RESEARCH SOLUTIONS TO WATERTABLE AND SALINITY PROBLEMS IN THE RICE GROWING AREAS OF SOUTHERN AUSTRALIA

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Abstract

The major threat to the sustainability of irrigated agriculture in the rice growing regions of the southern Australia is secondary salinisation as a result of rising watertables. Rice growing contributes about half of the accessions to the groundwater in these regions. A range of strategies for reducing the accessions from rice are applied, including restricting rice growing to soil assessed as suitable for rice. In the past this was based on soil texture, but increasingly EM-31 survey is being used, and the inclusion of soil sodicity constraints will further improve the ability to predict suitable soils. The net evaporative demand for rice growing over the whole season is well-approximated by reference evapotranspiration (ETo), which is used to calculate the seasonal rice paddock water use limit.

Potential methods for increasing rice water use efficiency and reducing recharge include shorter duration varieties and a range of water and soil management strategies. Intermittent and sprinkler irrigation can significantly reduce water use, however yields are also reduced due to cold temperature damage during early pollen microspore. Small areas of leaky soils can greatly increase total accessions to the watertable, and EM-31 surveys show that many “suitable” rice paddocks have leaky areas. Recharge from leaky areas can be reduced by puddling or by impact compaction. After rice harvest, soil water content is high, and recharge may continue, especially under the influence of winter rainfall and low evaporation. Research is underway to quantify the effect on accessions to the watertable of growing a winter crop immediately after rice harvest. Future work will investigate the conjunctive use of groundwater and surface water to promote watertable control while maximising agricultural productivity by making more water available for irrigation.

The SWAGMAN (Salt Water And Groundwater MANagement) series of computer models has been developed to determine the impacts of management and climate on watertables, salinisation and yield, and the tradeoffs between environmental objectives and profitability. These models include SWAGMAN Destiny, a point scale crop model that can be run for up to 30 years of climatic data. SWAGMAN Farm is a farm scale optimisation model which predicts the most economic cropping mixes that meet specified net recharge and root zone salinity objectives, taking into account farmer preferences. Regional groundwater models have been developed to evaluate the impacts of climate and management on watertables.

The development of shallow saline watertables results in the generation of saline drainage waters. Numerous evaporation basins ranging in size from a couple of hectares to a few hundred hectares have been created in recent years to receive saline drainage. Investigations into the salt and water balance of evaporation basins, the development of the model BASINMAN, and economic analyses have led to guidelines for the siting, design and management of evaporation basins. A pilot trial is also underway to investigate the feasibility of serial biological concentration, with the production of high value crops in the first 2 stages, followed by salt tolerant crops (stage 3), fish farming (4), evaporation basins (5) and a solar pond to generate energy.

Introduction

Recharge from irrigation has increased regional groundwater levels in the irrigation areas of southern New South Wales, leading to problems of waterlogging and soil salinisation. Another consequence of the development of shallow saline watertables is the generation of saline surface drainage waters. Ponded rice contributes 40-50% of the accessions to the groundwater, and the other major sources are other irrigated crops and pastures, channel leakage and rainfall (Dwyer Leslie 1992).

Reducing accessions from rice paddocks involves a range of approaches from the identification of paddocks or sites with excessive recharge to their elimination or amelioration. However, rice is only one of many activities with the potential to influence watertables at the farm and regional scales. Solutions for controlling watertables need to be derived from consideration of a complex mix of biophysical and socioeconomic factors, and over shorter and longer time frames. For these reasons novel modelling and practical approaches are being developed to identify combinations of on-farm and regional options that will achieve desired environmental objectives, and to evaluate the tradeoffs between environmental and economic objectives, taking into account farmer preferences.

1. INCREASING WATER USE EFFICIENCY AND REDUCING RECHARGE FROM RICE PADDOCKS

Numerous restrictions have been applied on-farm to minimise recharge from rice culture, based on a range of criteria including soil texture, rice paddock water use, the intensity of rice growing, elevation and proximity to water courses (Humphreys et al. 1994a).

1.1 Rice paddock water use limits

In a rice paddock, evaporation may occur via the plants (Erice), directly from the floodwater (Efw), or directly from the soil surface (Es) if the soil is not flooded. Thus the total evaporative loss from a rice paddock (Epdk) is: $E_{pdk} = E_{rice} + E_{fw} + E_s$

Reference evapotranspiration (ETo), estimated using a locally calibrated form of the Penman equation, has been shown to be a good estimate of rice paddock evapotranspiration for ponded rice over the entire season (Humphreys et al. 1994b). Thus: $E_{pdk} = ET_o$

The amount of irrigation water (I) used for rice growing has been monitored on a farm or paddock scale for many years in southern Australia. The total amount of water applied to a rice paddock also includes rainfall (R), and the rice paddock water balance may be written as: I = ETo – R + DSW + SD + DD where DSW is the increase in soil water content in the upper profile (0-1 m) and potentially available for loss to the atmosphere by soil evaporation and/or transpiration by crops after rice. DSW typically ranges from 20-200 mm depending on seasonal conditions and cropping history prior to rice sowing. SD is surface drainage (typically 0-50 mm). DD is deep drainage (below 1 m), considered to be unavailable to crops, and which will ultimately recharge the groundwater.

The purpose of monitoring I is to identify paddocks where DD is unacceptably high (say > 100 mm). At present the rice water use limit is determined as:

rice water use limit = ETo – R + 400

In an average season, for an average crop ponded for 5 months, ETo = 1,160 mm and R = 160 mm. Thus the average net evaporative loss (ETo - R) is 1,000 mm, but it can vary greatly from 650-1,300 mm. The rice water use limit is automatically adjusted for seasonal variation in net evaporative loss.

The constant (400 mm) is to allow for soil wetting, surface drainage, deep drainage and error. With current monitoring systems, deep drainage of up to 400 mm will not be detected in situations where DSW is close to zero (such as rice after rice and/or after wet winters). Furthermore, there is no allowance for crops where the duration of ponding varies significantly from 5 months. For example, for a shorter duration variety with a 4-month ponding period, ETo - R in an average season is reduced from 1,000 to 880 mm. Thus deep drainage of up to 500 mm could go undetected at present.

Finally, there is the problem of accuracy of the measurement of irrigation water supplied to the rice paddocks. In some situations one Dethridge meter supplies one or more paddocks either simultaneously or alternately, and the recording of water use against each crop relies on the farmer’s record keeping or estimates.

In future, the greatest gains for improving the ability to detect paddocks with unacceptable recharge will be by 1) more accurate monitoring of the irrigation water applied to individual paddocks, and 2) including the period of ponding and an estimate of the antecedent soil water content in the determination.

1.2 Rice soil suitability criteria

Current rice soil suitability criteria are based on the proportion of heavy or medium clay in the surface 2-3 m of the soil profile, as determined by hand texturing. In the past soil evaluation sites were selected on a grid sampling approach of 1 site per 4 ha. Alternatively these sites were located subjectively following air photo interpretation. In some areas, the soil's suitability for rice was assessed on the basis of soil type mapped regionally at a scale of 1:250,000.

This approach was based upon a general rule relating clay content to infiltration. However, infiltration and subsequent groundwater recharge are affected by a multitude of soil chemical, physical, biological and management factors. Therefore there are many exceptions to the clay content rule. Furthermore, the survey approaches used do not always identify spatial differences across a rice field, and do not allow effective delineation of problem areas. The direct measurement of infiltration is laborious and complicated by high spatial variability, and indirect assays of recharge are therefore needed.

Electromagnetic induction techniques can be used to rapidly assess within field variability due to textural discontinuities within a landscape (McNeill 1980, Williams and Hoey 1987). Oster et al. (1986) suggested using soil electromagnetic induction variability to estimate soil infiltration variability. The Geonics EM-31 instrument senses the apparent electrical conductivity (ECa) to a depth of 6 m from the soil surface. The ECa is related to soil salinity, clay content, moisture and bulk density. Field surveys with this instrument have been used to delineate rice fields into areas of distinctly different ECa. Targeted soil sampling and rice land assessment allowing for field variability can then be made on the basis of ECa measurements to infer the likely level of groundwater recharge.

Beecher and Hume (1996) showed the potential for using EM-31 instruments combined with GPS to provide spatial detail on variation in soil properties across rice fields, and for providing a methodology on where to investigate to assess rice soil using the current soil textural criteria. This methodology has been rapidly adopted by the irrigation companies responsible for the implementation of Land and Water Management Plans in all the major rice growing areas.

However, problems are still experienced with the existing soil suitability criteria. Within specific soil types, sites with shallow sand can be identified which, using current soil textural criteria, would exclude the land from rice growing. In many cases the soil has high sodicity, and these areas have rice water use which is claimed to be below acceptable limits. Conversely, many self mulching soils easily meet the existing soil textural criteria but have a stable soil structure which often results in high water use. Recent investigations indicate the importance of soil sodicity as a key factor in limiting groundwater recharge. Research is in progress to include a soil sodicity assessment in the rice soil suitability criteria.

1.3   Agronomic options for reducing recharge from rice

Shorter duration varieties. Short season rice varieties have been a focus of the New South Wales rice breeding program because of their benefits in reducing water use and deep percolation, and increasing on-farm flexibility. Since the release of the rice variety Jarrah in 1993 and Millin in 1995, rice growers have been able to reduce the ponding period by 20 and 10 days respectively, compared to full season varieties that require 150 days. While not necessarily early to flower, the long grain varieties such as Langi are also earlier to mature and have similar advantages to the short duration Millin. A reduction in ponding period gives growers an extra 20 days either prior to or after the rice crop to use their land for alternative purposes. By planting short duration rices later, pasture growth in spring can be maximised, increasing the return on pastures. By harvesting earlier, the chance of a successfully establishing a winter crop following the earlier rice harvest is dramatically increased. Grower experience is that short duration varieties do decrease water use, but the current varieties also have a lower yield potential. This lower yield, however, is greater than the water saved, reducing water use efficiency of the rice crop itself. Recent crop simulations (Williams et al. these proceedings) show that the lower water use efficiency of short season rices is likely to be a permanent feature of short season rices in NSW.

Intermittent irrigation. Considerable research on intermittent flood and sprinkler irrigation for rice was carried out in the 1980s. Heenan and Thompson (1984, 1985) found that flooding every 7 days throughout the season reduced water use by 60%, however yields were abysmal (1-2 t/ha compared with 9 t/ha for dry seeded rice with permanent flood commencing at the 3 leaf stage). When permanent flood was delayed until panicle initiation, a saving in total water use of ~30% was achieved, and deep percolation was reduced from around 900 mm to 540 mm. In their first experiment, yields with permanent flood delayed until panicle initiation were similar to yields with conventional flooding at the 3 leaf stage, provided that nitrogen application was split into 2 or 3 doses. In later experiments, yields with permanent flood delayed until panicle initiation were reduced by around 20%, whereas commencing permanent flood at least 2 weeks before panicle initiation gave no yield decline. It therefore seems that considerable water savings could be achieved, without yield penalty, by delaying permanent flood until approximately 2 weeks before panicle initiation. However, the associated delay in flowering and extended flowering period has serious implications for grain quality. Furthermore, technology which involves increased labour requirement is unlikely to be adopted readily. The work of Heenan and Thompson (1984, 1985) was carried out on a relatively free-draining soil, and delayed permanent flood and the time of drainage should be evaluated on heavier more typical rice soils.

Sprinkler irrigation has reduced water use by 30-70% on clay soils in NSW and in the USA (Ferguson and Gilmour 1978, Humphreys et al. 1989), and by even more on a free-draining loam (Blackwell et al. 1985). However, sprinkler irrigation to replace evaporative loss, even at frequencies of up to 3 times per week, has given yield declines of 35-70% on clay soils. For non-ponded rice culture to be viable, cold tolerance would need to be increased to cope with night temperatures as low as 10^{o}C during microspore development. With current varieties damage begins once temperatures fall below 18^{o}C.

Saturated soil culture. Research in northern Australia indicated that crop water use of rice grown on raised beds was 32% less than when grown using conventional permanent flood (Borrell et al. 1997). In the raised bed layout irrigation water is maintained in the furrows between the beds rather than ponded over the entire soil surface. Whilst recognising that there are likely to be agronomic constraints to rice production on raised beds in southern Australia, especially with weed control and cold temperature damage, investigation of potential water savings is being evaluated. Initial results suggest the reduction in water use is accompanied by lower grain yield and no increase in water use efficiency of the rice crop.

Soil amelioration. The majority of the southern Australian rice crop is aerial sown into the flooded bays, and land preparation typically involves 1-2 shallow (5-10 cm) cultivations, banding of urea below the soil surface using a combine seed drill, followed by ridge rolling or some other surface “levelling” process. The cultivated soil is generally fairly dry when these operations take place.

In the 1990s puddling and compaction were evaluated for their effects on infiltration, rice crop performance, soil properties, the performance of crops sown after rice and the economics of these techniques (Humphreys et al. 1994c, Ringrose-voase et al. 1996). The results showed that puddling reduced infiltration, although in some situations the reduction was not large enough to meet the rice paddock water use limit. Rice yields with puddling were generally comparable to those without puddling, and puddling appeared to be economic as the value of the water saved exceeded the additional cost of puddling instead of ridge rolling. Yields of wheat and canola direct drilled after rice harvest were not impaired, and there was no evidence of long term soil structural decline, consistent with the observation of no carryover effect on infiltration for consecutive rice crops. However, very few farmers adopted puddling. Major constraints probably included the slowness of the puddling operation at a busy time of year, turbidity problems where water management was not optimal, reluctance to operate machinery in the mud and water, and mixed results at the paddock scale. This led to some farmer-driven research to evaluate impact compaction for it's use in rice culture (Clark and Humphreys 1997, Humphreys et al. 1998a).

Impact compaction has the advantage of being able to be applied well in advance of preparation for rice sowing, whereas puddling is a "last minute" operation. Impact compaction was very effective in reducing infiltration on both high and low water use sites, with no effect on crop performance. For impact compaction to be economic, the effect needs to last for 2-3 seasons. The effects of impact compaction on soil structure were transmitted to depths below the soil surface of at least 0.4-0.5 m at some sites. The depth, nature, extent and reversibility of changes in soil structure as a result of impact compaction are not known. Therefore, widespread application is not recommended, although it may be useful in sealing small highly leaky areas.

Soil management practices that increase infiltration. While much attention has focussed on soil amelioration to reduce recharge, recommended management practices such as landforming and gypsum application have the potential to increase recharge in some situations.

Soils with a dense, dispersive clay subsoil are usually good rice soils because water moves through the soil only very slowly. However, for some soils, if the top of the sodic clay subsoil is removed to the depth where naturally occurring lime occurs, the soil becomes self-mulching, with high infiltration rates (e.g. 20 mm/day Humphreys et al. 1998b). On these soils, deep cuts should be avoided if they are to be used for rice growing. Deep cuts can be avoided by terracing, or by changing grades or angles through the paddock.

Highly sodic surface soils can create serious rice establishment problems, especially muddy water and seed burial. In recent years there has been increasing use of gypsum, broadcast on the soil surface before flooding to control turbidity. Gypsum is also used to improve the establishment of crops grown in rotation with rice. However, it is well-known that gypsum improves soil structure and infiltration rate, and can significantly increase deep drainage (Loveday et al. 1979, McIntyre et al. 1992). Slavich et al. (1993) showed that up to 7.5 t/ha of gypsum applied for wheat 18 months prior to rice sowing had no effect on deep drainage during the rice season, however as little as 2.5 t/ha increased deep drainage from rice when applied only 6 months prior to rice sowing. A series of experiments with gypsum broadcast immediately before flooding confirmed that even the low rates of gypsum (1.25-2.5 t/ha) typically used to prevent muddy water increased infiltration rate, and that the effect increased with gypsum rate (Humphreys et al. 1998c). However, this research also showed that these highly sodic soils have very low natural infiltration rates, and while the effect of gypsum on potential recharge is undesirable, total recharge remains low and within current limits. However, gypsum should not be relied on as the panacea for muddy water problems. Reduced cultivation, improved layout, shallow water management, retention of residues and pasture rotations are all key parts of the solution.

Effect of post rice crop management on recharge and water use efficiency. Rice land lies fallow for at least 6 months after rice harvest until the next rice crop is planted, or for longer periods depending on the crop rotation. Rice is ponded until shortly before the crop matures, therefore the soil profile has a high water content after harvest, and is predisposed to significant rates of recharge during the winter fallow period, especially in wet winters (Cai et al. 1994, Prathapar et al. 1994). There is some evidence (Muirhead et al. 1978) that growing winter crops or pasture immediately after rice harvest would decrease the potential for additions to the watertable. Furthermore, it may be possible for the crop to use upflow from the watertable, providing an additional source of water, and assisting in watertable control

(Meyer et al. 1996a). At present about 40% of farmers regularly grow crops immediately after rice harvest, but only one fifth of these do so on all of their rice stubble.

Field research commenced in 1998 to quantify the effects of growing wheat shortly after rice harvest on components of the water balance. The CERES Wheat and SWAGMAN Destiny models (see below) are also being used to predict the impacts of wheat after rice on recharge, upflow, root zone salinity, crop water use and yield for a range of seasonal, agronomic, site and management conditions.

2. CONJUNCTIVE USE OF GROUNDWATER

Conjunctive water management is concerned with integrating the use of surface water and groundwater to most effectively use the total resource in a sustainable way. For sustainable conjunctive water use, strategies are required to manage surface water and groundwater at farm and regional scales to promote watertable control and to maximise agricultural productivity by making more water available for irrigation.

These strategies need to be developed by regional water balance analysis to determine spatial and temporal variation in the demand and supply of water within the region, especially over the long term to include periods of limited surface supplies. Anticipated constraints include surface and groundwater availability, groundwater quality, slowly permeable clay soils and the capacity of the irrigation infrastructure. Analysis is also required to determine the potential volume and quality of groundwater and the impact conjunctive water use may have on water tables and long term sustainability. Beecher (1991) found that infiltration from ponded rice increased by 320 to 400 mm when the salinity of the irrigation water was increased from 0.25 to 1 dS/m.

To determine sustainable levels of surface water and groundwater use at a regional scale, the response of the groundwater system to changes in recharge rates and groundwater pumping rates needs to be determined. The aquifer model of Coleambally Irrigation Area (CIA) (described below) will be linked with solute transport options and used to assess the impacts of groundwater pumping and conjunctive use. In the CIA water allocation is currently based on the size of land holding. It does not take into account available groundwater and quality. A method for allocating the available surface water in an optimal fashion, considering delivery system constraints, environmental consequences and land use requirements needs to be devised. This will require a review of the currently available water allocation software, such as: REALM, a surface water allocation model developed by the Rural Water Commission in Victoria, the Indus Basin Model developed by the World Bank and IRAS, a model developed by Cornell University, USA.

3. MANAGEMENT TOOLS AND DECISION SUPPORT SYSTEMS

Several computer models have been developed to determine the impacts of management and climate on watertables, salinisation and yield. These models include SWAGMAN Destiny, SWAGMAN Farm, groundwater and policy models.

3.1 SWAGMAN Destiny.

SWAGMAN Destiny is a computer simulation model that examines how management and climate impact on crop yields, groundwater levels and root zone salinisation on a yearly basis for up to 30 years (Meyer et al. 1996b). The model is one-dimensional (point scale) and estimates water and salt distributions and balances using a daily time step. Inputs of weather data, crop type, soil type, water table depth, piezometric conditions and irrigation practice can be modified or added to the program. Operationally, the model has three inter-linked components: a) a crop growth simulation model, b) a database of soil, weather, crop and economic parameters, which can be edited and accessed by the user , and c) a shell program which controls simulation parameters, and access to the databases, graphics and analysis programs. The Destiny model has been validated using data collected from weighing lysimeters and field monitoring.

3.2 SWAGMAN® Farm.

A farm level model, SWAGMAN® Farm, has been developed to examine the effect of various cropping mixes and management on net recharge and root zone salinity. In essence the model is an annual salt and water balance model which optimises gross margins for nominated recharge and salinity constraints. The model determines the most profitable farm management options (what crops, with what amount of water) while meeting the nominated recharge and salinity constraints. SWAGMAN®-Farm can also be run in simulation mode.

3.3 Groundwater models.

A groundwater simulation model of the CIA was developed using the MODFLOW groundwater modeling software (Enever 1999). This model combines a number of data sets including aquifer hydraulic properties and sub surface geology. Development of the model requires that the area be represented by a discrete number of points, distributed throughout the area in a rectangular grid. The CIA model consists of four horizontal layers (Upper Shepparton, Lower Shepparton, Calivil and

Renmark formations) and a grid of 66 rows and 60 columns representing an area of 619,000 ha. The groundwater model has enhanced the understanding of surfacewater-groundwater interactions in CIA. The water balance for the CIA shows that during 1990 to 1995 period that total recharge is 38.6 GL/year out of which 18 GL/year is added to storage in the Upper Shepparton aquifer. The lateral outflow from Upper Shepparton for this period is 1.6 GL/year and 4.4 GL/year from the Lower Shepparton aquifer. A series of recharge and pumping scenarios was also investigated using the model.

3.4 Policy models.

A simulation model developed in Excel and a linear programming model that examined the effect on cropping patterns were used to evaluate policy options for the CIA. The effects on farm incomes and practices were assessed for policies such as reduced allocations, increased water prices and the introduction of a tiered water pricing scheme (Madden 1997, Madden et al. 1997). The effect of changing water pricing policies on farm trading surplus was determined for a representative farm. The results show that the introduction of tiered pricing has little effect on an ‘efficient’ farmer while an ‘inefficient’ farmer faces a greatly reduced trading surplus.

4. MANAGEMENT OF SALINE DRAINAGE WATERS

While better management practices to improve water use efficiency of all irrigated crops must be encouraged to minimise drainage, in the long term drainage is necessary. The management of this drainage in an environmentally sound manner is critical.

Traditionally, salt has been exported by drainage to deep aquifers and discharge to watercourses. This is no longer acceptable. Alternative options for disposal include evaporation basins, woodlots, serial biological concentration and pipelines to the sea. Using drainage water to irrigate downstream crops, by traditional means, avoids addressing the problem and may create further problems in the new locality. With restrictions on salt export ever increasing, the reuse of water and concentration of salt is necessary. This can be done with serial biological concentration systems. However, the salt mass still remains, for which evaporation basins are being investigated as a long term storage mechanism.

4.1 Serial biological concentration of salt (SBC).

The FILTER system for land-based treatment of secondary treated sewage demonstrated that high crop yields were possible using saline (1.2 dS/m) effluent where high leaching fractions (30%) were maintained with the aid of good soil preparation and a pipe subsurface drainage system (Jayawardane and Blackwell 1996). Building on this experience, it was proposed that a sequence of FILTER modules might enable the concentration of the Murrumbidgee Irrigation Area’s saline (median 1.2 dS/m) winter drainage flows to a manageable volume. This would provide a means of overcoming the traditional downstream problem and, in the process, produce a series of high value crops.

An SBC experiment has been established on an 11-hectare site near Griffith. Crops have been grown for two years in three cropping sequences with irrigation water salinities of 1.2, 3.6 and 10.8 dS/m. Adequate leaching fractions have been maintained to enable productive growth over this range of salinities. A fourth cell has been set up to demonstrate the potential for inland saline aquaculture. The fifth cell, a salt gradient solar pond, will demonstrate the potential of producing energy from the concentrated brine, and is now under construction. A series of sealed evaporation basins is also being constructed to demonstrate the possibility of sequentially collecting useful salts in the process of finally evaporating the waste stream down to a manageable level. These waste products could be disposed of in an environmentally sound way, either by transport to the sea or injection into the deep aquifer.

4.2 Evaporation basins.

Evaporation basins have long been proposed as a potential salt storage mechanism for irrigation areas. In the past, disposal to larger regional scale basins has been the most common approach. However, in irrigation areas, the number of on-farm and community disposal basins is increasing in response to larger volumes of drainage effluent and constraints on salt export. Current research aims to develop guidelines for siting, design and management of on-farm and community disposal systems to meet regional salt balance requirements. This has included field studies to determine salt and water balances for on-farm evaporation basins, and the development of a salt and water balance model linking the farm and basin system. Comprehensive financial analyses have been used to determine optimum basin design considering both construction and maintenance costs and the tradeoffs between losses due to waterlogging versus loss of cropping area due to the basin.

The BASINMAN model was developed with the aim of increasing the understanding of the hydraulic relationships between the farmed area and basin system (Wu et al. 1999). The model allows analysis of the design of on-farm basins to minimise the basin area whilst controlling waterlogging. The model has proved a useful tool for analysing management practices and impacts of climate variability for on-farm evaporation basins with subsurface drainage system.

The model allows multiple sets of basin areas to be run on a daily timestep using 35 years of weather records. The output daily watertable height can then be analysed to assess the duration and extent of waterlogging in the farmland. These data can be used to aid in selecting a minimum basin area whilst constraining waterlogging to an acceptable level.

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