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TOWARDS SUSTAINABLE LANDUSE WITHIN ACID SULFATE SOIL LANDSCAPES:

A Case Study on the Maria River, New South Wales Australia.

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SUMMARY
Landuse in the Maria River is afflicted with social inefficiency, brought on by the impacts from the drainage of Acid Sulfate Soil (ASS) for agrarian purposes since the early 1960s. This social inefficacy has manifested in the recurring losses in oyster and fishery yields and the reduction of non-market values inherent to the Maria River. Results from a rudimentary water balance model indicate over 3,300 tons of acid from management priority areas has discharged into the Maria since 1990. The management of ASS in NSW is now at the stage of implementing numerous rehabilitation programs of which one is for the Hastings catchment in which the Maria River is located. However efforts to resolve ASS impacts in NSW have been hindered by an alarming degree of farmer resistance which is fuelled by numerous socio-economic factors afflicting the primary industry.

This paper concludes that underlying socio-economic impediments afflicting farmers must be adequately resolved using a community-based management approach as a proviso to the successful implementation of technical strategies. Moreover this approach suffices the objectives of sustainability, of which Australia is committed to through the signing of *Agenda 21*.

The management of the Maria is cost efficient, even without the quantification of non-market values. The Benefit Cost Ratio of implementing the proposed management is in the range of 1.1 to 3. Or alternatively the full reinstatement of the oyster industry and an increase of 7-15% in the commercial and recreational fishery industries would justify the implementation of the proposed strategy. However the cost effectiveness of management is highly susceptible to the climatic fluctuations, farmer compliance and the ability to predict climatic fluctuations. Simulating acid discharges using a rudimentary water balance model can predict the majority of acid discharge events over a range of climatic fluctuations. However the prediction and quantification of acid discharged events can be further refined with the integration of water table dynamics and drainage behaviour and possibly the shorting of the interest period from 1 month to fortnightly water balance calculations.

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2 TABLES, FIGURES AND EQUATIONS

3 ACRONYMS AND ABBREVIATIONS

AASS	Actual Acid Sulfate Soil
AHD	Australian Height Datum
ANC	Acid Neutralising Capacity
ASS	Acid Sulfate Soil
ASSAY	Acid Sulfate Soil letter
ASSMAC	Acid Sulfate Soil Management Advisory Committee
CAMBA	China-Australia Migratory Bird Agreement
DLWC	Department of Land and Water Conservation
ENSO	El Niño Southern Oscillation
EUS	Epizootic Ulcerative Syndrome
FAO	Food and Agriculture Organisation
IUCN	International Union for the Conservation of Nature
JAMBA	Japan-Australia Migratory Bird Agreement
LFD	Lime Filter Drains
NSW	New South Wales
NWPASS	National Working Party on Acid Sulfate Soil
OECD	Organisation for Economic Cooperation and Development
PASS	Potential Acid Sulfate Soil
PPP	Polluter Pays Principle
SOEC	State of the Environment Advisory Council
SOI	Southern Oscillation Index
TEV	Total Economic Value
VA	Voluntary Agreement

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5 INTRODUCTION

Much of NSW's coastal floodplains have been drained to allow the establishment of agriculture and as a means of flood mitigation for coastal communities. However these government initiated actions has lead to the widespread acidification of groundwater and drainage networks due to the oxidation of Acid Sulfate Soils (ASS). Acid discharges from drained ASS pose a real and imminent threat to estuarine ecosystems and estuarine dependent industries, impacting on the livelihoods of many coastal communities in Australia. The oyster and fishing industries are at the brink of collapse in several catchments including the Hastings in which the Maria River is located. Nationwide ASS is threatening coastal investments and industries worth well over $10 billion dollars (Hicks *et al.*, 1999)

The management of ASS in NSW is now in the process of implementing proposed technical strategies on a state-wide basis. However many farmers are adamant to maintain the status quo; a "do nothing" attitude towards ASS management, proving to be a significant impediment to the successful implementation of proposed strategies. This situation is most apparent in the beef and dairy industries, of which make up the majority of landuse in the Maria River. Government and farmers and estuarine users on the Hastings Catchment and the Maria River in particular have clashed on numerous occasions. Stubborn landholders have proven to be significant impediments to the implementation of rehabilitation projects in the Hastings.

With the rise of the sustainable development paradigm resource management is slowing embracing alternatives to the traditional 'command and control' approach as nations have been compelled to address the ecological, economic political and social systems interfacing from the use of natural resources. This alternative is often in the some form of community-based management. There is growing evidence community-based management leads to more effective and acceptable resource management by arriving at more equitable resolutions while being just as cost effective as traditional means (see WRI, 1996; OECD, 1998; Mitchell, 1997; Stern, 1999). Such an approach is suggested for the Maria River as a mean of effectively and equitably resolving the impediments of ASS rehabilitation from a sustainability perspective.

5.1 Objectives and Study Scope

Current literature covering ASS in Australia is extensive, however to date no literature deals specifically at addressing and resolving the socio-economic impediments to implementing ASS management strategies. This report aims to consolidate all aspects of ASS literature applying to the Maria River, and place its ASS management strategy into the context of sustainable development. The main contribution of this report is to suggest a sustainable resolution to the current socio-economic impediments to ASS management in the Maria. A computer modelling exercise is also executed, aimed at exemplifying how modelling can prove to be advantageous towards the management of ASS. Objectives of this report are as follows:

- *Identify the problems associated with agrarian landuse within ASS of the Maria River floodplain and place them into the context of sustainable development and system analysis.*
- *Propose a holistic resolution towards identified problems and processes towards landuse in the Maria*
- *Describe and provide an economic assessment of the current state of management of ASS in the Maria River.*
- *Review and scrutinise possible technical and socio-economic solutions to the current impediments in achieving sustainable landuse for Maria River using local, regional and international comparisons.*
- *Model to the relationship between prevailing weather and acid discharge events.*

Structure and direction of the report and the connections between objectives are clarified in figure 1.

5.2 Methods

The implications of landuse in the Maria and solutions to the associated problems are discussed and analysed from the perspectives of sustainable development and ecological economics. A critic and further suggestions to the current proposed mitigation measures is also accomplished. Computer modelling is used to assess the efficacy of using a rudimentary water budget equation as a means of simulating acid discharge events for the Maria River. Regression analysis is conducted to analyse the relationship between monthly rainfall and the impacts of the El Niño Southern Oscillation (ENSO) phenomenon. Regression analysis is also used to analyse the efficacy of using ENSO values to predict rainfall several months in advance.

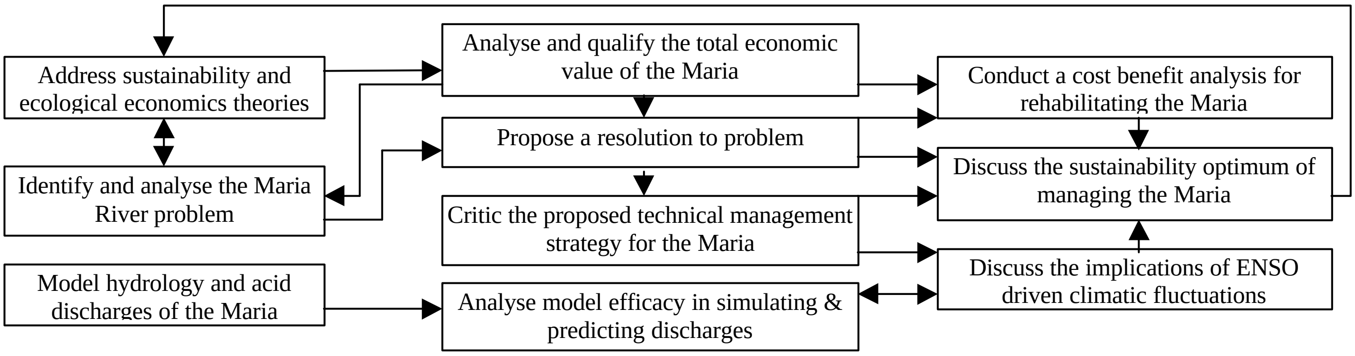

Figure 1: Objectives and structure of the paper

5.3 Study Site Description

Maria River is a coastal barrier estuary within the lower Hastings Catchment, northern New South Wales (NSW; figure 2). The floodplain consists of a mosaic of low-lying supratidal flats, levees, floodplains and backswamps (Tulau, 1999). This study is limited to two DLWC management priority areas, namely the Upper Maria- Connection Creek and the Lower Maria in the Maria River floodplain (figure 2) covering a combined area of 7,160 hectares[1] with elevation typically < 1m AHD[2] (Tulau, 1999). For convenience this report will refer to these two areas as the "*Maria River* or *the Maria*", unless otherwise stated. The Maria River has very shallow ASS, typically within 0.5 metre of the ground surface and in some areas at the ground surface (Tulau, 1999). Landuse is private freehold, dominated by beef cattle grazing, dairy, tea-tree plantations (*Melaleuca* sp) and horticulture (Johnston 1995; Tulau, 1999). Priority areas also include numerous saline and freshwater SEPP 14-coastal wetlands[3]. The Lower Hastings River system supports oyster industries, commercial and recreational fishing (Johnston 1995; Tulau, 1999) with a combined value of over $ 7 million yr^{-1} (Smith, 1999a).

6 SUSTAINABLE DEVELOPMENT

The term sustainable development originated in the 1970s and was first widely advocated within an international arena with the publication the *World Conservation Strategy* (IUCN, 1980). However sustainable development is most commonly defined through the publication *Our Common Future* (WCED, 1987), defining sustainability as "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p43). Principles and directives of sustainable development have been established through the publication of *Agenda 21* (United Nations, 1993), which can be interpreted as an alternative, operational definition to that of *Our Common future.* Within all the various interpretations of sustainable development there are a series of collective general principles (Selman, 1994; Hussen, 2000; Fricker, 1998; George, 1999: Mitchell, 1997):

- *Environmental protection and economic development cannot be perceived as antagonistic processes.*
- *Sustained economic growth is envisioned as a viable and desirable option*
- *A non-declining capital stock (both human and natural) is considered as a prerequisite to sustainability.*
- *The use of the precautionary principle[4], advocating caution when in doubt.*
- *The need to consider both intergenerational and intragenerational equity[5].*
- *The need to address the issue of transfrontier responsibility; development must not be at the expense of the environment elsewhere.*
- *There are biophysical limits (carrying capacity) to socio-economic growth.*

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[1] Upper Maria – Connection Creek priority area = 4,500 ha. Lower Maria priority area = 2,660 ha.
[2] AHD = Australian Height Datum, which is 0.46m below mean sea level.
[3] SEPP No.14-coastal wetlands are defined by the Department of Urban Affairs and Planning as wetlands of high natural value which cannot be drained or cleared without an Environmental Impact Statement.
[4] Where there are threats of serious or irreversible damage, a lack of scientific uncertainty shall not be used as reason for postponing measures to prevent environmental degradation (Mitchell, 1997).
[5]Intragenerational equity implies that the benefits and costs of development are shared equitably (social justice), and that the people that are affected by them have resolved these benefits and costs. Intergenerational equity implies development must stay within the carrying capacity of the environment to ensure equity for future generations (futurity)

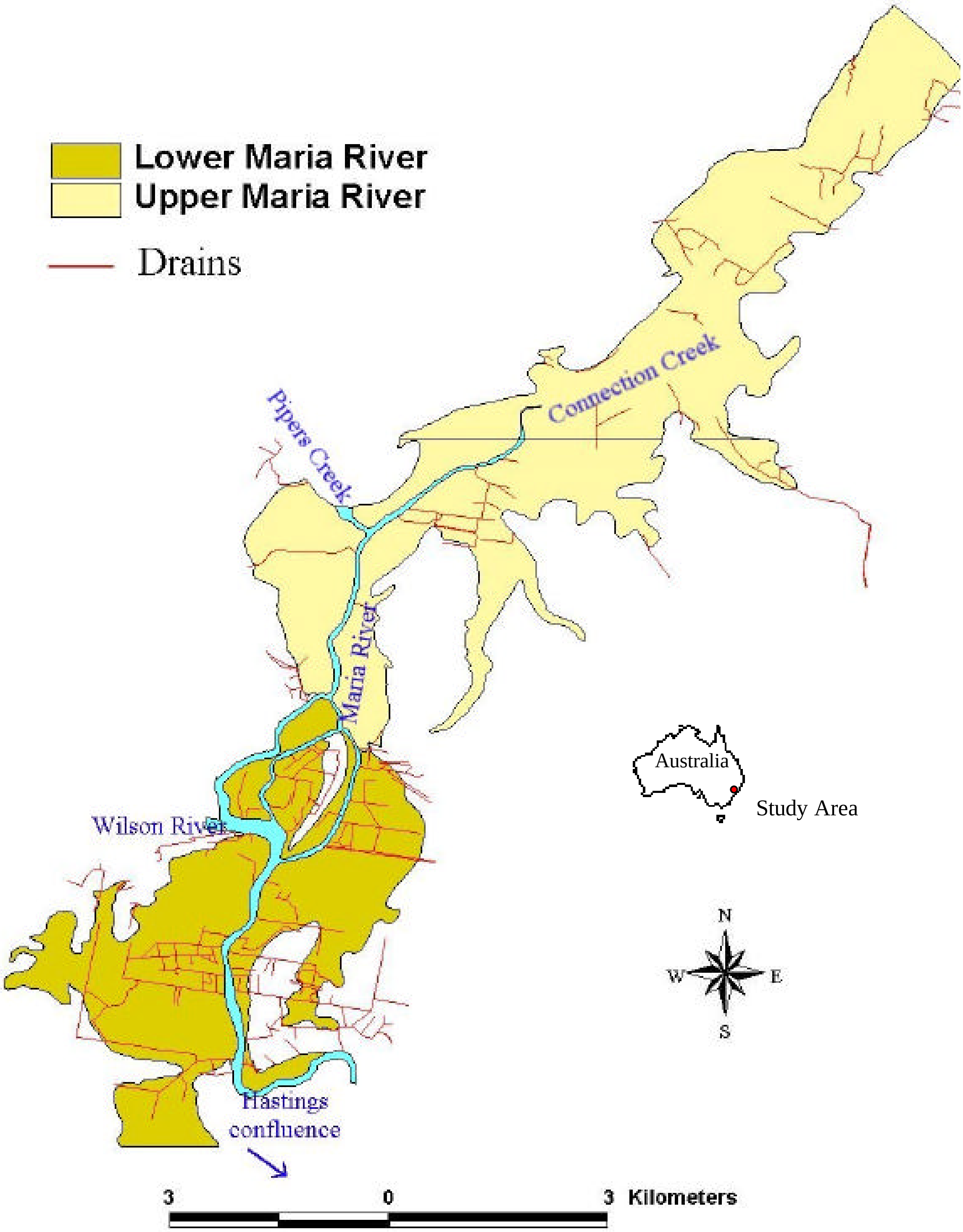

Figure 2: Maria River and associated drainage networks

Sustainable development can be divided into 3 broad categories; social, economic and ecological sustainability, all of which need to be jointly addressed within a holistic systems approach. Ecological sustainability refers to the maintenance of the biodiversity, ecological integrity and natural capital of an ecosystem. Biodiversity encapsulates genetic, species and habitat diversity. Ecological integrity infers to the general health and resilience of ecosystems and encompasses the ability to assimilate wastes, withstands natural and human induced stress. Natural capital infers the maintenance of renewable and non-renewable resources such as biodiversity, soil, air and water (SOEC, 1996). Society should live within the carrying capacity[6] of ecosystems, implying there are ecological constraints to development (Munro, 1995).

Social sustainability implies the continual maintenance of human and social capital, including income, wealth, basic services, information and education, and the capabilities and knowledge of individuals within a democratic setting (Munro, 1995). An activity is socially sustainable if it maintains and promotes social capital or does not stretch them beyond community's tolerance for change. Social sustainability also implies the process of *community building*, promoting participation and cooperation towards decision making processes within communities.

Economic sustainability implies that the benefits of development exceeds or balances the costs. Benefits and costs must also include the social and environmental externalities of production, such as the cost of water pollution. Furthermore development must not impoverish one group as it enriches another. (Munro, 1995).

Thus sustainable development is not a precise goal but a criterion for attitudes, morals, values and practices to which are applied (Munro, 1995), providing a framework for holistically managing complex multi-disciplinary human systems. It forces us to view the world through systems thinking considering the complex interrelationships between and within ecology, economy, society within a long-term vision (figure 3), marshalling political will and societal commitment to confront issues (Haimes, 1992). Thus the concept of sustainable development challenges the entrenched mono-disciplinary approach to resource management eliminating the dichotomy between economic growth and environmental protection.

The traditional perception towards resource management

The traditional view towards development, where economy is given primacy with society and environment having a minor influence on the state of the economy.

The sustainable development paradigm

Sustainable development recognises that the economy as a subset of society, upon which is constrained by the carrying capacity of supporting ecosystems.

Figure 3: The concept of sustainability and the traditional view of resource management

Source: SOEC (1996)

In accordance to signing *Agenda 21*, the Australian government has developed an approach to sustainable agriculture[7], aiming to promote initiatives, which support the sustainable use of Australia's land and water resources to improve the long term profitability of agriculture.

7 THE ECONOMICS OF SUSTAINABILITY

One of the main reasons for unsustainable resource use is that is it governed by conventional (neoclassical) economics which fails to apprise the total value of a resource and therefore the total cost of resource use (Faber *et al.*, 1996; Asafu-Adjaye, 2000). The prevailing market structure and policies leaves many common and public resources outside the domain of markets, undefined, unpriced and unaccounted for, inciting resource users to maximise profits through the appropriation of other people's resources and shifting their cost on to others. Furthermore under conventional economics, economic systems are perceived as closed,

[6] The capacity of an ecosystem to support society, while maintaining productivity, adaptability and capacity for renewal within a long-term perspective (Munro, 1995).
[7] Under the *National Strategy for Ecologically Sustainable Development* (COAG, 1992)

free of interactive constraints from ecological systems on the proviso that a technology and substitution will provide a means of sustained growth (Asafu-Adjaye, 2000). These ideologies are echoed with the current landuse in the Maria and are in direct conflict with the principles of sustainability (UN, 1993) and Australia's commitment to sustainable development (COAG, 1992).

Thus one of the crucial steps towards sustainable landuse in the Maria is to verify the true value (market and non-market value) of resources and to advocate the dynamic interactions between prevailing economic, ecological socio-political systems to stakeholders and governing bodies. The multi-disciplinary field of *ecological economics* studies the interrelationships between ecological and economical systems with an overall objective to effectively assess and provide a means for resource use within the context of long term sustainability (Faber *et al.,* 1996).

7.1 The economic valuation of a resource

From an ecological economic perspective, a resource has value if it makes a contribution to reach a perceived goal in society (Costanza *et al.*, 1998). Goals have traditionally focused on sufficing perpetual economic development, however with the rise of the sustainable development paradigm societies are shifting towards a goal of achieving sustainability between social, economic and ecological systems (Costanza *et al.*, 1998). Thus natural resources such as the Maria River can be considered to possess value, both market value and inherent non-market values. Market values are most often defined, as they are the direct economic value derived from conspicuous landuse such as fishing and agriculture. However the use of public resources are not purely restricted to the private sector. Resources are multi-functional and posses a multitude of benefits for a community[8] including intangible values arrived from the future desires, needs and wants of the community (Turner *et al.,* 1993). Thus indirect market values and non-market values are inherently difficult to define, however there are methods to estimate the market value of these[9] (Barbier *et al.*, 1998). An estuary such as the Maria exhibits an excellent example of indirect transboundary use value as 70% of commercial offshore fish species in Australia spend part of their life cycle in estuaries, mainly for spawning and fingerling development (Sammut *et al.,* 1996a).

By valuing both market and non-market values we arrive at the true total value of a resource; the Total Economic Value (TEV; Asafu-Adjaye, 2000). The TEV of a natural resource can be defined into two broad categories *use value* and *intrinsic value.* Use values, which are most commonly known and definable, refer to the capacity of a good or service to satisfy our needs or preferences. Uses include consumptive (ie; agriculture and fishing) and non-consumptive uses such as photo-tourism and recreation. Use values can be further partitioned into *direct* and *indirect use values*. Indirect use values as it implies is the value gained from supporting economic activities having directly measurable values. An example is nutrient pool supplied by an estuary that supports the receiving fishing and oyster industry.

An intrinsic value implies that benefits gained from these values are inherent and are not related to its consumption. They include environmental services such as the maintenance of geochemical and hydrological cycles. Intrinsic values compose of *existence value, bequest value* and *option value*. Existence value is the intrinsic value of a resource; the value to preserve it 'because it is', and thus requires subjective value judgements of individuals. Bequest value as the name implies arise from the value placed of conserving a resource for future generations. Option values [10] measures the value a person or community is willing to pay to ensure the use or availability of a resource in the future, should they decide to use it.

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[8] A community can be defined in a range of spatial scales from local, regional to global.

[9] Valuation methods such as The Contingent Valuation Method, Travel Cost Method, Hedonic Pricing Method, Energy Analysis and the Production Function Approach are commonly employed (Barbier *et al*, 1998; Barbier 1994).

[10] There is general consensus that option values are not a separate form of value but represent a difference *between ex ante* and *ex post* valuation. A variant of the Option value is the Quasi-option value, which is the expected value of the information gained from delaying explotation (Barbier, 1994).

7.1.1 Qualifying the total economic value of the Maria River

To fully asses the TEV of the Maria River is out of the scope of this paper due to data and practical constraints, however it is worth qualifying components give the reader an idea of the multi-functionality of an estuary and it's importance to a community. Table 1 qualifies the TEV of the Maria.

Table 1: Classification of the total economic value of the Maria River

USE VALUES		INTRINSIC (*non-use*) VALUES	
Direct Use	*Indirect Use*	*Option & Quasi-option*	*Existence and Bequest*
✧ Agriculture ✧ Fishery / oyster ✧ Recreation ✧ Tourism ✧ Residential	✧ River / Wetland aesthetics ✧ Nutrient pool /filtration ✧ Flood abatement ✧ Storm protection ✧ Groundwater recharge /filtration ✧ Transboundary ecosystem support ✧ Micro-climatic stabilisation ✧ Carbon sequestration	✧ Aforementioned future direct and indirect uses ✧ Culture and heritage ✧ Scientific research and information	✧ Species biodiversity ✧ Habitat biodiversity ✧ River / wetland aesthetics ✧ Culture & heritage ✧ Aboriginal spiritual significance & heritage

Source : adapted from Asafu-Adjaye (2000); Barbier *et al.*, (1998); Smith (1999b)

≷ is used to denote that option and quasi-option values can be loosely defined as both use and non-use values

There is growing consensus that estuaries and wetlands possess significant intrinsic and indirect use value (Turner, 1991; Costanza *et al.*, 1998; Loomis *et al.*, 2000; Barbier, *et al.*, 1998; Barbier, 1994). Turner (1991) and Barbier (1994) further stress the value of estuaries, arguing that most wetlands posses greater community value when retained in their natural state compared to their developed or drained state. Costanza *et al.* (1998) supports this view, noting that estuarine biomes have the highest Net Primary Productivity[11], which can be considered a function that determines the value for ecosystem services and the significance of use values based on the theory of energy analysis valuation. Costanza *et al.* (1998) estimates the value derived from ecosystem services from an estuarine ecosystem at US \$~19,000 to 23,000 ha^{-1} yr^{-1}. Thus a very crude, first approximation for ecosystem services possessed by the Maria may concluded to be in the order several millions. Loomis *et al.* (2000) and Turner *et al.* (1993) report similar values for indirect use values for wetlands in USA. Thus there is growing consensus that the non-use intrinsic and indirect use values of estuaries are at least in the same magnitude of commonly defined direct use values and if not far outweighs them. Considering the value of the Maria has historically been based purely on direct use values as shown in table 2, this resource has and is grossly undervalued and it's contribution to development has been severely underestimated.

Table 2: Direct use values from the Maria River.

Industry	Area (ha)	Gross value (\$M yr^{-1})
Fishing (recreational + commercial)	-	3-4
Oyster (plate, bottled and seed sales)	140	3
Tea Tree	~1000	1
Cattle (beef and dairy)	~5500	0.5-0.9
Bees & Horticulture	?	< 0.01

Source: Adapted from Johnston (1995) Smith, (1999 a/b); Mullen and Kaur, (1999)

7.2 The sustainable optimum for resource use and management

The aim of sustainable development is essentially to maximise socio-economic development while minimising adverse environmental impacts associated with resource use (Barbier *et al.*, 1998). In the world of ecological economics this goal is referred to as the optimum socio-economic benefit or sustainable optimum (Barbier, 1994; Asafu-Adjaye, 2000). The use of a public resource such as the Maria River should

[11] Biomes include estuary proper, seagrass /algae beds, tidal marsh, mangroves and swamps/ floodplains, with NPP's ranging from 1.5-3,5 kg m^{-2} yr^{-1}.

aim to maximise the community welfare associated with its use as a precursor to sustainability. However considering public resources often provides a multitude of functions, maximising community welfare is often problematic as resource use is commonly in direct conflict with each other. Thus resource use must undergo a holistic evaluation in order to move towards an socio-economic optimum. This concept of optimum sustainability is not restricted to resource use alone, as principles can be translated to assess the sustainable optimum level of resource management. Resource management aimed at mitigating the environmental effects of resource use is deemed economically feasible if the Net Benefits of Mitigation NB^M is greater or equal to zero (equation 1; Barbier, 1994). Furthermore the sustainable optimum (optimum net community benefit) of resource management / use is attained when NB^M is maximised (line db) as shown in figure 4 and equation 1 (Barbier *et al.*, 1998).

$$NB^M = (B^M - C^M) + NB^E \geq 0 \qquad (1)$$

NB^M = Net benefits of mitigation / use
B^M = Direct benefits of mitigation / use
NB^E = the net gain from environmental services (indirect use, option, existence and bequest values)
C^M = Direct costs of mitigation / use

Line edf in figure 4 is the net benefit curve for resource use implying that in many cases of resource use, the net benefit may actually decrease with increase use, indicating a net loss in community welfare. Furthermore at the level of no use, the community still recieves a benefit from the resource (level e), implying that a resource has significant intrinsic value non-use value as outlined in table 1. Line adc represents the net benefit curve of resource management, and line abc is the net cost associated with both resource management and use. Polygons abd and abde represent the total net economic benefit obtained from resource management / use respectively when the sustainable optimum of resource management / use is attained (M^*). C^* denotes the optimum cost of management / use respectively

In the context of the Maria River, the sustainable optimum of resource use is a balance struck between the net benefits of farming and estuarine use compared to the total net costs from these activities. Furthermore the sustainable optimum of resource management for the Maria is a function of the costs from mitigating acid discharges versus the total net benefit gained from estuarine and agrarian yield improvement.

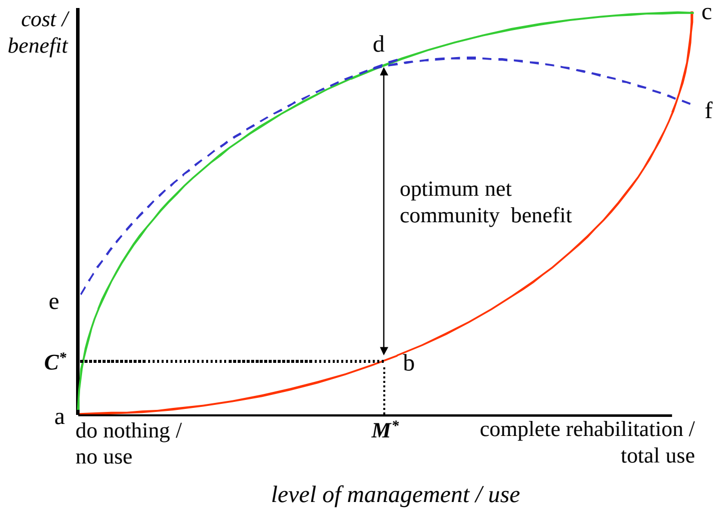

Figure 4: The sustainable optimum of resource management / use

Source: adapted from Asafu-Adjaye, 2000; Turner *et al*., 1993.

7.3 Discounting natural resources: a sustainable ideology?

A common practice in the economic evaluation of resource use is to apply a discount rate when calculating associated costs and benefits. Discount rate is a measure of the opportunity cost of capital; the value of a resource (natural capital) is higher at present than compared to reserving it for future, thus capital value and costs is time preferential (Turner et al., 1993). Or more simply, people prefer to have benefits now rather than later, and costs later rather than now. Thus economic theory suggests that future benefit and costs of resource use must be discounted to present values as a proviso to comprehensive evaluation. By discounting future natural capital to a present value, all forms of capital, whether they occur at present or in the future can be comparatively evaluated and exchanged. However discounting natural capital has some serious implications, suggesting that the loss of future natural capital can be substituted today for other forms of socio-economic capital (Turner *et al.,* 1993). This view is in conflict with ecological economic principles, stating that natural capital cannot be simply substituted as ecosystem functions and services are critical to the survival of socio-economic systems (Faber *et a*l., 1996). It is foolish to think that future generations can sustain themselves on a mass of material capital, without basic ecosystem functions such as geochemical cycles. Therefore the practice of discounting natural capital impinges on the principles of sustainable development on many levels. Neo-classical economic theory and the practice of discounting denies the fact that socio-economic growth has biophysical limits and it contradicts the prerequisite of maintaining a non-declining stock of natural capital. Moreover discounting discriminates future generations creating intergenerational inequalities. There is a growing school of thought that employing positive discount rates to long-term resource use actually serve as a means for environmental degradation, based on the assumption that a positive discount rate implies no weight is given to resource use or welfare beyond a generation hence (Turner *et al.,* 1993; Asafu-Adjaye , 2000). Thus a high positive discount propels resource users to consume as quickly as possible to secure a maximum value from that resource. While the impact of a discount rate would be minimal in the assessment of Maria River (time horizon for management / rehabilitation is no more than 5 years), it is against the principles of sustainability and hence Australia's obligations towards sustainable development and therefore will not be used in this report.

8 MODELLING COASTAL FLOODPLAIN HYDROLOGY

ASS modelling has historically concentrated on describing the changes occurring within the soil environment based on balance modelling (see Bronswijk and Groenenburg, 1993; Van Wijk *et al.,* 1993). However these models fall short in describing floodplain water budget, which has long been considered essential for effective management of ASS (White *et al.,* 1997). ASS modelling further evolved with the integration of water budgets with soil dynamics in a daily time perspective for sub-catchments (Palko and Weppling, 1995; Karvonen *et al*., 1999). While these dynamic models can accurately describe watertable heights, timing and magnitude of acid discharge events, they require extensive data collection and monitoring. Thus the applicability of these models for routine cost effective planning is questionable. A simpler more cost-effective alternative is proposed by Wilson *et al.* (1999); Sammut *et al.* (1996a); White *et al.* (1996), suggesting watertable budgets and the prediction of acid discharge events can more simply be defined based on water balance equations using readily available climatic data and limited monitoring. Considering the limited available data and the unique climate in Australia, this simpler approach has been used to model acid discharges in the Maria.

It is well established that the magnitude and timing of acid discharge events are controlled by the position of the watertable in relation to ASS (Johnston, 1995;Wilson *et al.,* 1999; Sammut *et al.,* 1996a; White *et al.,* 1997). Prevailing watertable height is governed by the dynamics of the water balance of the floodplain as shown in equation 2 (White *et al.,* 1996):

$$P + I + L_i = ET + L_o + R + D + DS \qquad (2)$$

Where P is precipitation, I is irrigation, L_i the lateral upland flow, ET is the total evapotranspiration, L_o lateral outflow (drainage discharge), R is any surface run off, D is drainage into groundwater and DS denotes soil water storage being negative or positive. Wilson *et al.,* (1999); Sammut *et al.,* (1996a); White *et al.,* (1997) confirm that under Australian climatic conditions the dynamics between ET and P are the principle controlling factor to changes in watertable height in ASS floodplains. NSW coastal floodplains are characterised by shallow watertables and are low relief thus, D and R can be considered to also play a minor role in controlling watertable height. Drainage networks significantly increase L_o enabling previously hydrologically isolated backswamps to be directly connected to the estuary. Drainage networks provide the principle means of transporting excess soil moisture to an estuary. Under natural conditions, excess soil moisture would be isolated from the estuary in the form of seasonally inundated backswamps. Furthermore drainage networks influence the height of the watertable height, both positive and negative. In times where the water table is above the mean invert depth of the drainage network, drainage and floodgate action lower watertable heights. However in periods of extended drought, watertable heights can be lowered further than the mean invert depths of drains through evapotranspiration. Under these conditions drains acts as points of recharge, balancing the watertable heights.

8.1 Estimating evapotranspiration

Estimating evapotranspiration on regional scale is well known to be problematic due to variations with small microclimatic changes, crop type and life cycle (Allen *et al.*, 1998). However in relatively small studies with relatively uniform climatic and agrarian practices, evapotranspiration can be confidently estimated on a regional scale when derived form climatic variables or pan evaporation measurements (Allen *et al.*, 1998). Deriving evapotranspiration from pan evaporation has been a common practice in ASS studies (Wilson *et al.*, 1999; Sammut *et al.*, 1996a; White *et al.*, 1997). Although the pan responds in a similar fashion to the climatic variables affecting crop evapotranspiration, several factors produce significant differences (Allen *et al.*, 1998). Discrepancies between the pan evaporation estimation method and the actual evapotranspiration of cropped surface include higher reflection of solar radiation within the pan, heat retainment and heat transfer, differences in air turbulence, temperature and air humidity immediately above the pan and crop surfaces (Allen *et al.*, 1998). For these reasons Allen *et al*. (1998) suggest the use of the FAO Penman-Monteith equation over pan evaporation to estimate local evapotranspiration .

The FAO Penman-Monteith equation (3) estimates daily evapotranspiration for a reference crop[12] based on various climatological and physical parameters as defined in equation 3 (Allen *et al*., 1998).

$$ET_O = \frac{0.408D\,(R_n - G) + g\,\left(\frac{900}{T+273}\right) U_2\,(e_s - e_a)}{D + g\,(1 + 0.34\,U_2)} \qquad (3)$$

ET_O = reference evapotranspiration [mm day^{-1}]
R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}]
G = soil heat flux density [MJ m^{-2} day^{-1}]
T = mean air temperature at 2 m height [°C]
U_2 = wind speed at 2 m height [m s^{-1}]
e_s = saturation vapour pressure [kPa]
e_a = actual vapour pressure [kPa]
g = psychrometric constant [kPa °C^{-1}]
$e_s - e_a$ = saturation vapour pressure deficit [kPa]

To limit the influences of regional climatic variation between the recording station and the study area, data used in the Penman-Monteith equation was interpolated using three Bureau of Meteorology Stations (DNR, 2000) to obtain daily evapotranspiration rates for the location 31°13′ S, 152°54′ E. Daily rainfall and evapotranspiration was transformed into monthly totals to be used for estimating the water budget of the Maria (equation 5). Water budget calculations were conducted over a period from 1990 to August 2000 to compare acid discharge events with recorded events (table 3) and to discuss events over a range of climatic conditions. Evapotranspiration from beef and dairy grazing is assumed to be approximated by the reference crop. However evapotranspiration from Tea Tree plantations is strongly controlled by the crop growth stages (Allan *et al*., 1998). Thus this approach requires the incorporation of a time depedent crop coefficient for Tea Tree. A Tea Tree crop coefficient (*Kc*) has been developed by Dept. of Agriculture (G.Robertson, Dept. of Agriculture *pers comm*., 02/09/00) based on average growth rates and crop harvesting times for the NSW Tea Tree industry. Thus the evapotranspiration (mm) from Tea Tree crops ET_{TT} is calculated as:

$$ET_{TT} = Kc \cdot ETo \qquad (4)$$

Total monthly evapotranspiration for the Maria River, ET_M is thus the sum of the evapotranspiration from Teat Tree and evapotranspiration from the beef and dairy grazing lands for month *T* (equation 5).

[12] The reference crop as a hypothetical crop with an assumed height of 0.12m having a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered.

$$ET_M = (ET_O + ET_{TT})\ _T \quad (5)$$

8.2 Estimating floodplain discharges

Based on the theory of Wilson *et al.* (1999), Sammut *et al.* (1996a) and White *et al.* (1997) we can assume that *ET* and *P* are the principle factors in controlling watertable height and hence discharges from a drained floodplain. By further assuming that drains provide a direct means of exporting all excess soil moisture to an the estuary, the total volumetric outflow (Q_o) from a drained floodplain during wet periods can be estimated by equation 6 (Sammut *et al.*, 1996a). A_t is the area of floodplain and ET_M is the total evaporation from grazing and Tea Tree surfaces.

$$Q_o \approx [(P + I) - ET_M)]\ A_t \quad (6)$$

Equation 6 provides a first order upper limit in estimating discharge events, presuming ΔS is negligible during the onset of the wet period. Furthermore all water excess generated when $P > ET$ is assumed to be directly transported into drains and into subsequent receiving estuaries without withdrawals from evaporation or groundwater recharge during transport. Equation 6 further assumes that the climatic factors controlling ET_M and *P* are essentially uniform over the floodplain, which is permissible considering the study area covers ~7000ha. While simplistic, Sammut *et al.*, (1996a) suggests this equation forms a basis for a first approximation of acid discharge event prediction, provided the period of interest *t* is sufficiently long (~1 month) to account for time lags involved in transport. By assuming all excess water during wet seasons is discharged from drainage networks at an average pH of 3.5[13] and with aluminium concentrations of 0.5mg l^{-1}, the quantity of acidic discharge events can be simulated using a computer model based on equation 6. Figure 5 shows a schematic simplification of the computer model:

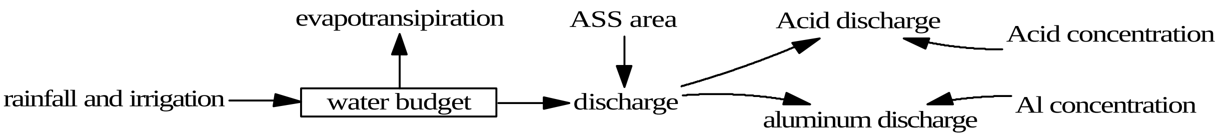

Figure 5: Schematic representation of computer model

9 ACID SULFATE SOILS

ASS is the generic term given to soil containing significant quantities of readily oxidisable or already oxidised sulfides (White *et al.*, 1995). The principle form of sulfides occurring is iron pyrite, FeS_2. The process of pyrite formation is *in situ* where iron oxide is reduced to iron pyrite though bacterial conversion[14] under a maintained anaerobic environment (equation 7; Dent, 1986).

$$\underset{\text{sediment}}{Fe_2O_{3\,(s)}} + \underset{\text{seawater}}{4SO^{2-}_4} + \underset{\text{organic matter}}{8CH_2O} + {}^1/_2\,O_2 \rightarrow \underset{\text{pyrite}}{2\,FeS_{2\,(s)}} + \underset{\text{bicarbonate}}{8HCO^-_3} + \underset{\text{water}}{4H_2O} \quad (7)$$

These soils are relatively young, of Holocene age, and are typically found in prevailing and prior estuarine environments, saltmarsh and shallow coastal lakes, as they provide the optimal conditions for pyrite formation (Dent, 1986). These soils are typically covered with a variable thickness of fluvial, non-ASS sediments derived from contemporary river processes (White and Melville, 1996).

As long as ASS are not excavated or drained, these materials are relatively benign and are termed Potential Acid Sulfate Soils (PASS). However if the sediments are exposed to air, pyrite is oxidised resulting in suite of oxidation products to be formed through a series of reactions. However sulfuric acid is the principle end product as shown in equation 8, with 1.6 tons of acid produced for every ton of pyrite that undergoes complete oxidation (Dent, 1986).

$$\underset{\text{pyrite}}{FeS_2} + \underset{\text{oxygen}}{{}^{15}/_4\,O_2} + {}^7/_2H_2O \rightarrow Fe(OH)_3 + \underset{\text{sulfuric acid}}{2SO^{2-}_4 + 4H^+} \quad (8)$$

[13] See table 3 for reasoning
[14] *Thiobacillus ferrooxidans*

When the rate of acid production exceeds the neutralising capacity of the parent material, Actual ASS (AASS) is formed typified by a soil pH value of less than 4 (White *et al*., 1997). Oxidation of PASS can occur naturally, however the principle mechanisms for PASS oxidation are drainage, crop evapotranspiration and excavation involved with agriculture and development (Stone *et al.*, 1998; White *et al*., 1997). Sulfuric acid subsequently reacts with soil constituents, mainly clay minerals, liberating dissolved iron and metals such as arsenic, aluminium, cadmium manganese and copper, into soil and drainage waters in often unnaturally extreme concentrations (NWPASS, 1999; Åström and Corin, 2000).

9.1 The impacts from drained ASS

The impacts from draining ASS and subsequent production of oxidation products are extensive, affecting both downstream estuarine users and landholders on acidified land. Impacts range from local and transient to irreversible, chronic and extensive, impacting on all social, economic, and ecological systems. These impacts result from a legacy of drainage and altered floodplain hydrology and are future discussed in this section.

9.1.1 The role of drainage networks and floodgates

In order to raise agricultural production and to mitigate the effects of floods on the broader community, eastern Australian governments in the 1960s and 70s encouraged and funded the dramatic alteration of floodplain hydrology through flood mitigation and drainage policies (White *et al*., 1997; NWPASS, 1999). Combined with one-way floodgates, drainage systems prevent tidal ingress and provide a means for flood mitigation control by removing water of low-lying areas quickly. Consequently floodplain drainage times have been reduced from 100 to 5 days (White *et al*., 1997) enabling pastures to be established.

Smith (1999a) indicates government flood mitigation schemes in the Hastings Catchment were particularly apparent after the 1968 flood. The Upper Maria Flood Mitigation Project is an example with the unsuccessful aim of improving pastures in landscapes with an elevation below 1M AHD (Smith, 1999a). Resultantly, the Maria River Floodplain is extensively engineered with 104.47 kms of drains (see figure 2) and over 50 tidal attenuating structures[15] in operation. Drainage networks are made up of large flood mitigation drains, smaller farmer-built trunk drains and field drains that feed into trunk drains. Over 63% of drains in the Maria are potentially penetrating ASS layers, providing a direct means of pyrite oxidation and acid groundwater export. However the potential ecological and agricultural implications from draining ASS were not realised until the early 1960s in Australia (Walker, 1963). Today drainage networks are now recognised to as the key to lowering watertables and enhancing the acid discharges through a number of processes as sown below (White *et al.*, 1997; Sammut *et al.*, 1996a):

- *Enhancing of acid transport rates from previously isolated acidified backswamps to estuaries.*
- *Impounding of acid waters behind floodgates for up to 6 months, resulting in seasonally episodic releases of acid water plumes "acid slugs" with extreme acid and metal concentrations.*
- *Prevent dilution and neutralisation of acid drain water by estuarine waters, prolonging land acidification by restricting landward ingress of flood tidal estuarine water.*
- *acid production from initial drain excavation[16] and subsequent maintenance[17]*
- *enhanced acid water transport rates into estuaries through efficient drainage networks*
- *Formation and mobilisation of Acid Volatile Sulfur (AVS) in deep drains and subsequent acidification[18].*
- *Combined with crop evapotranspiration, drainage causes the permanent lowering of groundwater tables and removal of surface waters [19].*

Sammut and Mohan (1996) stress acidified ground and surface waters provide the bulk contribution to an acid discharge event during seasonal wet weather, as large stores of acidic water are displaced into drains and eventually into estuaries. An acid discharge event, frequently as a result of drought breaking rains is

[15] Structures include floodgates, weirs, sluice gates and culverts. See Williams and Watford, (1997) for definitions.
[16] Excavated material (spoil) is mounded adjacent to drains, leading to oxidation of PASS and acid production
[17] Drains are seasonally cleared of weeds by farmers to maintain water flow, this practice often leads to the unintentional excavation of PASS from the drains, contributing to the overall production of acid from drainage.
[18] AVS are highly reactive iron monosulfides formed under reduced conditions and are precursors to pyrite formation.
[19] Smith (1999) notes the Upper Maria floodplain has a lowered the water level from 0.4m AHD to about -0.5m AHD.

typified by several hundreds of tons of sulfuric acid being discharged into a estuary and degrading water quality for weeks (Sammut *et al.*, 1996b; Wilson *et al.*, 1999). Johnston (1995) MHL (1997) and Manton (1992) have documented several acid discharge events in the Maria River, of which all occurred after significant periods of rainfall. These events are summarised in table 3.

Table 3: Recorded acid discharge events in the Maria River, 1992-1995.

Event	Extent	Estuarine water quality	Drain water quality
February 1992	Upper Maria Estuary	pH <5 Aluminium >0.5mg L^{-1}	pH range 3.0 – 4
June /July 1994	6km of Upper Maria Estuary, for over 3 weeks	pH < 5.5 Aluminium >0.5mg L^{-1}	Min pH 3.1 Max aluminium 19.73 mg L^{-1}
January-February 1995	4km of Upper Maria Estuary lasting for 8 weeks	Min pH 3.2 Max aluminium 2.32 mg L^{-1}	Min pH 4.2 Max aluminium 0.43mg L^{-1}
March-May, 1995[20]	Upper Maria > 20weeks[21]	pH range 3.2-5.5	N/A

Johnston (1995) further notes that during 1994-1995, 56% of all drains in the Maria River discharged water at pH values below 4.0,and 76% having maximum aluminium concentrations >0.5 mg L^{-1}, with one record indicating a soluble aluminium concentration of 81 mg L^{-1}. Smith (1999a/b) notes that pH 2.4 has been recorded mid-stream in the upper Maria, the most extreme acidification ever reported in a tidal stream in NSW. These recorded levels far exceed the Australian and New Zealand Environment and Conservation Council guidelines[22] for estuarine water quality (ANZECC, 1992; 1999).

9.1.2 Ecological impacts

The ecological impacts from drained ASS are well established and are wide ranging (see work by Sammut *et al.*, 1993-1999; White *et al.*, 1995; 1996; 1997) and are briefly reviewed. Severe ecological impacts are frequently caused from a large acid discharge event, resulting in large sections of estuarine habitat to be acidified and containing biotoxic concentrations of trace metals such as aluminium[23] (Manton, 1992; Sammut *et al.*, 1999; Åström and Corin, 2000). Sammut *et al.*, (1995; 1996a) notes short term exposure to acidic aluminium-rich water causes sublethal impacts to aquatic biota, including severe skin and gill damage in fish. Under extreme acid environments osmoregulation rates in fish are impaired from the fusion of gills, thus causing large populations to drown due to lack of oxygen. Fish can normally avoid acid plumes, however under a floodgated environment large populations are trapped and are exposed for extensive periods resulting in massive fish kills[24]. A significant fish kill in the upper Maria River was documented during the February 1992 discharge event (see table 3). Chronic effects on estuarine ecology have been identified by Sammut *et al.*, (1993-1999); Callinan *et al*., (1993) and Smith *et al.*, (1999), manifesting years after water quality has improved following an acid discharge event. Chronic impacts include:

- *Loss of spawning sites and recruitment failure in both estuarine and fresh-water species*[25]
- *Habitat degradation and fragmentation from acid plumes, thermochemical stratification of waters and the smothering of benthos from iron oxyhydroxide flocs*
- *Altered population demographics within species*
- *Simplified estuarine biodiversity with invasions of acid-tolerant exotics*[26] *and loss of native species*
- *Reduction in dissolved nutrients and organic matter entering the estuarine foodweb.*

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[20] Jan-Feb 1995 event and March-May event were two separate events, however the resultant period of estuarine acidification (below pH 6) was continuos from Jan, 1995 to August, 1995.

[21] While acid discharge event ceased in May 1995 estuarine pH levels remained below 5.5 until the end of August.

[22] Current guidelines: pH range of 6.5-9.0 and should not differ 0.2 pH units from ambient pH. Aluminium <5.0 μg L^{-1} when pH < 6.5. Draft revision guidelines (1999) : Aluminium <0.01 mg L^{-1}

[23] Aluminium concentrations >0.5mg L^{-1} and pH values less than 5 are considered to causes sublethal to lethal effects on aquatic biota (Sammut *et al.*, 1996 a/b)

[24] Fish kills have been documented to contain over 30,000 dead individuals (Sammut *et al.*, 1996b)

[25] 70% of commercial fish species in Australia spend part of their life cycle in estuaries for spawning and fingerling development. ASS impact may impact other ecosystems kilometres away (Sammut *et al.*, 1996a).

[26] Cape waterlily *Nymphaea caerulea* and Mosquito fish *Gambusia holbrooki* (Sammut *et al.*, 1996b)

Sammut *et al.,* (1996b) has documented such chronic effects lasting over 4 years. The frequency of acid discharges in the Maria River has been found to occur within time perspective as shown in table 3. Under these conditions the Maria estuarine ecology may be perpetually under stress, never fully recovering. This issue has major implications for both current and future users of the estuary and floodplains and severely questions the sustainability of current practices.

9.1.3 Transboundary implications

The production of CO_2 is a secondary by-product of ASS oxidation from the dissolution of bicarbonates and the oxidation of the organic matter. (Hicks *et al.,* 1999) have shown that during oxidation ASS can release up to 33t $ha^{-1\ -yr}$ of carbon. Using conservative estimates[27] the Maria River ASS has released more than 3.2 million tons of carbon over the last 30 years, a notable contribution to Australia's carbon dioxide emissions, which are the highest per capita in the world. Ironically in their natural state wetlands are significant carbon sinks (Hicks *et al.,* 1999), providing a local contribution to attenuating global atmospheric carbon trends and aiding the Australian society to meet it's international obligations under the Kyoto Protocol for reduced greenhouse emissions. Just as relevant, the Maria River is known to contain significant wetland habitats for migratory birds (Tulau, 1999). Thus drainage and subsequent degradation of wetland ecology in the Maria may be impinging on international obligations under CAMBA and JAMBA agreements for migratory birds.

9.1.4 Economic impacts

Dove (1997) has linked ASS discharges to shell dissolution and soft tissue degradation in Sydney Rock Oysters (*Saccostrea commercialis*) within the Hastings Catchment. Wilson and Hynes (1997) correlate acidic-aluminium rich waters[28] with significant developmental abnormalities in embryonic oysters. Both development abnormalities and shell dissolution lead to impaired growth, poor quality and even mortaility under prolonged exposure. The Hastings oyster industry has continuously been suffering suppressed yields from recurrent mortaility and poor oyster quality (NSW fisheries, 1999). The 1998-1999 financial production year proved to be one of the most devastating with only 1,396 bags of oysters produced at a wholesale value of $480,350 representing in an 80% loss in production for the Hastings (NSW fisheries, 1999. The prospects for the 1999-2000 production year is considered to have similar outcomes with at least 50% reduction in yields (L.Lander, Industry representative *pers comm*. 18/10/2000) This equates to an estimated loss of $2.4 to 1.5 M yr^{-1} for the Hastings oyster industry. The Maria usually experiences the highest mortality rates in the Hastings system, consequently the Maria has been recently abandoned by oyster and fishery industries (Henderson, 2000). Callinan *et al.,* (1996) has linked acid discharges form ASS to the production of EUS in commercial fish species (Epizootic Ulcerative Syndrome). EUS has been shown to significantly impacts on fisheries, effecting up to 80% of catch which are rendered useless for commercial sales (Sammut *et al.,* 1996a). Ascertaining the direct impacts from ASS on the Hastings fishery is formidable, as records on recreational fishing are not available. Furthermore fishery resources are not sedentary like the oyster industry, which further complicates the evaluation of ASS impacts. With these limitations in mind NSW fisheries data (Tanner and Liggins, 1998) indicates losses in the range of 30-60%, which may be attributed to ASS runoff.

Economic impacts are not restricted to downstream users of affected estuaries. White *et al.,* (1997) note acidified soil and water can effect pasture production and stock health. Poor pasture yields occur from weed invasion[29] and he the production of acid scalds that are devoid of vegetation. Scalded lands are useless for farmers and prove to be a long-term management problem. The economic effects of low pasture yields are exacerbated by the possibly of poor stock health and growth from drinking acidified aluminium-rich waters, caused by digestive disorders (Smith, 1999a; White *et al.,* 1996). The effects of scalding, poor pasture yields and stock water quality have contributed to the chronic marginal productivity for the beef and dairy industries (Mullen and Kaur, 1999).

[27] Estimations based on a carbon release rate of 15t $hectare^{-1}$ within 7160 hectares.

[28] pH below 6.75 or when pH values are normal and aluminium concentrations are of 150µg L^{-1} or greater

[29] A particular invasive specie is smartweed, *Fallopia sepies*

9.1.5 Community impacts

Estimating the indirect community costs from draining ASS is still yet to be accomplished and often goes unnoticed. Economic losses on the Maria community may be imposed through the indirect economic spin-off effects from suppressed agricultural, oyster and fishery industries, lowered tourism, infrastructure damage[30], and degraded recreational fishing resources. Thus economic losses may be transferred to the businesses supporting and servicing the affected industries in the Maria. Furthermore the drainage of ASS in the Maria is significantly impacting on its ability to provide environmental services and intangible community values, resulting in welfare losses for the Maria community and other communities depending on its services.

9.1.6 Human health impacts

Possible direct health impacts from the drinking of aluminium-rich acidified waters derived from ASS have been suggested on several occasions (NWPASS, 1999; White *et al.*, 1996; Smith, 1999a) in the form of stunted growth, poor health and nervous disorders. In Johnston's 1995 study, groundwater pH levels were often below pH 3.3 with aluminium concentrations exceeding 40mg L^{-1}. Health complications are possible in the Hastings as there are cases of groundwater use for drinking purposes The *Australian Drinking Water Guidelines (1996)* state a level of aluminium concentration at 0.2mg L^{-1} fit for human consumption. However these levels are based on aesthetic and palatable considerations (Commonwealth of Australia, 1996). WHO (1997) indicates that there are no proven causative long-term effects from gastrointestinal ingestion of aluminium at concentrations within the general population. Nevertheless WHO (1997) notes people with chronic renal failure are a significant risk group as they absorb aluminium 8-10 times greater than the normal population. Such cases are at risk from severe neurological dysfunction, the onset of symptoms resembling encephalopathy, vitamin-D resistant osteomalacia and microcytic anaemia if exposed to aluminium for an extended duration. Thus while there is no major risk to the general population, under prolonged exposure to acidified water significant health problems are possible within this aforementioned risk group.

9.1.7 Discussion

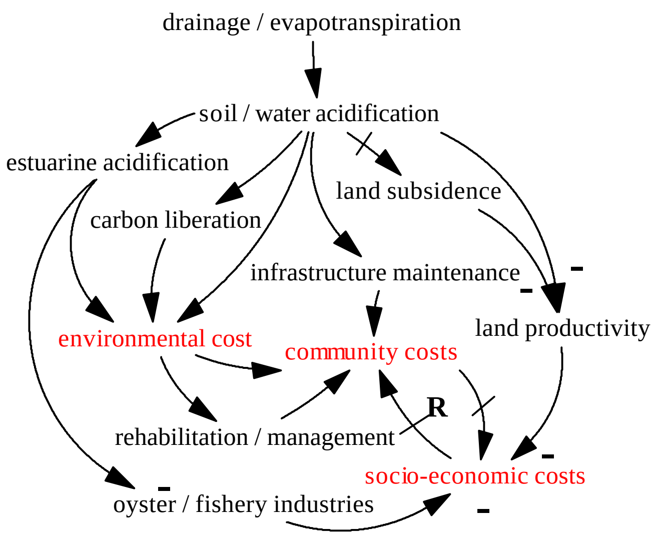

Figure 6: Impacts the draining of from ASS.

Drainage networks in the Maria have significantly increased the rate of oxidation of ASS resulting in the production of large stores of acidity in the floodplain. The current acid store in the soil profiles of the Maria is estimated at 22,000 tons of $H_2S0_{4(aq)}$ by molecular weight (Johnston, 1995). Stores of potential acidity are some 70 times greater than current, estimated at 1.5 x 10^6 tons of $H_2S0_{4(aq)}$ by molecular weight (Johnston, 1995). Assuming an acid production rate of 200kg ha^{-1} yr^{-1} (Smith, 1999a) the Maria has the potential annual acid flux of some 1,400 tons of $H_2S0_{4(aq)}$. Under current drainage and climatic regimes, it will take over 1000 years to completely oxidise all sulfide sediments in the floodplain by natural means, stressing the enduring consequences and intergenerational inequalities manifesting from draining ASS. Recorded acid discharge events in the Upper Maria indicate that this system is extremely vulnerable, with sections of the estuary (particularly Connection Creek) remaining acidified for weeks after a discharge event has occurred.

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30 NWPASS (1999) note acid waters rapidly corrode infrastructure such as pipes, bridges, floodgates and pylons.

Figure 6 exemplifies how drainage in the Maria River has been dynamically impacting on the livelihoods of individuals, multi-million dollar industries and the general community since the early 1960s and will continue far into the future without proper management solutions. Clearly the current agrarian landuse is unsustainable, creating severe and chronic ecological degradation and imposing significant intragenerational and intergenerational inequalities on Maria River communities. Thus the community value of the Maria is seriously being degraded, indicated by numerous externalities manifesting from the drainage of ASS. Furthermore the drainage of the Maria River landscape has long-term regional and global consequences through emissions of CO_2 and the possible impacts on marine fisheries and migratory birds. Aforementioned impacts clearly show that current agrarian practices are unsustainable and have created ongoing conflict within the community over several years.

10 LANDUSE CONFLICT IN THE MARIA RIVER: STAKEHOLDER MOTVIES

While it is evident that current agrarian practices are significantly degrading the Maria River and causing severe economic losses for a range of stakeholders, altering this situation is yet to be accomplished due to farmers resistance against an altered drainage regime. Currently many beef and dairy farmers refuse to accept that they have an ASS problem, that they are accountable for ASS impacts, their agrarian practices are unsustainable and are unwilling to cooperate and adopt government initiated management strategies (Woodhead, 1999; Atkinson, DLWC, *pers. comm.* 20/06/2000). Woodhead (1999, p16) notes several extreme cases in the Macleay-Hastings Catchment, where beef farmers believe in the further drainage of their land, desiring deeper and more drains stating "flood mitigation [drainage] has been the best thing since sliced bread". This resistance has fuelled the protracted conflict between government, estuarine users and farmers and is a fundamental impediment to successful rehabilitation of ASS (Tulau, DLWC, *pers. comm*, 28/06/2000). With the advent of litigation threats and the prospect of bankruptcy this conflict between stakeholders is ever increasing.

10.1 Government response

In 1998 the New South Wales Government developed a NSW Acid Sulfate Soil Strategy to address such landuse conflicts on a state-wide basis. As part of the strategy the Acid Sulfate Soils Management Advisory Committee (ASSMAC) was established to provide coordination, management guidelines, policy and finance for the management and rehabilitation of ASS. Furthermore a monthly newsletter (ASSAY) was developed as a means of extension to farmers and to heighten general community awareness. A National Strategy was released in August 1999 to provide holistic and comprehensive government approach to the management and use of ASS in Australia (NWPASS, 1999). The national strategy stresses the need for a multi-level government approach, with the need to establish and to mobilise industry and community groups to effectively tackle the problems of ASS. Currently NSW government has allocated $ 2.1M over 3 years for ASS management. A further $ 3M has recently become available under the Coastal ASS Program (CASSP; Federal Government, 1999). Tulau (2000) notes that funding may also be indirectly available from other National and State programs[31], totalling over $ 25 M. The National strategy for ASS is clearly focused on solving ASS issues with significant financial support. However to date this strategy has not been operationalised to any large extent in the Hastings, with only several small farm-scale projects established with cooperative farmers (Smith, 1999a).

In accordance to the State strategy, Hastings Council amended its Local Environmental Plan (LEP) to bring ASS under development control and prevent future uncontrolled drainage of ASS (Atkinson, 1999). Hastings Council has recently allocated $ 150 000 to be used for ASS remediation in the Maria River (Tulau, DLWC, *pers. comm*. 28/06/2000). Furthermore the Hastings-Camden Haven ASS Local Action Group (HCHASSLAG) originally a subcommittee of the Catchment Management Committee, has been recently established as a means of addressing ASS on a local scale (Tulau, 2000).

[31] Such as the NSW Wetlands Program, Estuary Management Program and the Flood Management Program

10.2 The basis for conflict and farmer resistance: ascertaining the underlying factors

While there are energetic initiatives and financial support from all levels of government to address and solve the issues of ASS, there has been strong farmer resistance and general unwillingness to act on issues and be apart of community groups. Opposition towards ASS management from the agrarian community is the most significant impediment to reducing the acidification of the Maria. Without farmer commitment and sanction to modify drainage and farm practices rehabilitation strategies cannot transpire. Farmer resistance is not motivated purely out of spite over government authorities but rather are a result of a legacy of underlying often intangible, social, political and economic forces affecting them namely:

- *A lack of a holistic understanding of ASS by farmers, and lack of available credible information*
- *Legacies of land tenure and government intervention*
- *The enforceability and appropriateness of legislation*
- *Poorly structured, inactive industries*
- *Failing economic returns within an uncertain market future*
- *An absence of constructive communication between agrarian and estuarine industries*

10.2.1 A lack of a holistic understanding of ASS, and lack of available credible information

Woodhead (1999) notes a general lack of knowledge regarding critical aspects of ASS in farmers throughout the state. This knowledge gap is more apparent in the beef and dairy industries (the major landuses in the Maria) which can be summarised by the following statistics:

- *All industries were not active in water quality testing*
- *Only 45% of farmers surveyed know they have ASS on their property, of these 45% less than half know the depth of their ASS. Only 17% of beef farmers knew the depth of their ASS.*
- *The majority of ASS information is from local media (53%, 82%) for beef and dairy farmers respectively.*
- *50% of dairy farmers and over 50% of beef farmers consider ASS management not important.*
- *30% of beef farmers said they could not control ASS problems and were at a loss on how to access help*
- *Industry bodies provides 35% and 9 % of the ASS information for dairy and beef farmers respectively.*
- *Only 12% and 9% of dairy and beef farmers read ASSAY newsletter respectively*

The above statements reveal that the current means of providing information (the ASSAY newsletter) seems to be failing, especially in the beef and dairy industries. This may be due to the fact the farmers are suspicious of all forms of government-supplied information and thus refuse to subscribe. Moreover if farmers consider ASS to not exist or be a problem there is little incentive to subscribe to ASSAY. Considering the main source for ASS information reaching farmers is through local media, known for sensationalising issues and providing uncreditable information, the rudimentary knowledge possessed by farmers and the scepticism held by farmers is somewhat justified. A lack of understanding towards ASS is compounded by the fact that many beef and dairy farmers possess a myopic simplistic view towards the role of agriculture and it's function in society, considering farming's foremost role is too feed the country. This is view is exemplified by Woodhead (1999, p16) with the quote " pack of shit! [ASS impacts]… it's [farming is] good feeding the country so it can't be too bad of a problem". However the role of agriculture is multi-functional of which land and resource management is an essential component. Farmers are essentially stewards of a multitude of public natural resources that interact with a farm ecosystem. Farmers are essentially caretakers of the Maria River estuary, which is currently not the general belief held in the Maria.

Information failure is further manifested on a community level. There is an apparent general lack of appreciation of the full economic value of the Maria River within the community has resulted in gross market failure for current landuses that are impacting on the estuary. The mere acknowledgment that the estuary provides a mass of services and has numerous intangible values (see table 1) is foreign to the general community. Such values have only recently been suggested (Smith, 1999b) yet the holistic valuation and public viewing is yet to materialise. If the Maria community was to ascertain the full value of the estuary and thus the full cost prevailing landuse activities, pro-conservation arguments would more apparent and justified, thus the current situation may well have been challenged long ago from community initiatives.

It is clear that the current extension program is simply not reaching farmers in the Maria and that farmers are not receiving adequate and credible information on ASS. The current information gap between what is known in the scientific /professional community and what is known in the farming community is the basis for many other impediments towards successful management of ASS in the Maria. This information gap manifests in negative attitudes towards ASS, a lack of farmer confidence to tackle ASS and hearsay and scaremongering, all which fuel the current destructive social climate between stakeholders.

10.2.2 Legacies of land tenure and government intervention

Since the discovery of ASS and their impacts in the early 1960s, Government authorities have had to take a completely new and contradictory view to the drainage of ASS. This may have instilled views that the government is not in control, is wasting time and money and thus generating general pessimism in farmers.

Furthermore the nature and legacy of drainage networks pose a serious impediment to the management of ASS. A large proportion of drainage works in the Maria were constructed as part of government flood mitigation schemes or by drainage unions on behalf of a group of landholders (Smith, 1999b). Farmers have subsequently connected private drainage too these larger networks often resulting in drains crossing many properties. Farmers are unwilling to take responsibility of drainage impacts on the grounds that the successive governments have advocated and funded these works and that many drains run through numerous properties. Consequently there is no clear ownership of the drains and associated impacts from drainage. Moreover any proposed modification of a single drain will inevitably effect all landowners within a drainage network. Thus it is imperative to seek broad consensus before any modifications are made to a drain or its operation. Obtaining cooperation with all landholders within a drainage system has proven to be futile on numerous occasions, resulting in fruitless strategy proposals often due to one 'rogue' farmer not cooperating. This problem of solving the lowest common denominator in rehabilitation agreements is considered the most significant impediments to achieving successful management (Atkinson, DLWC. *pers. com.* 20/06/2000).

10.2.3 The efficiency and appropriateness of legislation

The government has successfully prevented further inappropriate drainage of ASS through development control. While this has been an essential process, it has come at a price to both the agrarian community and the society. Over 14 articles of legislation may require consideration when managing ASS in NSW (Tulau, *in prep*) which has been primarily focused on preventing future inappropriate drainage in ASS and persecuting offenders through development application (DA) mechanisms. While current legislation has successfully halted any further deep excavation in ASS (Atkinson, 1999) the appropriateness towards regulating regular drain maintenance is questionable. Woodhead (1999) and Tulau, (*in prep*) allude to the issue of poor societal acceptance, noting that farmers are unsatisfied with the DA process due to the incurred costs and time associated with obtaining consent. This has created frustration for tea-tree, beef and dairy industries, perplexed and confused over the mass of legislation and particularly with the DA process for drainage and drain maintenance. Woodhead (1999, p9) quotes " A lot of income is lost due to red tape approval to clear drains, so even going through the correct channels hurts the farmer".

Current DA process also raises questions of environmental efficiency. The current process is cumbersome with each drain cleaning / excavation application being independently assessed, each attracting it own fees, monitoring and paperwork. Hence there is no holistic approach to address the compounding effects from numerous drainage activities. Moreover Tulau (*in prep)* notes that farmer frustration and confusion over the DA process has led to some cases of non-compliance, both intentional and unintentional. In some cases under the advent of prosecution farmers have not had sufficient resources to carry out necessary rehabilitation resulting in continued environmental degradation (Tulau, *in prep*). The legacy of government intervention and the associated problems with current legislation have instilled an alarming degree of scepticism, political dissatisfaction and mistrust, negativity, and a rebellious attitude in beef and dairy farmers towards the current management of ASS (Woodhead, 1999).

10.2.4 Poorly structured and inactive industries

Another significant impediment to ASS management has been the effect of poorly structured and inactive industries towards addressing ASS. Due to the geographically dispersed nature of broad-acre beef and dairy farming, industry structures are inherently fragmented with minimal control and cohesion. This has contributed to slow industrial response to the problem of ASS for both beef and dairy. While the NSW diary industry is planning to develop an industry wide response to ASS through the NSW Dairy Industry Development Company (Woodworth, 1999a) there are no industrial-led self-regulations or best practice guidelines for both beef and dairy. Williams and Porter (1999) suggest the main problem is that the beef and dairy industries cannot envisage what an effective self-regulatory mechanism may comprise.

The tea-tree industry is a more advanced in addressing ASS issues with the development of a environmental policy (ATTIA, unpublished). However this perceived industrial self-regulation is really a proxy to governmental policy, stating management and remediation of ASS areas should merely refer to the recommendations of an appropriate government authority. Furthermore Williams and Porter (1999) indicate not all tea-tree growers belong to this association due to its voluntary nature. Thus poor industry support contributes to the overall lack of understanding and unwillingness of farmers to tackle and address ASS on their properties.

10.2.5 Failing economic returns within an uncertain market future

The NSW beef industry has been enduring severe economic conditions due to low and fluctuating commodity prices and is currently achieving gross margins of just \$ 40-75 ha^{-1} (Mullen and Kaur, 1999). Woodhead (1999) notes over 20% of beef farmers are decreasing their production with most reliant on off-farm incomes. The dairy industry is slightly more stable with a static production (Woodhead, 1999) however current gross margins are only ~\$ 90 ha^{-1} (Mullen and Kaur, 1999). These margins are extremely lean in both beef and dairy farming and are insufficient to cover normal farm overheads let alone any additional capital investments needed to either improve productivity or reduce acid discharges. With low economic gains from farming and the reliance on off-farm income, Smith *et al.*, (1999) believes that farmers have no incentive to invest in farming or environmental rehabilitation, especially since there is no significant economic gain from ASS rehabilitation works for beef and dairy (NWPASS, 1999). This belief is reiterated with the quote "…..they [farmers] don't care about ASS because they don't get a living of it [land], so they don't care for it" (Woodhead, 1999 p17). Conversely the tea-tree industry poses opposite economic conditions, with gross margins of \$ 3,000 ha^{-1} (Mullen and Kaur, 1999). Clearly this industry has the financial capacity to invest in ASS best management practices.

10.2.6 An absence of constructive communication between stakeholders

Woodhead (1999) notes that the ASS debate largely been conducted within local media arenas resulting in the sensationalisation and polarisation of issues leading to misinformation and alarm raising between and within stakeholder groups. Fishing industries, environmentalists and oyster growers desire estuaries to be returned to their pristine state. Farmers want maximum production with minimal bureaucratic impediments while government may want cheap expeditious solutions with minimal public conflict. In the absence of constructive communication these needs and wants cannot be effectively communicated between conflicting stakeholders, a major impediment towards obtaining consensus over the problems at hand. Alternatively any communication occurring has been in the form of treats and "scaremongering", accelerating the conflict within ASS communities (Woodhead, 1999). In extreme cases farmer threats have been accompanied with shotguns (I.Crisp Manning Oyster farmer, *pers. comm.* 3/08/2000).

10.3 Discussion

Clearly current impediments to successful management to ASS don't lie within the financial means and willingness of the government. Farmer resistance to government objectives has proven to be a far more sinister and complex obstacle stemmed from a legacy of unfavourable social, political and economic pressures fuelling these attitudes in the Maria and in generally within NSW. Strong farmer resistance and poor industrial reaction towards ASS are particularly apparent in the beef and dairy communities, which make up the bulk of landuse in the Maria. Alone each factor is significant enough to cause the breakdown of any proposed solution to the Maria. However each factor does not work alone, they are interactive, reinforcing each other to produce overall negative feeling in farmers towards governments, environmentalists, the oyster and fishery industries and the science of ASS. The following casual loop diagram (CLD; figure 7) provides a systems perspective to the current problem of ASS in the Maria identifying the main contributing factors and the dynamics between stakeholders and the government.

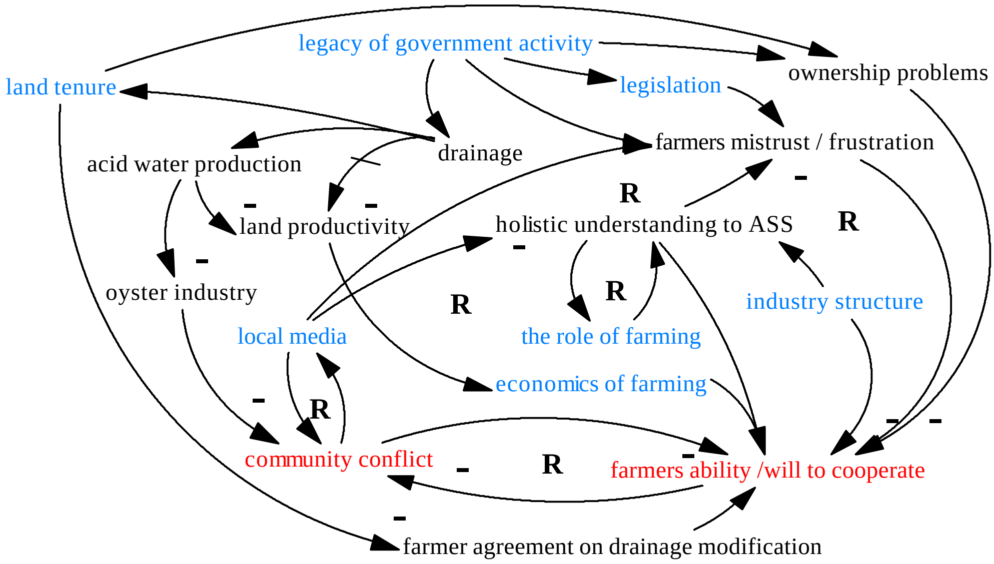

Figure 7: Casual loop diagram of the problem of landuse in the Maria River
Blue text denotes the underlying source factors, red text highlights resultant impediments to ASS management

Figure 7 reveals that the problems manifesting from farming on the Maria are complex and intensely political with multiple demands and interests over the future management of this resource. Developing an effective resolution for the Maria must equitably address conflicting stakeholder demands and amend the underlying socio-economic forces propelling farmers to be apprehensive against any form of change. Due to these complexities and nature of the problem of ASS, it would be futile to simply implement rehabilitation strategies from a 'command and control' approach. The prospect of farmer refusal, project collapse and future heightened community conflict is evident under such a strategy. Hence ASS management must address and resolve community conflict as a means to change the fundamental dynamics between farmers, estuarine users and government, concurrently with any technical rehabilitation strategy. To date there is no comprehensive strategy aimed at resolving these underlying socio-economic impediments in the Maria.

11 TOWARDS SUSTAINBLE LANDUSE IN THE MARIA RIVER

11.1 Community-based management: theory and relevance to sustainability

Natural resources are essentially community resources whether this community is defined at a local or global scale. Moreover natural resource use can be viewed as the interface between ecological, social, political and economic systems of a community. Under the theory of neoclassical economics this interface often manifests in the miss-appropriation of welfare, power and well being which is felt most at a local community level[32], the crux of most environmental problems. Thus the management of resources must address the dynamics between these systems at a local level by embracing community participation, thus equitably assess the various need and wants of affected stakeholders. This process is often referred to as community-based management, or 'civic science' which aims to mobilise partnerships and participation within affected communities, justified on the basis that they provide a far more equitable and transparent process to management (Mitchell, 1997; Selman, 1994). The community essentially becomes an interacting body with

[32] The author recognises large-scale transboundary impacts such as acid rain, greenhouse effect and ozone depletion leads to impacts on a larger scale than the immediate local community level.

the government through the two way process of education, goal setting, strategy review, implementation and monitoring. In several cases the community takes precedence over the several phases of management such as goal setting and on-ground implementation / operation of directives. Thus community-based management fulfils several principles of sustainable development, namely the empowerment of local people, public awareness and participation, self-reliance and social justice towards the management of natural resources (WCED, 1987; UN, 1993). There are numerous examples advocating the value and successfulness of community-based management over the traditional ‘command and control’ or ‘top-down’ approach (see WRI, 1996; OECD, 1998; Mitchell, 1997; Stern, 1999).

11.2 Community-based management for the Maria River

The above theory on resource use holds true for the Maria. The Maria is a typical multi-use resource problem, where legitimate interests and resource demands are in perpetual conflict at the local community level. These interests and demands are future complicated as they are driven by a suite of underlying interacting pressures that has created a legacy of mistrust and bitterness between stakeholders and the government. This can only be resolved or at least reduced through an explicit process of bargaining, consultation and compromise between stakeholders. Thus progressing towards a more sustainable agriculture in the Maria must first be concerned with creating visions, resolving conflict, building consensus and understanding over the facts and issues at hand. To effectively accomplish these prerequisites the Maria must be tackled from a community-based management approach.

The process of community participation for the Maria aims to provide the favourable climate to stimulate farmer cooperation by breaking down the interactions propelling their resistance to ASS management discussed in section 10.2. The overall process of community-based management for the Maria is represented in figure 8. Each loop represents the flow of information, knowledge, consensus / acceptance, participation, goal setting, strategy development and a means of conflict management. Community participation needs to be formalised in two stages. First and foremost, cooperation and understanding must be generated within the general Maria River community. This aims to provide a favourable vehicle for generating initial consensus, goals, education and general understanding over the credible information on ASS. This initial process is represented by the red loops in figure 8. The second stage aims at providing an effective means of implementing on-ground strategy specifics by developing farmer cooperation and consensus towards individual agreements over the management of multi-tenure drainage systems. This second process is represented by all loops in figure 8.

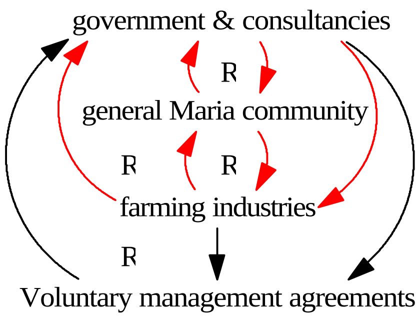

Figure 8: Community-based management process

Initial community cooperation needs to be addressed and discussed between stakeholders, the general public, local media and the government. The aim of this is to resolve several underlying forces driving the conflict in the Maria particularly eliminating “scaremongering” and threats, the lack of constructive communication, lack of credible information, the rudimentary understanding of ASS, and the perceived role agriculture.

In resolving these issues at a local community level a stable social platform for developing cooperation within the agrarian community can be established. Cooperation within the agrarian community in the form of adaptive voluntary farm management agreements (sections 11.4 & 11.5) is essentially a subset of the overall community-based management (see figure 8). The interactions between these two processes are reinforcing as shown in figure 8.

11.2.1 Providing a means for credible information

Providing a means of credible information is essential to heighten the awareness of ASS in farmers and the general community considering the poor successfulness of the current extension program. While the Maria River has received three information bulletins on ASS impacts in 1999, Smith (1999b) stresses that there is still and formidable lack of understanding and acceptance held by the agrarian community as a whole. Promoting ASS information enables farmers to realise and believe that they have ASS and the potential problems from drainage. Moreover information on the science of ASS, proposed drainage redesign and available management strategies would provide farmers and the general community with the tools to tackle ASS effectively from a common knowledge base. Providing such information also allows the environmental externalities of farming on ASS to be unveiled to farmers reinforcing the fact that they well may be significantly impacting on the Maria estuarine users. The distribution of information will also heighten general discussion within the community making ASS a forefront issue and stimulating stakeholders to join a management group. Community-based management provides a platform for the effective distribution of this information. From several experiences outlined by OECD (1998) the supply of information within and between community management groups leads development of community resource pools which intern promotes group cohesion and cooperation promoting a climate of innovation and self-learning.

While information and education can be conveyed during workshops and public forums, a local information outlet may be necessary to be established within the catchment to ensure availability of resources and to further stimulate farmers to enter a management group. A strategic component of this extension program will be to provide information and resources to the beef, dairy and tea-tree industry bodies. This will enable industries to acquire contemporary credible information and the skills needed to support farmers who are hesitant towards using government or consultancy-derived information. Providing information is supplied from a common base eliminates any contradicting facts allowing all stakeholders to receive the same credible information from their industry representatives. Distributing information through these channels takes advantage of existing social networks enabling farmers and estuarine users to obtain information through means that they feel most assured and comfortable with. This process helps to build on trust and acceptance of ASS and the issues of drainage within the community.

Gardner and Stern (1996) stress that while education provides a means to change attitudes, it has poor success rate in creating agreement and acceptance in cases where proposed management severely impinges on the embedded values, ethics and morals held by stakeholders. Considering the radical views held by some farmers and the need for farmers to adopt foreign drain management strategies a successful extension program may have to utilise alternatives other than the direct supply of information to farmers. Alternatives include *feedback*, *demonstrations* and *framing messages* (Gardner and Stern, 1996; Selman, 1994).

The theory of feedback is a simple application of operant theory from psychology, where people are motivated to change their behaviour based on attaining a “reward” mainly in the form of monetary savings (Gardner and Stern, 1996). However in the context of ASS such an alternative is problematic considering there are no direct economic gains for farmers to reduce acid discharges. However under a proposed incentive scheme (see section 11.6.2) informing farmers that any on-ground rehabilitation works can attract funding, the ‘reward’ of reducing acidic discharges without personal cost may overcome this difficulty and prove to be a valuable tool in generating farmer commitment and interest.

Other approaches to supply an effective extension program for the Maria lie within demonstrations and framing messages. Demonstrating successful management strategies and alternatively conspicuous impacts from the drainage of ASS provides a coercive approach to information supply (see section 11.2.5 for further discussion). Apart from the Tea Tree industry there are no working demonstrative examples in the Maria of landholder initiatives in managing acid drainage (Smith, 1999b). Pilot projects and educational field days need to be established proving an excellent coercive medium to convey information enabling farmers to see established working management strategies on farm properties. Currently there are very few cooperative farmers that are willing to embraced new management strategies (see Tulau, 1999; Smith, 1999a). Framing messages is another way of making information more effective and involves the close attention on how pro-environmental terms and activities are described (Gardner and Stern, 1996). Using terms such as ‘conservation’ and ‘preservation’ within information discussing the future farmers’ properties may evoke feelings of sacrifice and oblation in farmers. Such terms could be better referred as ‘improvement’ and ‘rehabilitation’ in future workshops and bulletins. Such a simple strategy may seem obvious however left unaddressed it serves as a threat to obtaining consensus over management.

11.2.2 Providing a means of common goal setting and consensus

Under a community setting constructive communication can be established allowing the development of common management goals for the Maria. The process of goal setting in a community setting provides the arena for common understanding, discussion and involvement, attaining equity between the various parties and the development of appropriate evaluation indicators. This also encourages horizontal decision-making (Selman, 1994), enabling all stakeholders and government to arrive at a more equitable goal and management objectives. Similar landuse conflicts in Ecuador’s estuaries exemplifies the need to strengthen communication between parties as a precursor to successful conflict resolution (Stern, 1999). Stern (1999) signifies how an initial process of mere listening and talking over the problems being experienced by parties with the help from facilitators can break the cycle of mutually destructive conflict enabling a progression towards consensus over what needs to be done. Similar community consensus needs to be developed over how the Maria River should be managed and more importantly perceptions and ownership of problems.

An integral component of goal setting is to define what is sustainable landuse and what is not within a local collective basis (United Nations, 1993). While this is an extremely messy and time-consuming process Fricker (1998) stresses that it is essential for community cooperation. While goal setting will vary with site specifics and time horizons, a general objective of maintaining maximal sustainable landuse and estuarine productivity while discharging no net acid production above the mean natural rate from undrained areas has been suggested (Sammut *et al.,* 1996a; White *et al.,* 1996; White and Melville, 1996). However natural rates of acid production from undisturbed soils are not known in NSW (White and Melville, 1996) thus it may be more pertinent to define levels of estuarine pollution that has no long-term impact on the ecosystem and estuarine users. OECD (1998) suggests such a process of goal setting through community participation and consensus provides a sense of ownership and stewardship to problems as they have been an integral part of the problem solving. Consequently outcomes and management strategies are more easily accepted and understood with improved chances of project success and longevity.

11.2.3 Providing a means for societal acceptance and utilising local knowledge

Integrating local knowledge and landholder input into proposed management strategies is essential to secure acceptance and a sense of ownership towards rehabilitation works. Farmers and estuarine users have been using the land and estuary for decades and have a wealth of local knowledge and can appraise new ideas within a historical context and any long-term perturbations such as ENSO related drought cycles. The voluntary agreement process outlined in sections 11.3 & 11.4 provide the mechanism to formally integrate local knowledge into the overall management strategy for the Maria.

11.2.4 Providing a means for conflict resolution

Providing a mechanism for conflict resolution or alternative dispute resolution has been advocated widely as prerequisite to successful and prolonged sustainable management of resources (Mitchell, 1997; OECD, 1998; WRI, 1996; Stern, 1999). It is inevitable that current community conflict will be transferred into the community-based management process considering people’s livelihoods are at stake. Without addressing such conflicts a momentum of destructive social climate could be re-established, undermining previous work and possibly causing the dissolution of established groups. While the suggested community-based management approach in it self is a form of conflict resolution a more formal complementary process may be needed in times of sustained disputes (see Mitchell, 1997). Such a process may involved the use of public forums, neutral mediation, and or 3rd party arbitration during the community-based management process. Moreover Mitchell (1997) notes that with similar controversial issues such as in the Maria, optimistic goal setting may actually provoke further conflict. Hence obtaining universal consensus within the community may be prove to be futile possibly undermining the cooperation process by provoking even more conflict. Mitchell suggests under such situations goal setting should be revised; instead of universal consensus a goal of merely obtaining informed consent to proceed with rehabilitation strategies may be more beneficial.

11.2.5 Incentives for Partnerships

Community based management is based on voluntary participation and hence its successfulness depends on the willingness for stakeholders to cooperate. While there are obvious motivations for estuarine users, the general community and the government to participate in community-based management, the motivations for farmers to follow suite is obviously limited. ASS rehabilitation requires such farmers to turn 180 degrees on their ideals and convictions, asking them to comprehend and accept completely foreign ideologies that they are fundamentally against. Moreover during extreme seasonal conditions farmers may suffer from a reduced yields under change drain management regimes. Thus the success of the extension program may fall short in generating farmer commitment and participation. Developing comprehensive farmer cooperation may need to take an alternative complementary means as outlined below:

- *Establishing that declining farm productivity is related to draining ASS*
- *Increase the awareness of the possible financial gains / economic stability from an altered drainage regime*
- *Suggesting farmers take "ownership" of issues in fear or threat that government will impose stricter regulations than the voluntary alternative.*
- *Cultivate the belief by taking their own initiatives, farmers may arrive at more satisfactory locally acceptable solutions are achieved than some outside authority.*
- *Generating group consensus that farmers have the knowledge, ability, tools and the opportunity to solve environmental degradation through a self-regulating process.*
- *Advocate that rehabilitation works can attract funding and professional support and technical appraisal*
- *Use of Coercive pressure from local demonstration sites proving that drainage management can improve their land*
- *Advocate the benefits of entering organised drain management groups*

Schoon and Te Grotenhuis (2000) suggest farmers are most likely to be influenced and adopt new management strategies from coercive pressures within the agrarian community ie; the family, industry bodies and neighbouring farmers. Within a community-based environment farmers are able to communicate in their own terms and outlook on issues. Farmers are very aware of neighbours actions and activities and are generally less responsive to government intervention. Establishing demonstrative pilot projects and field days as previously stated will provide a formal mechanism of invoking pressures from within the agrarian community to change and conform. This subtle peer pressure approach intends to create a reinforcing effect accelerating discussion and participation over ASS management between farmers and the community. Considering the extent of government mistrust in the Maria River such an approach will have immeasurable value towards attaining successful management of ASS. Smith (1999b) identifies a small collective of progressive farmers in the Maria. These farmers could be targeted to provide the setting for pilot projects and educational field days to stimulate apprehensive farmers into addressing ASS.

Once farmers are willing to confront the issue ASS management the second stage of community cooperation can be addressed, aiming to establish agreements between farmers within multi-tenure drainage networks over the long-term management of their farms. By establishing consensus or at least informed consent within these drainage networks effective holistic rehabilitation and governance can transpire. These agreements can be formed through the use of voluntary farm management agreements.

11.3 Adaptive voluntary agreements: rationale and relevance to sustainability

Voluntary Agreements (VA's) can be considered as an extension of the community-based management theory, providing a means of attaining 'lateral governance' through compromise and stakeholder consultancy, leading to the agreement of a landuse contract between a landholder(s) and a governing body (Connelly and Smith, 1999). VA's enable a more sustainable approach to management by integrating community and affected stakeholders right down to a property level. Often VA's are more semi-voluntary where farmers enter an agreement process under a financial incentive or business / trade contract which is essentially the case for the NSW sugar cane industry (ASSMAC, 1999). Resultantly the sugarcane industry has been very progressive in addressing ASS, considering themselves as providing state-of-the-art management solutions.

There numerous other examples advocating the benefits of voluntary agreements (VA's) over policy driven mechanisms in similar landuse management issues as in the Maria (see WRI, 1996; OECD, 1998; Kjær, 1998; Shiferaw and Holden, 2000; Greiner *et al.*, 2000; Cudlinova and Lepka, 1999; Connelly and Smith, 1999; Hussen, 2000). In most cases VA's provided the vehicle for significant increases in farmer commitment to successful environmental protection while optimising the socio-economic efficiency of environmental management. Furthermore from OECD experiences farmer acceptance of VA's over policy driven approaches proved to be ubiquitous (OECD, 1998). VA's provide a least interventionist approach to compliance, or a "bottom up approach" as regulation is obtained through agreement and compromise in a two-way process (OECD, 1998).

11.4 A Voluntary Agreement approach for the Maria River

To significantly reduce acid discharges in the Maria River there needs to be an overall alteration in current landuse activities and drainage regimes. To achieve this a strategy legislation must govern farmer activities from a collective approach, aimed at achieving effective environmental rehabilitation that is palatable within the farming community which is also as economically efficient as possible. Further governance will inevitably be dealing with the alteration of farmers' lifestyles, values, farm practices and income sources which can only be equitable attained through lengthy education and compromise. Current governance relies on policy compliance, providing little means of any two-way discussion between government and the community. Moreover Woodhead (1999) notes that the current perceived 'big stick approach' seriously afflicts farmers. Thus further governance needs to be turned a full 180 degrees from one of command and control to cooperation and compromise.

Figure 9 highlights that a VA is essentially a process of dynamic compromise between the goals of the government, the need and demands of the farmer and prevailing land /ecological constraints bounding the compromise process. By achieving VA's the demands from disgruntled estuarine users are resolved, thus providing the first step towards conflict resolution in the Maria. Achieving environmental objectives infers a change in land management, which can range from simple alteration of farming practices to land acquisition and retirement. VA's encourage farmers to consider environmental, economic and social factors of the farm in the short and long-term from a cooperative settlement approach.

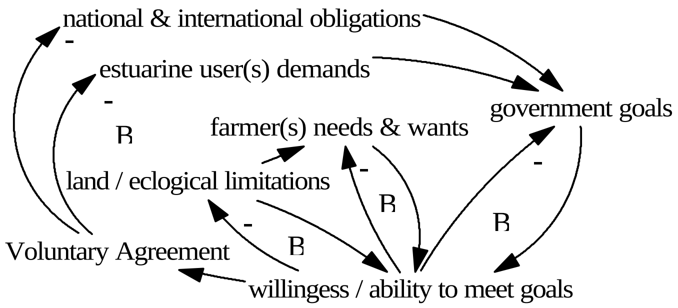

Figure 9: The Voluntary Agreement process

Voluntary Agreements can be formalised through a farm plan(s), which should include the following:

- *Contractual agreement over drainage / floodgate alteration, maintenance and operation.*
- *ASS and drainage map for the property / drainage network associated with the farmer.*
- *Map identifying zoned areas for different management strategies.*
- *Agreement over most appropriate landuse for farm(s) or for entire drainage network system.*
- *Information regarding technical aspects of rehabilitation such as liming rates, best management practices, drain and floodgate operation.*
- *Agreement over the continued monitoring of water quality, watertable levels, and soil pH.*
- *Reporting, plan reviews and group forum participation.*
- *Contractual agreements over possible conservation easements and related compensation.*
- *Additional compliance under any other policies such as SEPP 14-coastal wetlands.*

VA's are especially advantageous for governing landuse in the Maria River as they provide:

- *Is a least interventionist approach to management*
- *Is a capable means of managing multi-tenure / tenure exchange situations*
- *Employs the principles of adaptive management*
- *Provides a means of streamlining compliance*

11.4.1 A least interventionist approach

Allowing farmers to enter a farm management agreement provides a means of arriving at the most acceptable strategy for the farmer. Farmers ideas and local knowledge can be integrated with professional advice giving a farmer a heighten sense of project ownership. Moreover the farmer can gain a sense of control over the future farm management, thus reducing the problems associated with the current policy compliance approach. Moreover VA's may prove to be valuable in cases where conservation easements are considered the best option. Lengthy discussion and compromise would be required to establish equitable compensation and an understanding of the terms the easement.

11.4.2 Capable means of managing multi-tenure / tenure exchange situations

As stated previously obtaining broad consensus over multi-tenure drainage systems is considered to be one of the most serious impediments to ASS management. The Maria River contains several cases where the alteration of drainage networks requires multiple consent from landowners. A contractual agreement covering the entire multi-tenure drainage network enables management to address both the individual concerns of farmers while evaluating the aggregate effects from multiple alterations. Thus the possibility of establishing group consensus and compliance over the operation of drainage networks is heightened under a group VA process. VA's also provide a means of sustained compliance under the advent of a change of tenure. By bounding the VA to the title of the land any established drainage management strategy can be transferred to any future owner or leasee. Thus the advantage of developing VA's covering entire drainage network will prove to be invaluable.

11.4.3 Streamlining compliance

The NSW sugar cane industry provides a working example where compliance is currently being streamlined through the self-regulation process as previously mentioned in section 11.3. Such an approach can be adapted through the means of VA for the industries on the Maria. Drainage operations can be agreed upon using best practice guidelines in which the farmer is obliged to follow within the VA. Control over when and how drain / floodgate operations can be more effectively transferred to the farmer enabling him / her to apply the agreement under changing environmental conditions. Under government consent[33], VA's can provide a means of bypassing the current DA process for drainage in ASS, providing substantially less cost for landowner, reduced paperwork and confusion and thus higher rates of compliance. Farmers would gain confidence from being fully aware of the type and timing of works can be and can't be performed, enabling a more planned strategic approach to drainage operation and maintenance and thus reducing the risk of acid discharges from poor compliance.

11.5 Adaptive management: theory and value

Adaptive management is a flexible approach to implementing strategies using a continuous learning and refinement process (Bell and Morse, 1999). Management is subject to ongoing adjustment based on formative evaluation and stakeholder feedback (figure 10). Adaptive management takes an ecosystematic approach, considering ecosystem boundaries and biological time scales of resources (Bell and Morse, 1999). This approach embodies the premise that systems are moving targets evolving with of social, economic and environmental change (Mitchell, 1997).

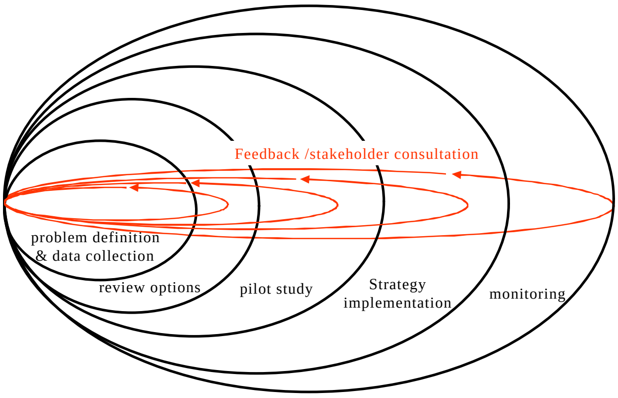

Figure 10: Adaptive management process

Source: adapted from Bell and Morse (1999)

[33] Consent through the Department of Urban Affairs and Planning.

Thus the appropriate management of such systems must evolve and change to accommodate systematic shifts. OECD (1998), Bell and Morse, (1999) exemplify the value of adaptive over programmed management in situations of complexity, variation, uncertainty and / or where a range of landuse are conflicting.

11.5.1 Application of adaptive management to the Maria River setting

The issues of systematic complexity, variation, and uncertainty and the pressure of conflicting interests are all associated with the management of the Maria. Complexity and variation are found within the environmental interactions between tidal fluctuation, drainage systems and the prevailing climate. Uncertainty is apparent in the pioneering of technical solutions on a large-scale application. Smith (1999b) stresses the need to install temporary structures and monitor outcomes before committing funds to more substantial and permanent works, verifying the experimental nature of proposed technical solutions (see section 11.7). Farmers are also faced with uncertain socio-economic conditions that strongly affect how effectively they can manage their farms.

Finally there are a polarised demands on the Maria River creating conflicting landuses. Thus the justification of employing an adaptive management strategy on the Maria River is evident. Adaptive management ensures that strategies can evolve with changing technology, environmental perturbations and socio-economic conditions of stakeholders. Through revisiting the VA process various components of a farm plan can be altered and fine tuned upon consultation and agreement with the farmer(s) enabling management strategies to be modified to optimise the balance between environmental efficiency and cost under such changing conditions.

However Mitchell (1997) stresses one drawback with utilising adaptive management. There are possible political risks from documenting poor outcomes or failures. Stakeholders may refuse to continue, funding may cease, or project outcomes may provoke community conflict. Considering rehabilitation strategies will undergo a trial and error experimental stage in the first years, an adaptive management approach is considered to be valuable yet may incur such political pressure. Thus there needs to be a clear understanding of the adaptive management process by all stakeholders and funding bodies with a capability and willingness to learn from errors and to be tolerant in situations of uncertainty and change.

11.6 Complementary governance mechanisms

While the farm management agreement process is a form of governance in it’s own right there needs to be complementary governance mechanisms to ensure widespread compliance and a means of control in the advent of non-compliance. It would be foolish to assume farmers will comply based solely on the morals for caring for the environment and answering the needs of estuarine users.

11.6.1 The Polluter Pays Principle?

The farming community is essentially discharging large quantities of pollution in the form of degraded water quality. Thus an initial reaction to a complementary governance solution would be to implement the Polluter Pays Principle (PPP; Connelly and Smith, 1999) in the form of effluent charges or discharge standards. While this approach is relatively easy to administer, enables environmental externalities to be internalities, generates funding, corrects market distortions and provides incentive for farmers to invest in pollution control strategies (Hussen, 2000) its suitability and successfulness rests on resolving several provisos.

Firstly who is the polluter and how much is he / she polluting? In the case of ASS the source-waters for acid discharges are essentially diffuse coming from acidified groundwater that is controlled by numerous multi-tenure drainage networks. Thus defining the polluter and his / her relative contribution is extremely problematic. Yang *et al.,* (2000) provide a possible solution to this with the development of a GIS based integrated drainage network analysis system (IDNAS). IDNAS is able to accurately modelling acid discharges and target specific drains at a paddock level. However this technique requires costly detailed soil, drainage and hydrological data and has yet been applied in any large scale due to its experimental nature.

Secondly even if IDNAS resolves the above issue, the dilemma of responsibility is still unresolved considering that the majority of drainage in the Maria was constructed under government initiated and jointly funded flood mitigation works. Thus forcing farmers to pay for government endorsed drainage is inconceivable. Thirdly the PPP rests on the presumption that the polluter can pay. Considering the aforementioned economic situation of beef and dairy farmers, the ability for them to comply under the PPP is seriously limited. This may force farmers to exit industries, discriminating between farmers and going against the objectives of maintaining and maximising agriculture productivity on ASS landscapes.

Finally Huseen (2000) stresses that the PPP has proven to be unsuccessful in many agrarian situations as farmers are philosophically against taxes in any form especially in cases of failing industries and uncertain market environments. Considering the current abhorrence towards governments held by farmers and the poor market situations for beef and dairy, employing PPP would merely exacerbate the current entrenched conflict and thus is unsuitable for the Maria River setting.

11.6.2 The need for financial incentives

Alternative to the PPP, funds could be directed to provide the 'big carrot' rather than the 'big stick' as a means of governance. One of the crucial aspects of the beef and dairy industry is that there is no direct economic incentive to carry out rehabilitation works and more importantly there are not in a financial position to do so (see table 2). Financial incentives aim at placing beef and dairy farmers in a more favourable economic position to react to ASS and more importantly provide a surrogate means to lift the profitability of farming under an altered drainage regime and thus increasing farmers desire to invest and rehabilitate the land. The current state government strategy on ASS acknowledges this and suggests the need for financial incentives (Williams and Porter, 1999). Current direct financial incentives occur in the form of catalytic funding from the ASSPRO program. Further incentives in the State strategy are proposed, including works grants and interest rate subsidies within a drainage adjustment package (Williams and Porter, 1999). The current and future proposed package is primarily aimed at providing funding one-off rehabilitation works that will alter drainage works. However it falls short in maintaining long-term farmer incentives to continue to carry out ongoing environmental rehabilitation such as liming, monitoring and best management practices towards drainage maintenance and floodgate operation after the initial one-off payment. This is a crucial issue for the Maria as the proposed management strategy by Smith (1999b) requires ongoing farmer compliance and participation to ensure acid discharges be reduced. A common solution to provide sustained compliance is in the process of *cross-compliance.*

11.6.3 Cross-compliance

Cross-compliance is a form of financial incentive where farmers receive direct financial support or access to vital resources such as water or market entry on the condition that they meet mandatory environmental requirements. If violated farmers do not receive such incentives (Kjær, 1998). Cross-compliance is no newcomer to governance and has been shown to prove to be a successful alternative in many cases (see OECD, 1998; Shiferaw and Holden, 2000; Kjær, 1998). Finland's environmental policy strategy on regulating farming provides a working example of cross-compliance in ASS (Finnish State Government, 2000a). Finland has established a joint EU- funded General Agri-Environmental Support Scheme (GAEPS) where farmers can join voluntarily. Almost 88 % of the total cultivated area in Finland is regulated by GAEPS. ASS rehabilitation works can attract general funding though the GAEPS for such measures including the development of farm environmental management plans. Finland has recently specifically targeted the regulation of farming in ASS through its Supplementary Protection Scheme (SPS) developed to provide financial incentive for special measures to protect the environment. ASS rehabilitation measures such as the installation of lime filter drainage[34], efficient surface liming and controlled drainage attracts funding and incentive bonus through the SPS. SPS funding is given providing farmers enter an agreement over a certain environmental protection measure for a time period of 5 to 10 years, thus providing a means of sustained cross-compliance (Finnish State Government, 2000a).

[34] See section 11.7.5 which further discusses Lime Filter Drainage.

Such a similar approach can be tailored towards management in the Maria. By entering a VA farmers are bounded to carry out works and requirements for an agreed duration, say 5 years, and thus are eligible for funding. Requirements relating to ASS management in the Maria River setting may include the establishment and continued monitoring of rehabilitation works, participation in the VA process and carrying out sustained best management practices over the contractual duration of the farm plan.

A successful local example of cross-compliance occurs in the NSW cane industry. International experiences also prove that cross-compliance is a more equitable approach over other market driven solutions such PPP and other financial disincentives as the market competitiveness are not diminished and thus not discriminating between regulated and unregulated farmers (OECD, 1998). Moreover it still enables low profiting farmers to engage in rehabilitation works while providing a means of sustained compliance. The structure of cross-compliance can be integrated into the VA process providing financial incentives to carry out aforementioned ongoing rehabilitation activities. The major drawback of employing an incentive base scheme is it has high resource demands and requires the auditing of environmental works. However the State government is currently in the process of providing a comprehensive strategy to ASS rehabilitation on private lands and proposes possible funding sources (Williams and Porter, 1999). The Hastings Municipality is also in a favourable position to fund possible rehabilitation strategies with a percentage of a recent rate-rise being allocated towards ASS management (M.Tulau, DLWC, *pers. comm*., 28/06/2000).

11.7 Technical strategies for the Maria River

Robert J Smith and Associates have recently proposed technical solutions in reducing acid discharges in the Hastings catchment (Smith, 1999b) which is currently being reviewed by the Hastings Council as a platform to initiate rehabilitation in the Maria (M.Tulau DLWC *pers. comm*., 28/08/2000). Therefore it is not the intention of this paper to provide a lengthy discussion on technical solutions towards the management of ASS in the Maria. However a short critic of the proposed solutions and discussion on alternatives is valid.

A range of technical solutions is available for ASS management that falls into four broad categories namely containment, neutralisation, dilution, and transformation (Tulau, 2000; Atkinson and Tulau 1999). From an initial understanding of ASS chemistry one could presume that the entire soil and water acidification problem could be simply solved through complete chemical neutralisation with the application of lime. However this option is simply not economically viable due to the expanse of drained ASS, the concentrations of acid stores, the technical constraints in incorporating lime into fine grained sediments, and the disturbance to agriculture production during application (White *et al.,* 1996). With a combined total of over 1.73×10^6 tons of potential and actual sulfuric acid stored in the Maria (Johnston, 1995), complete rehabilitation through liming would cost over $300M, an exorbitant cost that farmers and government cannot cover. Transformation has similar economic implications as it relies in a similar process where ASS undergoes complete forced oxidation with acid by-products contained and neutralised (Atkinson and Tulau 1999). Thus the challenge is to simultaneously provide a means of reducing / treating acid discharges while maintaining agricultural production in a more cost-effective means. Smith (199b) suggests that the most cost-effective means of rehabilitating the Maria is by managing watertable heights through drain and floodgate alterations. Smith (1999b) proposal aims to contain, dilute and to a limited extent partially neutralise acid stores using the techniques listed below:

- *Use of culverts with dropboards in drains*
- *dropboards or sluicegates on floodgates*
- *'mini sluicegates' on floodgates*
- *lifting devices on floodgates*
- *filling in spoil bank cutouts*
- *embankment ponding*
- *dish drains*
- *lime drain banks / scalded areas*

Several aspects of this proposal are worth critic to emphasis the theory, potential risks and the influence of prevailing weather conditions to the successfulness of this strategy.

11.7.1 Embankment ponding.

Embankment ponding has been proposed for several areas within the upper and lower Maria River as a means of treating severely acidified areas and scalds. This strategy is a combination of neutralisation and containment. Severely acidified areas are returned to there former hydrological regime through the impounding of freshwaters and the modification of floodgate operations with the use of a range on engineering options such as embankments, weirs, sluice gates and drop boards. This promotes the establishment of freshwater pastures through the ponding of surface water to a depth of ~0.5-0.9m. The theory behind ponding is two-fold, to attenuate acid production and transportation while providing freshwater pastures as an alternative grazing strategy.

However under reduced conditions pyrite oxidation, hence acid production is only halted *provided* there is a available storage of labile organic matter to maintain the feed this microbial catalysed reaction (White *et al.*, 1997. Furthermore under reduce conditions partially oxidised sediments containing $Fe3^+$ continue to oxidise producing further acidification (Equation 9; White *et al.*, 1997).

$$FeS_2 + 14Fe^{3+} + 8H_20 \rightarrow 15Fe^{2+} + 2SO^{2-}_4 + 16H^+ \quad (9)$$

Thus without the initial neutralisation of acidified surface waters and adequate quantities of organic matter, reflooding scalded areas may actually contribute to the short-term acidification of the floodplain. A further concern outlined in White *et al.*, (1997) is that reflooding reduces the capacity of the soil profile to absorb rainfall and thus prevent acidic groundwater displacement and subsequent discharge. Thus reflooding may increase the frequency and quantity of acid discharge events by facilitating the mobilisation of stored acid. Furthermore Stone and Auliciems (1992) stress that Eastern Australian rainfall is notoriously variable correlated with ENSO events (El Niño Southern Oscillation) that has the effect of producing extended droughts or conversely sustained wet seasons. This may pose a problem of maintaining permanent ponding on scalded areas resulting in the re-acidification events. Alternatively heavy rainfall may cause seasonal estuarine acidification from the breaching of embankments and other structures designed to retain acidified water. Tulau, (2000) notes the risk of reduced stock health from ponded pastures through the promotion of fluke, snails and botulism. Stock may also suffer adverse health if drinking acidic water. Williams and Porter (1999) suggest to minimise possible acid discharges from reflooding, scalds should undergo a neutralisation program for several months to years to reduce the overall acidity contained in soil profiles. During this time scalded land must be taken out of production.

Thus if careless reflooding may be more of a hindrance than a solution to reducing estuarine acidification. However the chance of acidification from reflooding can be significantly reduced under the following procedure (adapted from Tulau, 2000). This procedure is in the order of several years as may complement the embankment ponding solution suggested for ~50 hectares within the Maria River (Smith, 1999b).

- *Initially fence off stock to prevent further soil erosion from grazing and "pugging".*
- *Neutralise soil and water pH over a period of several months to years using lime.*
- *Inundate scalds with freshwater using drop boards, bunds and sluice gates.*
- *Establish water level, soil and water pH monitoring.*
- *Chemically neutralise any acid water discharges and short-term acidification from the reflooding process.*
- *Provide additional soil organic matter using such options as tea-tree mulch, hay, sugar cane waste, treated sewage sludge (providing it does not contain heavy metals or excessive salt) or other composted materials.*
- *Introduce Water couch (Paspalum distichum) and / or limpo grass (Hermarthria altissima), as grazing species.*
- *Provide exotic weed management through water inundation*
- *Once a vegetative cover is established, reintroduce selective seasonal grazing with stocking rates of 0.2– 1 beast ha^{-1} to prevent overgrazing.*
- *Immunise and treat any stock affected by fluke, snails and botulism.*
- *Provide alternative stock drinking water when ponded water is acidic.*

Providing this suggested ponding strategy is followed, reflooding can provide a viable long-term solution. However these additional procedures would significantly increase the current estimated cost of \$ 300 ha^{-1} (Smith, 1999b). Scalded land can be rehabilitated to provide agrarian productivity while simultaneously reducing the frequency and quantity of acid discharge events. With the application of freshwater grass species, ponded pastures can raise beef productively levels to levels that rival some of the best pastures in

Australia[35] while maintaining water depths of up to 0.9m. The Seven Oaks Drainage Union in the Macleay Catchment provides an example with more than 150 hectares of rehabilitated land with up to 95% water couch established (Smith *et al.,* 1999).

11.7.2 Acid containment through drain reforming

Drain reforming aims at minimising the displacement of acidic groundwater by maximising the soil moisture storage during rainfall events whilst maintaining a base water table level above the PASS layer in order to prevent further acid generation (Tulau, 2000). Soil moisture storage is enhanced by increasing surface-water drainage using a network of dish drains[36]. Thus this strategy is applicable where ASS are of depth greater than 0.5 m from the natural surface to enable a sufficient soil moisture storage layer to occur. The possible benefits from this strategy are increased agrarian output while reducing acid displacement. However the reduction in acid discharges is highly dependent on the prevailing climate and the ability to respond to changes. Under extreme dry periods this technique may result in overdrainage leading the production of acid due to dropping watertables. Conversely in times of unforseen intense rainfall, drainage may not be adequate enough to maintain watertables below the critical level for pasture growth[37] resulting in possible crop damage and displacement of acidified groundwater into trunk drains. Thus without the ability to predict and react to climatic conditions this procedure may not result in a net reduction in acid discharges. Smith (1999b) estimates the costs of this strategy at \$ 2000 km^{-1} and is be used within a proposed 21 hectares on the Maria.

11.7.3 Drain and floodgate management

Drain and floodgate management is the main option proposed for the majority of drainage networks in the Maria (Smith, 1999b). The function of drains and floodgates are altered with of use of culverts with dropboards within drains and / or the alteration of floodgates to accommodate dropboards, sluicegates or lifting devices. The aim is to be able to manipulate drain levels and flows in response to changing climatic conditions with an overall aim of maintaining high watertables and to dilute acid discharges. This strategy is highly cost effective[38] as large drainage network areas can be controlled with just a few structural changes to strategic drains and floodgates. However this strategy requires accurate knowledge of water table height and prevailing weather conditions to enable the effective manipulation drain levels. Furthermore there is a requirement that landholders are willing and able to affectively operate adjustable structures in the advent of tidal and climatic fluctuations. Smith (1999b) acknowledges this as a possible problem in the Maria due to the general rudimentary knowledge held by farmers regarding ASS and drain management techniques. Thus while this option is considered to be the most cost effective there are high maintenance and participation demands placed on the farmer (s). Moreover the environmental efficiency of this strategy is highly dependent on prevailing climatic conditions.

11.7.4 Tidal back flushing of drainage networks

White *et al.,* (1997) advocates the use of tidal flushing (back flushing) as means of diluting acidified waters and eliminating the need to clean drainage networks. This tidal flushing option has the advantages of a relatively high Acid Neutralising Capacity (ANC) and the presence of a twice-daily exchange of tidal water. It involves changes to the operating procedures for floodgates to allow regular tidal exchange between acid leachate in drains and the receiving waters (Williams and Porter, 1999). The Tweed catchment in NSW provides a working example of this where 40 kilometres of drains were opened for tidal neutralisation (Williams and Porter, 1999). Smith (1999b) advocates the use of tidal back flushing in both the upper and lower reaches of the Maria during seasonally dry periods through the utilisation of lifting devices on floodgates. However there is a growing body of evidence that tidal flushing may not be a panacea in all conditions (see White *et al.,* 1997; Tulau, 2000). Tulau (2000) stresses this noting the potential environmental costs from tidal flushing of extremely acid areas within poorly flushed estuarine systems. Tulau (2000) further

[35] Weight gains of 1kg per day are suggested under managed stocking rates with water couch.
[36] Dish drains have also been called field furrows, dish drains, spoon drains, mole drains and runnels which all have approximate dimensions ~ 0.3m deep and 0.5 - 3m wide which are linked and spaced some 25 to 60 metres apart
[37] Water tables must be 0.3m-0.6m below surface for beef and dairy pastures, 0.5m below for tea-tree.
[38] Costs of structures range from \$1500 to \$3000 per unit (Smith, 1999b).

notes that estuaries used to flood and flush highly acidified areas may result in calcium depletion, an essential nutrient of an estuarine ecosystem. Due to the extremely poor ANC of the Upper Maria River[39] and numerous SEPP 14- Coastal Wetlands, the suitability of this strategy may be limited to just the lower reaches where tidal action is much greater. A solution to this is to accompany tidal back flushing with seasonal drain liming to ensure calcium depletion in the estuary is limited. However this does pose significant extra cost to the overall strategy. Furthermore as floodgates need to be frequently altered in response to the dynamics of drain and watertable levels and tidal fluctuations, this strategy has a high demand on farmer participation and knowledge of floodplain dynamics.

11.7.5 Lime Filter Drainage

Lime Filter Drains (LFD) is a recently applied Finnish technology used to control surface runoff while neutralising acidic throughflow in the soil profile (Weppling *et al*., 1999). Small open drains (~1m deep, 2-3m wide) are replaced with sub-surface drainage (0.8-1.2m deep, ∅ 65mm) consisting of an agricultural pipe which is covered by base gravel layer and overlayed with a mixture of quicklime (CaO) and ASS. LFD density is in the order of 350~700m ha^{-1} which are connected to peripheral sub-surface collection drains. The advantages of LFD over the traditional practice of liming open drain banks[40] and / or drain reforming are several. Firstly the sub-surface nature of LFD enables farmers to cultivate over drainage lines, increasing available cultivable land. Secondly LFD attenuates capillary action within the upper topsoil layers that overlay the drainage. By reducing the capillary action harmful acidic-aluminium rich waters and other toxic cations are contained below the root zone of crops. Thirdly LFD provides an effective means at removing surface runoff while maintaining a desired pre determined watertable below or at the depth of sub-surface drainage. Fourthly LFD has an estimated neutralisation life span of some 30 years, thus once established this technology has a very low maintenance demand. Thus LFD is a combination of two strategies, an ‘end-of-pipe’ solution to acid discharges through the neutralisation of drain waters and secondly ASS containment by the increasing the efficiency of surface drainage and thus reducing the displacement of acidified groundwater (analogous to *drain reforming*).

However despite these advantageous qualities of LFD there are some possible drawbacks when applying to the Maria River setting. Considering LFD employs similar theory as drain reforming and drain and floodgate management strategies this efficiency of technology is also at the mercy of a variable climatic regime. This is especially important in episodically intense rainfall events considering sub-surface drainage has a maximal discharge rate which is a function of pipe diameter and roughness, and the permeability of the surrounding soil / lime mix. Thus in extreme events throughflow rates may exceed this maximal discharge rate resulting in surface flooding and possible crop deterioration. However pipe diameters could be dimensioned to accommodate predefined runoff discharge rates to minimise this problem.

To limit the precipitation of Iron oxyhydroxides (floc) and heavy metal precipitation, LFD are placed at the anoxic zone of the soil profile. Under severe climatic fluctuations the level of the anoxic zone may fall below drainage depths resulting in iron flocculation and possibility drain obstruction, hence reducing the neutralisation and drainage capacity of LFD. Furthermore Maria River has is typified by heavy estuarine clays which are renowned to be extremely problematic when trying obtain a homogeneous lime / soil mix. However Weppling *et al.,* (1999) argues that this is problem is somewhat overcome with the combination of a lime filter drainage trencher and quicklime, which aims to maximise soil mixing and the lime slaking reaction. Obviously the capital costs incurred from the purchasing of new machinery for the Maria example is a major impediment to its application.

The cost of LFD in Finland is estimated at ~\$7,400 km^{-1} (Weppling *et al.,* 1999). Also maintenance and re-liming every ~30 years is estimated to be an additional ~\$4,000 km^{-1}. Considering these limitations and capital demands, LFD may be most effectively used in industries that have significant capital which would directly benefit from improved yields and increased cultivatable area such as the Tea Tree industry.

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[39] 0.42×10^6 moles H^+ per day or alternatively 20.5 tons of pure sulfuric acid per day (Johnston, 1995).
[40] A total of ~30 hectares are proposed for liming in the Lower Maria River at \$60 $hectare^{-1}$

11.8 Timing of management phases

The need to resolve the underlying forces driving the conflict in the Maria and to obtain farmer cooperation towards the management of ASS is obviously a first goal in the management of the Maria. To implement technical solutions and or to attempt and achieve VA's before the establishment of a stable community environment would be futile. Thus the proposed components towards the management of the Maria must be strategically phased in. Table 4 details the possible timing of various phases of management, reiterating that management embraces an adaptive approach.

Table 4: Suggested timing of management for the Maria River

year	Management phases
1	Farmer and general community extension program, initial community building, collaboration.
2	Pilot projects / field days with progressive farmers / monitoring of pilot projects. Initial farm gate discussions with farmers / advocacy of possible solutions.
3	Revision of technical possibilities in the light of pilot projects / Community reporting on outcomes. Begin large-scale VA agreement process and the implementation of strategies.
4-5	Monitoring and review of VA / technical strategies. Community reporting on outcomes.

Dashed lines in Table 4 are used to demonstrate that the timing of each phase may vary between locations and farmers and that management may need to temporarily revisit a phase in times of reinstated conflict, new industrial entries or unforseen environmental conditions.

11.9 Economic analysis the management of the Maria

A limited cost-benefit analysis (CBA) of the current proposed management strategy based on direct use benefits and costs is worthwhile to provide a first approximation to socio-economic efficiency of management of the Maria. However due to dynamics associated with estuarine acidification, fishery habitats and resultant yield losses, it is necessary to assess the management of the Maria River within the overall management of ASS in the lower Hastings Catchment. Thus estimation on the cost of rehabilitating the third management priority area, namely Partridge Creek (Williams and Porter, 1999) is incorporated into the total costs of rehabilitating the Hastings estuary. Benefits from increased agricultural production is considered to arise from higher yields in the beef and dairy industry as a result of higher pasture productivity from less acid soils and from ponded pastures. Running costs (Extension program / VA process /admin; table 5) are calculated for a time perspective of only 5 years to coincide with current government time horizons (Williams and Porter, 1999). Improvements in estuarine production are assumed to occur with the completion rehabilitation works, some 3-5 years into the management process.

Table 5: Cost – Benefit Analysis of ASS rehabilitation

Qualification of costs and benefits		Pessimistic scenario ($M)	Optimistic scenario ($M)
COSTS:	Funding for on-ground works (incentive scheme)	$0.8	$0.8
	Data collection / monitoring	$0.3	$0.15
	Extension program / VA process /admin @ 5 years	$0.5	$0.3
	Precautionary liming / contingency program	$0.05	$0
	Additional Partridge Creek rehabilitation works	$0.6	$0.4
	Further investigations / studies	$0.05	$0
TOTAL COST		$2.3	$2.15
BENEFITS:	Increased agricultural production	$0.05	$1.0
(annual)	Increased oyster production	$1.0	$2.0
	Increased fish production (commercial and recreational)	1.5	3.5
	Reinstatement of prawn industry in the Maria	+ ?	+?
	Non-market benefits and enhanced values	+?	+?
TOTAL BENEFITS		2.55	6.5
Benefit-Cost Ratio		1.1	3.0

A Benefit-Cost Ratio of approximately 1.1 to 3.0 is attained based on pessimistic and optimistic scenarios respectively. Alternatively the CBA reveals that a full reinstatement of the oyster industry and an increase of 7-15% in the commercial and recreational fishery industries would justify the implementation of the proposed strategy.

11.10 Discussion

Table 5 suggests that even without the valuation of non-market values and the prawning industry, the proposed management strategy with the inclusion of the Partridge Creek rehabilitation works is socioeconomically worthwhile both in pessimistic and optimistic scenarios. While the economic gains from rehabilitation have the possibility to compensate costs in just one production year, benefits will not appear until some 4-5 years after project initiation. Thus the project payback period is in the order of 5-6 years. If a discount rate ranging from 3-8% were applied to the CBA, total benefits would be reduced by 1.5-4% respectively, yet a positive Benefit-Cost Ratio is still holds even under a pessimistic scenario.

However an overall drawback of the technical strategy proposed by Smith (1999b) is that it places significant participatory, maintenance and knowledge demands on landholders to ensure effective rehabilitation. Thus the effectiveness of this strategy is very dependent on the ability of stakeholders and professionals to manipulate structures and the overall range regime in the face of fluctuating climatic variables. This demand on stakeholder participation and cooperation to the overall workings of the management strategy justifies the need for a comprehensive extension program within an overall community-based management approach. Moreover the need to predict and monitor the hydrology budget of the Maria is essential to provide the foresight to optimise the efficiency of rehabilitation works.

12 MODEL RESULTS AND FURTHER DISCUSSION

12.1 Model critic and limitations

Figure 12a/b details the simulated acid discharges from 1990 to August 2000 based on equation 6. One of the most significant limitations of this method to model acid discharges is the use of a constant mean acid discharge pH (at pH 3.5) for the entire period under investigation. While this is valid during the years of monitoring outlined in table 3, erroneous estimations of total acid discharge may occur when interpolating this pH value for years outside these periods. Section 12.3 tries to quantify this limitation using a sensitivity analysis of a variable pH.

Moreover the modelling exercise assumes the Maria River floodplain is covered by grassed surface and Tea Tree crops and thus fails to account for spatial vegetative differences such as swamp vegetation, scalded bare soil or stands of *Casuarina* sp. Equations 3 to 6 inclusive assumes crops have an adequate water supply year round and thus fails to account for drought induced stress in plants, affecting evapotranspiration rates. Furthermore Sammut *et al*., (1996a) indicates that floodgated drainage networks can store acidic drain water for up to 6 months during an extreme dry season which is then subsequently realised with the following wet season. Thus this approach fails to account for stored acidic drain waters which may contribute to the proceeding acid discharge event. These limitations could be resolved with further model refinement in collaboration with monitoring of watertables and water quality.

12.2 The dynamics of acid discharge events

Under normal weather patterns for the Maria rainfall normally exceeds evapotranspiration from January to July resulting in a net surplus of soil moisture and subsequent discharge acidic groundwater and estuarine acidification (figure 11). Soil moisture deficit normally occurs from late July to early January, the time when AASS generation is most likely to occur. Figure 11 shows the dynamics of the 1995 acid discharge event showing the typical water budget behaviour, where an extended dry winter are broken by the onset of an intense rainfall at the beginning of summer. MHL pH data (figure 11) reveals that estuarine acidification can be much more significant than the actual discharge events. Acid discharge events occurring in March and May 1995 resulted in sustained acidification in the upper Maria well into August.

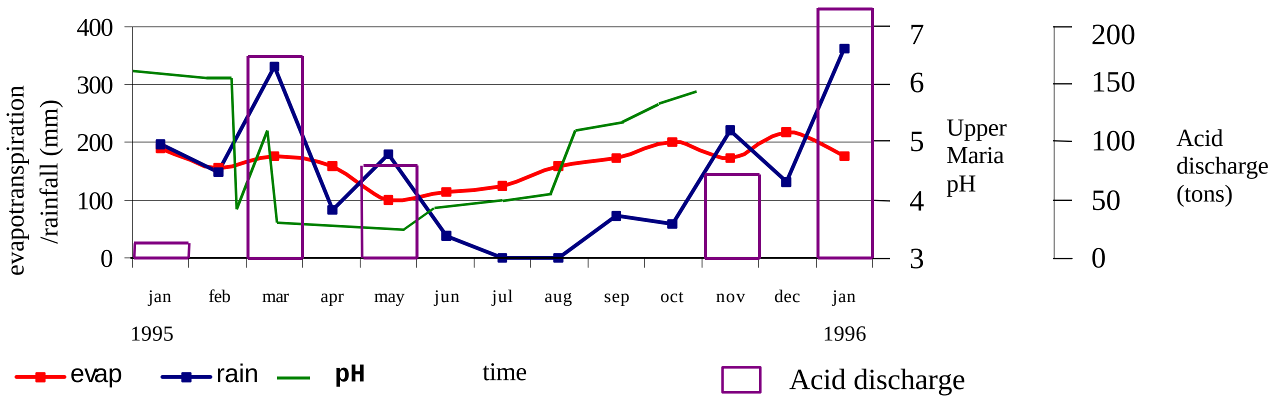

Figure 11: Climate, upper estuarine pH and acid discharges, Maria River 1995.

Johnston (1995) suggests that this sustained estuarine acidification in the upper Maria occurred from the interaction with the Wilson River. During periods of significant rainfall in the neighbouring Wilson catchment, discharge from the Wilson River significant enough to attenuate tidal action above the Wilson / Maria confluence. Resultantly the upper Maria is essentially isolated from tidal flushing casing this section to move towards an isolated freshwater system. Consequently the upper Maria's acid neutralising capacity was negligible for several months after the discharge event resulting in sustained acidic conditions as shown in figure 11. Thus the process of estuarine acidification in the Maria is extremely complex, governed by hydro-chemical interactions between acid discharges, prevailing ANC, and the dynamics between the Maria and Wilson.

Figure 12a/b details the simulation of the timing and magnitude of acid discharges events over the last 10 years. Figure 12a/b reveals a further limitation with the modelling exercise. The model fails to adequately simulate discharge events that are a resultant of a brief yet intense rainfall event. The June - July 1994 event, where 85% (53mm) of the monthly rainfall was accounted for in just two days (July 1-2) is one such example. Thus when intense rainfall event is the major contribution to the accumulated monthly rainfall during a particularly dry month or a month within a dry season, this model may fails to detect an episodic discharge event. In such conditions short-term excesses in soil moisture are counteracted in the model by the overall accumulated monthly evapotranspiration. Thus possible model improvements may lie within the calculation of the water balance using shorter interest periods, possibly on a fortnightly scale rather than monthly time periods. An interesting aspect of acid discharge events is that they are not purely confided to periods of generally wet conditions such as a La Niña event. The model outcomes (figure 12a/b) suggest that even during intense El Niño conditions, significant acid discharge events may occur such as in 1992. Figure 12a/b suggests that since 1990 the Maria has experienced 8 extreme acid discharge events with numerous smaller discharges. Furthermore figure 12a/b highlights the extreme variability in rainfall experienced in the Maria, typified by extended dry spells and intense episodic rainfall events.

The period from 1991 to 1994 was typified by below average rainfall resulting in relatively fewer and lower magnitude acid discharge events. In fact during 1994 the most severe drought was experienced in eastern Australia in the last decade, with recorded rainfall for June to November the lowest on record. The model suggest that this extended drought and low frequency of acid discharge events associates well with ENSO, with a sub- El Niño conditions (mean monthly Southern Oscillation Index; SOI of –8.4) sustained from 1991 to 1994, with two severe El Niño events in 1991 and 1994. The magnitude and frequency of acid discharge events is relatively higher during 1995 –2000, which is explained by sub-La Niña conditions (average monthly SOI of +5.08) prevailing for this period with the exception of the 1997 El Niño event.

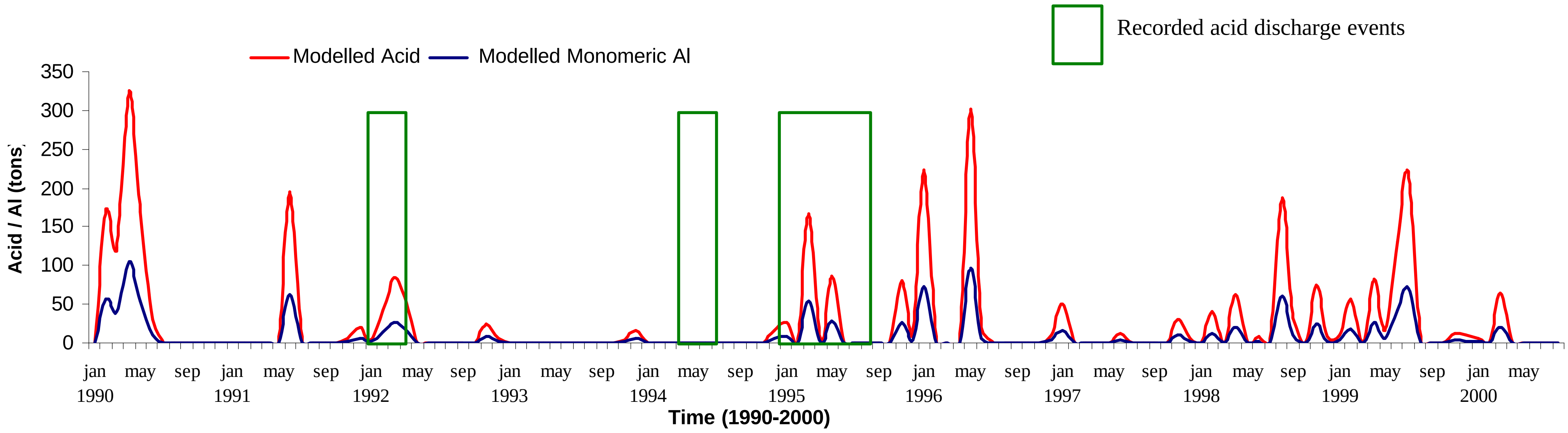

Figure 11a: Modelled acid and aluminium discharges, Maria River. 1990- August, 2000

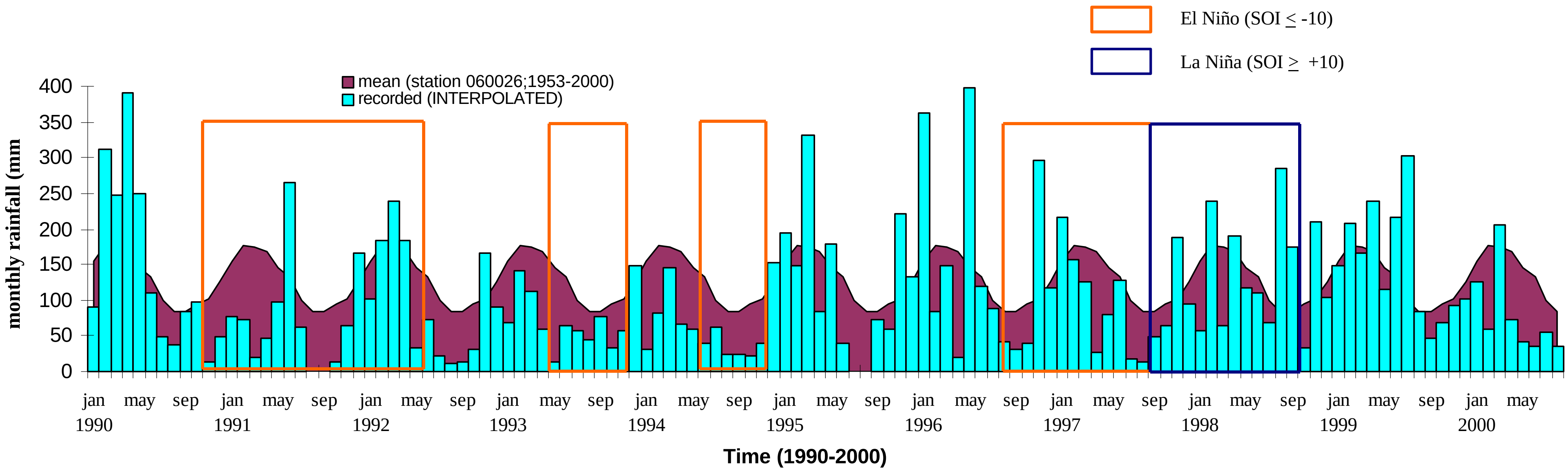

Figure 12b: Mean and recorded rainfall and extreme ENSO conditions, Maria River

The period from June 1998 to and the first half of 1999 was dominated by extreme La Niña conditions with average monthly SOI of +12.2.This La Niña event explains the above average rainfall and the numerous discharge events prevailing in this time as shown in figure 12a. Moreover the model emphasises the role of ENSO in possibly contributing to several consecutive acid discharge events over an extended period of time such as in the last three years. Sustained La Niña conditions consisting of one or more extreme events coupled with successive months of sub-La Niña conditions such as in 1998-1999 may have the ability to produce numerous acid discharge events over an extended period of time. This has serious ecological and economic implications for the Maria. The risk of developing sustained estuarine acidification resulting in perpetual ecosystem degradation and producing successive poor yields for fishery and oyster growers is significant in such La Niña conditions.

Several acid discharge events have occurred in the Maria since 1990 with the 1999s being particularly severe in terms of frequency and magnitude of acidification. While the model has several limitations it can adequately simulate the timing of acid discharge events. Further model improvements may well give rise to increasing the accuracy to enable the detection of intense episodic rainfall events over just a few days. With limitations in consideration, the model indicates that over 3,300 tons of acid and 1,100 tons of monomeric aluminium have been discharged into the Maria since 1990. An important point the reader should note is that this modelling exercise only estimates the quantity of acid discharged from the two DLWC management priority areas. While these area represent the bulk of acid discharges entering the Maria, ASS surrounding these priority areas may also be contributing. Hence total quantity of acid discharged into the Maria at any time period would be higher than modelled shown in figure 12a, possibly up to 20% more.

12.3 Monte Carlo sensitivity analysis

A Monte Carlo analysis of discharge pH was carried out to determine the significance of prescribing predefined pH value when estimating the quantity of acid discharges. The Monte Carlo function in STELLA samples a new random value of pH for each iteration of the model for a number of predefined simulations. A random pH value was chosen from a predefined normally distributed range of pH values (range 3.0-5.0 with a mean of 4.0) over 50 simulations. Figure 13 details the outcome of the Monte Carlo analysis for the period 1999-2000. The red line denotes the simulated acid discharged at pH 3.5 and blue lines represent Monte Carlo analysis generated discharges. Figure 13 reveals that the upper and lower extremes in the quantity of acid discharged at anyone time iteration varies by a factor of ~100. This is somewhat expected considering each pH level rise infers at 10 fold increase in hydrogen ions. Thus pH has a significant impact in simulating the quantity of acid discharges during any one event. This implies that while this model can adequately model the timing of discharge events, quantifying the magnitude of events may vary significantly to the real situation if pH monitoring is absent during the specific discharge event. Hence actual tons of acid discharged at any event lies within simulated upper and lower extremes of the Monte Carlo analysis as exemplified for the years 1999-2000 in figure 13. Hence future simulations of acid discharges should be integrated with pH monitoring to ensure acid discharge quantities are modelled with greater accuracy.

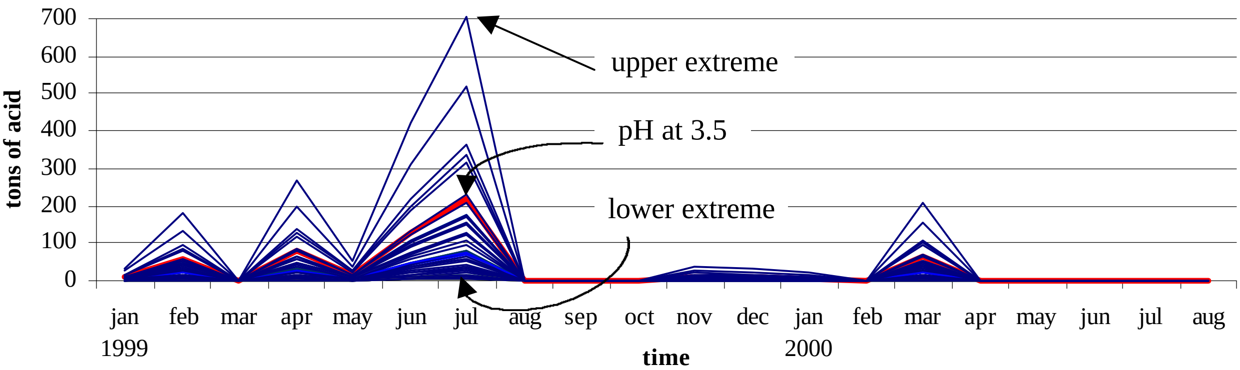

Figure 13: Simulated acid discharges under a Monte Carlo anaylsis of pH, 1999-2000, Maria River

12.4 ENSO teleconnections and forecasting capabilities

Stone and Auliciems (1992) have suggested the teleconnection between eastern Australian rainfall and ENSO. Figure 14 confirms this detailing significant teleconnections (at a confidence level of 0.05) between ENSO and spring and summer rainfall for the Maria River. Mean spring rainfall has a significant lag correlation of 0.55 compared to the previous mean winter SOI values. Similarly mean summer rainfall has a significant lag correlation of 0.51 compared to the previous mean spring SOI values.

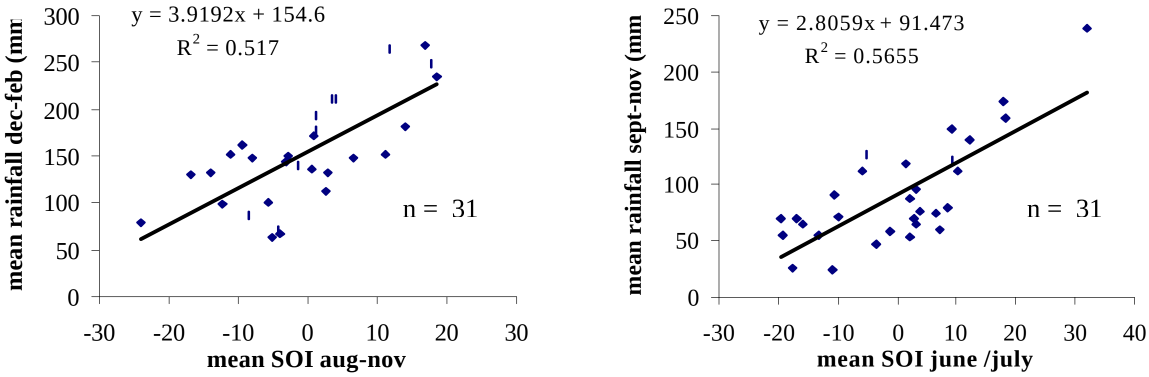

Figure 14: Rainfall versus SOI, Maria River 1970-1999

Unexplained variation in mean rainfall may be a resultant of the superimposing orographic influence from the Great Dividing Range and the dynamics between the marine and coastal environs and local topographical effects such as Big Hill. Considering acid discharge events are directly related to rainfall, a direct teleconnection between ENSO and acid discharges should be able to be established. However a significant teleconnection would require records covering several decades and thus precludes this study.

The significant teleconnection between rainfall and ENSO still enables the forecasting of spring and summer rainfall several months in advance that could be used for the future management of the Maria. However drain management and rehabilitation strategies are more to profit from predictions of rainfall within a daily to weekly scale. Thus ENSO forecasts may prove to be more useful for aspects of general farm management such as stocking densities to be more attune to upcoming weather patterns. Unfortunately due to the timing of this paper, the forecasting of the upcoming summer rainfall (Dec 2000 – Feb 2001) cannot be performed.

12.4.1 Possible consequences of an enhanced greenhouse effect

The future consequences of global climate change are wide ranging, with a general consensus over the possibility of altered global and regional weather patterns (Watson *et al*., 1997). A climate change for the eastern Australian region is predicted to result in a southward shift of current climate zones and the cyclonic belt and a general intensification of extreme weather episodes (Watson *et al*., 1997). Coupled with the possibility of intensified droughts, a southward shift of the monsoonal belt may result in more intense and seasonal rainfall patterns in the future. Considering the need to strike a delicate balance between over and under-drainage, the implications of an altered climate to the successfulness of ASS management is obvious. Moreover intensified weather extremes may well exacerbate the economic current hardship faced by Maria River farmers, from the likelihood of increased variability in production from greater seasonal weather fluctuations.

12.5 Assessing the optimum level of management

Analysis of the economics of landuse activities in the Maria stated in table 2 reveals that farming on the Maria has little economic value relative to the competing oyster and fishery industries. Moreover the economic losses afflicted on these estuarine users are several times greater than the economic gains from farming. Thus from a strict ecological economic perspective it is clear that the most economical course of action would be to abandon the marginal grazing lands, returning them to there previous hydrological regime as a means of preventing acid discharges and hence reinstating oyster and fishery yields to there original capacity. However this option has obvious equity implications and conflicts with the goals of sustainability.

A possible more socio-economical alternative to the option of acid discharge mitigation could be to minimise oyster growers impacts. The only conceivable economic option currently available would be to relocate oyster leases to estuarine habitat that is not affected by ASS runoff. However this also has equity implications, by forcing oyster growers to relocate. Moreover this option presumes that there are available estuarine habitat that is not affected by ASS. Every estuary in NSW suitable for oyster growing is affected by ASS runoff in some degree (NWPASS, 1999). Moreover optimal areas for oyster growing in NSW is already leased out, leaving only marginal growing areas and areas affected by ASS runoff. Furthermore this option does not solve the problem of suppressed fishery yields and a degraded estuarine ecosystem.

Thus the most sustainable course of action available is to reduce acid discharges as a means of rehabilitating estuarine use yields and ecosystem health. The proposed mitigation measures provide a means of moving towards this goal. However proposed mitigation measures are sensitive environmental efficiency variations. Environmental efficiency is controlled by the ability to return the floodplain to it's former hydrologic regime - a function the ability to control watertable hight for the benefit of both farming and as a means of containing acidic groundwater. Maintaining the right watertable height requires responsive drain management procedures to react to changing drain and watertable levels and tidal cycles. Thus the efficiency of preventing acid discharges is a function of several factors as shown in equation 10:

$$EE = (Cl + C + R + Cp). \qquad (10)$$

EE= environmental efficiency
Cl= climatic variation
C= stakeholder compliance
R= responsiveness of stakeholders/ measures to react to variation in the drainage and climatic regimes
Cp= ability to predict climate

By revisiting the theory of the sustainable optimum level of management, a fluctuating environmental efficiency of management has direct socio-economic implications as the sustainable optimum is a function net benefits which is controlled efficiency of mitigating acid discharged. Under a reduced environmental efficiency the benefits gained from mitigation measures will be reduced in the form of lowered oyster and fishery yields. Alternatively the costs of suppling a desired level of environmental rehabilitation or community benefit would rise in the advent of a lowered environmental efficiency in the form of additional measures. Thus in the case of the Maria the level of socioeconomic efficiency depends heavily on its ability to mitigate acid discharges under variable climate and level of stakeholder compliance and responsively to system variation.

The strategies of community-based management, adaptive management and climatic modelling provide a means to maximise the factors controlling environmental efficiency as shown in equation 10. Thus the effort and expense of a community-based management approach may well pay off by providing substantial economic benefits through the maintenance of a high socioeconomic efficiency of management (figure 15). However environmental efficiency is bound to vary particularly during the initial implementation stages and during unforseen extreme climatic variations. Considering such complexities and uncertainties afflict the efficiency of management in the Maria, adopting the precautionary principle is justified. The application of the precautionary principle may be in the form of a contingency plan such as additional drain liming and other preventative measures to ensure a sustained level of rehabilitation under possible fluctuating conditions.

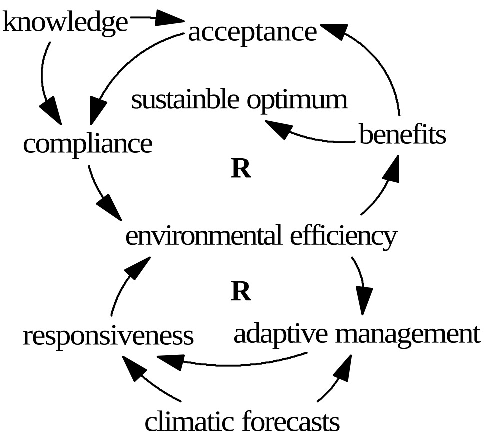

Figure 15: Benefits of propsed manageement in achieving a sustainable optimum

13 CONCLUSIONS

The Maria River provides a text book example for the need to assess and manage resource use from a holistic systemic approach, viewing resource use as the dynamic interface between the natural resource itself and the social, economic and political systems interacting with it. Moreover to fulfil the objectives of sustainability this interface needs to be sustained equitably for current and future generations. To accomplish this objective, non-market intangible values inherent to natural resources and the associated degradation of these must be fully accounted for and internalised into the socio-economic and political systems relying on them. The proposed management for the Maria under the umbrella of a community-base setting, aims to counteract or resolve the underlying forces preventing the successful rehabilitation of the Maria. While this community-based management approach places a considerable economic burden on the overall management costs of the Maria, it is considered an essential prerequisite in achieving successful equitable outcomes that is embraced by all stakeholders. Moreover a community-based management approach for the Maria suffices the principles of sustainability and provides a means of identifying the sustainable optimum level of management.

However this sustainable optimum level of management is constantly evolving based on variable net benefits attained under proposed mitigation measures. To fully assess whether the proposed management strategy achieves an optimum level is problematic. To do so we must be able to quantitatively describe the functions of marginal cost and benefits attained with increasing degrees of environmental rehabilitation and to fully account for intangible non-market benefits from restored estuary.

13.1 The value of floodplain hydrology simulations

Modelling the Maria River not only provides a benchmark for the quantity of acid discharges entering the Maria, pre-management, but may prove to be an invaluable tool to generate stakeholder understanding over the dynamics of acid discharge events. Furthermore such a modelling exercise could be scaled down to the drainage network scales enabling groups of stakeholders to develop an awareness of their particular contribution and enable management to target significant drainage networks.

Moreover hydrology modelling can reduce the uncertainty in rehabilitating ASS in the light of a fluctuating climate. Simulation provides a means of real-time observation of the prevailing hydrology of the floodplain enabling stakeholders and managers to strategically coordinate drainage activities such as liming, drain cleaning and floodgate operations, thus minimising the effect from any necessary releases and reducing the advent of unforeseen discharge events. Furthermore the simulation of simple floodplain hydraulics provides a means of greater understanding for stakeholders. Stakeholders and managers can obtain a better feel and understanding of the processes behind acid discharge events though the simplified yet descriptive display of floodplain dynamics. Quantifying and predicting the timing of severe acid discharges will prove to be invaluable for oyster growers. Given enough warning, oyster growers could temporarily relocate stock in the advent of predicted discharge events thus preventing personal costs currently incurred by this industry.

Thus this modelling exercise has worth both in its value to predict possible climatic trends and to give insight on the possible successfulness of retaining acid discharges in the months ahead. Moreover the risk of a breakdown in community-based management can be minimised by publicising the possibilities of extreme climatic conditions and thus the possibility of poor management performance several months in advance. The ability to predict such conditions and outcomes can be used positively to give reasoning behind possible poor management outcomes before they occur. Identifying the onset of possible acid discharges or floodplain inundation give valuable time for farmers and estuarine users to prepare thus reducing the personal costs incurred during time of extreme climatic conditions.

13.2 Future model improvements and directions

As previously discussed in section 8, the displacement of acidified groundwater is the main process in producing a significant acid discharge event. Thus understanding the dynamics of groundwater fluctuations and its relation to drainage regimes and prevailing climate is integral to the effective management of ASS under the proposed strategy. This sheds light on the necessary model improvements. By mechanising watertable dynamics in association with generalised drainage behaviour, the timing of and magnitude of acid discharge events may be refined. By doing so acid discharge events produced from an intense yet short rainfall event during an overall dry month (such as June- July 1994) may be identified.

Correlating the relationship between rainfall and subsequent mean pH of drain and groundwater over a range of conditions will prove to be extremely useful in refining the current model to more accurately simulate the quantity of acid discharged at any one time. Johnston (1995) details significant correlations between individual drain water pH and rainfall over a 6-month period. Such as approach can be adopted to extend over a range of climatic conditions preferably covering the extremes associated with ENSO events. Once established this correlation can limit the need for constant water quality monitoring to rehabilitation areas.

Modelling the resulting acidification of the Maria estuary from acid events would also prove to be beneficial in managing landuse in the Maria. However this direction would have high monitoring demands as estuarine acidification is a function of upland flows, tidal dynamics and the interactions between several tributaries, the Wilson River and the neighbouring Limeburners Creek Nature Reserve and Belmore Swamp. With this in consideration the modelling of estuarine acidification may prove to be a powerful tool to managing the Maria. Maximum allowable discharges could be estimated to ensure negligible impacts on the oyster and fishery industries, or to ensure a defined level of ecosystem health. Alternatively this modelling approach could provide a means of better assessing the effectiveness of future / alternative management strategies

13.3 General conclusions and summary

This paper provides a theoretical assessment and proposed resolution to the current socio-economic impediments to the rehabilitation of Acid Sulfate Soil in the Maria. This assessment has been undertaken from a systems perspective as a means of attaining a holistic resolution to the dilemma in the Maria, while sufficing the goals of sustainability. Several general conclusions can be drawn from this study:

- Current landuse in the Maria is not environmentally sustainable and is wrought with socio-economic inefficiencies and inequality, thus contradicting the principles of sustainable development.
- Current impediments towards managing ASS in the Maria lie heavily with underlying socio-economic condiments afflicting farmers. The current extension program (ASSAY newsletter) is clearly not adequately servicing the Maria community, as conflict and farmer resistance is still apparent. Impediments and conflict are best resolved through a community-based management approach using an economic incentive scheme to develop farmer cooperation and acceptance over government objectives.
- The proposed mitigation measures for the Maria is cost efficient (Cost-Benefit Ratio of 1.1-3), even without the quantification of non-market values. Alternatively the full reinstatement of the oyster industry and an increase of 7-15% in the commercial and recreational fishery industries would justify the implementation of the proposed strategy. A payback time for mitigation is in the order of 5-6 years.
- Modelling of acid discharge events can simulate the timing of events, however may fall short in accurately simulating events caused from short yet intense rainfall events (2-3 days) during a generally dry month. Utilising real-time pH data obtained during discharge events will dramatically reduce model inaccuracies associated with quantifying acid discharge events. With model limitations in consideration, the two DLWC management priority areas have discharged some 3,300 tons of acid and 1,100 tons of monomeric aluminium over the last 10 years into the Maria estuary.
- The climatic variables driving acid discharge events are significantly correlated with ENSO behaviour. Thus forecasting a general climatic outlook for the Maria based on ENSO behaviour may prove to be a valuable tool in reducing complexity and uncertainty in the future management of the Maria. Improvements in simulating the timing and magnitudes of acid discharge events can be gained by the integration of groundwater and tidal dynamics and the possible reduction of the period of interest.
- While Lime Filter Drainage technology has proved to be a successful widespread solution in Finland, financial and geomorphological constraints may limit it's application to the Maria setting to the Tea Tree industry. However LFD may be very useful outside the Maria, such as with sugar cane industries.

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