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Salinity Control Problems Associated with Irrigation in South-West New South Wales, Australia

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ABSTRACT

In common with irrigation in many other semi-arid regions, irrigation schemes on the Riverine Plain of south-west New South Wales have resulted in rises in ground water levels which have created problems of soil salinisation and waterlogging.

The raised ground water levels can also lead to salt intrusion into streams and impairment of water quality if they are not controlled. Sub-surface drainage presents problems of disposal of saline drainage effluent without increasing the salinity of water to unacceptable levels for downstream users.

The geomorphology of the region and its relationship to ground water and salinity problems are outlined. Three different case studies of problems and approaches to their solution are presented and discussed.

THE IRRIGATION ENVIRONMENT

Most of the Government sponsored irrigation schemes in New South Wales are supplied with water from regulated flows of the Murrumbidgee and Murray Rivers. The bulk of irrigation in these schemes is on soils of the Riverine Plain of south-eastern Australia (see Figure 1.)

The Riverine Plain is a broad geomorphological feature of low relief situated between the ranges extending through south-western New South Wales and central Victoria and the slightly elevated aeolian landscape more than 300 km to the west. It covers a total area of about 77 000 km^2.

The contemporary climate is characterised by high summer temperatures, and winters with mild days and cold

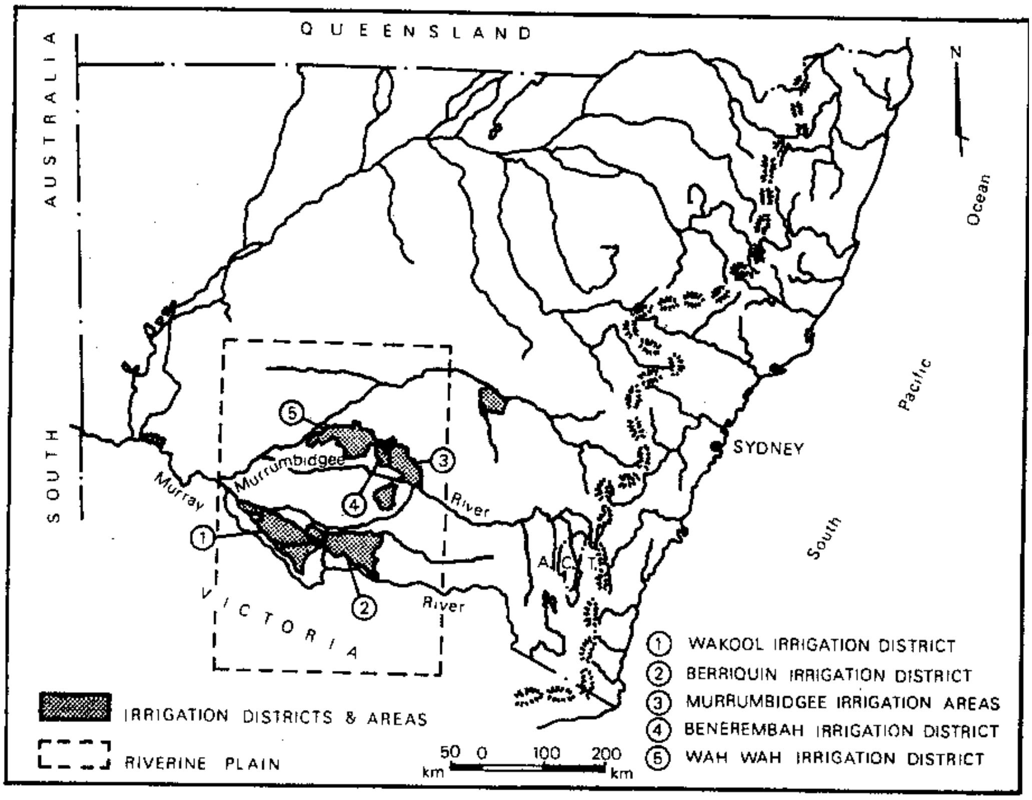

Figure 1. State of New South Wales showing location of Irrigation Areas and Districts and Riverine Plain of south-eastern Australia

nights. Annual average rainfall decreases from about 500 mm in the east to about 300 mm in the west. Evaporation ranges from 1300 mm to 1650 mm per year. Rainfall is highly variable, particularly in the summer months when it is unreliable.

The plain has been formed as a result of fluviatile deposition by systems of now relic streams which pre-date the present river system. These relic streams include an earlier series named "prior streams" [1] and a later series termed "ancestral rivers" [2]. The alluvium extends to depths up to 100 m and is underlain by unconsolidated lacustrine sediments to depths of up to 400 m.

Most of the alluvial plain contains prior stream sediments and the soils reflect the sedimentary pattern of the most recent prior stream activity. Lighter textured soils occur on the former streambed-levee systems and heavy textured soils on the former floodplains.

The Riverine Plain was formed under conditions of occluded drainage with prior stream waters being dissipated by evaporation towards the western margin. As a result, soils and ground waters in the western region of the plain have higher salinities than those in the eastern regions.

The underlying stratigraphy of the plain shows a series of sand and gravel aquifers interbedded with heavier textured materials. The aquifers were derived from a repetitive sequence of depositing prior streams. Deeper aquifers are more extensive laterally whereas the shallow aquifers associated with the most recent prior stream activity usually have limited lateral extent, but nevertheless have connection in places with deeper sand deposits.

Prior to irrigation the pressure levels in aquifers varied in depth from 20-30 m in the east to 10 m in the west. As a consequence of irrigation, ground water levels rose, the earliest effects becoming apparent where the more permeable soils associated with prior stream aquifers occur. During the earlier years of irrigation the shallow aquifers provided natural sub-surface drainage for irrigated land, but in time they became surcharged and high water tables developed leading in turn to problems of waterlogging and soil salinisation.

In some parts, high water table conditions have spread to lands underlain by deeper aquifers in which pressure levels have increased as a result of lateral movement away from the principal intake areas. In some localities in the plain where deep aquifers are confined, perched water table conditions have developed.

The next three sections present cases of problems and approaches to their solution in different irrigated areas.

WAKOOL IRRIGATION DISTRICT

The Wakool Irrigation District is situated in the western part of the Riverine Plain. It contains 350 farms comprising a total area of 210 000 ha of which up to 22 per cent is irrigated each year. However, in the central part, the irrigation intensity is higher than the average. At present, 60-70% of irrigation water delivered to farms is used for rice growing, with the remainder mostly for irrigated pastures and winter cereals.

The most serious salinity problems in New South Wales occur in a large part of this District. Irrigation commenced in 1935 and in the early 1950's waterlogging and soil salinisation appeared in low areas in the central part of the District and spread at a fairly rapid rate. Studies showed that salinisation was associated with shallow aquifers deposited by a system of prior streams and ancestral rivers.

A ground water mound had developed as a consequence of irrigation and continued to spread, affecting and threatening more land. Ground waters which developed in the shallow prior stream aquifers are very saline, up to 30 g L^{-1}.

If the ground water mound was allowed to spread unchecked, saline ground water discharges into nearby creeks would ensue, with consequent detrimental effects on water quality in the Murray River system.

Trials, commenced in 1964, showed vertical drainage to be effective in this environment for reclamation and protection against salinisation. However, an extensive sub-surface drainage scheme involved the disposal of large volumes of highly saline effluent. It could not be discharged to streams, and there are no natural depressions in the locality which could be used as disposal areas without any risk of salt accessions to the river system.

The Drainage Scheme

A scheme was developed to provide 39 drainage installations discharging through a buried pipeline system to artifically constructed evaporation basins. The aim was to lower water tables beneath an area of 22 000 ha and prevent further rises in an area of 25 000 ha. Construction commenced in 1978, Stage I of the scheme has been completed and work on Stage II is in progress. Stage I has been fully operational since April, 1982.

Stage I consists of 23 drainage bore sites linked by 48 km of pipelines discharging to an evaporation area of 770 ha. Stage II will involve drainage bores at a further 16 sites, about 50 km of pipelines and another evaporation area of 1 300 ha. The existing evaporation area is laid out in concentrating bays and crystallising ponds from which salt will be harvested by a commercial salt producer.

Bores are constructed of PVC casing with slotted PVC screens. Their depth ranges from 7.3 m to 22.2 m with an average of 12 m. Multiple bores are employed at some sites.

Performance

On the basis of pumping tests at the drainage sites, a total discharge of 300 L s^{-1} was adopted for each of the Stage I and II main pipelines, with an average delivery of 13 L s^{-1} for each of the 23 pumps in Stage I. In practice it varies from site to site, but the maximum pumping rates achieved so far in Stage I operation give an average pump discharge of 12 L s^{-1}. The salinity of the total flow to the evaporation area has been 20 g L^{-1}.

Effects are being monitored by regular readings of a grid of 300 observation wells. Table I gives an indication of effects through the period of ten months after full Stage I operation commenced, within the area of influence by then apparent. February 1981 was chosen as the base time for comparison because subsequent abnormally wet conditions in the winter caused rises in water tables which would have given exaggerated differences.

Table I. Wakool Sub-surface Drainage - Effects of Pumping.

Depth to Water Table	Area (ha)			
	February 1981	May 1982	August 1982	February 1983
> 2 m	1350	1600	3530	4950
1.5 - 2 m	2850	4040	4100	4090
< 1.5 m	7000	5560	3570	2160

BERRIQUIN IRRIGATION DISTRICT

This District, extending from the eastern to the central part of the Riverine Plain, contains 1316 farms with a total area of 317 000 ha. Up to 43% is irrigated each year. Irrigation commenced in 1939 but rice was not grown until 1968. It now constitutes about 20% of the total irrigated area.

Rapid rises in ground water levels have occurred in some localities as a consequence of irrigation. Whilst there has been no widespread salinisation yet, high water tables with accompanying problems of waterlogging occur in some areas, mostly associated with shallow aquifers underlying major prior stream formations. These aquifers occur to depths of about 12 m. Soils and irrigation induced ground water in these formations are of relatively low salinity compared to the more westerly part of the plain.

Some sub-surface drainage will be necessary to control ground water levels and possible salinisation along the prior streams, and to prevent lateral spread of high water tables. At present, water tables within 2 m of the surface occur in about 9% of the District.

Seven vertical drainage installations are operating in areas with high water table problems and are being monitored to evaluate drainage response for the different sub-surface conditions. Effects have been variable but experience so far indicates that about 1 ML ha^{-1} per year needs to be pumped to achieve protection within the area of influence of any installation.

The salinity of sub-surface drainage effluent from existing bores ranges from 0.36 - 2.7 g L^{-1}, but salinity increases in the shallow prior stream aquifers in a westerly direction. The effluent is being discharged to supply channels, in which the median salinity of irrigation water is 0.04 g L^{-1}. There is thus some scope to mix sub-surface drainage effluent with the supply water and still maintain good quality for irrigation, but this will require strict control of drainage operations in relation to channel flows and irrigation demands.

Some farmers are utilising the low salinity ground waters to augment their surface water allocations.

Current investigations are aimed at determining the ultimate extent of sub-surface drainage required, its feasibility, quantity and quality of drainage effluent and options available for disposal.

MURRUMBIDGEE IRRIGATION AREAS

The Murrumbidgee Irrigation Areas and the Benerembah and Wah Wah Irrigation Districts are situated north of the Murrumbidgee River (see Figure 1). A major crop is rice, occupying up to 30% of the irrigated landscape each year and using about 70% of all irrigation water supplied. There are about 15 000 hectares of horticultural plantings, mostly citrus and grape vines. The total area of farms is 265 000 ha, of which about 70% is irrigated each year.

Water is diverted from the Murrumbidgee River and is of excellent quality, 0.04 - 0.08 g L^{-1}, and SAR is low.

Runoff from farms, both from rainfall and irrigation, is collected by a drainage system in the Irrigation Areas and channeled further west, where it is reused. Such flows are mixed with fresh river diversions before reuse in the Benerembah Irrigation District. In the Wah Wah Irrigation District, however, only drainage flows are used for irrigation. Water is diverted directly from the end of the drainage system or via a 3000 ha en-route storage.

High watertables have been experienced for a long time in the older established parts of the Irrigation Areas, particularly in the lighter textured horticultural land. Vertical drainage bores are pumping at rates of 8 - 30 L s^{-1} where aquifer transmissivity is sufficiently high. In much of the horticultural areas, shallow aquifers are absent and horizontal (tile) drainage is employed to control waterlogging. Criteria for this are well established and checked against watertable behaviour [3].

In "large area" farms ponding in rice fields causes accessions to ground water. Rates of rise of 1 - 2 m per year have been observed in places. In most of the older parts of the Areas and Districts watertables and pressure levels are now at high equilibrium levels, 0.5 - 2.0 m below the surface. Whilst there is no widespread salinisation yet, it is occurring in particular situations and a proportion of the landscape will ultimately have seriously reduced production potential unless remedial measures are taken.

Effluent from vertical drainage bores and tile drainage is being discharged into the drainage system, increasing the salinity of water supplied to the Irrigation Districts.

Salt Loads in Drainage Waters

Drainage flows comprise escapes from supply channels, surface runoff (rainfall and irrigation) and sub-surface drainage effluent. Ground water seepage into waterways is negligible in this region. Surface runoff salinity is related to surface soil salinity, which so far has been low. Values of 0.08 - 0.25 g L^{-1} have been recorded in drainage channels. Most of the salt load added to the system is effluent from sub-surface drainage. This effluent has high salinity, 1 - 10 g L^{-1}, and high SAR.

The salinity at the end of the drainage system is about 0.3 g L^{-1} in summer but sometimes exceeds 0.5 g L^{-1} in spring and autumn. During winter, salinity may exceed 1 g L^{-1} at times when sub-surface drainage effluent constitutes a large proportion of the flow.

There is an increasing salt load due to increased sub-surface drainage. Tile drainage effluent from horticultural farms contributes at present about 22000 Mg per year but there is evidence that the average salinity of the effluent has declined over the last 5-10 years. More vertical drainage bores have been installed in "large area" farm lands where rice is grown. A total of 500 - 5000 Mg of salt per year may be discharged by each of these installations, depending on transmissivity and ground water salinity. Tile drainage in "large area" farms is not of significance as yet.

Constraints

The question arises as to the level to which salinity of drainage waters may be allowed to increase before they should be considered unsuitable for irrigation.

The permeability of the clay soils of the alluvial plain is low. The deep subsoils (1-2 m) show a large variation in hydraulic conductivity, ranging from 0.1 to 5 µm s^{-1}.

Much of the landscape where drainage waters are reused is not underlain by aquifers suitable for vertical drainage.

Hence horizontal drainage is left as the only alternative if sub-surface drainage is needed. It has to be determined whether this is feasible with the low hydraulic conductivities of many of the soils.

Hydraulic gradients with tile drainage are much less than unity, meaning that with these clay soils only a small amount of leaching could be achieved. The achievable leaching and water application then sets an upper limit on the salinity of the irrigation water that can be tolerated permanently. At present a limit of 0.4 g L^{-1} is used as a target but it requires further investigation.

At the end of the drainage system salinity exceeds 0.4 g L^{-1} during autumn and spring of most years. Water diverted from the en-route storage of drainage flows has exceeded 0.4 g L^{-1} during 1982/83, a drought season with less than average drainage flows. Alternative options of salinity control need to be evaluated, to prevent further water quality degradation in the future.

Modelling The System

Attempts are being made to model the system to simulate present behaviour and predict future salt loads as affected by different management options.

Factors used in this approach are predicted proportion of land at risk of salinisation, type of sub-surface drainage, volume and salinity of effluent and flow rates in irrigation supply and drainage systems.

The Irrigation Areas and Districts are subdivided into smaller areas to distinguish variation in soils and stratigraphy, cropping patterns and irrigation water salinity.

Computer calculations with these inputs yield salt loads from each area and water salinities at critical points of the drainage system. The parameters are varied to determine the effects of various options, such as specific dilution flows, improved channel management, different water consumption patterns (for instance, more wheat irrigation in spring and less rice in summer) or variable pumping periods of sub-surface drainage systems.

Figure 2 shows a preliminary result of such an analysis for the 1980 situation and as it may occur in the year 2005 at the end of the drainage system, if all predicted sub-surface drainage effluent is discharged to the system. The increased salinity, particularly during spring and autumn, is demonstrated.

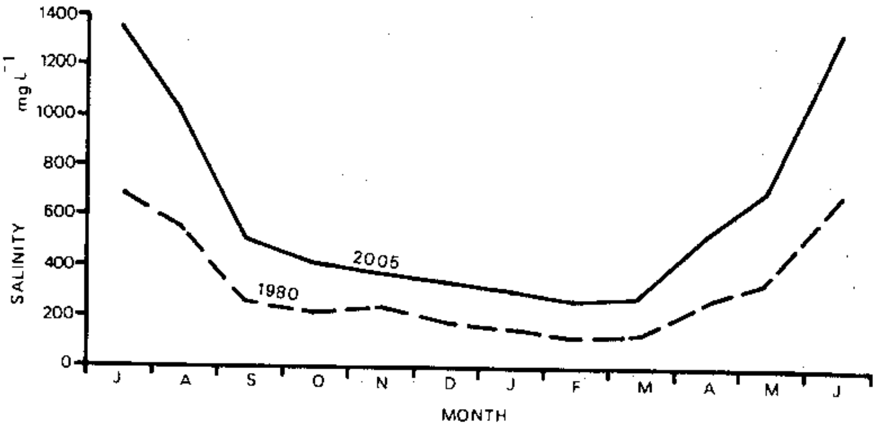

Figure 2. Present and predicted salinity at downstream end of drainage system.

Approaches to Salinity Control

Control of salinity involves measures to prevent development of the problem, means of protection and reclamation of the soil and of managing drainage flows to avoid undesirable consequences of water salinity.

Improved grading and irrigation layouts are recognised as providing better irrigation control and surface drainage. It is uncertain, however, whether these measures would significantly reduce accessions to the ground water in this area, because the largest accessions result from ponding in rice fields, which dominate the irrigation environment.

Ponding results in lateral ground water movement, through aquifers and salt transport to adjacent fields. The impact of rice growing can be minimised by ensuring that rice is grown only in the least permeable situations and by rotation of rice with other crops. Electromagnetic techniques to map salinity could be suitable to plan rice rotations, as intake areas and areas of salt accumulation can be detected.

Vertical drainage requires the presence of an unconfined or semi-confined aquifer to achieve soil drainage and leaching. This usually restricts pumping to the uppermost aquifer. Horizontal drainage is feasible only where subsoil permeability is high enough. Some clay soils of very low permeability are probably not drainable. Criteria for drain depth and spacing to achieve salinity control have to be evaluated.

Results with experimental vertical drainage bores have been encouraging to date. Typically, such a bore produces

1.5 - 3 ML ha^{-1} per year over the area of measurable pressure reduction, with continuous pumping. If only a small proportion of this land is salt affected, the volume of drainage effluent per unit area of salt affected land is high.

Electromagnetic techniques are being used to evaluate soil salinity in land within the influence of vertical drainage bores. This may assist with planning periods of pumping from these bores, so that total effluent and salt loads may be reduced.

Some installations of horizontal drainage in "large area" farms have shown promising results but subsoil hydraulic conductivity in these instances has not been very low. Whilst such systems have the disadvantage of high capital costs in relation to the type of agriculture practised, they do provide scope to reduce the effluent salt load as drainage would only be installed in areas at risk.

Effluent Management Options

A range of effluent management options are to be evaluated to achieve the target salinity of 0.4 g L^{-1} at the downstream end of the system. These include reuse of effluent upstream by discharge to and dilution in supply channels (limited scope because effluent salinity is often too high); dilution flows to reduce salinity downstream; diversion of the more saline winter drainage flows; on-farm retention of effluent during the irrigation season; disposal of some effluent in evaporation areas.

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