The Role of Carbon in Facilitating Coastal Processes and Innovative Water Treatment Options

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Abstract

Coastal rivers and coastal processes, particularly in the subtropics, have been heavily impacted by vegetation clearing, changes in hydrological conditions and additional nutrients from point sources. This paper presents examples of innovative subtropical land management and water treatment systems which use ecological processes to provide low energy intensive nutrient removal from point sources and diffuse sources. National and global carbon emission trading schemes have the potential to transform the economy and environment of the Richmond River catchment through the establishment of reforestation systems to sequester carbon and improve water quality.

Innovative water sensitive design can use well-understood principles of ecosystem processes to treat water from diffuse sources, such as agricultural and urban runoff. Case studies in wastewater systems over ten years indicate these approaches consume less capital and resources, reducing greenhouse emissions. Establishing ecological systems to improve water quality also creates opportunities for carbon sequestration. Provision of carbon offsets represents a source of potential income for Councils and landowners. Carbon markets can provide an economic mechanism that helps fund key ecological rehabilitation projects. The role of carbon in providing water treatment and sequestration is described, using ponds, wetlands and forests for point and diffuse source pollutants.

We find that a targeted restoration program on the most degraded floodplain lands of the lower Richmond could yield net benefits of up to $109m over thirty years from carbon revenue and fisheries. Large-scale rehabilitation would also result in other significant but unquantified financial and social benefits for tourism, indigenous people, the local community and biodiversity.

Introduction

The Richmond River environment, in particular the lower catchment, is degraded with over 60% of wetlands lost since European occupation (Earley, 2000). Contaminants in runoff and groundwater from drained, cleared and often burned wetlands pollute many coastal rivers and estuaries of New South Wales (Johnston *et al.*, 2003a; Tulau 2007). Much of the forested land within the lower catchment has been cleared and extensive networks of drains constructed to allow agricultural development of floodplain areas.

Major fish kills have been experienced in the Richmond River over at least a century, with recent severe events occurring in 2001 and 2008, when some 50km of the river was deoxygenated with a significant impact on aquatic ecosystems (Eyre *et al.*, 2006; Sydney Morning Herald, 2008). Substantial work has been carried out in recent decades to identify and define pollution sources in the catchment and estuary (e.g. see Eyre *et al.*, 2006; Corfield, 2000, Sammut *et al.*, 1996). The Richmond River Estuary Processes Study (ABER and WBM) (2006) identified primary factors influencing declining water quality as:

- Catchment disturbance (primarily replacement of forest by intensive agriculture and urban development);
- Sewage Treatment Plants (STPs) and urban pollutant inputs and diffuse pollutant loadings;
- A range of issues associated with floodplain drainage including deoxygenation of flood waters, and monosulfidic black ooze (MBO) development, resulting in massive fish kills as well as general degradation;
- Chronic discharge of acidic water with sublethal impacts, such as red spot disease and calcium depletion, over longer time frames.

Wetland areas play a major role in the global carbon cycle, fisheries production and biogeochemical cycles. Undisturbed wetland areas accumulate organic carbon in both soils and vegetation (Lugo *et al.*, 1990). Drainage and clearing transforms wetlands from carbon sinks to carbon sources. Drainage results in oxidation and subsidence of organic soils thus increasing carbon emissions. Drainage of histosols and gleysols (wetland associated soil types) is estimated globally to contribute 30 to 300Mt (110 to 1100t of CO_2e) to the atmosphere per year (Armentano in Lugo *et al.*, 1990). In contrast undrained wetland soils sequester approximately 14M/tonnes of carbon (51t of CO_2e) annually (Armentano in Lugo *et al.*, 1990).

Reforestation of degraded agricultural land is an important response to climate change (Harris *et al.*, 2006), through storage of carbon in vegetation and soil. Emerging carbon markets will increasingly fund reforestation projects to create tradeable carbon offsets. A recent CSIRO report (CSIRO, 2009) indicates that storing carbon in the subtropical and tropical planted forests (biosequestration) and changing rural land use can potentially offset 25% (105Mt) of Australia's annual emissions. The significant finance now becoming available for reforestation creates an opportunity to also achieve ecological outcomes such as improved water quality.

This paper presents an integrated approach to dealing with both point and diffuse sources of pollution. Ecotechnological solutions based on biological processes are being utilised at some STP's in the catchment to mitigate point source pollutants. Case studies presented in this paper demonstrate the economic and environmental benefits of ecotechnological solutions for treating point source pollutants. We also present an economic and environmental assessment of the role of carbon in rehabilitating the lower floodplain and addressing diffuse source pollutants from agricultural land. The complex issues surrounding land use change that result from large scale rehabilitation are recognised; however this paper focuses primarily on the economic and environmental factors that may inform the larger debate about the costs and benefits of land use changes.

Carbon

Carbon markets create a new economic and environmental opportunity for the lower Richmond. The Australian Carbon Pollution Reduction Scheme (CPRS) will drive substantial investment in reforestation in Australia. Reforestation projects of different types provide substantial differences in their contribution to ecosystem services and acceptance by local communities. Whilst CPRS regulations explicitly ignore externalities of reforestation (Australian Government, White Paper, 2009), existing carbon markets offer premiums for sequestration projects with enhanced community and environmental outcomes (Ecosystem Marketplace, 2009).

Whilst uncertainties surround the timing and magnitude of a carbon price, carbon finance is already available and would provide the regional economy with a financial hedge against climate change policy. It offers landholders a diversified income stream which can offset negative cost impacts for farm inputs.

This Paper evaluates the potential of carbon markets to assist in restoring ecological processes in the lower Richmond catchment and improve water quality. The model presents a framework for landscape-scale rehabilitation of vegetation communities and remediation of floodplain biogeochemical processes.

The Richmond River Catchment

The Richmond River Catchment area is approximately 6,900 km^2 in area (Ballina Shire Council, 1997; Eyre *et al.*, 2006). The catchment is characterised by steeply sloping areas in the north and west and a broad area of low lying floodplains in the south and east of the catchment. The tidal range of the Richmond River extends 40-50km inland to the junction with Bungawalbin Creek (McKee and Eyre, 2000). The floodplain area below the tidal limit of the Richmond River comprises an area of 1070 km^2 or approximately 15% of the entire catchment (Figure 1). Earley (2000) concluded that 60,000-120,000ha of the total catchment could have historically been occupied by wetlands. Current land use in the lower catchment is predominantly sugar cane production and cattle grazing, with smaller areas of tea-tree oil and soy beans (Eyre *et al.*, 2006).

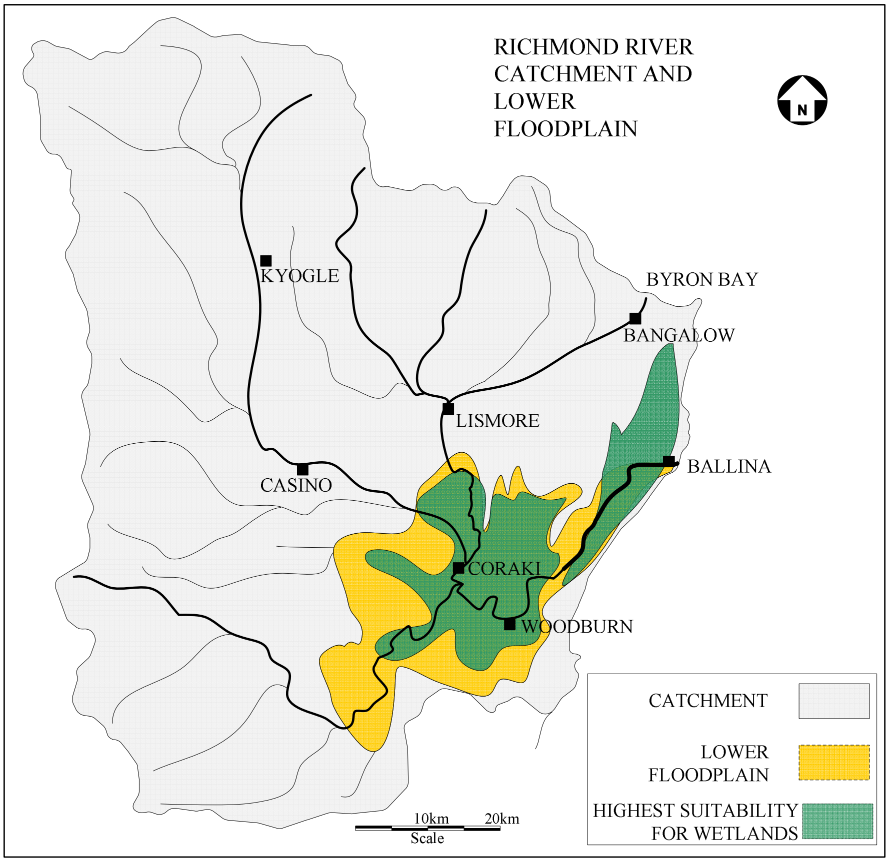


Figure 1: Richmond River catchment map
(Wetland suitability area sourced from Earley 2000)

Important diffuse pollutant sources in the lower Richmond floodplain include urban runoff, septic tanks, agricultural nutrients and acid sulfate soils. Floodplain drainage has altered carbon export rates on the floodplain by increasing the oxidation of stored carbon. Drainage also acts to increase deoxygenation and discharge of unstable materials such as iron and labile fast-degrading carbon in out-flowing floodplain waters (Johnston *et al.*, 2003b). Along with fish kills, these acidic materials are known to cause sub-lethal impacts such as Red-spot disease in fish, damage to shell development in prawns and crabs, and decreases in oyster production among other ecological changes.

Many studies have examined food chains in aquatic ecosystems and although the processes are complex and difficult to measure, a strong consensus has emerged about the role of carbon. McComb and Lake (1990) described the detrital pathway of bound carbon degradation and energy yield, beginning with plant photosynthesis in wetlands, then breakdown of the organic molecules with their rich energy stores and balanced nutrients, by micro-biota. These microbial virus and bacteria populations are then consumed by larger organisms in a food chain that features increasing orders of animal life (Dr. Mary White pers. comm. 2009). The aquatic food web is based on solar energy and its transfer through many trophic levels, expressed finally as fish stocks. The components of the Richmond River estuary food web and the linkages between organic carbon and primary and secondary production (ABER and WBM, 2009) are shown in Figure 2.

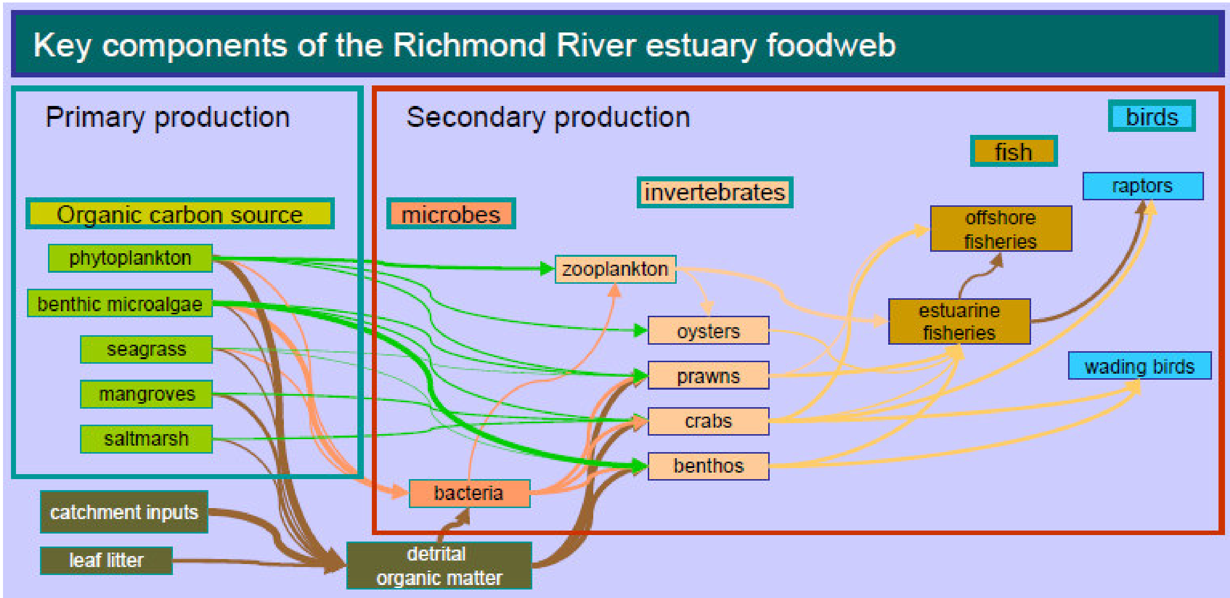


Figure 2: Components of the Richmond River estuary food web (Source: ABER and WBM Oceanics)

Eyre *et al*., (2006) estimated an inundation area for the Richmond River floodplain during the 2001 flood event of 31,000ha. The study concluded that that this area is likely to contribute to deoxygenation events in the lower Richmond floodplain, and that areas west and southwest of Coraki are critical to river water quality after flooding.

In addition to the diffuse sources, STP discharges are identified as point source pollutants in the Richmond River (McKee *et al*., 2000). The impacts from STP pollutants carry a higher risk in drier times when algae and warm waters provide favourable conditions for damaging blooms. In response to past water quality problems, Biological Nutrient Removal (BNR) systems with sequential aerobic and anaerobic processes have replaced trickling filters in many areas across Australia. Membrane Bioreactors (MBR) and variants involving fine filtration have also increased in number. The technology improves treatment but requires increases in capital and operational costs, and greenhouse gas emissions from construction and operational inputs.

Lismore provides a case study where a modern treatment plant and an ecotechnological system operate in the same city, and discharge into the Richmond River. The following section shows results from innovative ecotechnological systems offer a lower cost alternative for effluent treatment and reuse, and provide confidence in using these principles for biogeochemical remediation on the floodplains. We examined two years monitoring results from two medium-size STPs and associated wetlands. The analysis shows that treatment wetlands can consistently reduce Total Nitrogen concentrations to less than 1mg/L, and other parameters such as Suspended Solids and BOD_5 to low levels.

STP's and ecotechnological innovation

Case Study 1: South Lismore

The 22,000ep South Lismore STP was built in the 1930s as a trickling filter system with settling ponds. Constructed wetlands were added in the early 1990s but design and operational problems led to compliance failures for suspended solids and phosphorus. The wetland system has since been redesigned (by author D. Pont) and weekly Suspended Solids outflow concentrations over the one year period to March 2009 provide an interesting comparison with the BNR results from the modern East Lismore STP (Figure 3). Despite the use of older primary treatment technology the trickling filter-pond-wetland combination at South Lismore shows generally better and more consistent results (Figures 3 and 4), with these results being achieved at a far lower cost, and with much lower external energy requirements.

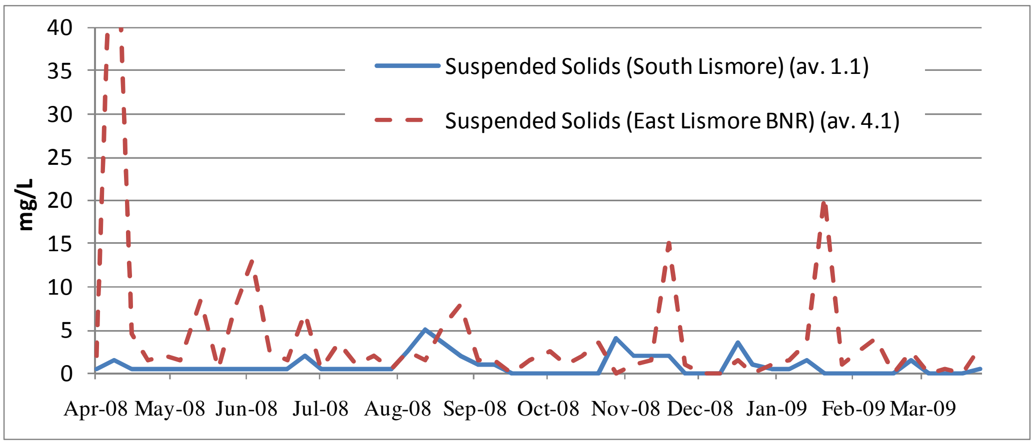


Figure 3: Suspended Solids outflow concentrations from two Lismore STPs

The results show reduction in TN concentrations, with one rainfall-related spike of 4mg/L removed to show a four-month mean of 1mg/L (Figure 4). These levels of STP outflow quality indicate Lismore City Council is working effectively to minimise the impacts of point source pollutants from STP's on the river.

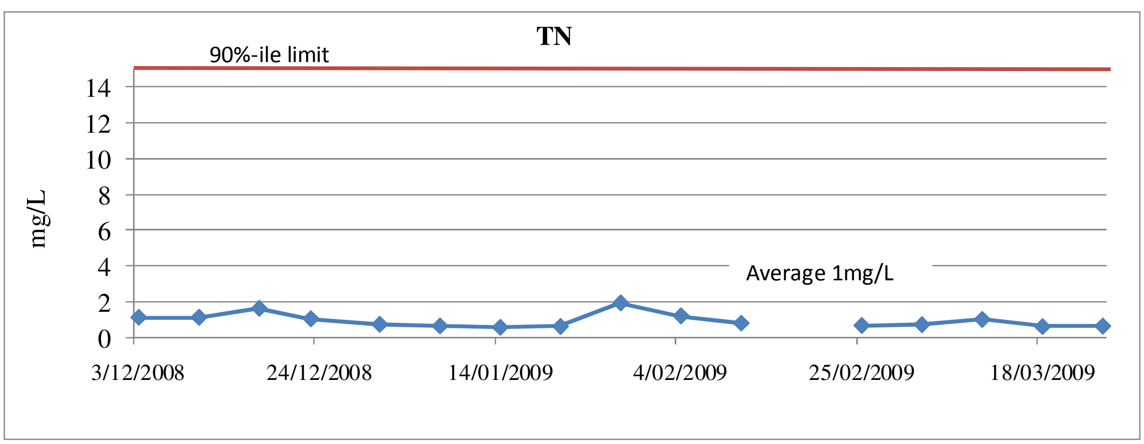


Figure 4: Total Nitrogen outflow concentrations from South Lismore STP.

Comparing capital and operational expenditure of an ecotechnological solution system with an Activated Sludge replacement plant, shows that treatment performance is not the only area where natural treatment systems surpass "steel and concrete" systems. We have also undertaken an economic assessment of an ecotechnological wetland treatment system integrated with an older trickling filter system and compared its operational and capital costs with an Activated Sludge replacement plant.

A hypothetical 10,000ep treatment plant in a regional area with alum dosing employed for both the Activated Sludge plant and trickling filter wetland system was costed over a 25 year period. Typical costs for wetland treatment systems were based on project experience with costs for Activated Sludge replacement derived from recent reports. The economic analysis demonstrated that the 25 year cost for a pond-wetland combination is $635/ML compared with $1,945/ML for an Activated Sludge plant.

Case study 2: West Byron

The West Byron STP is a 7ML/day modern BNR plant commissioned in 2005, with 6ha of constructed wetlands. The results from a two year monitoring period show substantial reductions in all water quality parameters (Figure 5) with wetland outflows approaching natural wetland outflow quality.

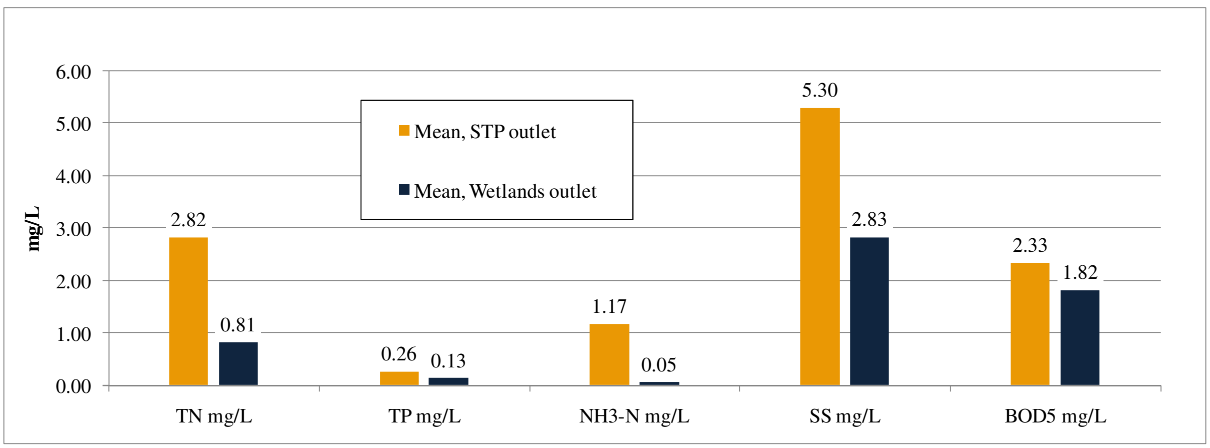


Figure 5: West Byron Wetland inflow and outflow concentrations, 2006-08.

Effluent reuse on melaleuca carbon sink forest

In association with the constructed wetland, 600,000 *Melaleuca quinquenervia* trees were planted across 24ha as part of a wetland forest effluent reuse trial. The project resulted in beneficial effluent reuse with a reduction of discharge and effluent impacts, restoration of original vegetation, acid-sulfate soil management, biodiversity and, in particular, recent monitoring demonstrates high carbon sequestration rates of wetland forest systems. The data obtained from measuring carbon stored at West Byron underpins later assessment of carbon sequestration rates in this Paper (Water and Carbon Group, 2009).

Rehabilitation and remediation framework

For this Paper an area of 10,000ha on the lower Richmond floodplain has been designated for rehabilitation as it is consistent with the Eyre *et al*. (2006) study and provides a suitable scale for economic assessment. The rehabilitated area must be of sufficient scale for ecosystem services benefits to be achieved.

At this stage no specific parcel of land has been identified for rehabilitation. Guidance on coastal floodplain rehabilitation projects is provided by publications issued by State and Commonwealth governments and research bodies. The NSW Government-endorsed documents *Restoring the Balance* (Johnston *et al*., 2003a) and the Acid Sulfate Soils Remediation Guidelines (Tulau, 2007) recommend a general strategy for practical remediation (simplified):

- Use water retention structures to reduce seepage of acidic groundwater to drains located in acid sulfate soil backswamps. These structures can also control unwanted intrusion of saline water and reduce the risk of peat fires. Water retention strategies can also be used to reduce the drainage of acidic or deoxygenated surface water and aid the establishment of wetlands;
- Drain redesign, including filling in unnecessary drains, and replacing deep drains that intercept groundwater with shallow drains which remove only surface water;
- Use of chemicals such as lime where appropriate;
- Modify existing floodgates to enable controlled tidal exchange of drain water to improve water quality in the drains and enhance fish passage and habitat (although this strategy carries the risk of decreased water quality in the river).

The site hydrology will be amended, primarily by raising the water table. Modifications to drainage will be carried out where impacts on neighbouring land uses and upstream properties are minimal. Holding water on the floodplain for longer, by reducing drainage, will approximate natural processes by allowing more infiltration, and by encouraging regeneration of inundation-tolerant wetland vegetation.

The depth, duration and seasonality of inundation are the major factors that influence wetland vegetation (Brock, Boon and Grant, 1994). A profile moving from the centre of a wetland outwards will show significant variation in vegetation type. The vegetation in the centre of the wetland will be comprised of aquatic species, whilst further along the profile emergent species tolerant of some inundation will be found, then shrubs tolerant of short periods of inundation and finally to species that are less tolerant of inundation.

In developing the model for rehabilitation, four broad ecological zones were defined: mixed terrestrial forest, lagoons, macrophytes and wetland forest, to reflect the likely topographic situation in many floodplain areas (Figure 6). The areas of each zone have been approximated in order to provide a basis for economic modelling. Distribution of lagoons and forest should be determined once site characteristics such as topography and soils have been ascertained. Figure 6 sketches an outline of a typical 10,000ha block for remediation.

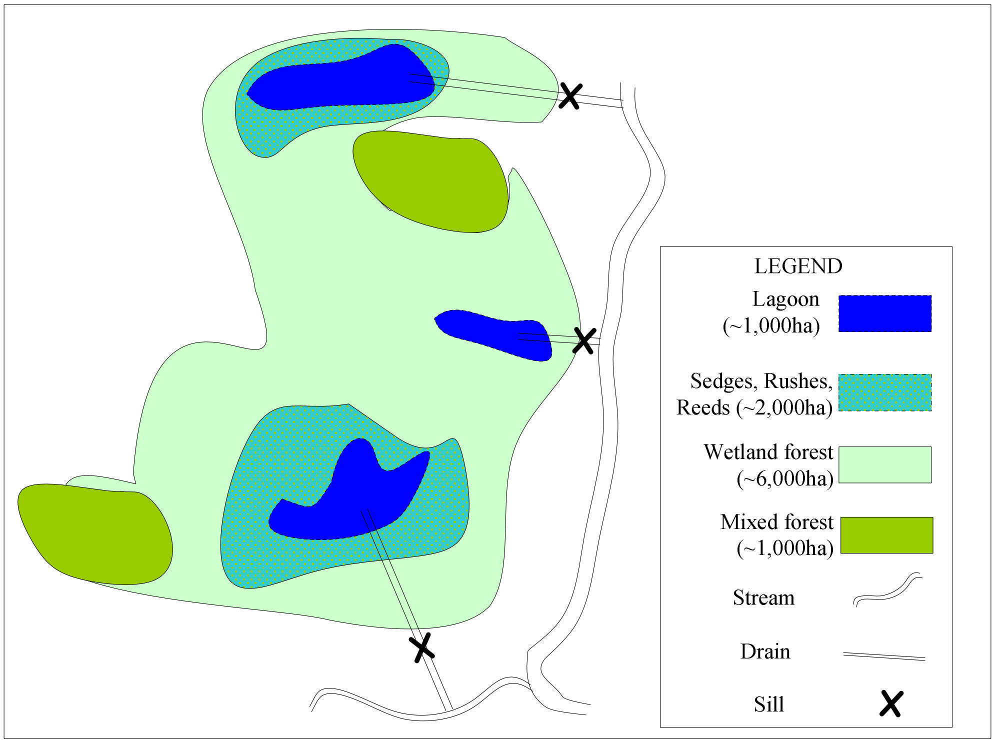


Figure 6: Schematic layout of a hypothetical rehabilitation site on the Richmond River floodplain

A large-scale rehabilitation program in the lower Richmond may follow these steps:

1. Obtain funding based on a detailed project description and application;
2. Topographic survey to determine fine-scale elevation contours, ideally at 100mm intervals, as a basis for Digital Elevation Mapping (as recommended by Earley, 2000);
3. Vegetation and drain mapping – relict and incidental wetlands are likely and should be used to guide management and design; many drains are currently mapped but fine-scale understanding of individual drains will be needed;
4. Hydrological and hydraulic modelling;
5. Integration of these components 1-4 into a remediation/management plan;
6. Community consultation on the draft plan;
7. Implementation of the plan with a strong focus on adaptive management: main implementation tasks include drainage amendments, vegetation planting, ongoing management of drainage and plantings, review and adaptation.

Economic modelling of rehabilitation on the Richmond River floodplain

The overarching economic question is: do the benefits from remediation of the nominal 10,000 priority hectares outweigh the costs? To answer this question our analysis seeks to review land use decisions from two perspectives: the landholder and the broader community. The former is important for considering what factors currently influence land use decisions. At the broader community level we seek to understand if proposed changes in land use have a net positive impact in social, economic and environmental terms.

When creating the economic model we have adopted conservative estimates, extrapolated costs and benefits across a 30 year time horizon, assumed scale efficiencies and accounted for uncertainties through sensitivity testing, and retained a 15% contingency of carbon credits to mitigate risk.

Economic model inputs and assumptions

Areas for each vegetation type and lagoon area that have been use to determine carbon sequestration and economic values are shown in Table 1.

Table 1: Nominal areas of proposed vegetation types and zones

Zone	Area (ha)
1. Lagoons	1,000
2. Wetland macrophytes	2,000
3. Wetland forest	6,000
4. Mixed forest	1,000

Net present value (NPV) analysis is a method of assessing project economics over a relatively long period. It expresses the future worth of a project in today's money. A lower discount rate will favour a project with a large initial investment and longer period to return on investment. A higher discount rate will favour a staged investment and earlier payback. We have modelled a 5% and 10% discount rate.

The total investment required at the NPV discount rate of 10% including project development, remediation of drainage costs, reforestation costs and land value is shown in Table 2. Conservative carbon sequestration rates have been informed by measured sequestration rates in wetland forest (Water and Carbon Group, 2009) and subtropical forest (Glencross and Nichols, 2005; Glencross, 2007), and National Carbon Accounting Toolbox models. Drainage and wetland rehabilitation costs include the cost of establishing lagoon areas in Zone 1, management of weeds, macrophyte planting, management and monitoring of drainage and installation of sills. Reforestation and wetland rehabilitation costs have been estimated based on project experience and from previous studies of the Richmond catchment (Read Sturgess and Associates, 1996).

Returns from carbon, produced over long time periods, are highly dependent upon the timing of sale hence many project developers forward-sell carbon. Our upper estimate of carbon income assumes the first 10 years carbon are forward sold at $20/t then moderate market prices pertain for years 10-30. Our lower estimate assumes low market prices for all 30 years.

Table 2: Total investment required

Item	Net present value 10% discount rate
Project development	$400,000
Drainage and wetland rehabilitation	$1,600,000
Zone 3 wetland reforestation	$16,400,000
Zone 4 mixed species reforestation	$3,600,000
Subtotal	$22,000,000

Whilst control of existing acid sulfate conditions in individual floodplain zones has been demonstrated, it will not be simple on a landscape scale. Many constraints to restoration and remediation are apparent including fragmented ownership across floodplain areas and the complexity of their hydraulic and hydrologic management.

Discussion of the economic model for rehabilitation on the Richmond River floodplain

The 1996 Tuckean floodplain study (Read Sturgess and Associates, 1996) provided benefit-cost estimates for the restoration of 700ha of Richmond River floodplain land, finding that investment would yield benefits in excess of costs by 1.1 – 6 times due to higher fish yields and increased productivity of connected agricultural land. Considerable increases in the value of nature-based tourism were forecast but not estimated due to measurement costs. Despite this compelling investment proposition, very little has changed, river water quality has not improved, and fish kills continue, although excellent individual projects have been carried out on a small scale. The new market for carbon presents the opportunity for income from reforestation which was not included in the Tuckean floodplain study.

Although important, we have not modelled any land purchase costs since:

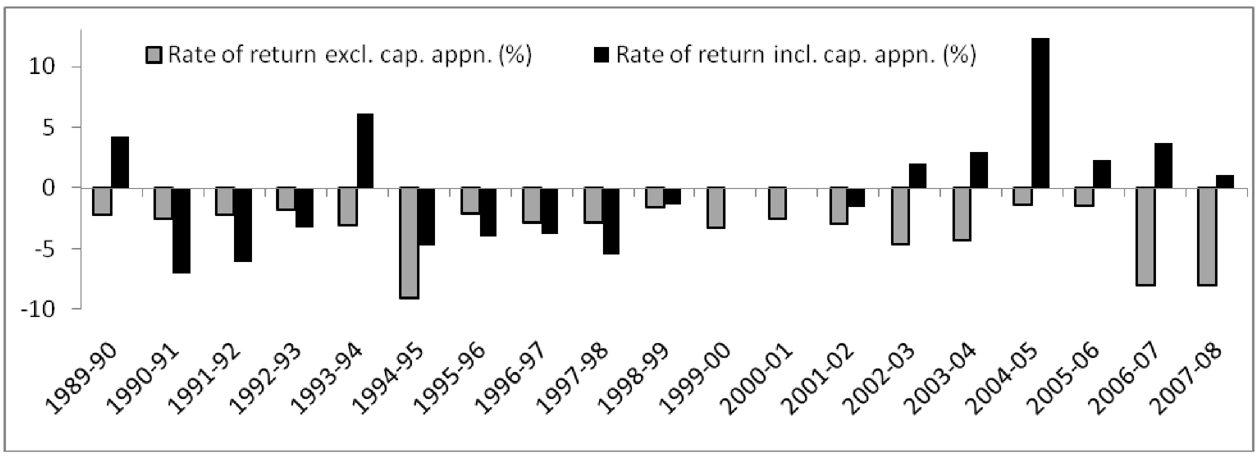
- Existing landholders may make the investment;
- Higher land-use values typically increase land prices. Although we expect our system to increase land-use returns from carbon and potentially water quality payments, the market impact of converting land from an agricultural system to a carbon system has not been observed;
- Land values on the north coast significantly exceed production values owing to strong demand for lifestyle properties. Our system does not conflict with feasible floodplain development.

We expect the rehabilitation project could involve incentives to assist landholders undertake the investment themselves, lease payments or land purchase under a rolling fund approach, for example as under the Bush Heritage model.

ABARE data for the return on investment for NSW coastal region grazing, the predominant land use across the lower floodplain area, estimate that the average grazing enterprise has recorded negative operating returns since 1990 (Figure 7). Northern NSW sugarcane producers have also recorded operating losses over the last three years (ABARE, 2009). Whilst land capital appreciation and off-farm income often provide overall profitability the average rate of return on capital since 2000 is well below commercially attractive returns at 2.8%.

Economic multiplier effects from agriculture are not unimportant. However they are eroded by environmental degradation such as the loss of fisheries value and, we believe, dwarfed by the multiplier effects resulting from the upfront capital investment of $22m (excluding land purchase) into the region and ongoing economic benefits from fisheries, biodiversity, tourism and community well-being.

Figure 7: Average beef enterprise returns including and excluding land capital appreciation: NSW Coastal Region (Source: ABARE, 2009)



Ballina recreational and commercial fishing values are significant. Geolink (2007) estimated a recreational fishing value of $5.3M per annum to the Ballina regional economy. The commercial value of the fishery, has increased steadily, valued at $3,800,000 in 2005-06. This resulted in a net margin of $950,000 to the Ballina fishers. 428 tonnes were harvested from the river in 2005-06, down from highs of 785t (1991-92) and 715t (1995-96).

We don't have data for the commercial ocean fishery component but, conservatively, we estimate it to be 3 times the size of the river fishery. There is abundant research confirming close linkages between the wetlands-estuary-nearshore fisheries continuum hence we estimate that the river's health influences 80% of the ocean fishery, which would extend over a substantial area of the continental shelf zone north and south of Ballina. We have therefore assigned a value of $20.6M to the total current fisheries value of the Richmond River and its offshore fisheries.

Table 3: Commercial and recreational fisheries values

Fishery	Amount ($)
Recreational (total value for visitors and resident anglers)	$5,372,100
Commercial (river)	$3,800,000
Commercial (estimated ocean prawns, crabs and fishes)	$11,400,000
Total	**$20,572,100**

Whilst a more abundant fishery enables a proportionately larger commercial catch we do not know of a straightforward relationship to describe how it would impact recreational fishing values. We forecast it to be strongly positive but for our purposes recreational fishing values are not modelled. We estimate that the remediation of 10,000 ha of high-value floodplain wetlands will lead to at least a 10-25% increase in fish stocks after 5 years through reduction of fish kills and other impacts, as well as resulting in positive benefits from food chain processes. Results are presented below in Table 4.

Table 4: Estimated increases in commercial fishing values following rehabilitation

Increase in Commercial Fisheries Value following rehabilitation			
% Resource Change	+1.8%	+10%	+25%
NPV @ 10% discount rate	$1,711,929	$9,510,715	$23,776,786
NPV @ 5% discount rate	$3,235,731	$17,976,281	$44,940,702

The drainage component of the remediation investment costs approximately $1.6M. Using a commercial discount rate of 10% a fishing resource increase of just 1.8% starting 5 years hence would provide a break-even benefit-cost ratio. Given we expect the fisheries resource to increase by at least 25% following the remediation of the 10,000ha we expect benefits to exceed costs by 14-27 times.

Northern Rivers tourism is estimated at $847M/yr (Tourism NSW, 2009). As with recreational fishing we provide no estimate of the benefits of environmental rehabilitation. Whilst many tourists enjoy non-environmental aspects of the region and the beach, it is still worth considering the broader consequences for local tourism from fish kill events which also result in nuisance odour and mosquito plagues.

Costanza *et al*. (1997) argued that the critical services provided by ecological systems should be realistically priced in strategic assessments of land use. Ecological services such as clean air and water, and natural capital stocks such as forests and soil directly and indirectly contribute to human welfare and should be regarded as part of the total value of the economy. The study assessed the values of services from a range of ecosystem functions such as CO_2 balance, storm and flood protection, erosion control, nitrogen fixation, pest control and many others. The study concluded that the highest value ecosystem type on the planet is estuaries, with a value of $US22,832 per ha per year. Second highest was "Swamps/floodplains" at $US19,580 per ha per year. These are surprising figures and may not be seen as realistic. However, the question arises: what *is* a realistic valuation model for these ecosystems? Table 5 presents a summary of results for our modelling of the proposed scheme.

The major financial benefit of the reforestation and rehabilitation system proposed is revenue from carbon credits. The investment produces a positive NPV at a 10% discount rate under all scenarios evaluated. Carbon returns are between $16M and $66M at a 10% discount rate (Table 5). This result indicates a strong business case for the proposed project. The addition of projected fisheries income further enhances the economic case for rehabilitation.

It is important to note that the return from fisheries will not be realised without hydrological remediation. The income from fisheries will be delivered offsite so there is a risk that if carbon sequestration is the only driver, land holders will not undertake the necessary remediation. Whilst there is now an incentive to fund reforestation from the carbon market, there is currently no incentive for landholders to fund the required hydrological works alongside reforestation. The optimum action in an economic sense for a landholder is to plant trees without implementing hydrological works. There is also no mechanism to encourage a landholder to plant a biodiverse forest rather than a monoculture. We anticipate that a large scale change in land use of this extent will require environmental impact assessment. The process should facilitate hydrological remediation and establishment of a biodiverse ecosystem.

Table 5: Summary of Investment returns

		10% Discount rate	**5% Discount rate**
Costs		-$21,974,601	-$25,041,473
Carbon	Moderate	$66,798,920	$83,191,074
	Low	$16,869,035	$29,310,405
	Tax Rebate*	$3,761,250	$3,761,250
Fisheries	High Response	$26,154,465	$47,187,737
	Low Fisheries	$5,230,893	$9,437,547
Total	**Upper**	**$74,740,034**	**$109,098,589**
	Lower	$125,328	$13,706,479

**Tax concessions are available for reforestation projects. We have not included this benefit in the low estimate.*

Since hydrological remediation across all 10000 hectares is required to improve water quality, carbon financed reforestation will not fund the entire remediation project. Hence government intervention can play a positive role in facilitating the provision of funding for necessary remediation works. It can either provide the funding itself or it can enable investors to access the benefits. To complement carbon income, some mechanisms that could be used to assist an investor, public or private, to recoup funds include:

1. *The government purchases the target land and funds the reforestation and remediation*

Full or partial funding could be treated as a community development expense justified on the same grounds that governments utilise to subsidise roads, electricity or water infrastructure e.g. economic growth, employment and environmental sustainability.

2. *Government facilitates funding for remediation*

The government could support private investment through creating a mechanism to enable landholders to benefit from investing in the hydrological works and biodiverse forest (as opposed to a monoculture). This could be a payment via an annual tourism or fishing licence levy, tax incentives or a special purpose biodiversity fund. Alternatively, landholders could be levied for discharging acidified water.

3. *A premium carbon credit brand is established to fund reforestation and remediation*

The establishment of an eco-brand for carbon credits produced by the scheme could attract market premiums that help to fund the additional works. Government and local business could support the scheme through committing to long term secure off-take agreements for branded carbon credits. This is the only option that could proceed without government intervention. It would require commercial risks and, due to the competitive nature of the carbon market may not be capable of providing all the funding required. Unless a clear investment return mechanism is created for the additional benefits it's unlikely they will be provided at a sufficient quality.

Summary and the case for rehabilitation

There is an urgent need for a change in land use and management on some of Australia's damaged landscapes in the interest of resource management and biodiversity. Our financial modelling based on a nominal 10,000ha of floodplain remediation strongly suggests a positive business case for seed funding by government with a possible beneficial scheme for landholders. Our economic modelling although based on limited data demonstrates that income from carbon could facilitate change whilst providing an income from land rehabilitation.

The benefits to fisheries are currently poorly quantified but improving water quality, catchment health and increasing the supply of refractory organic carbon will undoubtedly produce benefits to commercial and recreational fisheries. In addition to the income from carbon sequestration, benefits such as a reduction in fish kills will flow from the rehabilitation project.

A range of supplementary benefits are likely to result from rehabilitation including improved productivity of aquatic systems, biodiversity, water quality, flood mitigation and moderation of climate change impacts. These benefits would enhance fisheries resources, improve tourism appeal, create opportunities for indigenous community participation, and diversify and thus increase the resilience of the local economy and improve local community well being.

This Paper has demonstrated that carbon-based water pollution solutions are effective and can assist in rehabilitating the severely degraded Richmond River. The advent of a carbon market provides a new source of funding the landscape-scale land use change that is necessary for river rehabilitation.

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