The Importance of Channel Complexity for Ecosystem Processing:

An example of the Barwon-Darling River.

M.C Thoms[1] *and F Sheldon*[2]

ABSTRACT: Interactions between flow, channel morphology and the retention of organic matter in the Darling River are outlined. Data from a preliminary study indicate the presence of in-channel horizontal surfaces, at various elevations, influence organic matter accumulation and retention within the channel. Each morphological feature is associated with a specific flow band. Flow regime changes in the Darling Basin, via flow regulation and diversions, is indicated to have the potential to: reduce in-channel habitat complexity which leads to a decrease in the quantity of organic matter trapped; and, thus a reduction in the quantity and quality of organic matter available as a food source for aquatic organisms.

INTRODUCTION

River channels in semi-arid environments are often characterised by highly variable or compound cross-sectional shapes (Graf, 1987). Compound channels generally have several modes of operation: a high flow channel or 'trough', shaped by high magnitude, low frequency flood events and a series of lower flow channels within the larger 'trough'; which represent adjustments to a highly variable hydrological and sedimentological regime (Thoms and Walker, 1993). Prolonged flows at different levels within the larger 'trough', which have the ability to erode and transport sediment, shape the cross section to form a series of inset low flow channels. Compound channels have also been reported by Graf (1987) to occupy a single meandering channel at low flow whilst having a wider 'braided' channel at high flow. This low flow meandering channel is nested inside the larger braided component. Complex cross sectional morphology is a response to highly variable hydrological and sediment transport regimes; a feature of semi-arid river systems (Davis et al, 1994).

Discharge and channel complexity are known to influence the ability of a lotic (river) system to retain and process organic material (c/f. Speaker *et al.*, 1992; Sandon *et al.*, 1992). The retention and processing of allochthonous organic matter is important in structuring aquatic assemblages (cf. Rounick & Winterbourn, 1986; Cummins *et al.* 1984; Prochazka, 1991) as it provides a complex habitat and a vital food source. In small, low-order, temperate streams which experience regular overbank flows a large proportion of the allochthonous organic biomass enter river channels from the surrounding floodplain environment. However, floodplain inundation in semi-arid river systems does not occur as frequently (Walker et al 1995). Thus, in-channel features are relatively more important for ecological processes. In-channel features, such as concave benches act as minor floodplains; in the sense that they increase the habitat complexity of the main channel, provide surfaces for organic matter accumulation, retention and transformation, and promote invertebrate colonisation and productivity (Sheldon and Thoms, 1995).

The effects of riverine and water management are catastrophic for semi-arid riverine ecosystems. Semi-arid systems are adapted to highly variable flow and sediment regimes and complex habitat structure (channel morphology). Channel maintenance activities and flow regulation often reduces this natural variability. In the River Murray for example, flow patterns have been fundamentally altered with a five fold reduction in the frequency of monthly flows and an increase in flows maintained at or near bankfull capacity (Thoms and Walker, 1993). Moreover, decades of snag removal has significantly reduced available habitat for native fish (Lawrence, 1988). Effective management of these systems requires the recognition and acknowledgment of the importance of the inherent variability of these systems.

This paper presents the preliminary results of an investigation into the importance of in-channel complexity for ecological processes in the Barwon-Darling River, a major semi-arid river system in central Australia.

STUDY AREA

The Barwon-Darling catchment (650 000 km2) drains the inland slopes of the Eastern Highlands of Australia (Figure 1) and spans 11 degrees of latitude and longitude. The headwaters of the major tributaries of the catchment originate in south-east Queensland and flow inland in a south-westerly direction before joining the Murray River, near Wentworth. It is subject to a vari-

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[1] School of Natural and Environmental Science, University of Canberra

[2] Department of Zoology, University of Adelaide

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ety of climates, but most of the rainfall occurs in a small part of the catchment; average annual rainfall and evaporation ranges from 200-1000 mm and 500 and 1800 mm respectively.

The Barwon-Darling catchment is arid to semi-arid with significant areas contributing no runoff. Mean annual runoff is derived from less than 10 percent of the catchment and only less than 3 percent of average annual rainfall (MDBMC, 1987). Flow variability is a feature of the Barwon-Darling River. Long term variations in average annual flow for selected stations throughout the basin range from 0.04 percent to 911 percent (MDBMC, 1987). In general, discharges for the major rivers in the basin are highly skewed with a large proportion of average flows occurring in very wet years and during major floods. In-channel flows in the Barwon-Darling system are important with over 90% of all flows retained within the main channel (Walker, 1992).

Secular changes in the catchment's hydrological regime further influence natural flow variability. It has been demonstrated that the hydrological regime of the period 1900-1946 differs from the preceding and succeeding periods (Riley, 1988). Periods prior to the 1900s and that from the mid 1940s have been wetter and hence have produced greater runoff than the period 1900 to 1945.

Regulating structures, notably headwater dams and weirs, and water diversions have had a large impact on the flow regime of the Barwon-Darling. The median monthly flow at Mungindi and Menindee, for example, is now only 40 and 50 percent, respectively, of its natural value.

The Barwon-Darling is a suspended load river; it is deep, highly sinuous and has a 'complex' river channel cross section (see Woodyer, 1968; Woodyer *et al.*, 1977; Riley and Taylor, 1978). Similar complex channels have been reported along the lower River Murray in South Australia by Thoms and Walker (1993).

THE APPROACH

Two reaches were chosen along the Barwon-Darling River. An 'unregulated' reach at Culpaulin Station, downstream of Wilcannia and a 'regulated' reach at Studley Station downstream from Pooncarie. A series of cross sections from each reach were surveyed, to AHD (Australian Height Datum), to investigate the presence of in-channel morphological structures and assess in-channel complexity.

At selected sites within each reach the extent of organic matter accumulation within the channel was investigated. Coarse organic matter (CPOM - >2mm) and the percent organic content of the <2mm fraction were determined from material collected from the surfaces of various in-channel morphological features. Ten samples were collected randomly from each surface feature using a 25 cm2 quadrat. Sediment in each quadrat was sampled to a depth of 5 cm and returned to the laboratory for processing. Material was collected from both the vertical and corresponding horizontal surface of each feature and processed according to the methods outlined by Aloi (1990). Differences in the weight of CPOM and the percent organic content between the surfaces of each identified in-channel feature were explored using the Mann-Whitney U test.

RESULTS AND DISCUSSION

1. In-channel habitat complexity

A series of cross sections from the two reaches are illustrated in Figure 2. A notable feature of the unregulated reach cross sections are five distinct morphological features located at different elevations within the channel. Identification of these horizontal features was largely a matter of subjective field assessment along with the verification of the morphometric index employed by Riley (1975). Not all the morphological features were present on any one cross section, although all five were present within the unregulated reach.

There are a lack of in-channel morphological features in the 'regulated' reach of the Darling River in comparison to the 'unregulated' reach. Cross-sections of the Darling River near Pooncarrie depict the channel as being relatively shallower with few horizontal in-channel features present compared to that near Wilcannia (cf. Figure 2). The cross sections indicate the presence of features at relatively high elevations in the channel (ie, Level 1 and 2 features) but features at relatively lower elevations (Level 3, 4 and 5) appear to be absent. Old photographs of the river, taken at the turn of century near Pooncarrie do show the presence of many morphological features, at various levels within the channel, which may suggest a once complex cross-section.

Bank erosion is common in highly regulated rivers. Rates of bank retreat in excess of 1.5 metres a year have been recorded in the regulated sections of the River Murray (Thoms and Walker, 1989). In the Murray most of this retreat occurs following rapid falls in water level. For example, water levels may drop by

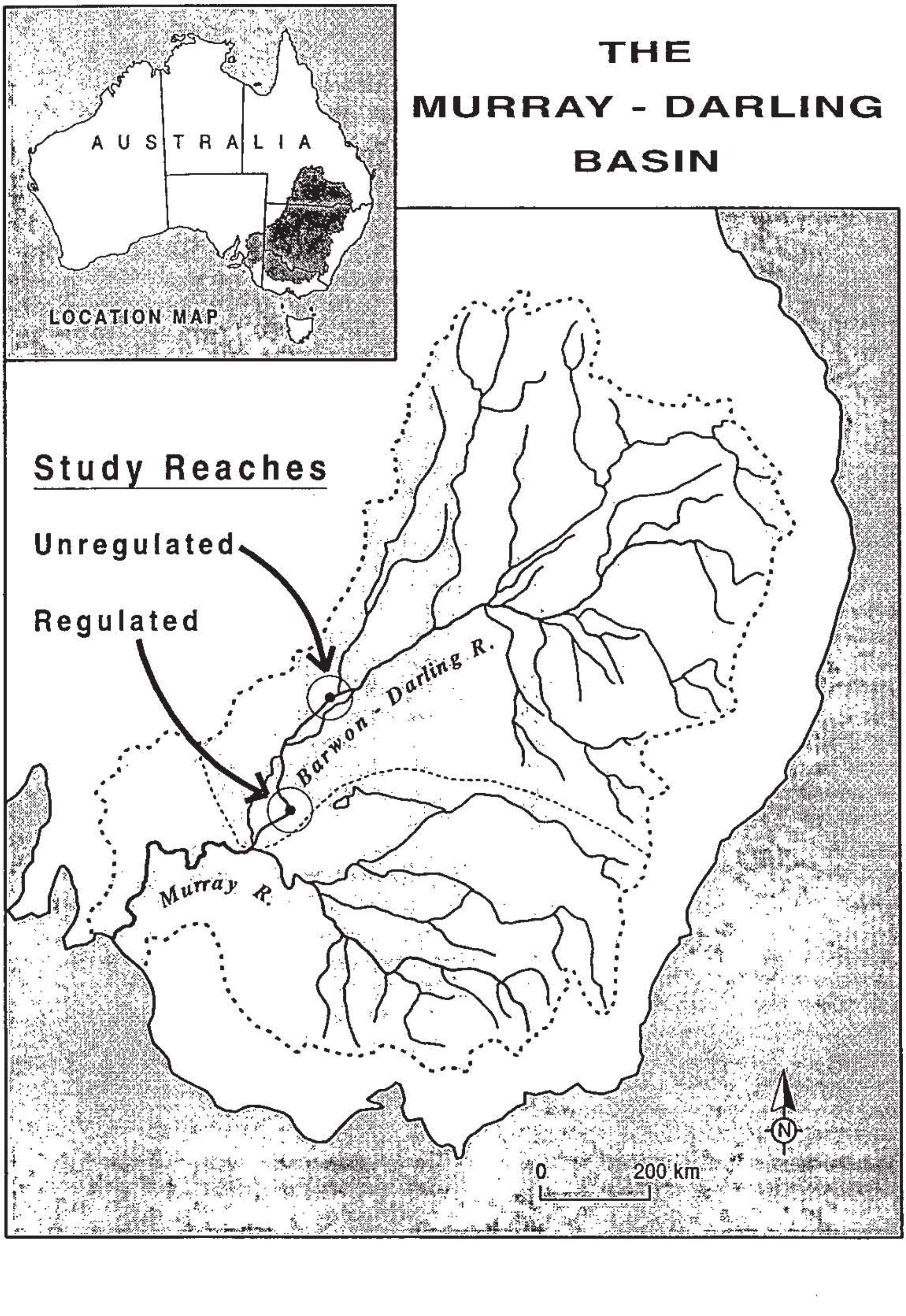

Figure 1. The Barwon-Darling Basin. Location of study reach are indicated.

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2.5 m in a week downstream of some regulating structures, leaving saturated banks prone to sliding. The relatively steep slopes and general morphology of the channel banks of river in this reach of the Darling River, below Menindee, suggest that abrupt block failure is an important erosion mechanism. Furthermore, smaller more frequent changes associated with routine weir operations may also undermine the toe of the bank, leaving it vulnerable to larger falls. Changes in bank morphology and the subsequent loss of in-channel benches is a feature of highly regulated sections of the River Murray.

The geomorphology of in-channel features in the Barwon-Darling is not well known. However, depositional benches have been reported by Woodyer et al (1979) to be a prominent feature of the Barwon-Darling river channel. These benches are defined by horizontal sections of a cross section, excluding the bed. Woodyer et al (1979) identified and described the stratigraphy underlying four surfaces within the channel of the Barwon River, near Walgett. The two lower surfaces were considered to be formed by suspended-load deposition. These surfaces form as point, concave, convex and lateral benches and are composed of laminations of fine inorganic sediments and enriched organic mud. These muddy laminae range in thickness from 0.1 to 14 cm (Woodyer et al 1979). The upper surfaces, also termed benches, were identified by Woodyer (1968) and Riley (1975) as part of the present floodplain. It is postulated that they are relic surfaces, being inundated about once in every 15 years, although on a number of the high surfaces sand laminae were identified. Nevertheless each bench surface in the channel is considered to be a response to change in flow regime (Woodyer, 1968; Riley 1975; Woodyer et al, 1979).

Observations of the stratigraphy of a number of the in-channel features were made at various sites within each reach. The stratigraphy and sediments contained within the upper four features concur with the observations of Woodyer et al (1979). Each morphological feature contained a series of fine sand-mud laminations. The extent of the deposits and individual laminae were dependant upon the size of the in-channel feature. A continuous banding of fine sand and mud up to 4-5 metres in thickness was noted at several sites.

The lower most feature (Level 5) was easily recognised as a distinct break in slope near the base of the channel. This feature resembled an erosional or cut bench similar to that reported by Partheniades (1965) in channels with highly cohesive bed sediments. The formation of these features was suggested to be independant of bed material shear strength and more a factor of geomechanical processes resulting from prolonged low flows.

2. In-channel habitat complexity and flow variability

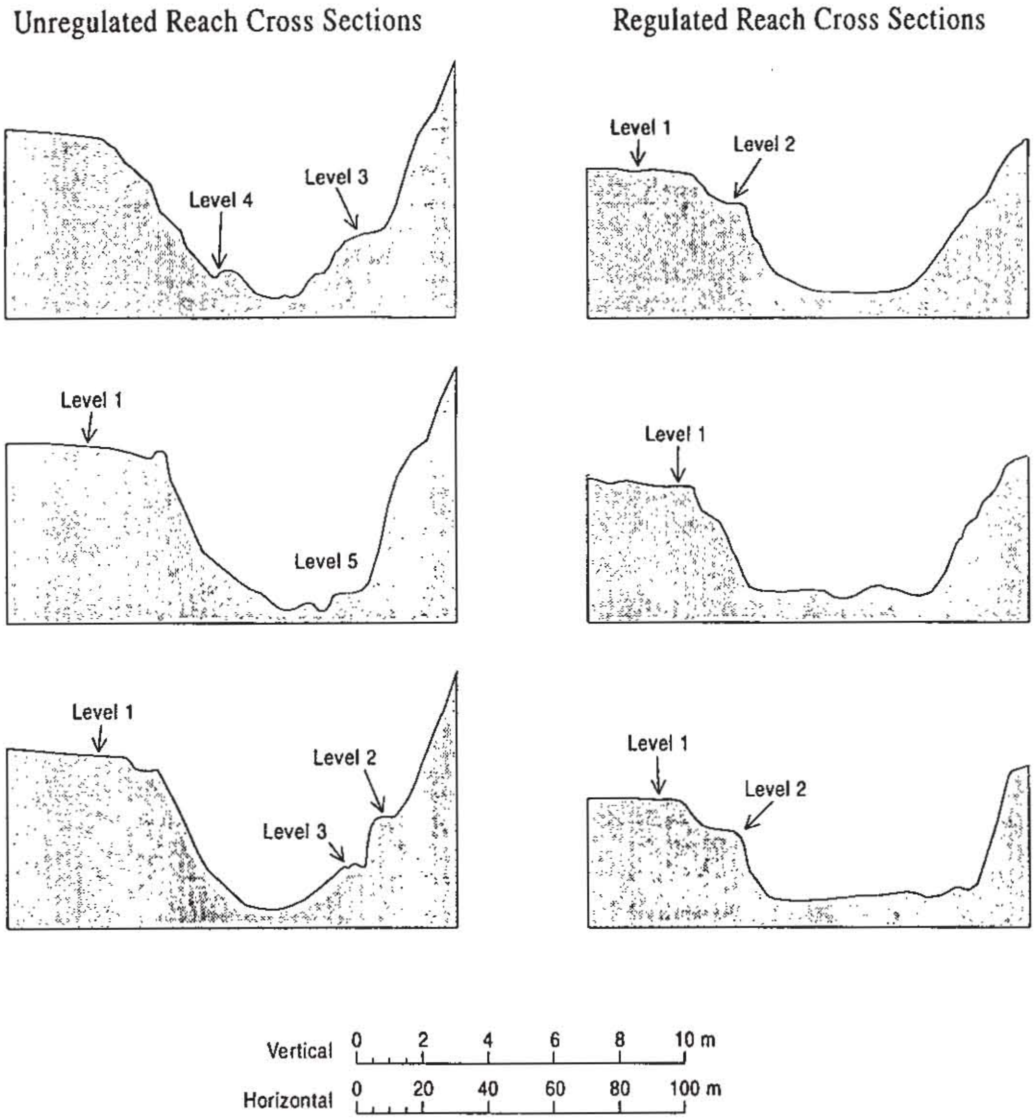
There is an apparent banding of flows at five distinct stage heights in the 'unregulated' reach of the Barwon-Darling River. Figure 3 is a frequency histogram of stage heights at the Wilcannia gauge, for the period 1972 to 1994. The height (AHD-m) of these bands correspond to the levels of the various in-channel morphological features. The highest number of flows occurs between 0.5 and 1.5 metres, corresponding to the low water mark on the channel banks and the location of the Level 5 feature. There is a grouping of levels between 3.25 and 3.75 metres, within the range of the Level 4 feature; another between 5.5 and 6 metres, the Level 3 feature; another group around 7.5 metres or the Level 2 feature and another at approximately 9.75 metres in the range of the high Level 1 feature. This apparent banding of lows was not evident in the 'regulated' reach of the river.

This preliminary analysis suggests there is an apparent association between flow regime and the presence of morphological features which contribute to in-channel complexity. Thus an interaction between flow and morphology; the nature of this interaction requires further investigation, particularly the impact of changes in the flow regime on in-channel complexity.

3. In-channel habitat complexity and organic matter retention

The quantity of organic matter on the horizontal and corresponding vertical surface of each morphological feature were determined at sites in the 'unregulated' and 'regulated' reaches. Four features were identified at Culpaulin (unregulated) and only one at Studley (regulated). The overall aims of this section of the study were to:

- assess the amount of large course particulate organic matter (CPOM), >2 cm, retained on each surface;
- assess the percent organic content of the fraction < 2 cm, providing an indication of the ability of the different surfaces and features to retain organic matter.



Unregulated Reach Cross Sections

Regulated Reach Cross Sections

Figure 2. Representative cross sections for the Barwon-Darling River. A: cross sections from the 'unregulated' reach downstream of Wilcannia; B: cross sections from the 'regulated' reach downstream of Menindee.

Mean weights of organic material collected from the quadrats and standard errors for both surfaces for each feature at the two sites are given in Table 1. The horizontal surface only was sampled for the Level 4 feature as the corresponding vertical surface was inundated. Results of the Mann-Whitney U tests for each feature are given in Table 2.

For the CPOM fraction (>2 cm) statistical differences were found between both surfaces for all features sampled at each site (Table 2). Horizontal surfaces retained a greater weight of CPOM than vertical surfaces. This difference was repeated for the percent organic content, with significant differences between both surfaces for all features except Level 3 (Table 2).

In-channel morphological features do accumulate and trap significant quantities of organic material. However some appear to accumulate more than others. Differences in the ability of the in-channel morphological features to trap organic matter may relate to one or a combination of the following: the mode of formation of the feature, the surface roughness of each feature and the relationship between input of organic matter and the time of deposition. It is also apparent that the horizontal and vertical surfaces of each morphological feature differ in their ability to accumulate

Site	Feature	Surface	COM>2cm (g)		% Organic Content	
Culpaulin (unregulated)	Level 1	Horizontal	62.47	*(10.49)*	11.18	*(0.67)*
		Vertical	4.23	*(1.17)*	3.53	*(0.19)*
	Level 2	Horizontal	21.29	*(5.69)*	8.38	*(0.58)*
		Vertical	0.57	*(0.31)*	4.99	*(0.16)*
	Level 3	Horizontal	61.87	*(15.14)*	3.68	*(0.57)*
		Vertical	4.11	*(1.26)*	2.59	*(0.28)*
	Level 4	Horizontal	11.09	*-2.55*	7.28	*-0.15*
Studley (regulated)	Level 2	Horizontal	63.62	*(11.19)*	9.79	*(0.32)*
		Vertical	11.47	*(3.95)*	6.25	*(0.15)*

Table 1. Means (SE) for the CPOM fraction >2 cm (g) and the percent organic content for both surfaces of each feature sampled at the two sites.

Site	Feature	COM>2cm (g)	% Organic Content
Culpaulin (unregulated)	Level 1	U=100, p<0.001	U=100, p<0.001
	Level 2	U=98, p<0.001	U=100, p<0.001
	Level 3	U=90, p<0.001	U=58, p<0.05
Studley (regulated)	Level 2	U=86, p<0.001	U=90, p<0.001

Table 2. Results of the Mann-Whitney U comparisons between the horizontal and vertical surfaces of each feature for CPOM >2 cm and percent organic

CPOM of a size range greater than 2 cm; twigs, leaf litter and other woody debris. The horizontal surface of each feature accumulated a greater weight of CPOM. Differences in the amount of CPOM accumulated on the horizontal surfaces for the range of features may reflect differing proximity's to overhanging riparian vegetation. This analysis, however, clearly indicates that horizontal surfaces have a greater ability to collect woody debris than vertical surfaces.

The horizontal and vertical surfaces also differed in the quantity of organic matter (% organic content of <2 cm fraction) retained within the sediment; with the horizontal surfaces retaining greater quantities of organic matter than vertical surfaces. The Level 3 feature at Culpaulin Station was the only feature in which there was no significant difference in the percent organic content between horizontal and vertical surfaces. Interestingly, the sediment composition of both surfaces of this feature was predominantly sand, whereas the sediment composition of all other features was dominated by silt and clay.

The lack of horizontal surfaces in 'regulated' reaches of the Barwon-Darling River may limit the in-channel trapping of organic matter. Horizontal surfaces not only provide a site of deposition, hence the accumulation and retention of organic matter, but also influence the form roughness of the channel. Increased roughness enhances in-channel deposition. Changes in river morphology have occurred in the Murray-Darling Basin resulting in the erosion of in-channel features such as depositional features (cf. Thoms and Walker, 1993). The influence of flow regulation and channel maintenance activities on the stability of river morphologies is well documented. These activities are common through out the basin.

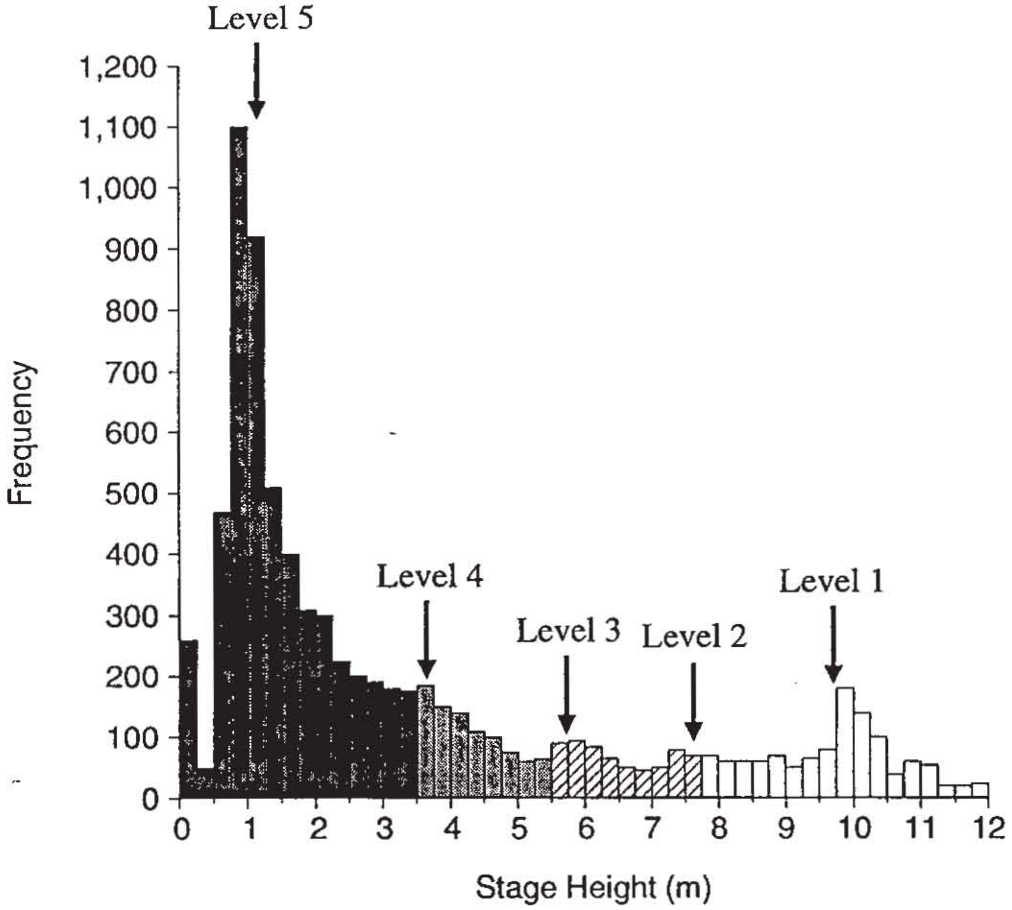


Figure 3. Frequency histogram of stage heights in theDarling River at Wilcannia (1972-993) with levels of the in-channel features observed in the cross sections.

SIGNIFICANCE

There is a growing body of opinion that channel complexity in rivers such as the Barwon-Darling is critical for ecosystem health. In-channel morphological features play an important role in the energy transfer throughout the system. During low flow periods, litter accumulates on these flat features. When flow levels rise, inundating the accumulated organic matter, it becomes available to certain aquatic organisms whereupon it is processed and becomes part of the food chain. In effect, the function of these features is similar to wetlands, except that they would be inundated more frequently.

The greater the complexity of the channel, the greater the surface area available as a food source and as habitat for lower order aquatic organisms such as macroinvertebrates. Conversely, if the degree of complexity is reduced, this could have repercussions for overall ecosystem health. A hypothetical association between in-channel complexity, hydrology and food source availability is presented in Figure 4.

Water resource development can give rise to dramatic changes in the character of riverine ecosystems. In order to assess the environmental flow requirements for a specific ecosystem it is important to understand how aspects of the physical environment impact various components of the ecosystem. For the Barwon-Darling River it is imperative to maintain both the natural flow and habitat variability.

Ecological sustainable development of Australia's inland rivers requires sound environmental knowledge. However, the character of riverine ecosystems is the result of many interacting parameters, and it is difficult to discuss individual factors in isolation. Indeed, physical, chemical and biological, factors operate in conjunction with each other to produce unique systems, both in terms of their character and functioning. The

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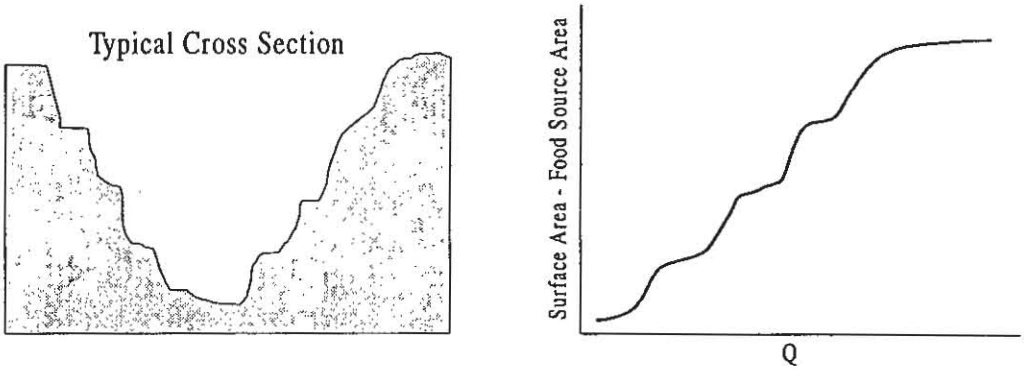

Figure 4. Hypothetical association between available habitat-food source area and discharge.

integrity of river ecosystems relies on a balance between all parameters. This fact is often neglected with a tendency for a focus on 'flows' in the management of our rivers.

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