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Review

Ecosystem Effects from Nutrient and Pesticide Pollutants: Catchment Care as a Solution

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Abstract: Agricultural chemicals include fertilisers (nitrogen and phosphorus) and biocides (herbicides, fungicides and insecticides). Environmental impacts in surface waters include algal blooms and disruption to ecological function. Strategies for protection of rivers from eutrophication include improved agricultural land management, conservation farming methods, recycling or retention of drainage and runoff water, and use of buffer strips and riparian vegetation for filtration. Reduction in pesticide use has been achieved by improved application technologies, precision farming, adoption of organic farming, and use of biological control methods. Australian river health audits show widespread deterioration, and protection using the "Polluter Pays Principle" is attractive. However, who should pay for environmental assessment, for adoption of new technologies or change in land use, and how will this be determined? Unfortunately, as demonstrated in two case studies on algal blooms and cotton pesticides, the links between pollutant source and environmental impact remain poorly understood, and the complexity of assessing environmental benefit of agricultural changes makes sheeting home the costs of pollution sources difficult. Alternatives to imposition of penalties include catchment-based targets and guidelines, benchmarking, and adoption of best management practice with an emphasis on incentives and encouragement. Many strategies for risk reduction in agricultural cropping systems are available for inclusion in a "Catchment Care" approach.

Keywords: sustainability; watershed protection; eutrophication; pesticides; risk

1. Introduction

The United Nations Millennium Ecosystem Assessment, carried out between 2001 and 2005, assessed the consequences of ecosystem change for human well-being, and attempted to bring the best available information and knowledge on ecosystem services to bear on policy and management decisions. The use of land use change in the Catskill/Delaware catchment to protect water quality in New York City is a well-known example of the economic value of ecosystem services: the relative costs of land use change were $1.5 billion compared with the construction of massive water filtration infrastructure at a cost of $6–8 billion and an annual operating cost of $300–500 million [1].

In Australia, national workshops on environmental management systems in agriculture were held in 1999 [2] and 2005 [3], and a national strategy was proposed in 2008 [4]. The first ecosystem services project was conducted in 2003 in the Goulburn Broken Catchment in Victoria [5]. Also in Victoria, the Australia Rural Land Stewardship Program is an innovative approach to bring about sustainable agriculture while safeguarding the environment and rural communities [6]. However, as noted in a report on estimating the value of environmental services provided by Australian farmers "Quantification is constrained by an existing focus on measuring or recording the adoption rates of farm management practices rather than measuring environmental outcomes. Economic valuation is also constrained by the limited number of non-market valuation studies available for use to infer values for particular environmental services" [7]. Also, in a recent review on the broader benefits of aquatic systems in water planning in Australia, it is noted that "less emphasis has been placed on systematically identifying and incorporating the benefits of non-consumptive uses of water and aquatic systems since these 'non-market' values are difficult to value quantitatively" [8]. As in much of the world, it seems that limited progress has been made towards the valuation and protection of water quality and aquatic ecosystems.

This review focuses on agricultural chemicals that impact the aquatic environment in Australia, notably fertilisers (nitrogen and phosphorus) and biocides (herbicides, fungicides and insecticides). Audits of many rivers and estuaries in Australia show a general widespread decline in condition [9,10]. The contribution of agricultural chemicals to these deteriorating trends is analysed in case studies on the history of algal blooms and the ecological impact of cotton pesticides. Also, water quality protection is considered as a feature of ecosystem services that can be achieved by improved agricultural land management and policy. Five areas of intervention are listed in a manual for practitioners in strategies for ecosystems and human well-being: the provision of knowledge; reform of institutions and governance; societal and behavioural innovation; use of markets and incentives; and development of improved technologies [11]. These will be considered together with the "Polluter Pays Principle" which has been gaining momentum as a policy for water quality protection in Australia.

2. Phosphorus Fertiliser and Algal Blooms

2.1 Historic Analysis

Eutrophication has been the subject of international concern in developed and developing countries because of impairment of water for use in recreation, industry, agriculture, and drinking, while loss of biodiversity and aquatic ecosystem function is often reflected in fish kills through de-oxygenation [12].

In Australia, the effects of toxic blooms on drinking water quality were studied in Armidale, New England from about 1973 [13], and a major bloom occurred in the Darling River in the summer of 1991, making water unsafe for drinking and stock watering along about 1000 km of the river. Subsequently, many more rivers and storages were overtaken by algal blooms, and task forces were established by State and Commonwealth Governments. A Senate Inquiry reviewed the expert advice available on how to manage the problem [14].

Initially it was thought that algal blooms resulted from enrichment of clear, warm water with phosphorus. The Murray-Darling Basin Commission (MDBC) commissioned an audit of phosphorus export from different land uses and sewage point sources [15] and then embarked on a strategy for phosphorus management [16]. Intensive trials of the computer software CMSS (Catchment Management Support System) began with the objective of providing catchment management agencies with a simple tool to determine sources of nutrients and to explore options for controlling these sources [17].

However, it soon became apparent that the management of algal blooms required focusing attention not only on nutrient enrichment, but also on flow management, which is severely disrupted in Australian inland rivers by impoundment and diversion so that in drier seasons much of the inland river system becomes a series of static pools [18]. Static water gives a competitive advantage to buoyant blue-green algae, so work began on infrastructure to prevent stratification or avoid off-take from contaminated layers in stratified storages. Weir pool flows were also managed by a range of techniques that included flushing out at critical times, and use of siphons to transfer water over the weirs [19].

The major algal bloom outbreaks in the early 1990s stimulated greater interest in aquatic ecology, and biological and ecological processes began to be considered more seriously. Several State and Commonwealth Government agencies made large research and operational investments. For example, the Murray-Darling Basin Commission synthesised the best knowledge available through a series of Technical Advisory Groups (TAG) which were used to underpin the development of a policy for algal bloom management [20]. A TAG on bio-manipulation was convened to consider whether native fish could be used to change grazing pressures on zooplankton and hence aid management of algal blooms by manipulating the food web [21]. Several studies later reported on the success of "top down" control of cyanobacteria by freshwater zooplankton [22,23]. Other questions concerned: the role of carp, an introduced species in Australia, which disturbs the sediment in water by its roiling feeding habits; whether bank-side riparian vegetation or artificial wetlands could be used to filter out nutrients; whether pesticides might have a subtle effect on zooplankton, reducing their grazing pressure on algal blooms; and the role of submerged plants and seagrasses, noting that they have disappeared from many rivers and estuaries. The loss of macrophytes is a complex issue that could reflect many influences including the effects of carp, nutrient enrichment that enhances algal dominance, or the occurrence of low levels of photosynthetic herbicides. Could algal blooms partly reflect the loss of macrophytes which would otherwise capture some of the nutrients in the water [21]?

The Land and Water Resources R&D Corporation began projects on biomanipulation and other biological solutions, notably the use of riparian vegetation for filtering nutrients in runoff water and use of off-river watering points to protect stream and river banks from trampling by stock [24]. A whole river (the Belubula near Blayney, New South Wales) was diverted into a constructed wetland by the then New South Wales Department of Water Resources [16]. Wetlands began to be very fashionable solutions [25].

A Cooperative Research Centre for Freshwater Ecology (later eWater CRC) grew out of the Murray-Darling Freshwater Research Centre at Albury in partnership with several universities and state agencies [26], CSIRO (Commonwealth Scientific and Industrial Research Organisation) began a three million dollar multi-divisional research program [27], and Land & Water Australia in partnership with the Murray-Darling Basin Commission invested in a National Rivers Contaminants Program [28].

2.2. Problems of Linking Land Use to Impact

This substantial investment in research produced new insights into the cause of algal blooms. In summary, CSIRO reported that while flow management is a practical short-term tool for managing blooms in impoundments in inland rivers, nutrient management, particularly phosphorus management is a more limited tool for reducing algal blooms than was previously believed. Nitrogen, not phosphorus, was often the limiting nutrient in both estuarine and freshwater systems [18]. Unfortunately nitrogen is more difficult to control than phosphorus in catchments since it leaches more readily, is not removed by entrapment of soil particles, and can also be accessed by fixation from the atmosphere by some blue-green algae. Also, since sediments provide a larger source of nutrients than run-off from catchments, this will change the emphasis from controlling nutrients in catchments to locking up nutrients in sediments, for example by keeping the water aerated [27].

Later, the critical importance of river flow emerged as a key driver of river health and ecological function and “water for the environment” or “environmental flow” is now a major research topic [29]. States’ responsibilities for water allocation and management are implemented through water allocation plans in Western Australia, South Australia and the Northern Territory, water resource plans in Queensland, water management plans in Tasmania, and regional water strategies in Victoria. Water sharing plans, implemented in New South Wales in 2004, include changes to “environmental flow rules” which are intended to maintain a minimum outflow downstream and to improve river health by re-allocation of water from consumptive use to environmental needs. In some plans, a component of environmental water was reserved for flushing out algal blooms but generally other environmental needs such as the restoration of icon sites, bird breeding and watering of red-gum forests have taken precedence.

More recently, the Council of Australian Governments agreed on principles for national water reform [30] and the Murray-Darling Basin Authority embarked on a plan to reallocate water from consumptive users—mainly irrigators—to the environment through water purchase and investment in more efficient infrastructure [31]. The plan has been hotly debated and met with resistance both from irrigators and third parties who fear the increased costs for those remaining in the industry, and the demise of services in small communities [32]. Consequently, the meaning and assessment of river health is also being seriously debated at present, especially how it should be measured and who should pay to maintain it. Equity must include concern for the environment, the water user, and the community downstream.

In summary, it can be seen that assumptions about the cause of algal blooms have changed and phosphorus enrichment of water has been overtaken as a key driver of water policy. It is clear that algal blooms are affected by a complexity of physical, chemical and biological factors so that any policy of “polluter pays” on the basis of fertiliser use would be both difficult to implement and contrary to scientific advice. Nevertheless, most scientists accept the need for improved and best practice land management, as further discussed later.

3. Pesticides

3.1. Historical Analysis

A review of the ecological impact of cotton pesticides in Australian rivers was commissioned in 1996 to try to resolve a conflict in evidence about the impact of pesticides on river health [33]. Endosulfan was observed in rivers at very high concentrations, well above guidelines for the safety of aquatic life, but there was little evidence of biological impact. In particular, reports of fish kills were infrequent and on-farm storages containing recycled water appeared to be well-stocked with fish and other aquatic life. Also, macro-invertebrate communities at various river sites showed little or no difference even though communities downstream of cotton farming were expected to be more impacted than those upstream.

Initially the problem was to find a logical framework for selecting the pesticides of most concern, since more than 60 pesticides were used. A hazard rating or Q value (Table 1) was determined by calculating the estimated environmental concentration for the worst case of a direct overspray to 15cm depth of standing water at the use rate divided by the LC50 of the most sensitive organism [33] where toxicological data was obtained from the US EPA “Red Book” [34]. A “Q value” of less than 0.1 means that the maximum concentration expected in the environment is less than one tenth the LC50 value, and adverse effects are unlikely. Most pesticides exceeded the Q value of 0.1 and some had very high values of up to several thousand. More recently, the approach was adapted to include observed environmental concentrations [35] and extended to other crops [36]. The very high Q value of 5000 for endosulfan reflects extremely high use rates and biological sensitivity, so the lack of observed environmental damage was unexpected.

3.2. Problems of Linking Land Use to Impact

Some of the main difficulties in interpretation and impact assessment are: finding appropriate control sites that are near to cotton farms but do not receive inputs of pesticides from drift or volatile endosulfan; selecting good biological indicators of aggregate impact for a cocktail of different pesticides; describing exposure patterns, noting that local difference might result from rapid uptake of pesticides on to sediments; taking into account the protective effects of vegetation in creating “safe havens” of clear water; assuming that individual species or communities are reasonable indicators of impact, while their role in the aquatic food web processes is complex and uncertain; and separating impacts of nutrient enrichment, stock trampling and flow changes from effects of pesticides [33].

In contrast with the cotton pesticide case study, where fish seemed to be resistant to pesticides, two more recent developments imply that greater caution is required. In many field study sites, stream macroinvertebrates were 1000–10,000 times more sensitive than expected from ecotoxicological risk assessment determined using EC50 values, perhaps reflecting indirect effects of pesticides on predators, synergistic effects of pesticide mixtures, effects of pesticide pulses, and interaction with other stressors such as extreme temperature, salinity and dissolved oxygen [37]. Also, a new generation of insecticides—the neonicotinoids—are very widely used in cotton and other crops in Australia and globally [38]. These insecticides have low toxicity to the test organism *Daphnia magna* measured using acute lethality, but aquatic larvae of many other aquatic species are highly sensitive through delayed and cumulative uptake [39,40].

Hence, it is difficult to demonstrate the impact of pesticide use on water quality and aquatic ecology or to justify policies requiring "polluter pays" or restriction of pesticide use. However, most aquatic ecologists would argue that this is no reason for complacency or for lack of action.

Table 1. Q values and other properties of selected cotton pesticides, where Q = maximum concentration in water/ LC50 [33].

Pesticide	Lowest LC50 (μg/L)	Test organism	Q
endosulfan	0.1	carp & copepod	5000
chlorpyrifos	0.16	mosquito	3125
monocrotophos	0.24	cladoceran	2220
profenofos	0.5	rainbow trout	1334
phorate	0.7	fish	571
fenvalerate	0.17	rainbow trout	547
parathion-methyl	3.5	cladoceran	267
cyfluthrin	0.14	cladoceran	193
fluvalinate	0.89	bluegill	112
alpha-cypermethrin	0.3	cladoceran	111
esfenvalerate	0.27	cladoceran	85
lambdacyhalothrin	0.18	cladoceran	78
chlorfluazuron	1.0	cladoceran	67
diuron	1200	stonefly	40
deltamethrin	0.39	rainbow trout	31
fluometuron	3000	rainbow trout	19.3
methomyl	29	stonefly	19
trifluralin	50	copepod	15
dicofol	53	rainbow trout	12
atrazine	720	midge	11
omethoate	21	cladoceran	7.1
glyphosate	1400	rainbow trout	1.5
thiodicarb	1210	rainbow trout	0.4

4. Land Use Systems and Risks to Ecosystem Services

4.1. Relative Risks

Relative risks to water quality and aquatic ecology from different enterprises are summarised (Table 2) under the headings nutrients and pesticides and, for aquatic ecology, disruption to flow. Assessment is based on the author's review of the literature [41]. A decade ago, the impact from cotton growing was critical because of the very high use of pesticides, and the difficulty of managing storm flow to capture runoff to inland rivers. However, the advent of pest-resistant transgenic crops has substantially reduced the risks, particularly for use of endosulfan in cotton [42]. Sugarcane is an emerging issue because of concerns about sediment, nutrient and pesticide impact on coastal rivers and national heritage areas such as the Great Barrier Reef [43]. The vulnerability of groundwater to nitrate pollution from leaching of irrigated pastures and from intensive rural industries remains poorly documented [44,45].

4.2. Strategies for Risk Reduction

A major research program on cotton pesticides was described as one of the most successful programs in natural resource management in Australia, resulting in a best practice manual for reducing the impact of pesticides on river systems [46]. Reduction in the use of pesticides has been achieved by a range of strategies which include: breeding transgenic crops [42]; legislative reforms including more stringent approval processes and national targets for reduction in pesticide use [47]; improved application technologies and formulation to reduce pesticide drift, volatilisation and over-spraying [48]; precise application of pesticides and fertilisers, rather than broad acre treatment ("precision farming") [49]; use of decision-support systems to optimise the timing of spray application with pest or disease development, for example AUSVIT used in viticulture mainly for the control of fungal diseases [50]; various biological control methods including insect predators and mycoherbicides [51]; encouragement of the development of natural protectants, for example canopy management in grapevines to encourage the production of stilbene natural antifungal compounds in grape berries [52]; use of natural weed control agents (allelopathy) including breeding of allelopathic capability into plant varieties [53]; crop and pesticide rotation to avoid or postpone the development of resistance [54]; and use of organic farming to manage pathogens, insects, nematodes and weeds which do not rely solely on chemicals, but place more emphasis on biological methods [55]. Integrated pest management incorporates all of the strategies listed above, including the concepts of managing pest populations below an economic threshold level, an understanding of pest population dynamics, the economics of cropping systems and the potential for environmental impact [56].

Solutions for reducing pollutants, particularly nutrients and suspended particles, include: the use of conservation farming methods to minimise tillage and reduce runoff of particles and associated nutrients [57]; the use of buffer strips and riparian vegetation for interception of turbid particles and associated adsorbed pollutants that include particulate phosphorus and many pesticides [58]; the use of artificial wetlands for improvement of water quality, including their strategic placement in the landscape to give optimum interception of particulate material, and to a lesser extent nitrogen runoff [25]; and irrigation water re-use or retention on-farm and regionally to protect rivers from pollution with contaminated drainage water.

Advances in assessment and monitoring can help with the identification of hotspots of pollutant sources, so providing a focus for intervention. These include: inexpensive reliable and rapid immunoassay methods for pesticides in soil and water [59]; satellite monitoring of water quality [60] continuous nutrient and salinity monitoring [61]; isotopic tracer analysis to support investigation of catchment sediment dynamics and nutrient budgets [62]; and vulnerability assessment using spatial analysis to identify combinations of landscape characteristics and cropping patterns which make ground and surface waters vulnerable to pollution [45,63]. Improved methods for eco-toxicological assessment of river condition can also help to distinguish the effects of different pollutants and synergies between them [64].

Risk assessment is complicated by changes to the hydrological cycle caused by impoundment and diversion for irrigated crops; changes to the water balance of the landscape caused by clearing, afforestation [65,66], climate change [67], and the emergence of a diverse range of new pollutants such as those originating in coal seam gas “fraccing” processes [68]. Consequently, separating the effects of agricultural pesticide and fertiliser use from other influences on aquatic ecology is complex and difficult.

Table 2. Relative risks to water utility (surface and groundwater) and aquatic ecology from irrigated crops, broadacre crops and forestry (+++ indicates the greatest risk) [41].

Crop	**Surface water**		**Groundwater**		**Aquatic Ecology**		
	Nutrient	Pesticide	Nutrient	Pesticide	Nutrient	Pesticide	Flow
Cotton	+	++			+	+++	++++
Rice		++			+	++	++++
Sugarcane					+++	++	+
Irrigated Pasture and IRI		+	+++				++
Viticulture		+					++
Horticulture (other)		+	+	+			++
Forestry		+	+	+	+	+	
Broad acre	+	+	+	+			++

Note: [1] Intensive Rural Industries.

5. The Polluter Pays Approach

Recent trends in the management of natural resources and river basins suggest a change in balance between payment by polluter and beneficiary to increase the share of costs paid by the polluter (the “Polluter Pays Principle”, PPP). In policy on pesticides and nutrients, as well as on salinity (not covered here), key questions are: how environmental benefits can be valued, noting the high degree of uncertainty involved in assessing river health, and how pollution and impact should be measured. Difficulties include: the expensive nature of pesticide and nutrient analyses; the problems of assessing river health by use of indicators; and, as revealed earlier in this review, the recognition that the links between chemical analysis and environmental impact are often extremely complex and tenuous.

Equitable solutions are required that do not penalize land managers unjustly, provide for the needs of the water-users for access to good quality water, and safeguard environmental processes. Policy is required on the extent to which future private investment in or on-farm activities is justified to bring about downstream public benefits and how public investment in private land should be targeted and focused to minimise or prevent pollution.

The beneficiaries of pollution reduction include a range of stakeholders who are dependent on adequate water quality for safe irrigation, drinking and industry, and communities who are increasingly interested in the aesthetic, cultural and spiritual value of healthy rivers. Choice modelling suggests that the aesthetic and biodiversity values of rivers are important, not only to rural and indigenous communities, but also to people living in cities far away [69–71]. This puts pressure on governments, in accord with recent trends in natural resource management to rebalance payments from beneficiaries towards polluter.

The “Polluter Pays Principle” (PPP) is often endorsed on the ethical grounds that it is fair for those who are responsible for pollution to bear the costs of remediation. Further, some PPP options such as fees on fertiliser, manure and pesticide use can generate revenue. These have been used in Belgium, the Czech Republic, Germany, Denmark and the Netherlands; while the Nitrate Directive in the UK mandates the type, quantity and timing of manure application [72]. Much of the international literature on the implementation of the PPP approach appears to be focused on groundwater contamination and cost for treatment for water utilities, rather than the broader impact on aquatic ecosystems. For example, the PPP approach is proposed in Israel to supply clean drinking water that is subject to contamination by nitrogen fertiliser [73]. In a review of the literature on the use of economic incentives [73], critical questions that emerged included whether prevention or treatment policies are more cost-effective and whether taxes are feasible in view of the low profitability of the agricultural sector. A "social planner solution" or burden-sharing solution was proposed that causes the farmer (the polluter), with the aid of a fixed input tax, to absorb part of the groundwater contamination treatment cost leaving residual costs to be borne by the drinking water consumers (the victims). In practice, many variables need to be considered in the design of the PPP approach such as crop rotations, the marginal treatment costs for nitrogen, the value of the marginal product of the crops for nitrogen and water and specific hydrology at contamination sites.

Clearly, the links between individual pollutants generated by agriculture, and water quality and aquatic ecosystem responses are uncertain and changing so sheeting home costs to the pollution source is tenuous. For example, in a review of water pollution by agriculture in Europe it is noted that "the effect of individual agricultural activity can be measured in a general way and modeled with varying degrees of uncertainty but the sort of processes demanded by legislators and lobbies will never be attainable and this has been a major weapon used to delay regulation of agricultural activities" [74].

6. Catchment Care as a Solution

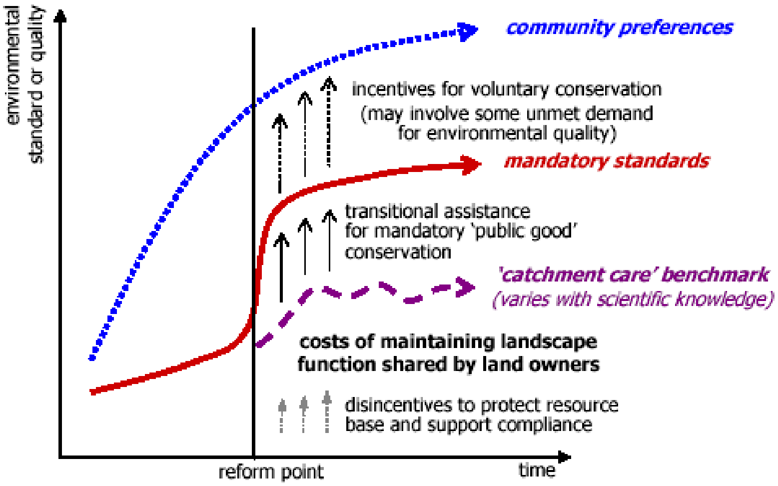
Alternatives to the "Polluter Pays Principle" include the use of a range of risk-reduction strategies as reviewed above (Section 4.2). In Australia, the use of best agricultural management practices and incentives are preferred over regulation and penalties [75]. Cocklin *et al.* [76] reviewed the conditions under which farmers can provide ecosystem services as well as being producers of food and fibre, finding that many landholders would be drawn to an initiative that gives recognition, support and financial assistance, rather than use of market-based mechanisms, with "command and control" regulation as a last resort. A price premium for produce through an eco-labelling scheme is one option, but is difficult to implement. Direct financial assistance is advocated, as an increasingly attractive option for landholders and an urgent imperative for Australian governments [76]. However, since these incentives would be funded by the taxpayer, a substantial amount of auditing, compliance and reporting would be required, so many leading growers are opposed to this approach. Similarly, in the US the strategy of getting farmers to adopt best management practice has been unsuccessful in improving water quality and the "Pay the Polluter" approach is reported to be unacceptably expensive for constrained federal budgets [72].

In Australia, many landholders do not have management options available that are both environmentally sustainable and commercially attractive [77]. In these situations new approaches to environmental planning incorporate the value of ecosystem services through both public and private investment. The Victorian government has published a review on issues and options for ecosystem service provision and information papers on market-like policy options, duty of care and private investor needs as a foundation for stakeholder engagement [78,79]. Stewardship payments "differ from traditional approaches in that they do not impose new duties or obligations on land managers through public regulation, but instead offer payment as a motivator of behavioural change. This essentially voluntary approach is appropriate for encouraging actions that are considered desirable, but are not widely considered to be a legal or moral duty" [80].

"Catchment Care" [80] is a possible solution that moves beyond the conflicting approaches of "beneficiary pays" and "polluter pays" to a burden-sharing approach. The "Catchment Care Principle" was advocated by an independent group of scientists, the Wentworth Group [81], who were concerned about landscape conservation and clearing of vegetation in New South Wales. The principle states that individual resource managers have an obligation to avoid land or natural resource management practice that harms the long-term interests of resource users as a whole. This implies that resource management practices should not damage ecosystem integrity or landscape function.

As shown in Figure 1, the principle combines disincentives, cost-sharing by landholders, traditional assistance for mandatory conservation practices for the public good, and incentives for voluntary conservation, resulting in higher overall environmental standards than could be achieved by land-holder cost-sharing alone [80].

Figure 1. Burden sharing and transitional assistance under the "Catchment Care Principle" [80].



It is anticipated that "priorities will include supporting innovative approaches to delivering environmental outcomes; exploring farm-level and regional approaches for enhancing conservation outcomes; and engaging with land managers and investors who are willing to establish new enterprises to deliver environmental benefits that are difficult to achieve through changes within existing businesses" [82]. The approach improves investment security for landholders because it separates their personal responsibilities from changes in community attitudes. It also improves investment security for the farming community by preventing one farmer's actions undermining the overall value of the natural resource base.

As noted above, farm level and regional approaches are a critical component of Catchment Care. Regional groups bring local knowledge to the implementation of policy principles and integrate consideration about on-farm profitability and off-farm ecosystem services [83].

International examples include: programs on sustainable land and water management and conservation agriculture in Indonesia, Ethiopia, Tunisia Spain and Bolivia [84], integrated river basin management plans in the UK [85]; watershed protection for the control of diffuse source pollution in the USA [86]; integrated catchment management in New Zealand [87] and a range of decentralised conservation arrangements in Canada [88]. In England and Wales, the term "integrated catchment managing" was used to describe the activities and interactions of multiple stakeholders operating in complex situations that allowed good practices to emerge through social learning as an alternative to governance mechanisms based on regulation, fiscal measures and information provision [89]. In a review of the "wicked problem" of non-point source pollution, several key "enabling capacities" were identified including: recognition of the history and context of community interaction; institutional arrangements of appropriate scale; opportunities for collaboration between stakeholders to enable social learning to occur; development of collective visions and strategies; use of multiple types of knowledge; appropriate resources; development of entrepreneurship and leadership; and inclusion of reflection and adaptation [90].

In Australia, bilateral agreements between the federal government and six state and territory governments were signed as part of the Natural Heritage Trust in 2002–2004 and 54 catchments or bioregions were identified with the objective of giving communities more direct input to landscape management [91]. (In New South Wales, Catchment Management Authorities are audited by the Natural Resources Commission to assess performance of catchment action plans through standards and targets [92] and Local Land Services will be established in early 2014 to consolidate technical knowledge and advice from several agencies and to deliver agricultural advice that is better integrated with natural resource management [93,94]). In the last decade, many catchment groups and regions have made excellent progress towards reshaping agricultural enterprises to match land use capability [95]. Examples include winners of the national river prize at the annual international Riversymposium [96]. As noted in recent reviews, the capacity, authority and resourcing of these regional groups needs to be strengthened [83,97,98].

A new program, Caring for Our Country, will be funded with two billion dollars over five years [99] but has been criticized because of increased central government control and priorities given to projects demonstrating short-term, measurable outputs [100]. It seems that a regional approach to Catchment Care, together with adequate resourcing remains a critical challenge.

Conflicts of Interest

The author declares no conflict of interest.

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