Hydraulic habitat in confluences: an ecological perspective on confluence hydraulics

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Abstract The near-bed hydraulic characteristics of a confluence were monitored over a range of stages to assess the variability of hydraulic habitat and its influence over distributions of benthic macroinvertebrate communities. Spatial variability of hydraulic characteristics was observed in the confluence, and there is some suggestion from macroinvertebrate data that the hydraulic conditions influence the distribution of macroinvertebrates in the confluence.

Key words confluences; near-bed hydraulics; spatial variability; temporal variability; benthic macroinvertebrates; East Midlands; UK

INTRODUCTION

Benthic macroinvertebrates are becoming increasingly important in aquatic research, with many uses in water quality assessment techniques (e.g. RIVPACS and AusRivAS), and even as forensic indicators (Keiper & Casamatta, 2001). However, there is still much insight to be gained into the natural spatial and temporal variability of benthic macroinvertebrate communities in aquatic environments. In this study, the role of confluence hydraulics in determining habitat variability and distributions of benthic macroinvertebrates in stream beds is investigated.

Confluence hydraulics

Confluences are hydraulically complex fluvial systems. The geomorphic and hydraulic characteristics of the two confluent channels amalgamate into one downstream channel, resulting in rapid changes in flow, sediment entrainment and hydraulic geometry (Best, 1988). The hydraulic regime in a river channel determines the sediment transport and deposition processes in operation there, which in turn are responsible for the formation and evolution of the bedforms characteristic of confluences (McLelland *et al.*, 1996).

Best (1987) identified six major zones of hydraulic significance within river channel confluences. These were flow stagnation, flow deflection, flow separation, maximum velocity, flow recovery and three-dimensional shear layers which form in the mixing zone of the two confluent channels (Fig. 1). The exact positions of these zones are site-specific, and are controlled by factors such as channel geometry, the junction angle and the discharge ratio of the two channels (Best, 1987). The study by

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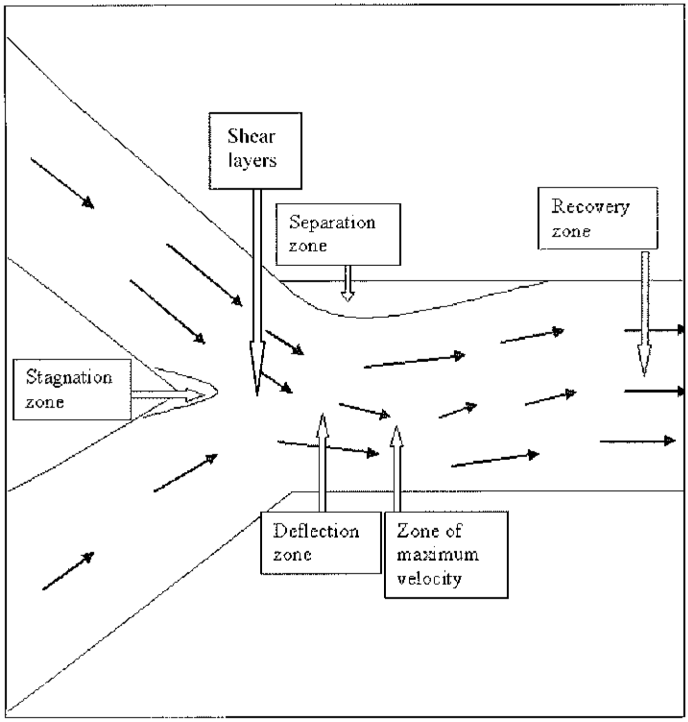

Fig. 1 Diagram to show zones of flow in a typical confluence (adapted from Best, 1987).

Best (1987) also demonstrated that distinct sediment transport pathways through the confluence were produced as a result of these particular flow dynamics, and that the formation of the geomorphic structures typical of confluences, such as scour holes, avalanche faces and separation bars, occurred in response to these processes.

Benthic macroinvertebrates and hydraulic habitat

Benthic macroinvertebrates are found in all but the most degraded fluvial systems. The majority of benthic macroinvertebrate species inhabit the surface layers of sediment on stream beds, and so near-bed hydraulic conditions are particularly important for these communities. Macroinvertebrates are often very susceptible to physical disturbance, especially to changes in hydraulic habitat. Statzner & Higler (1986) suggest that stream hydraulics are the most important abiotic factors controlling macroinvertebrate community structure, and data show that distinct changes in species assemblages are associated with changes in hydraulic conditions. Hydraulics are especially important in defining physical habitat conditions, since streamflow exerts control over many important structural attributes in streams, including habitat volume, substrate stability and channel geomorphology (Poff & Ward, 1989).

Confluences are associated with chaotic and heterogeneous near-bed flow conditions, and velocities, shear stresses and turbulence intensities may attain maximum range in confluence environments. The temporal variability of stage further increases the complexity of the hydraulics in confluences, and can result in the physical disturbance of macroinvertebrate habitat patches at high and low flows. However, little research has been carried out to study the distributions of macroinvertebrates within a confluence environment, where hydraulic conditions are unique in fluvial systems. Therefore, this study incorporates hydraulic monitoring with ecological sampling to assess the relationships between biota and hydraulic conditions in confluences through two main objectives:

- to investigate the spatial and temporal variability of hydraulic parameters in the confluence, and
- to determine the influence of hydraulic habitat conditions on distributions of benthic macroinvertebrates in the confluence.

STUDY SITE

The confluence of Wood Brook and Burleigh Brook near Loughborough in the East Midlands, UK, was used for this study. This is a Y-shaped, channelized confluence with a junction angle of 60°, and upstream channel widths of approximately 2 m, merging into a downstream channel of width 4 m at the confluence apex, narrowing to 2½ m by a distance of 10 m downstream. The suitability of this urban confluence for the proposed study was assessed by ascertaining the presence of the hydraulic zones and geomorphic bed forms typical of most confluences, as described by Best (1987). A topographic survey demonstrated the presence of a scour hole and a separation bar, and avalanche faces were observed visually in the confluence. A preliminary assessment of near-bed flow velocities in the confluence demonstrated the presence of Best's (1987) flow zones at this site. Slower flow velocities were indicative of the flow separation zone and the flow stagnation zone just downstream of the confluence apex. Faster flow velocities were found in the flow deflection and recovery zones.

METHODS

Hydraulic monitoring

High resolution hydraulic measurements were taken at 25-cm intervals along seven transects across the confluence area and two upstream channels. A Marsh-McBirney series 511 two-dimensional electromagnetic current meter was used in conjunction with an Eltek series 1000 datalogger to collect near-bed downstream and vertical velocity time series data on several occasions over a range of stages (0.10–0.42 m). Measurements were made at a frequency of 5 Hz for a period of 2-min at each site along the sample transects. To describe hydraulic habitat conditions in the confluence at each stage, these time series data were subsequently detrended and used to calculate several hydraulic variables which influence near-bed and benthic habitat conditions. These were mean near-bed downstream velocity (U), mean near-bed vertical velocity (W), root mean square (r.m.s.) values of U and W to describe velocity fluctuations, nondimensional turbulence intensity (TI) and mean Reynold's shear stress (R_e^*), using equations (1)–(3) (after Clifford & French, 1993):

$$\text{r.m.s.} = \frac{\sqrt{\sum(x-\bar{x})}}{N} \quad (1)$$

$$TI = \frac{(U_{rms} + W_{rms})}{2} \quad (2)$$

$$R_e^* = -\rho u'w' \quad (3)$$

where u' and w' are the fluctuations from the mean at each point in the time series. These hydraulic parameters were calculated because of their direct influence on the stream bed, and hence on benthic habitat.

Macroinvertebrate sampling

The confluence was divided into five hydraulic zones using hydraulic data collected previously in conjunction with Best's (1987) description of confluence flow zones: shear zone, separation zone, recovery zone, upstream Wood Brook and upstream Burleigh Brook. Macroinvertebrate samples were collected using a Surber sampler on four occasions during April 2001 from sites within each of these hydraulic zones. Macroinvertebrates were identified to the lowest taxonomic level possible with the available keys.

DATA ANALYSIS

Spatial hydraulics

One-way Analyses of Variance (ANOVAs) were carried out on values of mean U, mean W, TI and R_e^* calculated for sites within each of the five hydraulic zones identified in the confluence. Root mean square values of U and W were excluded from these analyses due to their strong correlation with TI values (r = 0.95 and 0.92

Table 1 ANOVA output: the statistical testing of differences in mean hydraulic conditions between zones.

		Sum of squares	Degrees of freedom	Mean square	F statistic	p
Mean U (m s^{-1})	between groups	0.250	4	6.246×10^{-2}	4.942	0.010*
	within groups	0.190	15	1.264×10^{-2}		
	Total	0.439	19			
Mean W (m s^{-1})	between groups	5.724×10^{-3}	4	1.431×10^{-3}	6.047	0.004*
	within groups	3.550×10^{-3}	15	2.367×10^{-4}		
	Total	9.274×10^{-3}	19			
TI	between groups	1.323×10^{-3}	4	3.306×10^{-3}	0.265	0.896
	within groups	0.101	15	6.726×10^{-3}		
	Total	0.114	19			
R_e^* (N m^{-2})	between groups	0.560	4	0.140	0.492	0.742
	within groups	7.923	15	0.528		
	Total	8.483	19			

* Significant at the 0.01 level.

respectively, significant at the 0.01 level). No significant differences in values of *TI* and R_e^* were found between zones (Table 1). However, significant zonal differences in mean *U* and mean *W* were identified, with *p* (probability) values of 0.01 and 0.004 respectively (Table 1). *Post hoc* tests revealed that mean *U* values were not significantly different between the separation zone and upstream Burleigh Brook zone, both slower flow areas, or the shear zone and upstream Wood Brook zone, where flow velocities are higher (Wood Brook is the dominant channel at this confluence.) Also, the shear and Wood Brook zones exhibit significantly higher mean *U* values to the separation and Burleigh Brook zones. The recovery zone has significantly different values of mean *U* to all of the other flow zones in the confluence. *Post hoc* tests also revealed that the recovery zone downstream of the confluence had significantly different mean *W* flow velocities to the other hydraulic zones. These analyses highlight the hydraulic spatial complexity of this confluence system, and demonstrate the potential for benthic macroinvertebrate habitat heterogeneity at this site.

Temporal hydraulics

Additional ANOVAs were carried out on the hydraulic data to investigate the changes in hydraulic conditions in each flow zone with variations in stage. Values of *p* produced by these analyses showed that the only significant differences in hydraulic conditions with stage were for mean *U* in the shear zone, recovery zone and upstream Burleigh Brook zone, where p = 0.000, 0.032 and 0.032 respectively (Table 2). No significant changes in other hydraulic parameters with stage in any other zone were evident from these analyses. Therefore, it can be inferred that although there is evidence of spatial variation in hydraulic conditions in the confluence, each zone maintains a relatively stable hydraulic habitat over the range of stages monitored.

Table 2 ANOVA output: the statistical testing of differences in mean *U* in each hydraulic zone with variations in stage.

Hydraulic zone		Sum of squares	Degrees of freedom	Mean square	*F* statistic	*p*
Shear zone	between groups	0.379	7	5.409×10^{-2}	6.091	0.000*
	within groups	0.364	41	8.881×10^{-3}		
	Total	0.743	48			
Separation zone	between groups	3.621×10^{-2}	6	6.035×10^{-3}	0.634	0.701
	within groups	0.114	12	9.517×10^{-3}		
	Total	0.150	18			
Recovery zone	between groups	0.216	7	3.080×10^{-2}	2.720	0.032**
	within groups	0.272	24	1.132×10^{-2}		
	Total	0.487	31			
Upstream Wood Brook						
	between groups	8.773×10^{-2}	6	1.462×10^{-2}	0.489	0.806
	within groups	0.419	14	2.990×10^{-2}		
	Total	0.506	20			
Upstream Burleigh Brook						
	between groups	5.123×10^{-2}	6	8.538×10^{-3}	3.266	0.032**
	within groups	3.660×10^{-2}	14	2.614×10^{-3}		
	Total	8.783×10^{-2}	20			

* Significant at the 0.01 level; ** significant at the 0.05 level.

Benthic macroinvertebrate distributions

ANOVA analyses of temporal macroinvertebrate data generally produced high p values, demonstrating few significant differences in taxa distributions with varying stage in the confluence. However, since hydraulic habitat remains relatively stable temporally over the range of stages monitored, little change in macroinvertebrate distributions would be expected if hydraulic conditions were a major controlling factor.

Spatially, some species with particular habitat requirements were found in the hydraulic zones exhibiting suitable physical habitat conditions. For example, *Gammarus pulex* require high oxygen levels, stable substrate and a constant food supply. The majority of *Gammarus pulex* were collected from the recovery zone (Table 3) where higher flow velocities maintain high oxygen levels and organic matter influx, but lower shear stresses and turbulence intensities support greater substrate stability. Higher abundances of *Erpobdella octoculata* were also found in the recovery zone (Table 3). *Erpobdella octoculata* and other leeches are predatory organisms and macroinvertebrates are their primary food source in stream ecosystems. It is possible that the higher numbers of this species of leech observed in the recovery zone are due to the fact that this zone has the highest species diversity in the confluence, and also demonstrates consistently high abundances of macroinvertebrates in comparison to the other hydraulic zones. A small number of macroinvertebrates requiring higher flow conditions for feeding and oxygen supply, for example *Sericostoma personatum* and *Hydropsyche* species, were also found in the upstream Wood Brook zone and the recovery zone (Table 3) where flow velocities are generally higher. Oligochaetes are deposit feeders, often found in marginal habitats where slow flow velocities promote the deposition of organic matter. High numbers of Oligochaetes were collected from the separation zone (Table 3) where flow velocities are generally low. Some gastropod

Table 3 Total abundances of benthic macroinvertebrate taxa collected from each hydraulic zone.

Taxa	Shear	Separation	Recovery	Wood Brook	Burleigh Brook
Sericostoma personatum	2	3	9	14	2
Hydropsyche sp.	0	0	1	2	0
Tinodes waeneri	1	0	0	0	0
Baetis rhodani	1	1	3	0	1
Ephemera danica	1	2	0	0	0
Gammarus pulex	3	1	32	6	4
Asellus sp.	2	2	0	1	0
Chironomidae	55	20	42	47	16
Ceratopogonidae	2	0	8	0	2
Oligochaeta	85	290	161	179	89
Tabanidae	0	0	0	1	0
Tipulidae	0	0	1	0	0
Hydracarina	34	7	8	18	12
Glossiphonia complanata	0	3	2	2	0
Erpobdella octoculata	8	6	35	11	0
Sphaeriidae	0	0	1	2	2
Lymnea sp.	3	2	0	0	0
Total	197	337	303	281	128

species bury themselves in sand. Low numbers of Sphaeriidae were found in the confluence, in the upstream Burleigh Brook zone where sediment texture is finer, and also in sandy patches in the upstream Wood Brook zone and the recovery zone (Table 3). However, despite these apparent trends in the distributions of some macroinvertebrate taxa, ANOVA analyses revealed that only two taxa, *Gammarus pulex* and *Erpobdella octoculata*, demonstrated significant differences in their abundances between hydraulic zones (p = 0.010 and 0.002 respectively), with the recovery zone exhibiting higher numbers of these organisms than any other zone in the confluence. However, since species diversities and abundances of macroinvertebrate organisms were generally low in this confluence, it is suggested that low abundances of "indicator" organisms are responsible for the lack of statistical significance of macroinvertebrate distributions.

CONCLUSIONS

Although some spatial hydraulic variability has been identified, these conditions do not vary temporally, with the exception of mean U, within the range of stages monitored in the confluence. Very high floods in this confluence were not sampled due to the safety risks involved, and it is likely that the relatively narrow range of stages sampled limits the temporal aspect of this study. It is difficult at this early stage of the research to conclude that the hydraulics in the confluence are influencing macroinvertebrate distributions, due to the lack of significant corroborating evidence. In most stream systems, streamflow regimes are intermediate between high and low flow extremes, so that both abiotic and biotic factors contribute to community structure at various times (Poff & Ward, 1989.) However, the results of the spatial analyses of macroinvertebrate distribution are encouraging despite the lack of significant statistical evidence, since small numbers of macroinvertebrate species with varying physical habitat requirements are found in particular zones of the confluence. It is suggested that further hydraulic sampling at a greater range of flow velocities including extreme events be conducted to develop this research—it is these extreme events which are potentially most destructive to physical habitat, and hence macroinvertebrate communities.

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