Hydrological effects of floodgate management on coastal floodplain agriculture

Final report for project DAN13

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for Land and Water Australia

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Abstract

Extensive drainage systems have been constructed on coastal floodplains to mitigate the effects of floods and to enable the development of agricultural industries. They have also greatly increased the rate of acidity entering creeks and estuaries from acid sulfate soils, resulted in a loss of fish breeding habitats and led to changes in the vegetation composition of backswamps. Coastal drains usually have floodgates which prevent tidal inundation of backswamps and reduce the ingress of saline water along the drainage system. The floodgates also prevent fish movement and increase drainage of acidic groundwater.

This project has examined the processes causing poor drainage water quality from acid sulfate soil backswamps, quantified the water quality improvements resulting from floodgate opening strategies, quantified the effectiveness of acid groundwater retention strategies, and examined the salinity risks to sugar cane from opening floodgates.

The research identified that some acidic backswamps soils have very high saturated hydraulic conductivity (K_{sat}). These sites also have very high rates of acid export from groundwater seepage to the drainage system. An 'acid export window' concept was developed to explain observed acid export behaviour. It was shown that acid groundwater seepage can be reduced by up to 80% by managing drain water levels to reduce hydraulic gradients towards the drain. High K_{sat} sites are also at greatest risk of saline intrusion if floodgates are opened. The project also identified that drainage induced vegetation changes in backswamps has strong influences on both drainage water acidity and redox condition. Increased drainage acidity was associated with encroachment of *Melaleuca quinquenervia* into backswamps, whilst drainage water with very low redox potential and high deoxygenation potential was associated with inundation of flood intolerant pastures. The project produced a set of guidelines aimed at reducing the adverse environmental impacts associated with floodgates and coastal drainage systems.

Land and Water Australia: Final Report Summary

Project no: DAN13

Title: Hydrological effects of floodgate management on coastal floodplain agriculture

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Principal Investigator: Dr Peter Slavich
Research Team: Dr Peter Slavich, Scott Johnston, Phil Hirst
Date of report: June 2004

Project Objectives:
1. To identify and quantify the effects of changes to floodgate and land management practices on groundwater and surface water drainage processes (quantity and quality), soil water chemistry, fish habitat quality, and the agricultural productivity of land adjacent to tidal drains/streams and in low-lying acid backswamps.

2. To use this knowledge with councils, industry, and landholders to develop floodgate management guidelines based on general principles which when coupled with appropriate site specific knowledge will help improve water quality and fish habitat whilst maintaining productive agricultural industries and flood control on coastal floodplains.

Outline of project and methods
To fulfil the primary research aims (objective no. 1) the project was divided into a series of sub-projects, each with more specific aims and focus. The sub-projects encompassed issues belonging to four key research areas that relate to changing floodgate and land management practices. A summary of the four key research areas and associated sub-projects topics follows below (sub-project number in brackets);

1. Salt management and coastal floodplain agriculture
- (1a) Investigating the potential for lateral seepage of saline drain water into adjacent aquifers when opening floodgates.
- (1b) Identifying the source of salts in low elevation parts of the floodplain and assessing their effects on sugarcane yield.

2. Backswamp vegetation management
- (2a) Quantifying the extent of *Melaleuca quinquenervia* encroachment in a drained acid sulfate soil (ASS) backswamp and assessing the changes this has caused to groundwater and sediment geochemistry, particularly enhanced acidification of soils and water.
- (2b) Comparing forage pasture biomass / productivity and surface soil acidification processes in a 'wet managed' vs a 'dry managed' ASS backswamp.

3. Floodgate management and acid export management
- (3a) Quantifying the effects of opening floodgates and promoting tidal exchange on improving in-drain water quality characteristics.

- (3b) Assessing and comparing the acid flux dynamics of drained ASS backswamps in order to improve the understanding and of acid flux pathways.
- (3c) Quantifying the effect of using a drain water retention device (weir) at reducing acid flux from a coastal acid sulfate soil backswamp.

4. Re-flooding of backswamps – hydrology and surface water quality
- (4a) Assessing changes in drainage water quality from ASS backswamp after major flooding and quantifying the contribution of artificial drainage to an estuarine deoxygenation event.
- (4b) Assessing the effects of different vegetation types (grass species vs *Melaleuca*) on surface water quality following re-flooding of surface soils from an ASS backswamp.

Sub-projects were designed to address priority knowledge gaps. While most of the sub-project topics were developed via consultation with stakeholders prior to the implementation of the research, some sub-project topics emerged during the course of the project in response to new findings.

The main research methods used during this project were field based investigations / experiments combined with time series logging of environmental variables. This was augmented by laboratory analysis of soil / water / vegetation samples and some laboratory experiments. The main data types include; soil chemistry and soil physical properties; drain water and groundwater physico-chemical characteristics and chemical composition; river, drain and groundwater levels; drain flow volumes; cane yield; pasture yield; elevation surveys; aerial photograph analysis; EM38 surveying and meteorological data. Detailed descriptions of project methods are contained in each of the sub-project technical reports (Appendix C).

The major extension aim of the project (objective no. 2 – development of floodgate management guidelines) was completed in collaboration with the FRDC funded project and launched in January 2004. This document is hereafter referred to as the “Guidelines” (Appendix B). In addition to the Guidelines a more ‘farmer friendly’ series of six A4 leaflets was developed. The leaflets address key topics found in the Guidelines and were published in hard copy and are also located on the Guidelines website (Appendix B).

Summary of project results and activities to encourage adoption of project outputs
The main project results and a discussion of their practical significance, as well as specific activities undertaken to encourage adoption of this information is presented in relation to each of the four key research areas. See Appendix C for the full technical report of each sub-project and detailed lists of references relevant to each research area.

1. Salt management and coastal floodplain agriculture
<u>(Sub-project 1a).</u> The potential for floodgate opening to cause saline tidal overtopping and/or salt seepage into groundwater was investigated at a variety of sites. While there is potential for overtopping at many sites, there are floodgate opening designs that provide automatic closure and ensure a high degree of reliability in water level control – thus the risk of overtopping is relatively easy to manage. Salt seepage into groundwater is more challenging to manage. Key factors controlling the risk of salt seepage into groundwater were identified and include; soil hydraulic conductivity (K_{sat}), groundwater gradients, the balance between rainfall and evapotranspiration, site elevation and local tidal ranges. Among these factors K_{sat} was particularly important. Most sites on NSW coastal floodplains are likely to have soils with relatively low K_{sat}. In such cases lateral salt seepage is likely to be confined to several metres from the drain, depending on the balance of the other factors.

However, a significant finding of this project was the discovering the existence of soils with very high K_{sat} (>100 m/day) in some ASS backswamps (note that this is *not* universal to all ASS backswamps). Such high values had not been reported previously in Australian ASS and are due to the existence of dense soil macropore networks combined with the unique physical and chemical ripening processes that can occur in ASS. It was demonstrated that in such cases floodgate opening can cause tidal forcing of groundwater over large distances (>300 m) and also cause rapid (weeks) lateral salt seepage into shallow groundwater over 80 m from the drain. The ASS risk maps prepared for NSW provide a very useful existing means of identifying possible areas which *may* have high K_{sat}. These ASS backswamp areas constitute a relatively small proportion of the total area of coastal floodplains (~5 to 10%). In most cases in NSW they are used for low productivity grazing.

These results highlight the need for some assessment of the risk of lateral salt seepage *prior* to opening floodgates. A simple strategy to manage the risk of saline overtopping or salt seepage was developed and included in the Guidelines (pp. 31) and takes the form of a decision tree. Part of this assessment may require determination of soil K_{sat}. Given that many K_{sat} assessment methods are either technically challenging (relative to the target audience) or subject to substantial limitations, a very simple, semi-quantitative method based on pit-bailing techniques was developed by the project team for use in ASS areas (method includes a data analysis spreadsheet). A series of workshops are being conducted in NSW to extend this method to local Government, NGO's, agency staff, sugar industry extension officers and other key users of the Guidelines (6 attendees to date, a further 17 registered to attend). A downloadable copy of the method is available on the Guidelines website. The results and implications of this sub-project have specifically been extended to the sugar industry via newsletter articles and oral presentations to key sugar industry extension personnel (Appendix A). Managing salt water when opening floodgates was also the subject of one of the series of six leaflets and a conference abstract (Appendix B). A paper on this sub-project has been submitted to the international journal *Agricultural Water Management.*

<u>(Sub-project 1b).</u> The source of salts in low elevation parts of the floodplain and their effects on sugarcane yield was assessed at a number of sites on the Clarence River floodplain. At all sites the source of the salts was a combination of both connate marine salts and sulfide oxidation derived (acid) salts, with their relative dominance being site dependant and influenced by site geomorphic history. Both the marine and sulfide oxidation derived salts were directly associated with the underlying estuarine sulfidic material and their concentration in soil and groundwater was generally greatest at the sites with lowest elevation. A strong negative correlation between normalised cane yield and topsoil EC_e confirms cane is moderately sensitive to salt. Negative correlations between cane yield and the dominant saline anions in topsoil suggest cane has a higher degree of sensitivity to marine derived salts than acid salts; thus highlighting the importance of salt management when opening floodgates.

The normalised cane yield and topsoil EC_e data are presented in the Guidelines (pp. 29) along with discussion about the source of salts and the vital importance of skilfully managing floodgate opening to prevent saline contamination of agricultural land. This information was also the subject of a conference abstract, several extension newsletter articles and several oral presentations to key stakeholders and sugar industry extension personnel (Appendix B).

2. Backswamp vegetation management

<u>(Sub-project 2a)</u>. Analysis of time series aerial photography and original portion maps revealed that substantial encroachment of *Melaleuca quinquenervia* (broad-leaf paper bark) has occurred in some ASS backswamps since European occupation and drainage. Apart from the loss of productive grazing land, data show that the soil and groundwater acidity is much higher (7-10x) beneath these encroached areas. Intense, localised changes in groundwater and soil chemistry are evident with individual trees being the loci. Soil surface concentrations of acidity and soluble aluminium are also substantially higher in these areas. A range of possible mechanisms to explain these differences are discussed (Appendix C).

This is a completely new finding and has serious implications for the longer term management of vegetation and acid export from ASS backswamps were this phenomenon has occurred. In particular it is likely such areas are making a disproportionate contribution to acid flux and thus there is potential for targeted management of drains. Information from this sub-project was included in the Guidelines and was also published in *Australian Journal of Soil Research* (2003) (Appendix B). This sub-project has also been the subject of a conference abstract and has been extended to key stakeholders and industry via many oral presentations and several newsletter articles.

<u>(Sub-project 2b)</u>. The soil chemistry and biomass / productivity of two key forage pasture species was assessed in two acid sulfate soil backswamps. While the sites had similar elevations, soils and groundwater chemistry they also had a long term difference (>30 yrs) in their respective water management strategies. One site (Morans) was 'wet managed' with annual harvesting of freshwater from the adjacent river system by opening floodgates and using penstocks to retain surface water. The other site (Sweenys) was 'dry managed' and was drained in a passive fashion with no attempts to impede drainage or retain any surface water. Monitoring began in the spring following the large floods of 2001. The largest differences in biomass / productivity were evident in the *Paspalum distichum* ecotone, with Sweenys backswamp scalded and bare due to high concentrations of solutes and acidic ions in near surface soils. The solutes and acidic ions were derived from upward evaporative flux of sulfuric horizon groundwater from the capillary fringe. The 'dry managed' site was lacking a surface organic layer – an important feature which effectively enhanced the process of upward evaporative solute accumulation.

While 'wetter' management may encourage surface organic matter accumulation, reduce upward evaporative flux of toxic solutes and thereby improve productivity over time, this is not a certain outcome. Gains made in surface organic matter accumulation can be easily destroyed by other management activities such as overstocking or fire. This information is included in the Guidelines and has also been extended to key stakeholders and industry via oral presentations. A summary of the key principles related to wet backswamp management was outlined in an extension document sponsored and facilitated by this project (i.e. 'Coastal backswamps – restoring their values'; see Appendix B and Guidelines website). Further research at a wider range of ASS backswamp sites is required to evaluate grazing management systems that maximise both productivity and water quality outcomes.

3. Floodgate management and acid export management

<u>(Sub-project 3a).</u> Floodgate opening trials demonstrated the effectiveness of floodgate opening at improving in-drain water quality was largely dependant upon the frequency, magnitude and duration of opening. Short duration openings often caused limited, short term water quality improvements. Rapid reversion (hrs / days) in drain water quality often occurred after floodgate closure. This has led to a strong emphasis in the Guidelines on encouraging the use of automated systems that provide frequent tidal exchange, thus promoting more stable improvements in drain water quality.

Floodgate opening also caused changes in longitudinal drain water gradients and has potential to slow net drainage rates during non-flood periods. However, complex site specific interactions between drain water and adjacent groundwater can also occur. At one location, a four day floodgate opening event actually caused enhanced acid export in the period immediately following floodgate closure. There are also practical considerations which limit the efficacy of floodgate opening as a stand alone acid management strategy. The low elevation (close to mean sea level) of some acid sulfate soil backswamps combined with seasonal migration of the estuarine salt wedge means there is considerable potential for saline overtopping of what is currently agricultural land. This constrains the magnitude and duration of controlled tidal exchange. Also, it is during wet periods when acid drainage outflow to the estuary is greatest. At such times the salinity and acid buffering capacity of estuarine water is often low, thus reducing the capacity of tidal exchange waters to neutralise acidity.

Key information related to this sub-project was included in both the Guidelines and leaflet series and was also the subject of several workshop proceedings (Appendix B). This sub-project has been extended to key stakeholders, agencies and industry staff via many oral presentations and several newsletter articles as well as general media (Appendix A and B). A paper on this sub-project has been submitted to the international journal *Agricultural Water Management.*

Sub-project 3b). Understanding acid export pathways and dynamics is a key to developing sound management strategies to reduce export of acid and toxic metals. A major outcome of the project is improved understanding of acid export pathways and temporal dynamics as related to local hydrology. Differentiation is made between surface and groundwater pathways and a conceptual model of the typical acid flux dynamics associated with these two pathways has been developed and included in the Guidelines (pp. 25). The key characteristics that will cause a site to be dominated by one pathway or the other have also been identified (i.e. K_{sat} and the elevation of sulfuric horizons in relation to the local tidal minima in bisecting drains).

The sub-project led to the development of a new and important concept – i.e. the 'acid export window'. This refers to the backswamp water level elevation range within which most acid export takes place. Site specific identification of this range allows for better targeting of management efforts to reduce acid export. The soil hydraulic conductivity and groundwater gradients are identified as key factors driving acid groundwater seepage at high hydraulic conductivity ASS sites. Tidal modulation and local low tide levels play a vital role in regulating acid flux by a) controlling effluent groundwater gradients and also b) determining the lower boundary of the acid export window.

The understanding of acid export pathways and processes gained during this study has been used to develop a quantitative model (ASSESS) to predict acid export from drains carrying water from ASS backswamps. This is being used currently in assessing Environmental Services Scheme project sites. Information from this sub-project was included in the Guidelines and leaflet series and is also *in press* to be published in *Australian Journal of Soil Research* (2004) (Appendix A and B). This sub-project has also been the subject of a conference paper and has been extended to key stakeholders and industry via many oral presentations, newsletter and general media articles (Appendix A and B).

(Sub-project 3c). Following findings from sub-projects 3a and 3b, an acid retention trial was conducted. The aim was to reduce acid export by containing acid groundwater in the landscape and prevent it from entering the drain in the first place. The trial was conducted at a site where the main acid flux pathway was groundwater seepage. The method of achieving containment was to reduce the gradients that drive groundwater seepage by keeping the drain water level high and stable using an in-drain weir - specifically targeting the 'acid export window'.

Trials showed that this reduced acid groundwater seepage to the drain and increased the proportion of shallow groundwater lost from the system via evapotranspiration. The weir affected 60% of drainage network and observed and modelled data suggest acid flux from groundwater seepage was reduced by about 65-70%. Effluent groundwater gradients behind the weir were reduced by about 80%. The main effect of the weir was to reduce discharge volumes, although reductions in H^+ and acidic metal cation concentrations were also observed. This study demonstrated that a weir can be a highly effective means of reducing acid flux in coastal acid sulfate soils where main hydrological pathway of acid export is groundwater seepage.

However, the use of weirs raises a potential issue regarding fish passage. Collaboration with the FRDC project has ensured this issue has been integrated into the Guidelines. The Guidelines place an emphasis on site assessment and the use of such structures *only* in situations where there is likely to be substantial water quality benefits. Information from this sub-project was included in the Guidelines and leaflet series and is also *in press* to be published in the international journal *Agricultural Water Management* (2004) (Appendix B). This sub-project has been extended to key stakeholders and industry via many oral presentations, newsletter and general media articles (Appendix A and B).

4. Re-flooding of backswamps – hydrology and surface water quality

<u>(Sub-project 4a).</u> This sub-project led to a substantial improvement in current understanding of post-flood water quality dynamics and 'black water' events. Major flooding in 2001 was followed by extensive fish kills and deoxygenation in large areas of the Clarence River estuary and many other North Coast estuaries. Results showed that artificial drainage from ASS backswamps made a very significant contribution to the magnitude of the deoxygenation event – by influencing both drainage volumes and the chemical composition of drainage waters. Key factors include the rapid removal of anoxic surface waters from floodplain backswamps beyond what would have occurred naturally, and the anaerobic decomposition of flood intolerant pasture species coupled with Fe and S reduction / oxidation. A conceptual model of these processes was developed and is included in the Guidelines (pp. 38).

Without significant changes to the modified hydrology of floodplain ASS backswamps, drainage enhanced estuarine deoxygenation events of similar magnitude are likely to occur episodically in the future. This study suggests that retaining the last ~0.5 m of surface water in ASS backswamps after major flooding could substantially reduce the contribution of artificial drainage of ASS backswamps to estuarine deoxygenation.

Key information related to this sub-project was included in the Guidelines and was also published in the *Journal of Marine and Freshwater Research* (2003) (Appendix B). It was also subject of a conference abstract and has been extended to key stakeholders, agencies and industry staff via many oral presentations and several newsletter articles as well as general media (Appendix A and B).

<u>(Sub-project 4b).</u> Given the findings in sub-projects 2a and 4a and the fact that changing vegetation composition in ASS backswamps can potentially influence surface soil acidity and is also likely to have altered the characteristics of the surface vegetative carbon pool, there was a need to assess the implications of this for surface water quality following inundation.

Surface soils from an acid sulfate soil backswamp which had contrasting vegetative cover (i.e. grass species and *Melaleuca quinquenervia* litter) were inundated and monitored. The different vegetation types had similar biomass and carbon content, but large differences in the quality and lability of that carbon which strongly influenced decay / redox processes and the chemical composition surface waters. The grass species had more labile carbon. Their surface waters displayed rapid sustained O_2 depletion, sustained low Eh (~0 mV), high dissolved organic carbon (DOC) and moderate pH (5-6). Their soil acidity was partially neutralised, sulfides were re-formed and reductive dissolution of Fe (III) led to the generation of stored acidity in the water column as $Fe^{2+}_{(aq)}$. In contrast, *M. quinquenervia* litter was high in decay resistant compounds. Its surface waters had lower DOC, low pH (<4) and only underwent a short period of low O_2/Eh. Its surface waters also had higher titratable acidity due to soluble Al and neutralisation of soil acidity was limited. Concentrations of Cl^- and Al in surface waters were strongly correlated to initial soil contents, whereas the behaviour of Fe and SO_4^{2-} varied according to pH and redox status.

This study demonstrates that changes in vegetation communities in ASS backswamps which substantially alter either a) the pool of labile vegetative organic carbon or b) the concentration of acidic solutes in surface soil, can have profound implications for the chemical characteristics of backswamp surface waters. This study has implications for managing the quality of surface drainage waters associated with any projects which attempt to restore / manage or modify ASS backswamp hydrology in such a way that causes subsequent changes to vegetation communities. This study also has implications for the interpretation of surface water quality draining from ASS backswamps. This sub-project has been extended to key stakeholders and industry via oral presentations (Appendix A). A paper on this sub-project has been submitted to the *Australian Journal of Soil Research.* However no information was included in the Guidelines due to some of the experimental work still being undertaken while the Guidelines were in final production phase.

Summary of publications, and communication and extension activities

A wide range of publications, communications and extension activities were undertaken during the lifetime of this project (see Appendix A, B and D for full details). A brief summary is included here.

- **Guidelines**: 2000 copies of Guidelines printed (full colour). Launched by Federal Senator in January 2004. ~1200 copies distributed inter-state to key agencies, stakeholders and organisations.
- **Leaflet series**: 500 copies of each printed (full colour). Distribution to key agencies and stakeholder organisations.
- **Other extension documents**: ‘Coastal backswamps – restoring their values’ and ‘Hydraulic conductivity field test for shallow coastal acid sulfate soils’ developed and available on website.
- **Journal publications**: Four International Journal articles either published or in press to date. Three more have been submitted for publication.
- **Conference / workshop proceedings**: Nine in total, ranging from international conferences to local workshop proceedings.
- **Oral presentations**: A total of 29 presentations to a wide ranging audience with a combined total of over 1100 people.
- **Field method workshops**: Two to be held in northern NSW; 6 attendees at 1st workshop, 17 registered to attend the 2nd workshop.
- **Industry newsletters / articles**: A total of 21 articles specifically targeting industry groups or key stakeholders via various media.
- **Local print media articles**: 20.
- **Website**: Established in January 2004. Contains a summary of the project and copies of key extension outputs, including the Guidelines and Leaflet series.