Imports Can Be Dangerous - Appropriate Approaches to Australian Rivers and Catchments

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ABSTRACT: *Some of the reasons are offered why Australian streams and catchments are or might be different from those in other parts of the world, and examples are provided. The example that is discussed most in this paper is the relationship between land use and exports of sediment and phosphorus. The appropriateness of current models of this relationship are explored using data from the Upper Murrumbidgee River Catchment.*

1. INTRODUCTION

In 1984 the Ecological Society of Australia organised a symposium entitled: 'Are Australian Ecosystems Different?' (Dodson and Westoby, 1985). The answer to the question is both yes and no, depending not surprisingly on the ecosystem under examination. Aquatic ecosystems received little attention at the symposium, a situation that has only been redressed since 1984 by Harris (1995).

If the natural resources of this country are to be managed effectively, the question posed in the title of the Ecological Society's Symposium needs to be answered. Without an answer, we will continue to import ideas and models from other places without determining their appropriateness for Australian conditions.

In this paper, some of the features that may make Australian catchments and rivers different from those in other parts of the world are explored, although the degree of difference is not always obvious. We then explore one particular way in which at least some Australian catchments and rivers are different from those where many of our concepts of catchment behaviour were developed. It is hoped that this paper will stimulate others to explore the degree to which Australian fluvial systems differ from those in other lands.

2. AUSTRALIAN DIFFERENCES

Of all the continents, Australia is the driest, has the lowest relief and least elevation (Garrels and Mackenzie, 1991). Sheet and rill erosion rates are on an area-weighted basis higher than the global average, but the sediment discharge to the oceans is lower than the global average. The continental sediment delivery ratio is <3%, much lower than the global average (Wasson, Olive and Rosewell, in press). Much of the flora and fauna is endemic, and human population density is on average very low with concentrations around the coast. A large fraction of the soils are sodic and/or saline (Isbell et al, 1983), the continent's specific runoff is low, and both rainfall and runoff are the world's most variable (McMahon et al, 1992).

The major disturbance to the land caused within the last 200 years by the introduction of European agricultural practices is one of the most recent in the world, and since this disturbance there have been no major excursions of climate. The most recent significant climatic excursion occurred about 6,000 years ago when the continent was both warmer and wetter than present. Since then, climate has on average become drier and cooler. The massive perturbations to climate, soil and biota associated with the major ice sheets of the Northern Hemisphere did not occur in Australia. The major post-glacial environmental shift was largely driven by changes to available moisture rather than temperature (Wasson and Donnelly, 1991).

The very general statements listed above do not allow assessment of the degree of difference of Australian fluvial systems, or other ecosystems. They simply suggest reasons why we might search for differences. Differences worthy of more detailed consideration follow:

- The specific water yield of Australian catchments is low by world standards (McMahon et al, 1992). River channels are therefore likely to be smaller per unit of catchment, and under natural conditions dried out frequently. Paradoxically, many inland streams like the Darling River probably flow more often as a result of reservoir construction. Australia stores more water per capita than any other nation (Department of Environment, Sport and Territories, in press), to secure a water supply in the world's most variable rainfall regime.

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- Long periods of weathering, uninterrupted by uplift and major mechanical erosion, have produced highly weathered soils (eg, McLennan, 1993). As a result suspended and deposited sediments in inland streams contain a large proportion of clay minerals (typically <2µm; eg, Woodyer, 1975). In addition, long periods of dry climate have allowed the accumulation of salts in soils (Chivas et al, 1991). These salts, and very fine clays, make the interior streams naturally saline and turbid (Williams, 1982). Phosphorus is strongly attached to suspended sediments and the major loads of this nutrient therefore move with the sediment during floods (Donnelly, 1995). Most of this phosphorus is natural (or native), derived from weathering.

- Sodicity, a characteristic of soils also related to aridity, produces highly dispersible subsoils that, once surface soil horizons are breached by erosion, suffer rapid and often deep gullying. Subsurface tunnel erosion occurs in these soils, also contributing to gully formation (Ford et al, 1993). This form of erosion liberates both fine sediments and native phosphorus.

- The low specific discharge of inland streams, combined with their low gradient, produce rates of lateral migration of rivers such as the Murrumbidgee and Barwon that are much lower than the global pattern identified by Hooke (1980). By contrast, coastal rivers with higher specific discharges, migrate laterally at about the global average rate (Rutherfurd, in press).

These few examples are merely indicative of the characteristics that distinguish Australian fluvial systems.

3. THE BALANCE OF SEDIMENT SOURCES

Golosov (1988) measured the fluxes of sediment in the 3,640 km^2 catchment of the Protva River near Moscow. Careful measurements have produced a sediment budget (Fig. 1) that exemplifies, it will be argued, the paradigm underlying most catchment management in Australia. In the Protva landscape of low relief, gentle slopes, erodible chernozems, and cultivation, about 94% of the annual average mobilisation of sediment is by sheet and rill erosion. The remainder is mobilised by channel and gully erosion. Only 11% on average leaves the catchment, and fully 83% of the mobilised sediment is stored on footslopes as colluvium each year.

A reasonable extension of this model of landscape behaviour is that land use substantially modulates the flux of sediment by affecting the rate of sheet and rill erosion. In this model, land use is a key driving force, and so is used as the pre-eminent variable in catchment modelling. At its simplest, land use affects fluxes by changing export coefficients of water, sediment, phosphorus and nitrogen (eg Young et al, in press; Phillips et al, 1992). In more mechanistic models, land use changes the vegetation cover and therefore sediment fluxes.

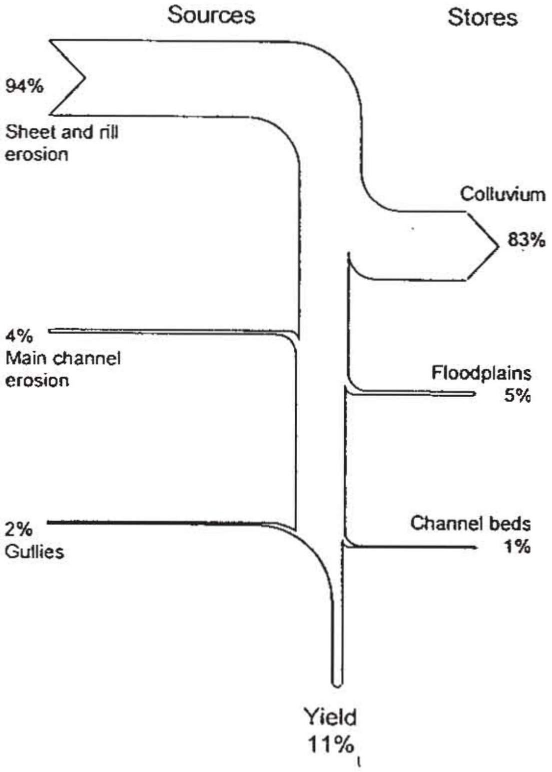

Figure 1: Protva Catchment

In landscapes where sheet and rill erosion rates are low and channel incision pervasive, a different model of landscape behaviour prevails. In the Jerrabomberra Creek catchment near Canberra, Wasson (1994a) and Wasson et al (in press) have shown that channel and gully erosion mobilised about 96% of the sediment moved in this 130 km^2 catchment since 1850 A.D. (Fig. 2). Here about 49% of the mobilised sediment leaves the catchment in an average year, a higher figure than in the Protva case because the Jerrabomberra catchment is smaller and the channels not only supply most sediment but also act as efficient conduits for its transport. Most of the mobilised sediment that does not leave the catchment is deposited on floodplains, near the sediment sources - unlike the Protva case where hillslopes both produce and store most mobilised sediment.

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The two models (Figs 1 and 2) are probably end members (Wasson, 1994; Wasson and Sidorchuk, in press), and each requires radically different management strategies to control sediment flux. Additional evidence in support of Fig. 2 as a model for Australian catchments is now presented.

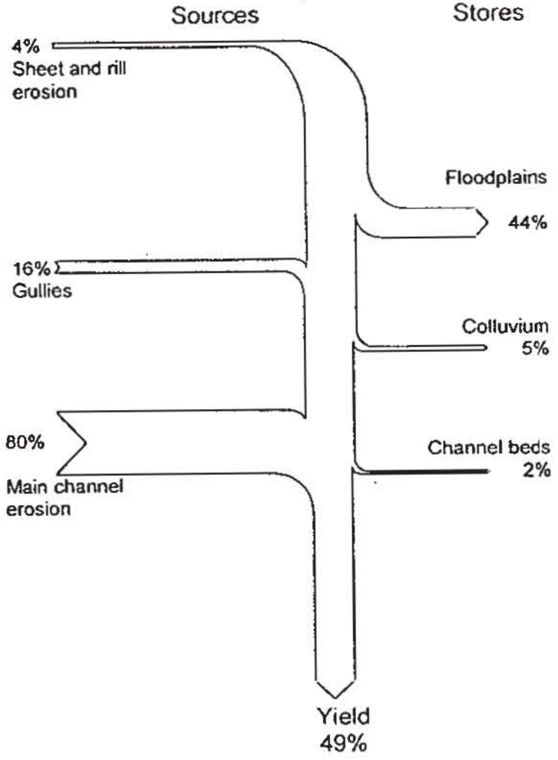

Figure 2: Jerrabomberra Catchment

Surveys of farm dams on the Southern Tablelands of NSW and the ACT have shown that ungullied catchments yield on average 5 ± 3 to 21 ± 15 times the amount of sediment leaving native forested catchments of ≤ 10 km^2 (Table 1). Gullied catchments yield 40 ± 26 times the forested catchments, between 8 and 2 times ungullied pasture and cropped catchments. These results come from small catchments, and Wasson (1994b) has shown that drainage density is a useful explanatory variable of sediment yield and land use is often not. Wasson (1994b) also summarised data from other parts of the country showing that gullies are a significant and often dominant source of fluvial sediment.

In larger catchments, the currently available test of the idea that channels dominate the sources of sediment is provided by the surface soil radionuclide tracers ^{210}Pb and ^{137}Cs (Wallbrink and Murray, 1993). These radionuclides are at their highest concentrations in the top few centimetres of soil. If diluted by unlabelled soil during transport, their concentrations in river sediments fall dramatically. Using this reasoning, Wallbrink et al (this volume) showed that about 90% of the suspended sediment in transport in the lower Murrumbidgee River comes from channel and gully erosion; that is, erosion of subsoils unlabelled by surface soil tracers. In the upper Murrumbidgee catchment, Wallbrink and Fogarty (in prep.), using this technique, have shown that in the Molonglo sub-catchment 96 ± 11% of the fine sediment in transport

Table 1: Mean annual specific sediment yield from catchments ≤10 km^2 on the Southern Tablelands (based on Neil and Fogarty, 1991; Lawrence, pers. comm.).

Catchment class	n	Mean annual specific sediment yield (t/km^2/yr)	Multiple of forested sediment yields
Native forest	5	4 ± 2	1
Native pasture	17	19 ± 5	5 ± 3
Native pasture with discontinuous gullies	5	31 ± 2	8 ± 4
Cropped	4	57 ± 15	14 ± 8
Overgrazed native pasture	2	68 ± 19	17 ± 8
Pine plantation	7	84 ± 42	21 ± 15
Established urban (industrial)	1	160	40
Native pasture with continuous gullies	10	161 ± 68	40 ± 26

Uncertainties are standard errors

in the rivers comes from channel and gully erosion, an estimate consistent with either a very small or zero surface soil input. Whenever a catchment is gullied, the sediment yield increases and the surface soil component is relatively small in catchments between 8 and 100,000 km^2 in area (Wallbrink et al, this volume).

4. MODELLING OF SEDIMENT AND PHOSPHORUS FLUXES

4.1 Modelling of Sediment Fluxes

Most mathematical and statistical models of sediment movement through catchments, that are suitable for routine use, are based on the concept of Fig. 1. ANSWERS, for example, has no channel erosion component, nor does TOPOG or CMSS. We take as our detailed example AQUALM, a model designed to assist planners, designers and managers (Phillips et al, 1992). This model has been applied to the upper Murrumbidgee River catchment (National Capital Planning Authority, 1994), thereby affording an opportunity to compare results with those available from field measurements and tracer studies.

The EXPORT mode of AQUALM generates runoff and pollutant exports using daily time steps, and then routes the pollutants through a stream network. The pollutant exports depend on land use type, and so the model does not explicitly produce pollutants from channels and gullies.

A test of AQUALM is to compare the model results with those estimated from reservoirs, lakes and sediment traps in the same area (Wasson, 1994a). Table 2 shows the comparison between the modelled median annual load of sediment, for a number of subcatchments in the Upper Murrumbidgee catchment, and the mean annual load calculated from the regression equation relating catchment area and load for this region. For the near-natural catchments, the pre-European settlement regression relationship of Wasson (1994a) has been used.

With only two exceptions, AQUALM underestimates the load for disturbed catchments and overestimates it for the near-natural catchments - by factors up to nearly eight. Mean and median loads are likely to be different by no more than about 50% from calculations done by C. Barnes (pers. comm.).

The underestimation of loads in disturbed, often gullied, catchments could result from: the failure of AQUALM to generate sediments from gullies and channels; or inadequate model runs to produce reliable median values to compare with the long-term means in the 'observed' data.

4.2 Modelling of Total Phosphorus Fluxes

There is an extensive literature on the factors that control TP export from catchments (eg. Chang et al,

Table 2: Modelled and Observed Suspended Sediment Yields in the Upper Murrumbidgee Catchment

Catchment	Area (km^2)	Median model yield (t/yr)	Mean 'observed' yield (t/yr)	Difference between modelled and 'observed'
L. Goodradigbee*	625	1990	260	- 8
L. Yass	1110	9250	24000	- 3
Woodstock	42	260	1110	- 4
Sturt	9	120	260	- 2
L. Queanbeyan	91	330	2290	- 7
Uriarra	249	930	5900	- 6
Williamsdale	107	1130	2660	- 2
Buchan	152	400	3710	- 9
L. Numeralla	37	1380	980	+ 1
Adaminaby*	1110	800	410	+ 2
Yaouk	378	40	170	- 5

* Near-natural

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1983, Hill, 1981, Hartley et al, 1984, Young et al, in press). There is a general opinion that land use controls the export, modulated by topography, runoff, and soil type. This opinion in the case of TP is the equivalent of the conceptual model shown in Fig. 1, and AQUALM reflects that model. It is interesting, however, that for Australia Young et al (in press) show considerable overlap between TP generation rates for native pasture, improved pasture, and dryland cropping, the three major rural land use types in the Murrumbidgee catchment. This indicates that, in small catchments, land use does not correlate strongly with TP yields.

Most studies of phosphorus movement in catchments has been carried out in areas of intensive agriculture in western Europe and/or North America. In these landscapes, land use and fertiliser applications are likely to be important sources of TP, along with urban and industrial wastes. So the conceptual model based on intensive agriculture in a system resembling Fig. 1 is unlikely to apply to Australian catchments where broadacre agriculture, active channel incision, small areas of intensive agriculture, and small quantities of urban and industrial wastes are the norm. Yet there are few explicit tests of the appropriateness of the conceptual model.

Table 3 presents the calculated mean annual specific yield of TP for the same catchments documented in Table 1. The TP yield is calculated by multiplying the sediment yield by the mean concentration of TP in the soils of the catchment; ie. 0.03 ± 0.001°/₀ TP. Not surprisingly, gullied catchments yield most TP (48.3 ± 22.0 kg/km^2/yr). This result indicates that catchment managers attempting to reduce TP impacts to waterbodies should pay more attention to channel erosion as a source of native TP.

5. CONCLUSIONS

In this paper, reasons have been given to support a search for differences between Australian fluvial systems and those in other parts of the world. The motivation for this search is to ensure that we only import and use ideas and models that are appropriate to this landscape. The use of inappropriate imported ideas and models is dangerous (cf. Harris, 1995).

Some specific examples are given, and one is developed in some detail. A model (AQUALM), built on an idea derived from other parts of the world, is shown to poorly estimate observed yields of sediment. The model underestimates the observed data, possibly because the model did not include the key sources of sediment, namely gullies and channels.

From first principles, it is expected that models of phosphorus sources developed in more intensely used catchments in other countries will not apply to most Australian catchments. Some evidence is offered to support this view. More importantly, there is currently little effort in Australia to test the appropriateness of the phosphorus models, or indeed any other catchment models.

Table 3: Calculated mean annual specific Total Phosphorus (TP) yield from catchments ≤ 10 km^2 on the Southern Tablelands.

Catchment class	Mean annual specific TP yield (kg/km^2/yr)
Native forest	1.2 ± 0.6
Native pasture	5.7 ± 1.7
Native pasture with discontinuous gullies	9.3 ± 0.9
Cropped	17.1 ± 5.1
Overgrazed native pasture	20.4 ± 6.4
Pine plantation	25.2 ± 13.4
Native pasture with continuous gullies	48.3 ± 22.0

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