farms to other parts. All factors discussed in Section 3 are incorporated in the process. The principle is to divide the area under consideration into a grid of cells of suitable dimensions. For instance a 500 m by 500 m grid gives 25 ha cells which are often small enough to represent individual paddocks, although finer details such as small depressions would not be represented.

Groundwater flow between cells is the main component modelled, with transmissivity and hydraulic gradients the main governing factors. The hydraulic gradient is a function of the watertable depth in each cell during each time step. Other components can also be introduced, including channel seepage, percolation from other crops, tubewell drainage (if any), deep aquifer leakage and capillary rise. Each can be introduced as routines affecting watertable height of the end of each time step.

In shallow watertable areas the percolation and capillary rise components tend to be larger than the groundwater flow component, meaning that suitable routines need to be developed capable of predicting these factors accurately. Such work is presently still subject to experimental verification by special research projects.

Once a model has been developed and suitable input data exist, it should be possible to predict rates of capillary rise and percolation over long periods. The difference between capillary rise and percolation is a measure of the potential risk of soil salting. A preliminary such model of a test area of 2000 ha gave good results when compared with actual salinity data, being statistically significant at the 1% level. Following calibrations of this kind the models can be used to predict the effects of different levels of rice growing and the resulting risk to the landscape in terms of the proportion of land that may become salt-affected in the long term in the absence of, or with only limited, tubewell drainage. The above model development is being planned in conjunction with the CSIRO Division of Water Resources at Griffith.

5. RISK ASSESSMENT FOR VARIOUS RIVERINE PLAIN ENVIRONMENTS.

5.1 PRIOR STREAM ENVIRONMENTS.

In many instances prior stream soils are excluded from rice growing or are restricted to a rotation of once every two to four years. The objective has been to limit percolation.

With deep watertables the percolation rates are controlled by the permeability of the B-horizon. Experience has shown that often percolation rates on these soils are high (e.g. Yanco Irrigation Area during 1940s). In some areas the permeability of the B-horizon has been affected by sodicity (e.g. South Coleambally) and rice growing on a rotational basis has been allowed.

In some southern Riverina districts the classification of land in regard to suitability for rotational rice growing has been based on soil type, while in the northern areas soil borings have been required.

In most instances prior stream soils are at or slightly above the general plain level. Once the watertable rises to within 2 m, accessions from rice are substantially reduced.

Prior stream soils are likely to allow relatively rapid rates of capillary rise from a shallow watertable. To balance the salting process, therefore, there is a need to grow rice on a regular basis. The need for restrictions on rice growing based on soil profile interpretation is therefore of little importance and can be eliminated except on the sandiest parts of these environments.

It would be desirable to carry out salinity surveys using electromagnetic induction (EM) techniques to assist the planning of rice crop rotations in shallow watertable situations.

5.2 FLOODPLAIN AREAS UNDERLAIN BY SHALLOW AQUIFERS.

The soil profiles in these environments are often characterised by clay soils of medium to heavy texture gradually merging into light clays and loams several metres below the surface. These soils are underlain by aquifer systems 2-3 m thick starting at depths of 6-9 m. Not all the land surface is underlain by these sands, and transmissivity is subject to spatial variability as well. Where duplex transitional red brown earth soils occur the percolation rates are usually very low, whilst where self-mulching cracking clays occur they are often higher.

High percolation rates have occurred in many areas in this category in the past, with many having total rice water consumptions well in excess of 20 ML/ha for a season, 27 ML/ha being not uncommon. Examples include parts of Yanco and Mirrool I.A.s during the 1940s and 1950s. Once shallow watertable conditions developed rice water consumptions became much lower, usually 12-16 ML/ha. Rice water consumption in the Coleambally Irrigation Area is still high, but is diminishing in the central part where 20,000 ha of land now have shallow watertables.

5. RISK ASSESSMENT FOR VARIOUS RIVERINE PLAIN ENVIRONMENTS.

5.1 PRIOR STREAM ENVIRONMENTS.

In many instances prior stream soils are excluded from rice growing or are restricted to a rotation of once every two to four years. The objective has been to limit percolation.

With deep watertables the percolation rates are controlled by the permeability of the B-horizon. Experience has shown that often percolation rates on these soils are high (e.g. Yanco Irrigation Area during 1940s). In some areas the permeability of the B-horizon has been affected by sodicity (e.g. South Coleambally) and rice growing on a rotational basis has been allowed.

In some southern Riverina districts the classification of land in regard to suitability for rotational rice growing has been based on soil type, while in the northern areas soil borings have been required.

In most instances prior stream soils are at or slightly above the general plain level. Once the watertable rises to within 2 m, accessions from rice are substantially reduced.

Prior stream soils are likely to allow relatively rapid rates of capillary rise from a shallow watertable. To balance the salting process, therefore, there is a need to grow rice on a regular basis. The need for restrictions on rice growing based on soil profile interpretation is therefore of little importance and can be eliminated except on the sandiest parts of these environments.

It would be desirable to carry out salinity surveys using electromagnetic induction (EM) techniques to assist the planning of rice crop rotations in shallow watertable situations.

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5.4 TRANSITIONAL MALLEE ENVIRONMENTS.

The transitional Mallee environment in the Wah Wah Irrigation District is characterised by light to medium clays in the surface couple of metres, underlain by an old landscape of medium clays containing kaolin. The surface soils contain lime throughout and have permeability values higher than similar clays in the rest of the plain. At the interface of the surface and deeper layers gypsum bands are often found. The soils usually contain high levels of salt.

The same comments apply as for the soils described at the end of Section 5.3. Frequent flood irrigation or ponding is inadvisable, as it would hasten the salinity process. Thorough desiccation of the profile followed by rainfall or a light irrigation, and maintenance of a vegetative cover, are measures which can be adopted to try to keep the salts in the subsoil. Rice growing is suggested only once every four or more years.

In some transitional Mallee soils, however, fairly high rice water consumption rates have been observed (18-24 ML/ha). In such situations the risk of land salting is much reduced, and restrictions would need to be based on the principles applying to the soils described in section 5.2. Aquifer systems are common at 15-20 metres depth.

Soils adjacent to the transitional Mallee soil category are often of the self-mulching variety, and have a relatively high free lime content. High percolation rates have been found to occur in these soils in the Wah Wah Irrigation District.

5.5 DEPRESSIONS AND LOW LYING LAND.

Soils in this category are similar to those considered above but are more at risk environmentally than the rest of the landscape because low areas are often used as part of the on-farm drainage system, either temporarily or permanently. In most shallow watertable areas the natural vegetation dies or is seriously affected, the root system of Black Box trees (the most significant of the native species) usually being unable to adjust to the new conditions. In addition salt accumulation occurs, particularly where there are transmissive layers below the land surface.

Where depressions become salinised the decision is usually made to refrain from rice growing on them. Apart from yield depression due to soil salts, harvesting difficulties in waterlogged conditions are a serious problem, and the depressed lands are often abandoned in favour of better drained fields.

As the proportion of land under rice increases the average watertable level between rice fields becomes higher (Section 4.7) and the proportion of land that suffers problems increases. Thus other crops such as wheat or pastures would also suffer yield reduction.

At the present time the proportions of land at risk under various levels of "hydraulic loading" have not been accurately assessed. It may not be possible to do this precisely for every situation.

6. OPTIONS FOR RICE GROWING CONTROLS.

6.1 GENERAL

A Rice Review Working Group was set up during 1984 to review methods and procedures for rice growing controls to limit groundwater accessions. The Group's report suggested the combined use of soil criteria and target rice water consumption figures assessing rice land suitability [17].

The objectives of Section 2 aim at the environment as a whole, whilst the terms of reference of the Rice Review Working Group referred to specific criteria in order to delineate suitable and unsuitable lands. The various methods for control are discussed below bearing in mind the objectives of Section 2.

6.2 SOIL PROFILE INTERPRETATION.

Where deep watertable conditions exist the soil profile characteristics of the top 3-4 m determine the rate of percolation. Where a reasonable relationships exists between soil texture and permeability the interpretation of a soil profile is relatively easy and effective. This method was adopted widely and was believed to be satisfactory until it was found that self-mulching clay soils often have relatively high permeabilities, causing high rates of percolation. Land classification based on soil profile interpretation then became problematic.

The problem of interpretation mostly applies to the northern part of the Riverine Plain, the Murrumbidgee Region. In the southern Riverina districts the method adopted is still believed to be valid.

The discussions in Sections 4.2, 4.7 and 4.8 demonstrate that once watertables rise to high new equilibrium levels the use of soil profile interpretation as a sole method of land classification is incorrect. Aspects of hydraulic gradients, transmissivity of aquifers and the soil salinity status should also be considered. A questionnaire type of assessment of a given situation, taking into account all these parameters, is discussed in Section 6.4.

6.3 RICE WATER CONSUMPTION.

Rice water consumption was used in the past as an indicator of high percolation rates. The recommendations of the Rice Review Committee include the use of target consumption values as a means of identifying land which allows high groundwater accession rates. These targets are being reduced annually to meet a long term objective of 16 ML/ha for all areas except Coleambally, where 18 ML/ha will be allowed.

When landholders exceed the target in a given year they are interviewed by a local committee to establish reasons for the exceedance. If the reasons are acceptable no action is taken, but if the reasons indicate the likelihood of excessive percolation then all or part of the land is to be retired from rice growing. The procedure has been found to be unsatisfactory in many instances, mostly due to on-farm water management reasons or of incorrect recording of crop water use. Channel attendants rely on farmers for their information and do not check the destination of water on-farm. The information provided may be incorrect, by mistake or by deliberate action. The possibility therefore exists that the application of the target rule affects farmers inequitably.

As a result of this the members of the local committee, in making their recommendations, have to rely on other information, particularly soil profile information, to make up their minds. The system becomes no less subjective than using soil profile interpretation methods.

In shallow watertable areas rice water consumption is usually low so target setting does not help to detect areas where rice growing could cause environmental problems. Even low rates of percolation can pose a risk in this regard. For instance percolation of groundwater with a salinity of 10 dS/m at a rate of 1 ML/ha over an area of 80 ha represents 480 tonnes of salt which will be dissipated to the discharge areas.

The setting of rice water consumption targets is an unsuitable method to meet the objectives of environmental management in shallow watertable areas. It is necessary to take into account a variety of factors, as discussed below.

6.4 QUESTIONNAIRE TO ASSESS RELEVANT FACTORS.

Several years ago a questionnaire was devised which aimed at assessing in an integrated fashion all factors to do with the management of rice growing. The flow chart of questions is shown in Figure 5.

Question 1 enquires whether the assessment is for a shallow or deep watertable area. If the former, the method relies on soil profile interpretation for assessment (Question 2). If the latter is the case another range of questions (Question 3 to 7) may need to be answered.

Questions 2 and 3 are to ensure that the surface 3 m of soil is sufficiently impermeable. If it is not, then under deep watertable conditions (Question 2) the land may be unsuitable for rice growing or suitable for rotation only. Under shallow watertable conditions the land may still be suitable but this then depends on Questions 4-6.

In Question 4 the topographical conditions are considered. With relatively depressed land the watertable would tend to be shallower, the hydraulic gradient for percolation reduced and the risk of land salting greater. No restrictions need to be applied, even when the soil profile is relatively permeable. Relatively high land may not be suitable, unless it passed the permeability check (Q3). Land of average elevation needs to be considered further, in Questions 5-7.

Question 5 relates to the salinity of the most shallow groundwater. If high, the land has low leaching potential or it has suffered from salt accumulation in its recent history. Ponding of rice fields would be a suitable management strategy. If the groundwater salinity is low, leaching may have been high and more caution should be applied.

In Question 6 similar reasoning is applied to topsoil salinity. If the salinity is low the aquifer characteristics are evaluated (Question 7). In many typical situations it would be necessary to answer the fairly difficult Question 7, which actually assesses the anticipated seepage rate from a number of parameters.

The procedure is logical but fairly cumbersome, and is time consuming and relatively costly. It depends on the measurement or assessment of 6 factors (watertable depth, soil profile, elevation, groundwater salinity, soil salinity and transmissivity). The allocation of values to some of these requires special skills and experience. Nevertheless, it is not impossible and the procedure has been applied at Griffith and is being applied at Deniliquin for some marginal cases. It is difficult to quantify the environmental benefit relative to the effort expended. In the end a choice has to be made between an intensive evaluation of individual cases and a broad brush approach such as the imposition of rotations and maximum areas on certain categories of rice farms. (see Sections 6.4 to 6.6).

6.5 AREA CONTROLS.

Area controls could be implemented in two ways. For individual farms the area of rice could be fixed (e.g. 73 ha) or it could be expressed as a proportion of the landscape. From an environmental point of view the latter is more desirable. The fixed area alternative is mainly a convenient tool for administrative purposes or for reasons of equity. For many smaller farms the 73 ha limit may represent 40-50% of the farm, whilst in other areas it may be only about 20% of the farm.

When assessing risk as a function of the proportion of land under rice, a judgement is necessary regarding the level of rice growing at which the risk to the environment is acceptable. Results of investigations to date suggest it should be 25-30% in areas underlain by shallow aquifers and in saline areas with relatively permeable surface horizons. Prior stream environments should be subjected to only intermittent rice growing once shallow watertables develop, whilst rice should always be permitted in depressions when shallow watertable conditions exist no matter what the soil profile characteristics. No restrictions should apply to floodplain lands which are not underlain by aquifers.

Another issue is whether the area control should apply to all land, including sandhills and other areas where rice would not be allowed, or whether it should apply only to the part of the landscape on which rice is grown.

Area controls would limit the 'hydraulic loading' on the landscape and, if applied in association with a support service to help farmers plan their rotations, might provide a suitable option. By controlling the areas of rice in sensitive land categories the rate of accessions could be kept down, and the watertable levels in the non-rice areas could be kept at reasonable levels.

6.6 ROTATIONS

Rotational restrictions could take several forms. A strict rotation might be adopted (e.g. once in four years with a three year non rice rotation), or it could involve a requirement to grow rice in rotation in such a way that the environmental risk is minimised. The latter is preferred, although less easy to enforce.

To maintain the optimum salinity balance in the environment, it is necessary to grow rice on some parts of the landscape more or less often than on other parts. It is not feasible for an authority such as the Department of Water Resources to advise how such rotational policy should be applied. It can only be achieved through the use of education/publicity and the creation of public awareness since, where soils are permeable, the farmer needs to be aware that, by growing rice in parts of the farm only, he is putting at risk the other parts of his farm.

The above indicates that, although rotational guidelines exist, they cannot be implemented without the knowledge of several factors, such as on-farm watertable behaviour and land salinity. These issues may be the responsibility of the Department of Agriculture.

Where watertables are deep the objective of rotational policies is to ensure an even spread of percolation to the groundwater system. This approach is not necessarily appropriate once shallow watertables develop.

It is considered worthwhile and environmentally effective to monitor rice growing areas in the landscape as a whole, and sensitive parts in particular, to determine to what degree rotations are being adopted. This can be carried out using satellite imagery or aerial photography, whichever is considered more effective. Currently the use of aerial photographs is recommended, particularly since these are useful for other types of investigations within the Department of Water Resources, e.g. seepage investigations, detection of salt affected areas, EM surveys, land use issues, water allocation matters etc.

6.7 WATER PRICING/ALLOCATION.

For the last 15 years in New South Wales water has been charged for on a tiered system, in which effectively the unit price becomes less with increasing use. With this system there has been little incentive for farmers to consider alternative crops when the rice water consumption for a particular field has been high.

No suggestion is made that the price for water should increase overall, but obviously a single flat rate per ML would increase the incentive to reduce wastage. Other systems are also feasible, e.g. a flat rate and a fixed charge option. The main objective is to eliminate the idea that water is cheaper when used in larger quantities per hectare of rice.

The Rice Review Working Group in 1985 also considered the use of special allocations of water for rice, the rice allocation being part of the overall farm allocation. It was rejected because of the administrative difficulties involved.

7. OTHER CONSIDERATIONS

7.1 BUFFER AREAS

Since the early 1940s buffer area restrictions have been in force to protect horticultural plantings in the M.I.A.. Problems with potential seepage from rice fields which could raise the watertable on the horticultural farm were foreseen. A general policy of 100 m wide buffers including existing roads and channels was introduced and has been enforced since that time. Where a rice grower desired to reduce the width of the buffer area, this was allowed when the horticultural landholder gave written consent and the Department of Water Resources considered that soils were of sufficiently low permeability that no harmful effects would result. Recently it was decided that such consent could be given on a multiple year basis, or the Department could reduce the buffer width on application by the rice grower, considering permeability of the soils, the potential seepage flow and the degree of protection of the horticultural farm by tile drainage.

It has also been claimed that buffer areas are useful to avoid very high levels of humidity in the horticultural plantings, which are claimed to create conditions conducive to the development of fungi and diseases. The potentially harmful effects have not been investigated. There may also be positive effects of higher humidity in summer on crop growth and development.

7.2 AREAS INFLUENCED BY ARTIFICIAL DEEP DRAINAGE

Where salting or waterlogging occurs the installation of sub-surface drainage, usually by pumping from drainage bores or multiple well point systems, may be used to protect the land. The increased gradient for leaching may also result in excessive percolation where rice is grown close to the drainage installation. Excessive percolation where the land is already reclaimed is considered to be wasteful, from the viewpoint of both energy usage and water resources. In addition the additional drainage effluent needs to be disposed of, which may involve expensive schemes such as evaporation areas.

It is considered that, where there are drainage bores, particular attention should be given to avoid the above. Rice growing on certain categories of land within say 400 m of the installation may need to be prohibited. In marginal cases occasional rice growing might be allowed, with the option to switch off the pump for most of the period that the rice field is flooded. In reaching decisions of this nature use may be made of EM salinity surveys and/or other information.

Where pumping is from the Calivil or Renmark Formations the situation is somewhat different. The leakage from the shallowest aquifer to these deep formations is usually very slow, and would not exceed about 100 mm (1 ML/ha) over a fairly large area. Such a rate may be considered desirable to maintain a favourable salt balance in the shallow aquifers. It is suggested that no special rules other than possibly area restrictions should be applied.

7.3 GROUNDWATER USE FOR RICE GROWING.

Currently pumped groundwater may not be used to grow rice. However, there is discussion about whether this restriction should be lifted, groundwater apparently being fairly abundant and the perception being that there would be additional benefits in terms of drainage of shallow watertables.

An experimental deep bore scheme is in hand, with the effluent pumped into the irrigation supply system of the Coleambally Irrigation Area. This effluent will be used to grow rice.

Multiple well point systems in the Berriquin Irrigation District produce effluent not approved for rice growing. Drainage bore effluent in the Murrumbidgee Irrigation Areas is unsuitable for irrigation, but after mixing with other fresh drainage flows is reused in the Wah Wah Irrigation Area for irrigation, including rice.

Groundwater used for irrigation is usually more saline than the water from river diversion, by an increment of 0.3 - 1.0 dS/m. The investigations at Whitton by G. Beecher indicate that this higher salinity may increase the percolation rate from a rice field by as much as 2 ML/ha over a rice season. This would add to the cost of pumping if the rice water supply was derived from bores only.

The question arises whether tax rebates on fuel should be given if the water pumped will only generate a small return in produce for every ML pumped.

Generally there are no valid objections to the reuse of groundwater for rice growing purposes within irrigation areas as additional benefits in terms of drainage are possible. Outside the limits of the irrigation areas, however, much more care is needed, particularly where subsidies exist for the pumping costs of the groundwater.

7.4 SURFACE DRAINAGE VOLUMES FROM RICE GROWING AREAS.

Runoff from rice fields can be readily controlled when weather conditions are even with only small fluctuations in temperature. A small amount of rice drainage is sometimes desirable, to avoid salinity build up in the lower bays of the field. When the weather changes, however, the continual adjustment in demand can increase the amount of rice drainage and the channel system may more frequently have to escape flows.

The rice runoff rate following rainfall has been estimated from computer modelling studies and found to be sometimes more than the 5.5 ML/farm/day criterion used for surface drainage design in irrigation districts. Often this runoff can be absorbed in other fields on the farm, but with repeated rainfall the drainage system has to cope with most of the flow. In irrigation districts without drainage large areas may be inundated for lengthy periods, as in 1988.

The above is affected by factors such as the proportion of land under rice, the watertable conditions in the remainder of the irrigation areas, the moisture conditions and gradients in the landscape, the extent to which the irrigation supply system is coping with the demand, as well as the rainfall and evaporation.

In the Murrumbidgee Irrigation Areas all these factors are such that large volumes of drainage are likely. Rice areas are large, producing considerable runoff following heavy rain. The watertables are high and the soils above the watertable can absorb little moisture following rain. The channel is stressed to maximum capacity, reducing the efficiency of delivery of water and increasing escape flows. As a result the drainage flows towards Willow Dam and Barren Box Swamp are greater than would otherwise have been the case and problems with disposal of these large volumes occur.

Whether or not the rice areas should be limited to ease the problems with excessive volumes of drainage flow is a question which is beyond the scope of this report. The discussion mainly highlights the need to consider these issues when considering further increases to rice areas.

8. CHOICE OF CONTROL POLICIES

The Rice Review Committee in 1985 reviewed the existing restrictions at the time, examined criteria to assess rice land suitability, and formulated a programme to phase out rice growing on all unsuitable land, to commence in the 1985/86 season. It considered a methodology for identifying land on which rice growing is undesirable and how this should be organised.

The methodology adopted, a combination of soil profile interpretation and rice water consumption target setting, appeared to rely on the mistaken belief that once land was classified as either suitable or unsuitable, further monitoring would not be necessary.

This report highlights the proposition that, although some land may be classified as suitable and some as unsuitable (e.g. sandhills, or mallee soils), there are large tracts of land which are in a marginal category and in which rice growing is acceptable within certain restrictions based on environmental management principles. These include lands underlain by shallow aquifers and the transitional mallee soils.

The discussion has shown that reliance on either soil profile interpretation or rice water consumption has problems in terms of scientific application or administration, in that it only addresses those situations where downward percolation is significant. Where watertable levels are high the procedures used have less relevance.

It has also been shown that area controls are potentially of benefit in striking a balance between accessions and discharge from the groundwater system. This measure would be more effective if suitable rotations were adopted, with rice growing during most years on the heavy clay soils, but occasionally also on other parts of the landscape to leach some of the salts that may have accumulated in the soil. The problem is that while area controls can be applied easily, the rotational controls cannot, unless there is an understanding amongst the farming community that it is a worthwhile system. This means that education and awareness campaigns relating to the hydrogeological processes are necessary.

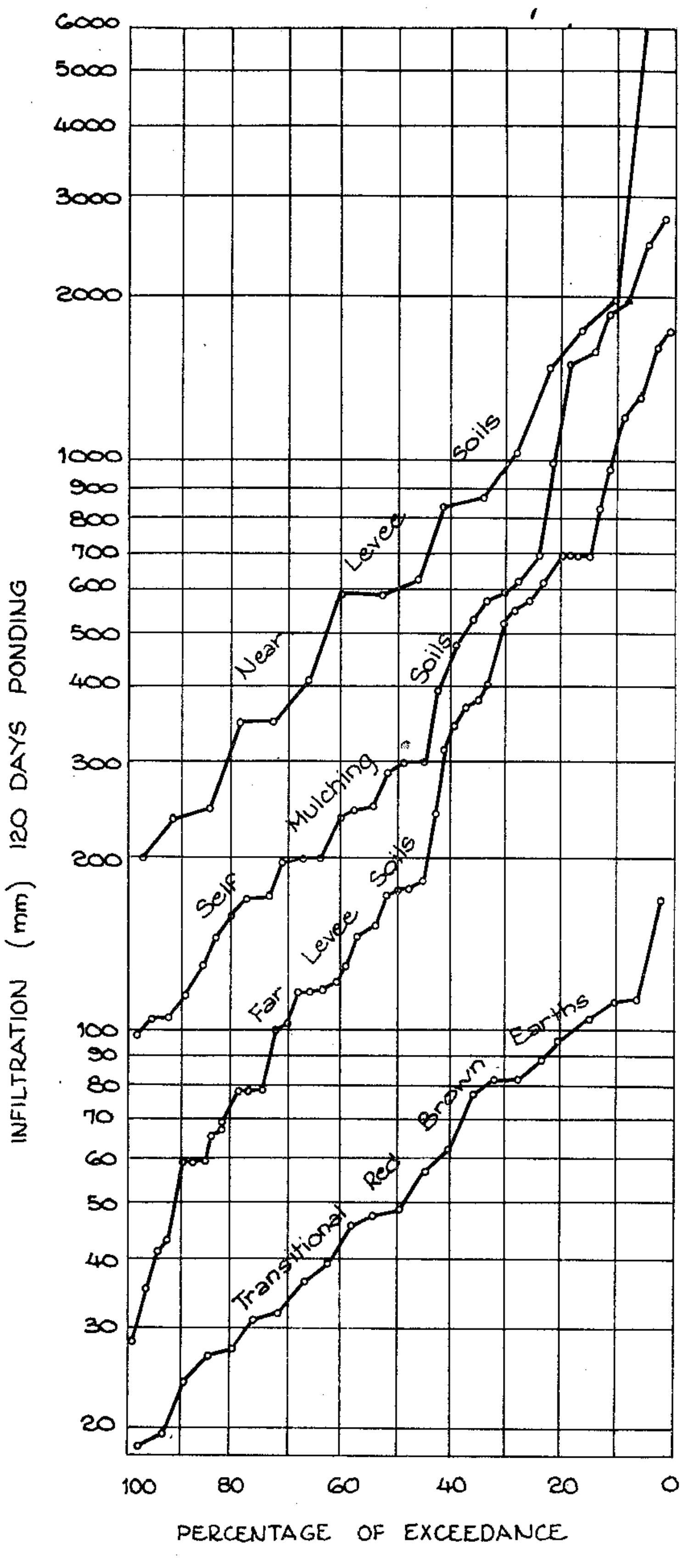
Water pricing has a role to play in helping to convince farmers that excessive rice water consumption is undesirable. It is a complementary factor, however, and not an effective measure by itself. The use of special rice allocations is not considered workable.

In shallow watertable areas the use of area controls offers the most promise, in that such controls have the potential to provide a reasonable degree of protection to the environment as well as being feasible administratively. This method should be backed by encouragement to apply rotations across the landscape. In deep watertable areas the current method of setting targets for rice water consumption backed up by the soil profile interpretation techniques should be continued (until shallow watertables develop).

One of the objectives of rice growing controls in the eastern part of the Riverine Plain is stated to be the protection of environments in the western part of the Plain. The discussion in Section 3.1.5 found that the risk is more a function of the total area under irrigation rather than the intensity of rice growing (hydraulic loading) in any part of the irrigation areas.

9. REFERENCES

1. W.R. Evans and J.R. Kellett, 1988. "Overview of the Hydrogeology of the Murray Basin." Proc. Murray Basin '88 Conf., Canberra, 1988 :p65-69.
2. A. van der Lelij, 1977. Infiltration and Water Movement in Riverina Plain soils used for rice farming. Proc. Conf Hydrogeology of Riverina Plain, Griffith, p 89 - 98.
3. J.K. Taylor and P.D. Hooper, 1938. A soil survey of the Horticultural soils in the M.I.A., N.S.W. Bulletin 289, CSIRO, revised edition by B.E. Butler, Melbourne 1979.
4. G. Beecher, 1988. Results of Rice Ponding Experiments on duplex Tr. Red Brown Earths. Report being prepared.
5. A. van der Lelij 1987 Groundwater Hydrology of the Coleambally Irrigation ARea". DWR report ISBN 7240.3740.3
6. G. Beecher 1988. Rice Growing Experiments at Whitton. Report being prepared.
7. A. van der Lelij, 1978 "Some aspects of Rice Field Hydrology - Irrigated Areas of NSW", Rice Research workshop, Yanco, 1978.
8. T. Talsma and A. van der Lelij, 1976 "Water Balance Estimates of Evaporation from ponded rice fields on a semi-arid region." Agric. Man. Vol. 1 No 1:p89-97.
9. A. van der lelij, "1987 Groundwater hydrology of the Coleambally Irrigation Area. DWR Report, ISBN 7240-3740.3
10. A. van der Lelij, 1987. "Groundwater Hydrology of the Coleambally Irrigation Area." DWR Report ISBN 7240 3740 3.
11. A. van der Lelij 1980 "Soil Salinity Hazard caused by lateral Groundwater Flow from rice fields to adjacent lands". Prac, Conf. Salinity and Water Quality, Toowoomba p211-218
12. F.J. Kwan, EROMYN, 1972 "Geohydrology". In Fieldbook for Land and Water Experts 11LR1, Wagemingon 1972:p299-378.
13. A. van der Lelij, H. Percy and W.S. Meyer, 1988 "Problems with wheat growing in high water table areas". Paper to SIRAGCROP meeting Yanco, Feb. 1988.
14. A. van der Lelij 1984 "Soil Permeability and Drainage Factors affecting Irrigation Water Quality in the Murrumbidgee Valley of NSW". Proc Rootzone limitations to crop production on clay soils, E & W.A. Muirhead and E. Humphreys, Griffith, 1984.
15. A. van der Lelij, H. Percy and W.S. Meyer 1988 "Problems with wheat growing in high water areas". Paper to SIRAGCROP meeting Yanco February 1988.
16. A van der Lelij 1981 "Tubewell Drainage Requirement Associated with Rice Growing near Griffith, NSW "Proc Drainage of Agr. Lands Seminar, ICID, AWC, Melbourne 1981:p84-90.
17. Working Group (DWR/Dept Ag., Rice Ind. Co-Ord. Comm, 1985), "Land suitability for Rice Growing". Report to Minister for Natural Resources.



6000
5000
4000
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2000
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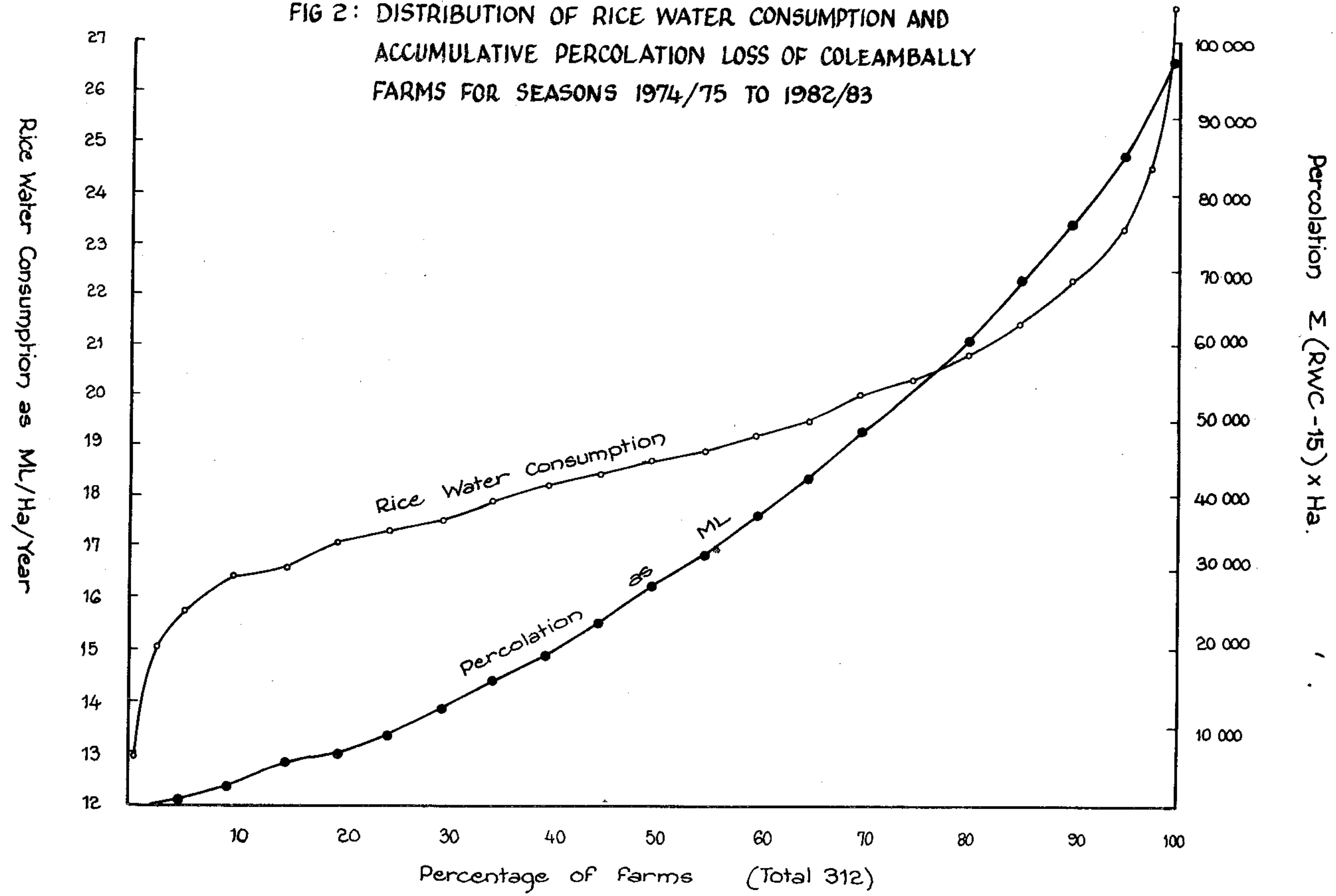
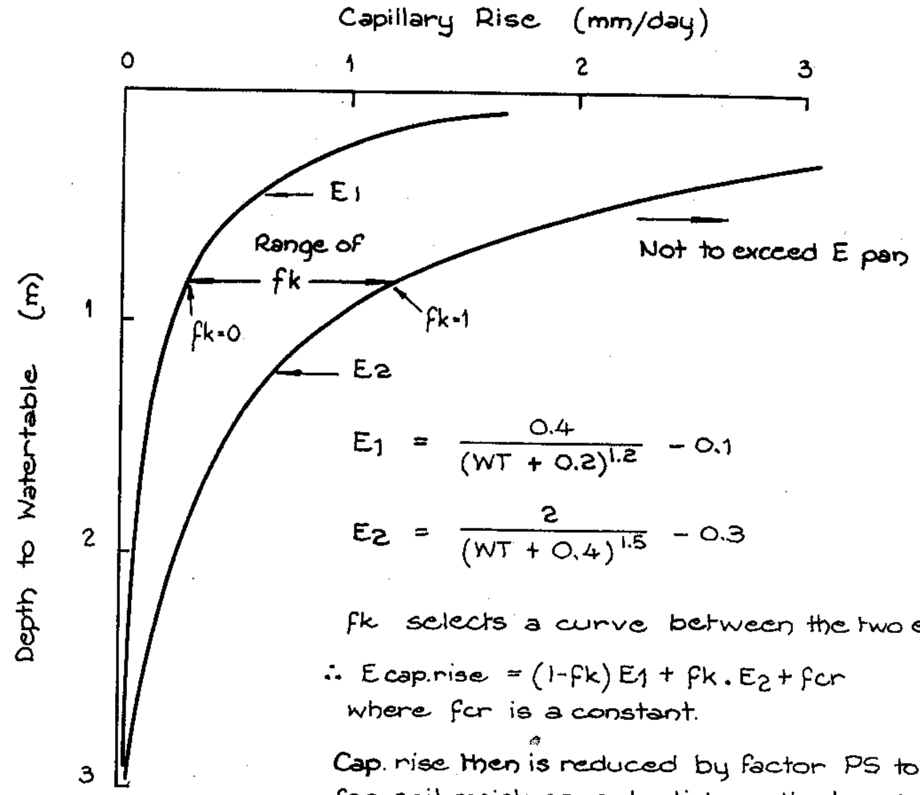
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
INFILTRATION (mm) 120 DAYS PONDING
Near Levee soils
Self Mulching Soils
Far Levee Soils
Transitional Red Brown Earths
100
80
60
40
20
0
PERCENTAGE OF EXCEEDANCE

FIG 1

FIG 2: DISTRIBUTION OF RICE WATER CONSUMPTION AND ACCUMULATIVE PERCOLATION LOSS OF COLEAMBALLY FARMS FOR SEASONS 1974/75 TO 1982/83





$$E_1 = \frac{0.4}{(WT + 0.2)^{1.2}} - 0.1$$

$$E_2 = \frac{2}{(WT + 0.4)^{1.5}} - 0.3$$

fk selects a curve between the two extremes:

$\therefore$ E cap.rise $= (1 - fk)\, E_1 + fk \cdot E_2 + fcr$

where fcr is a constant.

Cap. rise then is reduced by factor PS to account for soil moisture potential gradient and unsaturated hydraulic conductivity

$$\text{Cap. rise} = \frac{PS}{10} \times E\ \text{cap.rise}$$

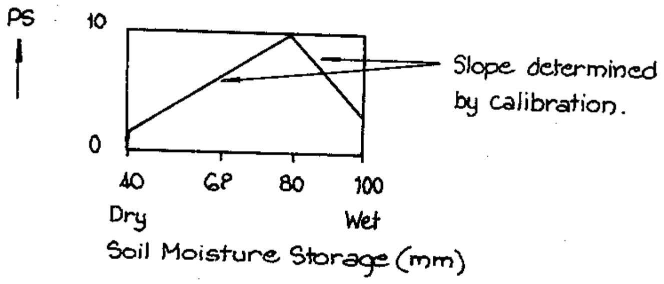
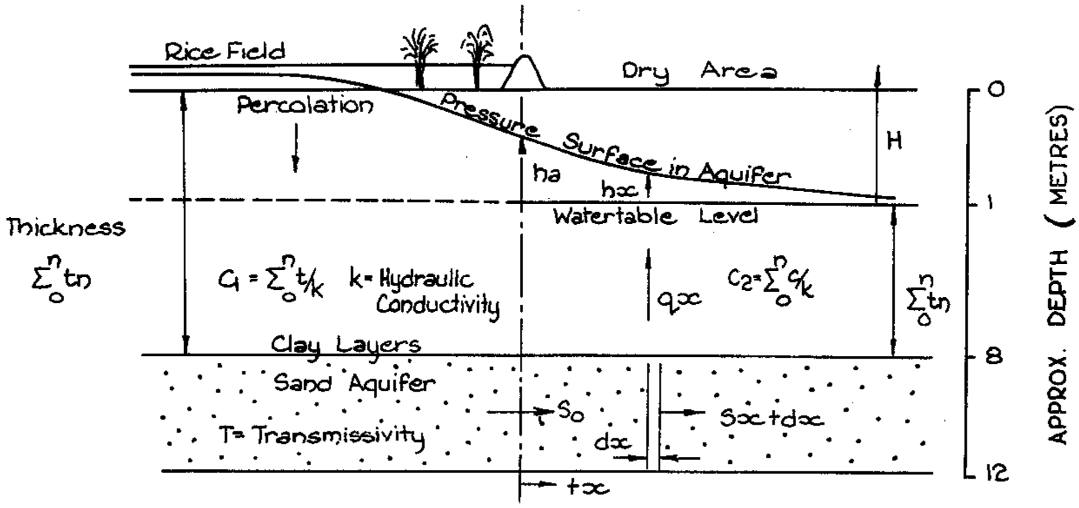
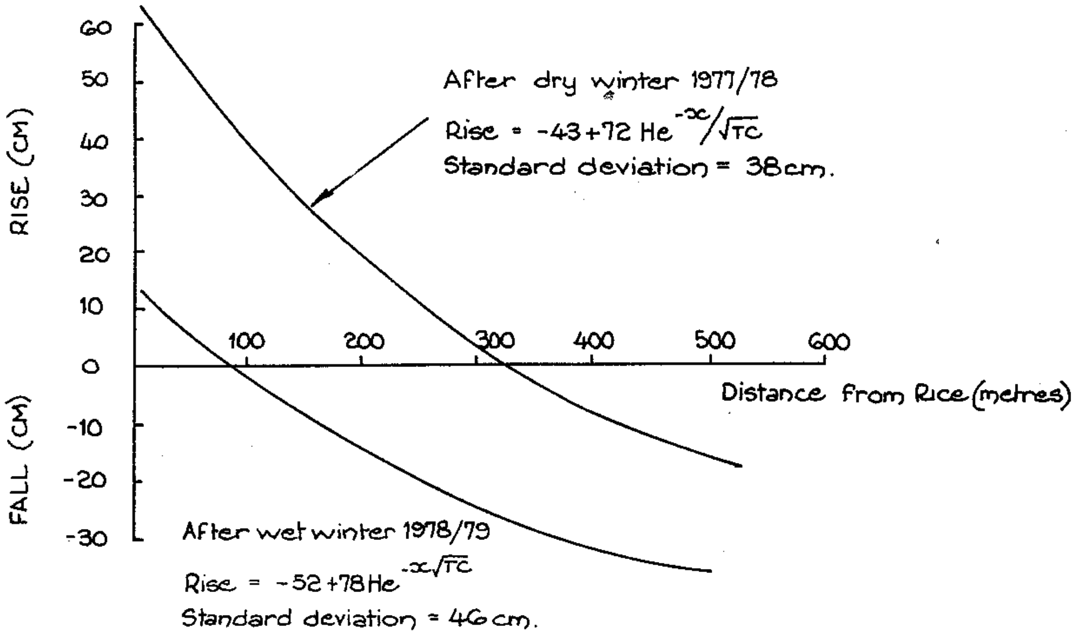


FIG 3 : CAPILLARY RISE FUNCTIONS
WAKOOL GROUNDWATER MODEL



GROUNDWATER MOVEMENT FROM RICE TO ADJACENT AREA SHOWING FLOW COMPONENTS USED IN MODEL



RISE IN PRESSURE LEVEL FROM SEPTEMBER TO MARCH VERSES DISTANCE FROM RICE FIELD. LINES FOR "RISE" ESTIMATED USING REGRESSION WITH $h(x)$ (EQUATION 8) $T = 125\ m^2/DAY$, $C = 1000$ DAYS

CHECK LIST FOR RICE LAND SUITABILITY

Q1 ARE PRESSURE LEVELS IN THE AREA HIGH OR LOW ?

If LOW (deeper than 2.5m) go to Q2
If HIGH (within 2.5m) go to Q3

Q2 IS THERE AT LEAST 2 METRES OF GOOD MC + HC IN TOP 3 METRES ?

YES → Suitable
NO → Rotation (1.2 - 2.0 m) or Unsuitable.

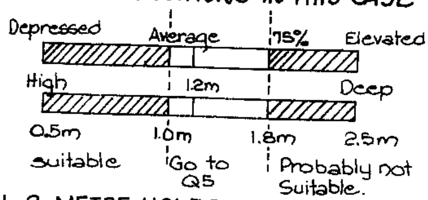
Q3 PRESSURE LEVELS ARE WITHIN 2.5 METRES
IS THERE AT LEAST 2.0 METRES OF GOOD HC + MC IN TOP 3 METRES ?

YES → Suitable
NO → Go to Q4

Q4 LOOK AT BAR CHARTS AND DETERMINE POSITIONS IN THIS CASE

Relative Land Elevation

Water Table Level (Make allowance for weather conditions)



Q5 GROUNDWATER SALINITY IN 3 METRE HOLES

HIGH : Above 5000 - 10000 → There is a case to approve rice growing, this year at least.
LOW : Go to Q6

Q6 TOPSOIL SALINITY LEVELS (EM 38 Survey)

HIGH : > 4 mS/cm = ECex, there may be a case to approve this year only.
LOW : Go to Q7

Q7 LATERAL GROUNDWATER MOVEMENT THROUGH AQUIFER TO ADJACENT LAND

a) Small Aquifer : Couple of metres of loam only → Negotiate rotation
b) Medium to large aquifer : Make an assessment using the formula :

$So = \frac{1}{2} H \sqrt{T/C}$ with T = transmissivity (m^2/day)
C = vertical flow resistance in clay (m)
H = depth to watertable (m)
So = flow under rice field boundary (m^3/m/day)

Use table below to calculate T and C

Gravel	K = 50 - 100 m^2/day	T = t x K
CS	K = 25 "	
FS	K = 2.5 "	
FSL	K = 0.5 "	
LC	K = 0.1 m/day	C = t/K
MC	K = 0.01 "	
HC	K = 0.001 "	

t = Thickness of layer

CRITERIUM :	So < 0.10 m^3/day	OK for RICE
	So 0.10 - 0.20 m^3/day	ROTATION
	So > 0.20 m^3/day	REFUSE

Example Profile :

0 - 0.5	DRB	HC	0.5/0.001	= 500	C
0.5 - 1.5	RB	MC	1.0/0.01	= 100	
1.5 - 2.5	LB	LC	1.0/0.1	= 10	
2.5 - 3.5	yB	FSC			
3.5 - 5.5	L	FS	2 x 2.5	= 5	T
5.5 - 8.5	L	CS	3 x 25	= 75	
8.5 - 9.0		Gravel	0.5 x 50	= 25	

WT = 1.0 metre deep.

$C_1 = C_2 = 610$ m^2/day
T = 105 m^2/day

Therefore $So = \frac{1}{2} \times \sqrt{105/610} = 0.20$

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FIGURE 5