

## Is it Feasible to Restore the Salinity-Affected Rivers of the Western Australian Wheatbelt?

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**ABSTRACT:** Salinisation of rivers and associated low-lying land in the Western Australian Wheatbelt has already devastated large areas of stream, riverine and wetland ecosystems. The trend in salinisation is forecast to at least triple the area of land presently affected, with associated rises in stream salinity. The issue is whether this process can be reversed by revegetation and engineering works, and the extent of these works required to significantly remedy the situation. Against the background of vast stores of salt in the Wheatbelt landscape, the low hydraulic gradients and low hydraulic transmissivities, we conclude that it is unlikely that restoration of these systems within normal human time scales and under the present climatic conditions is achievable. Revegetation (tree planting) of up to 80% of the catchments would be required, and response times of salinity control would be long. Engineering (pumping) can have very local impacts on water levels if pumping is maintained in perpetuity and there are means to dispose of the resultant saline groundwater. Pumping can also restore the freshness of streams if maintained over a long enough time (many decades), but the disposal problem remains. Ethics compel a serious attempt at revegetation; practicality dictates local engineering solutions to protect our highest priority natural assets, possibly at the expense of systems downstream.

### THE MAIN POINTS OF THIS PAPER

- The salinity trends in the riverine environments of the Western Australian Wheatbelt are serious and are causing massive losses in biodiversity, productivity and asset value.
- Catchment scale remediation via revegetation, even extensive revegetation, will have only minimal effect in reversing salinity trends in the foreseeable future.
- Engineering solutions would also have to be extensive, may not produce significant salinity remediation in the short term, and are associated with off-site salinity impacts.
- Given the intractability of the salinisation problem in this region, investment in restoring these rivers may be better placed elsewhere, or focussed on the protection of (a few) key natural assets.

### 1. INTRODUCTION

In this paper we present the thesis that the river and riverine environments of the Western Australian wheatbelt are undergoing a process of induced salinisation on a spatial and temporal scale which precludes effective protection or restoration as a whole. We base this argument on an understanding of how these hydrological systems operated prior to land clearance and how they have changed, salinity trends and forecasts, and empirical and theoretical considerations regarding response to remediation.

### 2. THE SEVERITY OF SALINITY

The tributaries of the Avon River down to York, the Blackwood River down to Bridgetown, and the upper reaches of the Kent and Pallinup Rivers, all originate in the <600 mm annual rainfall zone, loosely termed the Wheatbelt of Western Australia.

Salinities in streams in this region have reached very high levels and are rising continuously (Salama and Bartle, 1998). The current estimate (Ferdowsian et al., 1996) of the area of these catchments affected by salinity at equilibrium is 40%; at present it is

approximately 10%. The impacts on the biota to date are most obvious in the lower parts of the landscape (Figure 1), but the relief of the wheatbelt is so low that a much larger area will be affected. At risk, or already affected, is 80% of susceptible remnant vegetation on farms and 50% on public lands (George et al., 1995). To date, degradation is focussed on wetlands and drainage lines. The beds and banks of 80 percent of the region's rivers and streams are seriously degraded (Anon, 1996). The degradation of wetlands is well advanced but largely unrecorded (Sanders, 1991; Anon, 1996).

### 3. THE ORIGIN AND CAUSES OF SALINITY

Salinity has always been, and will continue to be, a feature of the Wheatbelt landscape. From a geological perspective, the causes of salinity are ultimately the influx of airborne salt of oceanic origin and its accumulation in the regolith since a change in climatic conditions associated with widespread precipitation decrease in inland areas during the Late Miocene and Early Pliocene (Kemp, 1978). The native woodland vegetation developed under these arid conditions essentially deprived the rudimentary aquifer systems of recharge.

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**Figure 1.** A large salt scald in the upper Avon River system. The physical and biological character of the drainage lines has dramatically changed following clearing of the catchment.

The concentration of salts in the unsaturated zone, the concentration of groundwater following diffusive discharge upstream from geological structures (Salama et al., 1993), density driven flow from saline water ponded in flat areas behind geological structures (Wooding, 1989), and the damming of the major course of the Avon River during the uplift (Salama, 1997) all contributed to a naturally salinity-prone landscape. The decrease in precipitation and the prevailing aridity also caused the formation of sand dunes across river courses in the upstream parts which lead to the formation of series of ephemeral saline inland lakes (Salama, 1994). There can be up to 10,000 tonnes of salt per hectare beneath the Wheatbelt landscape (Anon, 1996).

It is therefore paramount to accept the fact that salt is part of the landscape and that there are huge amounts of salt stored in the ground. The intervention of human activities during the last 200 years (Olsen and Skitmore, 1991) disturbed the very delicate balance established during the last wet period (Hatton and Nulsen, 1998).

The modern rise in surface salinity is due to the increasing discharge of saline groundwater following clearing of the native vegetation. In uncleared subcatchments stream flow only occurs after periods of heavy rainfall and is low in salinity (typically less than  $500 \text{ mg L}^{-1}$ ). In cleared catchments, increased recharge has resulted in groundwater levels at the surface in most of the low-lying areas, and increased groundwater discharge along the channels that greatly increases the flow of the streams, with salinities fluctuating between 2000 and  $30\,000 \text{ mg L}^{-1}$  from first and second order catchments. Much of the high salt load comes from saline groundwater discharging along an extensive length of the stream channel.

Further, changes in river morphology due to increased flow velocities and duration are associated with the loss of surface clay layers and the exposure of more permeable sand layers in the river beds. This change provides greater connectivity between the saline aquifers beneath the streams and the streams themselves, thereby accelerating salinisation.

#### 4. THE EFFECTIVENESS OF REVEGETATION IN RESTORING THE SALT BALANCE

Given our understanding of the causes of induced salinisation, it is a logical expectation that planting deep-rooted perennials (especially trees) will restore a salinised landscape. While there is ample evidence that water levels decline under tree plantations, there is little empirical evidence that (a) the impacts on the groundwater hydraulic head surface propagate significant distances down gradient from the trees, or (b) that existing salinised land at the discharge end of a regional groundwater system recovers following tree planting upslope.

The only systematic catchment-scale studies of tree planting impacts on salinisation are associated with a region west of the Wheatbelt, with higher rainfall and hydraulic gradients (Bell et al., 1990; Bari and Boyd, 1994; Bari, 1998). Even in these more favourable catchments for remediation, low density plantings of less than 18% of the cleared area had little impact on catchment-scale responses (15% in Bell et al., 1990). High density plantings of 76% of the cleared area had a sustained and significant impact on salt loads, groundwater levels and streamflow. Plantings of 20-50% of the cleared area (focussing on lower slopes and discharge areas) have had insignificant impacts on stream salinity to date.

Arguments based on the results of Specht (1972), Pierce et al. (1993), Hatton and Wu (1995) and George et al. (1998) suggest that however trees are put back into the landscape, effective control of groundwater recharge will be achieved only at a leaf area index approaching that of the natural state, involving revegetation of most or all parts of the catchment.

There is the option of intercepting shallow (fresh) groundwater with trees before it interacts with deeper, saline aquifers. This is a more economically and socially attractive idea, because potentially less land may have to be afforested to achieve the same result. The idea is to place trees or similarly deep-rooted vegetation in landscape positions where they can access not only local rainfall but shallow, fresh groundwater from upslope areas as well. Thus, recharge can be intercepted before it reaches saline discharge areas. Where aquifers are sufficiently fresh and transmissive, this option is feasible. For instance, George (1990) demonstrated the potential for drying up sandplain seeps supplied by a perched hillslope aquifer by planting trees in an interception belt. The long-term effectiveness of such treatments is less clear, given the potential for these sites to eventually accumulate sufficient salt to kill the trees.

The key feature of the groundwater interception strategy is the placement of trees in landscape positions in which (a) the groundwater is reasonably fresh, (b) the groundwater is reasonably close to the surface, (c) the aquifer has reasonable transmissivity and gradient, and (d) the saturated thickness of the unconfined aquifer is limited (<10 m). This generally precludes the planting of trees on saline discharge areas *per se* and restricts application to a very limited fraction of the Wheatbelt. The lack of sustainability of trees at saline sites without sufficient periodic leaching of salts which otherwise accumulate in the root zone is well documented and modelled (Thorburn et al. 1995).

In a comprehensive assessment of the hydrologic effects of tree planting in the Wheatbelt, George et al. (1998) found that (a) trees planted in discharge areas have only a small impact on water levels, and only when the groundwater was reasonably fresh; (b) water levels *in local aquifer systems* only fall significantly in areas with a significant fraction (50-80%) of the land planted to trees; and (c) trees have little or no effect (yet) on watertables more than 10-30 m from the planted area.

There is no doubt that tree planting has local effects on groundwater levels, but major impacts on catchment-scale behaviour require significant areas of high density plantings and perhaps decades to show results in terms of reduced salt loads and stream salinity in the Wheatbelt.

## 5. THE EFFECTIVENESS OF ENGINEERING OPTIONS

Given the above constraints on reversing salinity with tree planting alone, we must consider engineering interventions to restore the Wheatbelt rivers. Detailed studies of engineering solutions such as extensive pumping in the Salt River and small pumping systems (windmills) and drains are described below. The results indicate that although groundwater levels and salinities can be reduced, the overall effect is small, local, and can take a long time.

### 5.1 The Salt River experiment

The Salt River lies within the Swan-Avon palaeodrainage system and is described by Salama (1997). Salt deposits occur extensively in lakes in the palaeodrainage system. Salt leached from the uplands is increasing and is discharged into the lakes through surface runoff and groundwater seepage, with associated loss in biodiversity.

Detailed hydrogeological studies were conducted in the Salt River system to study the aquifer characteristics, the recharge – discharge mechanisms and effects of extensive abstraction of brines from the paleochannels on the stream salinity (Salama et al. 1989). Three questions were asked in this study: (a) would extensive abstraction of groundwater reduce water levels in palaeochannels, (b) would pumping reverse salinity trends, and (c) would extensive removal of brines restore stream salinity?

The pumping tests indicated the alluvial sandy sediments of the Salt River System form a series of horizontally permeable layers that are interconnected with the stream through vertically permeable layers. In most cases these layers are separated by aquicludes that increase in thickness towards the banks.

Preliminary estimates of the region of influence of an extraction borefield were considered, assuming radial flow through spatially uniform aquifer materials. At a pumping rate of  $14\,000\text{ m}^3\text{ d}^{-1}$ , a transmissivity of  $100\text{ m}^2\text{ d}^{-1}$  and storativity of 0.01, the drawdown in pressure head after 1 year would be 1.0 m at a distance of 5 km and 0.1 m at a distance of 7 km. After 10 years the drawdown of 1 m will extend to 15 km while the 0.1 m drawdown would extend to 22 km. Due to recharge during winter it is more realistic to assume that the drawdown due to pumping will be seasonal with some effect being carried over into subsequent years. In some areas of the Salt River system the drawdown in pressure extends beyond the divide of the catchment. Such factors along with the variability of the aquifer structure and unknown distribution of geological discontinuities, suggests that drawdown of pressures within and along the River catchments may be irregular.

Given the uncertainties in the recharge rate during pumping, groundwater salinities were calculated for four different rates of recharge relative to the assumed rate of pumped discharge ( $8\text{ Mm}^3\text{ y}^{-1}$ ). Modelling indicated that, when the rate of recharge is 25% of the rate of pumping, the decrease in salinity will be very small over an extended period of time. For example, aquifer salinity is reduced by 16% of its original concentration after 50 years of continuous recharge with water 1/8 of the initial aquifer salinity. This rate of decrease in concentration increases with increase in rate of recharge. If the rate of recharge is set equal to the rate of discharge, which would be the best scenario, then after 15 years of pumping, the salinity of the pumped groundwater will still be 71% of its initial concentration.

The volume of brines in storage in the aquifer between Quairading and Qualandary Crossing is  $200\text{ Mm}^3$ , giving an average brine volume of  $4\text{ Mm}^3\text{ km}^{-1}$  length of the stream. The aquifer was found to be in direct hydraulic connection with the stream, receiving annual recharge from the streambeds, indicating that pumping during winter will increase these rates of recharge to the aquifer. Modelling of groundwater quality changes due to induced recharge rates from the stream showed that brine quality, taking the best scenario of 1:1 ratio of recharge to discharge, would lower the aquifer salinity by 30% in 15 years.

Pumping the required volume of brines from groundwater is likely to reduce pressures in the aquifers for distances up to 3 km depending on aquifer variability and will decrease discharge of saline water to the surface. If brines were taken from surface water within the Salt River system, surface discharge to the

Avon River may cease except in exceptionally wet years.

The extraction of salt from surface brines of the Salt River system at the rate of  $8 \text{ Mm}^3 \text{ y}^{-1}$  would reduce TSS levels at Brouns gauging station (615014) on the Avon River by between 5 and 42%, depending upon annual stream flow. This very expensive operation would require the construction of large evaporation ponds and/or finding a market for the produced salt.

### 5.2 The effect of small scale pumping in first order catchments

Long term field experiments and modelling in three wheatbelt catchments have shown that windmill pumping ( $15\text{-}30 \text{ m}^3 \text{ d}^{-1}$ ) in the wheatbelt can reduce water levels by 1 to 2 m at a radial distance of more than 1 km after several years of pumping (Salama et al., 1994). In most cases, discharge to streams of highly saline effluent is not allowed and saline water disposal requires on-farm evaporation ponds or sacrificial regional basins. The results also show that this is an interim solution only, as the water levels go back to original levels if pumping is discontinued and no other controls are in place.

### 5.3 The effect of drains

Agriculture Western Australia evaluated several types of drains intended to control surface salinisation (George, 1985; George and Nulsen, 1985; George and Frantom, 1991). Their studies indicate that due to the low hydraulic conductivity and gradients, the effect of drains on groundwater levels does not extend beyond a few metres from the drain. Thus, the density of such drains needs to be quite high before significant inroads are made on land salinisation, and the problem of the discharge of this saline water into drainage lines remains.

## 6. CONCLUSIONS

Salinisation in the Wheatbelt of Western Australia has already destroyed or degraded the majority of river and riverine ecosystems. Because the area affected by salinity is expected to triple or even quadruple, further loss of biodiversity and productivity is anticipated. The question we asked in this paper is whether or not it is feasible to try to completely save or restore these systems.

It is unlikely that salinisation can be significantly reversed with revegetation, at least within the time scales normally applied to human endeavours. The hydrogeological systems of the Wheatbelt are too saline, too flat and too untransmissive to respond quickly to tree planting. It is likely that there is substantial hysteresis in the relationship among tree clearing, salinity and tree planting.

Engineering can have positive local impacts on the salinity and water levels of Wheatbelt groundwater systems, but to substantially change the salinity of drainage lines would require pumping over very long

time scales, and with the associated problems of disposal of saline water.

We may have to accept that some changes in the hydraulic and hydrochemical characteristics of the system may be irreversible, at least from a human standpoint. The most pessimistic assessments suggest that the Wheatbelt will not be renewed (in a salinity sense) until the next geologic orogeny, a large change in climate, or until a new equilibrium is established between salt accession and discharge. Any of these eventualities is far in the future. Nevertheless, there is an ethical compulsion to bring to our land management as much of the original hydrologic function as possible. This apparently involves reforestation (the control of recharge) over large fractions of the landscape. In the short term, we may have to prioritise our natural assets and locally apply (expensive) engineering solutions to save them, perhaps at the cost of other assets downstream.

Many Australian streams are affected by or at risk from salinisation. In regions like the Western Australian Wheatbelt, there may be little we can realistically do to control or reverse this process. It is important to recognise, however, that there are many hydrological systems for which much can be done to control salinity.

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