Flume Studies of the Effect of Perpendicular Log Obstructions on Flow Patterns and Bed Topography

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It is known that woody debris in stream channels modifies morphology in many ways, ranging from scour of the bed to lateral migration of the channel over time. Since the occurrence of woody debris in streams results in a complex set of inter-related processes, it is useful to use controlled conditions in laboratory experiments to aid in the understanding of these processes. A flume study was undertaken to determine the spatial dimensions of influence on flow patterns and on bed topography of woody debris oriented normal to flow. Fluid depth was varied over three sets of stage conditions (stage condition 1 = low stage; condition 2 = medium stage; condition 3 = high stage) to change the obstruction ratio (the diameter of the debris to the depth of unobstructed flow), and speed of the fluid was varied to maintain a constant Froude number. Bed profiling and flow velocity sampling were used to determine the effects of the obstruction ratio. Results show that as the percentage of obstruction increases, there is an increase in scour pool area, and a corresponding morphological effect on the shape of the influence zone (or zone of reverse circulation) immediately behind the obstruction, which is attributable to fluid passing under the obstruction. Geometric relationships of the length of this influence zone to obstruction diameter are presented and discussed in terms of aquatic habitat in natural channels.

Keywords: *Woody debris, fluid speed patterns, bed topography, flume experiment*

There are a number of studies that take a biological perspective towards woody debris in streams and its importance in aquatic habitat creation (eg. Zimmerman et al., 1967; Bilby and Likens, 1980; Angermeier and Karr, 1984; Robison and Beschta, 1990; Sedell and Beschta, 1991; Smith et al., 1993; Gippel, 1995). However, less attention has been paid to this issue from the perspective of fluvial geomorphology. The first noted reference to alteration of channel form is attributed to Bevan ('...large organic debris causes more changes than any other agent':1948-49). More recent research has focused on the creation of log steps (Heede, 1972), channel erosion and deposition (Keller and Swanson, 1979; Mosely, 1981; Gregory et al., 1985) and channel morpho-dynamics (Beschta and Platts, 1986; Lisle, 1986; Gregory, 1992; Gregory et al., 1993; Nakamura and Swanson, 1993). Consideration has also been given to the stabilizing effects of woody debris (Smith, 1976; Keller and Swanson, 1979; Bilby, 1984), and the effects of debris on fluid patterns and sediment transport (Beebe, 1997). A large portion of the research conducted on woody debris in streams focuses on small streams in mountainous regions of western North America, where contributions from logging alters the type of debris that is supplied naturally to streams (Keller and Talley, 1979; Hickin, 1984; Lienkaemper and Swanson, 1987; Andrus et al. 1988; McDade et al. 1988 and others). Little attention has been paid to the contribution of log obstructions to low-gradient streams in non-forested regions.

The potential effects of in-channel woody debris on channel morphology are a function of the size of debris relative to the channel and the positioning relative to the flow (Hogan, 1986; Beebe, 1997); however examining the relationship between woody debris in river channels, and how it may influence flow and bed morphology under field conditions, is a concern due to the large number of potentially 'interfering' variables which are difficult to identify and control. In order to understand the processes involved in the interaction between woody debris and stream flow, research must start at a scale that is workable.

Laboratory studies on the effects of woody debris have been limited. Beschta (1983) was the first to describe an experiment on the relationship between PVC cylinders (which represented woody debris in cross-section) and bed patterns with increasing flow. Other laboratory experiments continued along this vein. Cherry and Beschta (1989) found that upstream oriented dowels caused significant local scour at the bed while downstream-oriented dowels caused reduced scour and greater bank protection (confirmed in experimentation by Gippel, 1995; Shields and Gippel, 1995). These studies provided a limited body of process information which may be applied in the field. What is needed is more detailed information on the distribution of fluid speeds downstream of a woody debris obstruction, and the spatial dimensions associated with these flow modifications. The reason for this need is clear: determining the spatial influence of logs will allow aquatic biologists and geomorphologists to make decisions on which logs to remove (if a channel is choked with logs) or where to place logs to create habitat zones. Therefore it is necessary to use controlled experiments to make initial attempts at examining these relationships. Once relationships are generally understood, they may be applied to field conditions to support management decisions on woody debris in streams.

The purpose of this study is to examine the spatial extent of disturbance to flow by outlining the down-flow distance which fluid patterns are disrupted, taking into account the influence of scour at the bed as a contributing variable. The expectation is that results might then be transferred to the field scale and be applied to the creation and maintenance of aquatic habitat. Due to the numerous scaling problems associated with working in flumes, these experiments are not intended to make direct comparisons to field-scale conditions, rather, they are intended to stimulate further research into the relationship between woody debris in streams and alterations to bed morphology and flow patterns.

Methods

A 10m-long, 0.63m-wide, tiltable, flume with a variable speed pump (recirculating water and sediment) was used for these experiments. Each series of experiments (a series was comprised of three runs under identical conditions) started with a plane bed (initial bed thickness = 250mm, D_{50} = 0.40mm, slope = 0.007) at constant flow depth and speed. Discharge varied between the three conditions of flow (Table 1).The flume ran unobstructed for up to two hours to allow the bed to stabilize (characterized by migrating ripples), flow was then halted briefly to allow introduction of the obstruction, and then slowly increased to the speed required for each representative run. A single log (0.582m x 0.063m), with bark and branches left intact was placed 10mm above the bed and used as the obstruction. Obstructed flow was allowed to continue until a stable scour pool formed (average length of time = 2.5 hours). Once the bed stabilized (assumed through observation of a stable scour pool and migrating ripples along the unobstructed bed), flow velocities were sampled using a Marsh-McBirney Model 2000 electromagnetic current meter, which is a unidirectional meter that operates at a frequency of 1 Hz. The probe head of this current meter is elongate in shape, with dimensions of 250mm in length and 200mm in thickness. Sensors at the head of the probe (three leads spaced over 150mm) record disturbance to an electromagnetic field, which is converted into a velocity. Individual experiments lasted for a total of about six hours. Each series was repeated three times under the same stage conditions. Table 1 summarizes characteristics of the flume runs. A number of parameters were held constant between series (obstruction location, length, diameter, protrusion length, protrusion angle and Froude number), while others were varied between series to make the relevant inquiries (depth and flow velocity).

Fluid velocities were recorded at five-second intervals for a period of 150 seconds, a total of 30 samples for each location. Each recording represented an average velocity over five seconds, to reduce scatter. This was done to factor out some of the turbulence in the influence zone area. Analysis of RMS values for turbulence collected prior to the experiments showed no difference whether 30 samples or 100 samples were collected, so the smaller number was chosen for the experiments.

Measurements were made at 20mm intervals, starting near the surface (within 10mm) and increasing with depth until the probe was 10mm above the bed, the distance that ensured the bed was left undisturbed. Velocities were sampled along five panels (equal width spacing) across the flume and in 20mm transects starting immediately behind the obstruction and moving downflume (Figure 1). An interpolation algorithm (the multiquadric technique of Hardy, 1971) was used to estimate the intermediate values between the known points on the fluid velocity grids for each panel. This allowed for the delineation of zone boundaries at a higher resolution. Output from the interpolation runs were then graphed for those sections immediately behind the obstruction in the downflume direction.

Table 1 Parameters for Different Flume Runs

	Stage Condition		
Parameter	**1**	**2**	**3**
% Obstructed[a]	50	70	97
Obstruction Location (m)[b]	4.0	4.0	4.0
Length (m)[c]	0.582	0.582	0.582
Diameter (m)[d]	0.063	0.063	0.063
Protrusion Length P_L (m)[e]	0.582	0.582	0.582
Protrusion Angle (deg)	90	90	90
Flow Depth (m)	0.126	0.09	0.065
Mean Fluid Speed	0.278	0.234	0.199
Discharge (m^3 sec^{-1})	0.022	0.013	0.008
Water Temperature (°C)	14	12	16
Froude Number	0.25	0.25	0.25

[a] percent of the total flow depth obstructed by the diameter of the wood (diameter|depth ratio).

[b] distance downflume from the tank

[c,d] characteristics of the wood debris used

[e] distance that the wood protrudes across the flume

The *x-y* sets of data (representing channel location for each velocity measurement: the grid crossings in Figure 1) were averaged across each series and then processed through the multiquadric interpolation algorithm (see Saunderson, 1992) in order to generate a family of two-dimensional surfaces of velocities to test between-sample differences. This allowed creation of a tightly-spaced grid of mathematically-derived *z* values in the *x* and *y* direction, resulting in a digital surface which accurately represented the actual sampled surface.

Bed profiles were measured from a datum above the flume using a point-gauge (error +/- 2.5mm) according to a pre-determined sampling grid. These profiles were sampled after the flume was allowed to drain and the bed was dried, in order to increase accuracy. Measurements from the datum to the bed surface were carefully taken every 20mm cross-flume and every 50mm downflume, from a starting location well upflume of the scour pool to a point well downflume. This resulted in a surface profile which was used in conjunction with the interpolation algorithm to generate detailed topographic surfaces. Here, the *x-y* values represent channel location in the downflume (*x*) and crossflume (*y*) direction, with *z*-values representing depth. Pre-obstruction bed profiles were also recorded to determine the mean depth-to-bed, which was used in determining the size and shape of the scour pool.

Results

Bed Profiles

Figure 2 shows the average stable bed topography after obstruction for stage conditions 1 through 3. Each plot shows the entire bed topography starting ~0.20m upstream of the obstruction location and extending ~0.55m downstream (obstruction located at 22.00 on the *x* axis). Filled contours indicate that the post-obstruction bed was below the pre-obstructed elevation, that is, the bed was scoured as a result of flow through the obstruction area.

The scour pool created under stage condition 1 (low stage: 50 percent obstructed: Figure 2) has the smallest areal extent (53.1 percent of the sampled area) and the greatest maximum depth of scour (0.059m : see Table 2; although there is little difference in maximum depth between the different stage conditions). The upflume boundary of the scour pool is less regular than under the other stage conditions, an indication that the flow is not as constricted as it passes under the obstruction. Under stage condition 2 (medium stage: 70 percent obstructed: Figure 2) the resulting scour pool is larger than under other conditions, and there is a well-defined upflume boundary. General scour pool shape is consistent with both condition 1 and 3 (high stage: 97 percent obstructed: Figure 2). Under stage condition 3 the scour pool is somewhat smaller overall, and again shows a distinct upflume boundary. Scour pool areas range from 53.1 to 63.4 percent of the measured area, and maximum scour depth ranges from 0.057 to 0.059m (essentially an equal depth of scour under all stage conditions) below mean bed elevation (Table 2). The ratio of scour depth to obstruction diameter under all stage conditions is approximately 1:1.

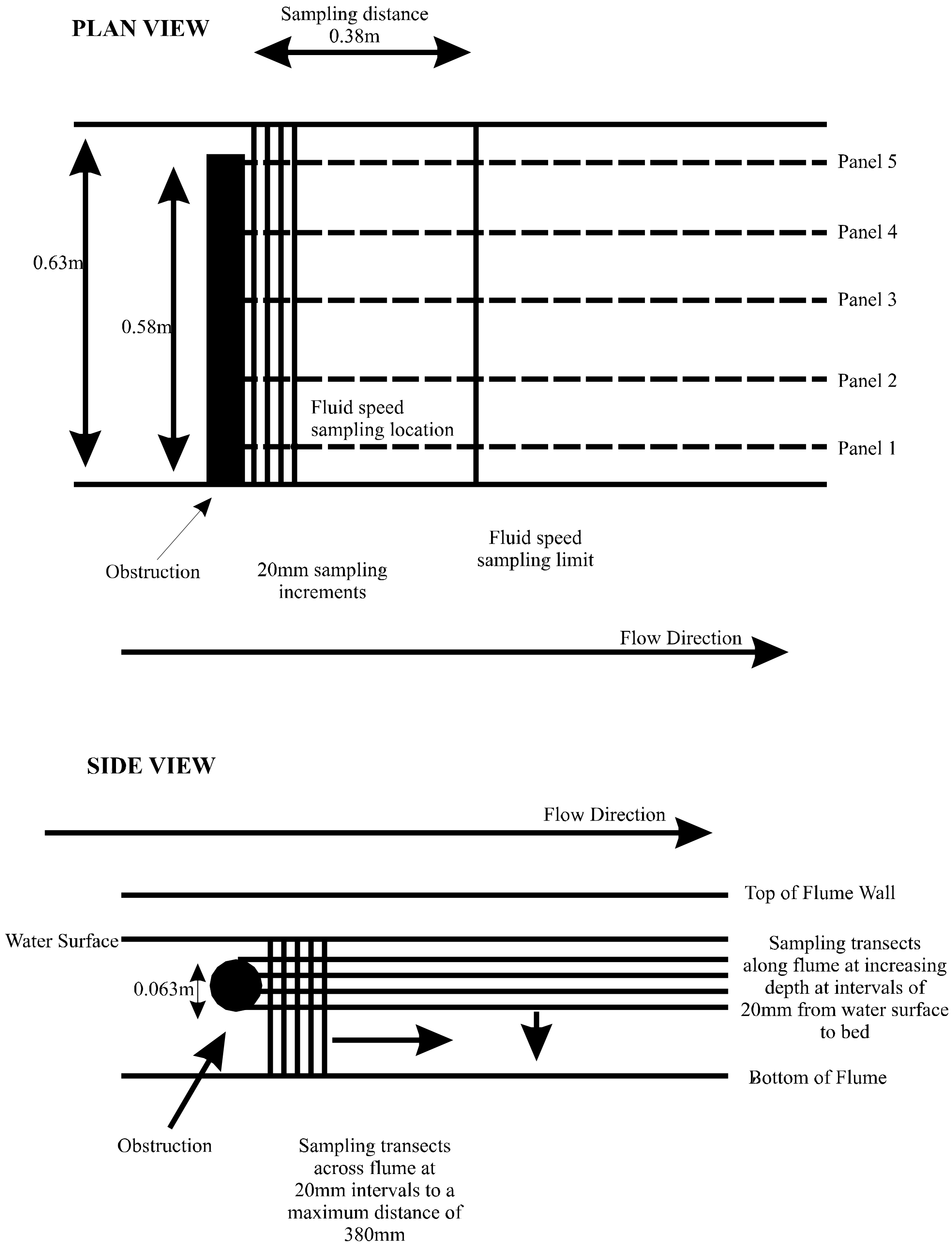

Figure 1: Schematic showing the experimental set-up and location of sampling transects. Top: Plan view showing position of the obstruction and the location of fluid speed sampling Panels 1-5. Bottom: Side view depicting sampling grid through the vertical column.

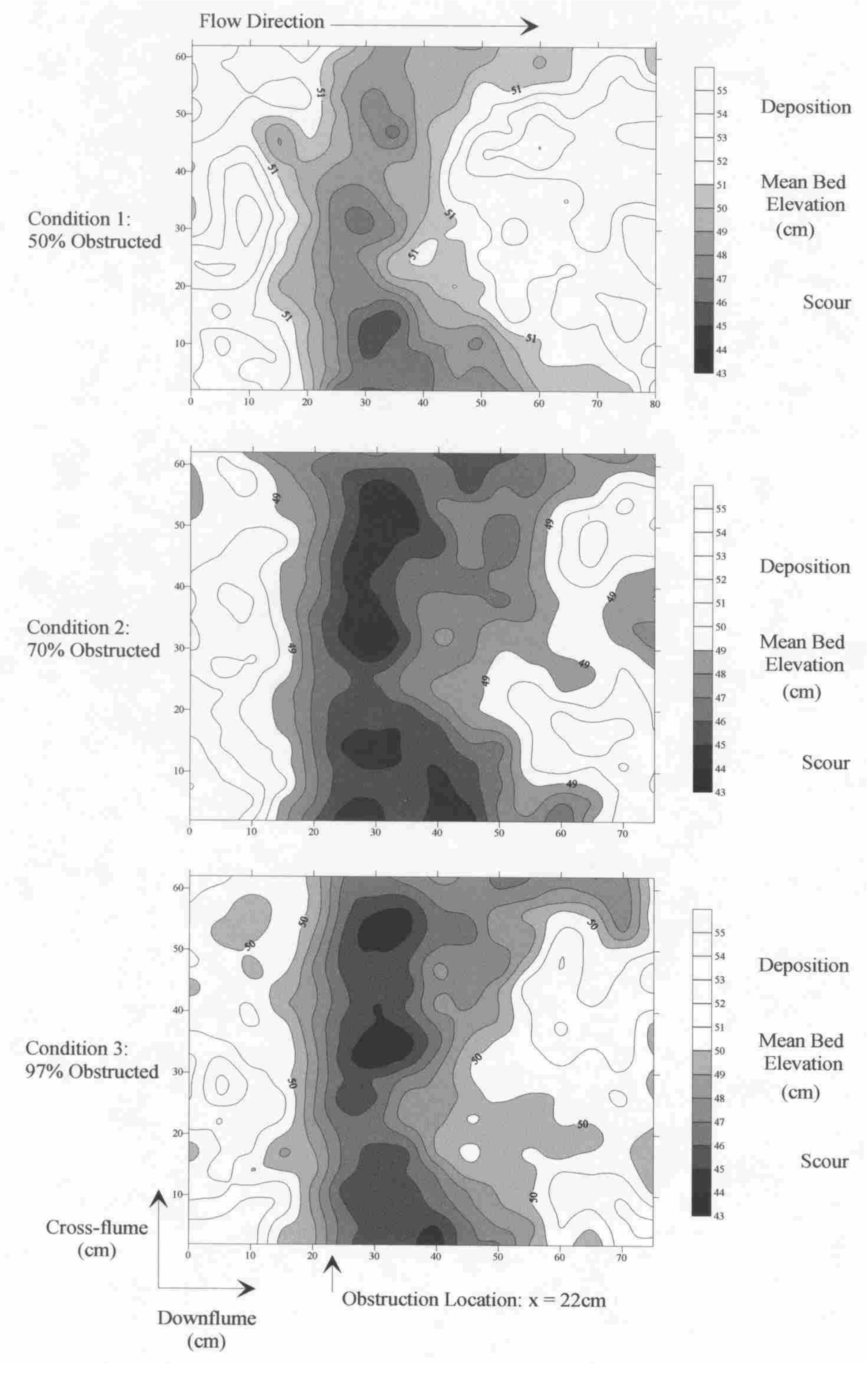

Figure 2: Bed topography showing scour pool morphology for each of the sets of stage conditions. Obstruction was centered along x=22.00 axis. Contour interval is in centimeters referenced to a fixed datum. Mean pre-obstructed bed elevation is indicated by the interval at which shading of the contours ends (eg. 51cm for stage condition 1: top). Those contours not shaded represent areas of deposition, and those contours which are shaded represent areas scoured. Scour pool area was determined and is presented in Table 2.

Table 2 Results of Bed Scour for the Three Runs[a]

	Stage Condition		
Parameter	**1**	**2**	**3**
% Obstructed	50	70	97
Flow Depth (m)	0.126	0.09	0.065
Sampled Area (cm^2)	4500	4500	4500
Scour Pool Area (cm^2)	2389	2853	2756
% of Total Area	53.1	63.4	61.2
Max. Depth of Scour (m)	0.059	0.057	0.057
Ds/H ratio[b]	0.47	0.64	0.88
Ds/Obst. Diameter	0.94	0.91	0.91

[a] results for each condition represent values averaged over the series of experiments; variation between series within each run were less than 1.0 percent of the mean value.

[b] ratio between maximum scour depth and average flow depth (after Cherry and Beschta, 1989).

Under all stage conditions the downflume side of the scour pool is marked by an inconsistent boundary, which may be the result of the influence of roughness on the obstruction. Other experiments (not reported here) with PVC pipe for obstructions resulted in much smoother upstream and downstream scour pool boundaries. Visual analysis of ripple crests and troughs in this area indicate they may have been formed by differential rates of downwelling, resulting from flow cresting the rough boundary of the obstruction. In all cases the shape of the overall scoured area seems relatively consistent among runs.

Fluid Velocity Profiles

Figure 3 shows fluid velocity contours moving away from the obstruction in the down flume direction under stage condition number 1. There are very distinct areas of slowed flow immediately behind the obstruction, and in some instances, for example panels 1 through 3, these areas exhibit reverse circulation. For the most part, the patterns of obstruction in the flow are relatively consistent across the flume. The one exception, however, occurs at panel 4, where the upturned pattern in the contours indicates a heavy influence of underpassing flow moving along the bed. The relatively high speeds at the surface of panels 1 through 3 indicate that flow is less inhibited from flowing over the obstruction, therefore the obstruction is having less influence on flow.

The patterns in stage condition 2 (Figure 4) are somewhat similar in that there is a definite area of slowed flow immediately behind the obstruction, but the primary difference between conditions 1 and 2 are in the patterns of flow near the surface. Under stage condition 2, the surface flow is more affected by the obstruction, thereby creating a disturbance to flow through the entire water column, which is an expected result considering the ratio between flow depth and log diameter (Table 2).

When flow is almost entirely obstructed (stage condition 3: Figure 5) the pattern of flows is significantly altered. Zones of reverse circulation extend farther downflume and at times extend to the surface (panel 3). Patterns indicate that flow accelerating along the bed has a direct impact on the influence zone.

Figures 3 through 5 clearly show that there are patterns of flow disturbance behind obstructions in streams, and that these disturbances extend for relatively consistent distances under repeated experiments. Analysis of the variables and relationships guiding the persistence of turbulent wakes is well documented in the fluid dynamics literature (see Bays-Muchmore, 1993; Giralt and Ferre, 1993 and others). However, for applications with regard to management of log obstructions in streams, a more simplified approach is warranted. It is therefore important to determine the extent of these disturbances immediately behind the obstruction as this information may have management implications. Detailed sampling of flow velocities was undertaken in the area directly behind the obstruction to determine the distance at which flows appeared to return to mean velocities. Table 3 gives the downflume distance where velocities return to mean pre-obstructed values for each of the panels within each of the series of experiments. This data permits mapping of the zone in a manner that has not previously been used, and this ‘map’ can then be used to visualize the effect of a non-uniform boundary on flow.

Figures 6, 7 and 8 show the zone boundaries for the three runs in this study. Under stage condition 1 (50 percent obstructed, Figure 6) there is evidence of slowing flow at the surface across all panels, with evidence (see Figure 3) of accelerated flow

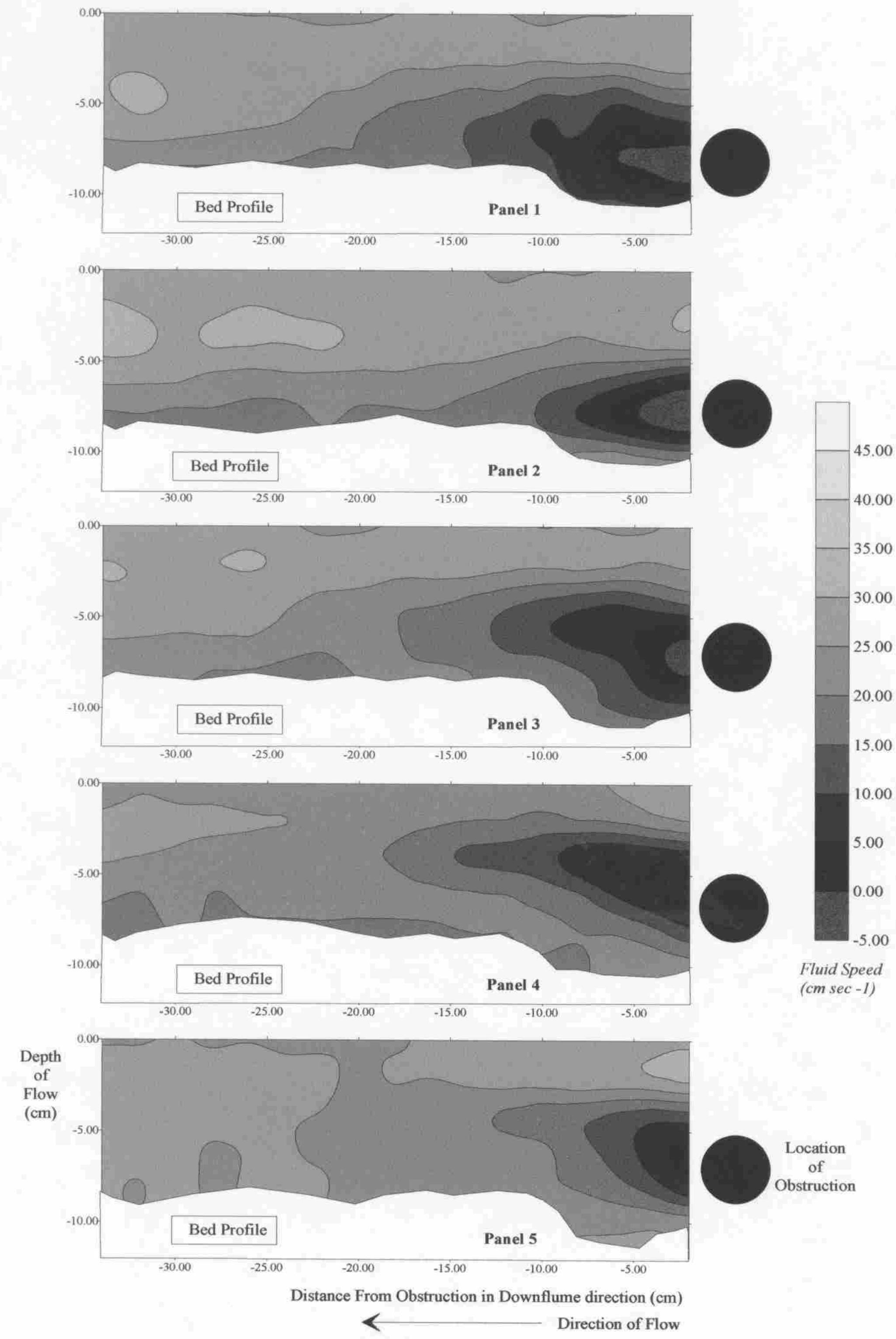

Figure 3: Diagram of fluid speed patterns in the downflume direction for stage condition 1 (50 percent obstructed). The panels represent transects downflume as indicated in Figure 1. Flow is from right to left.

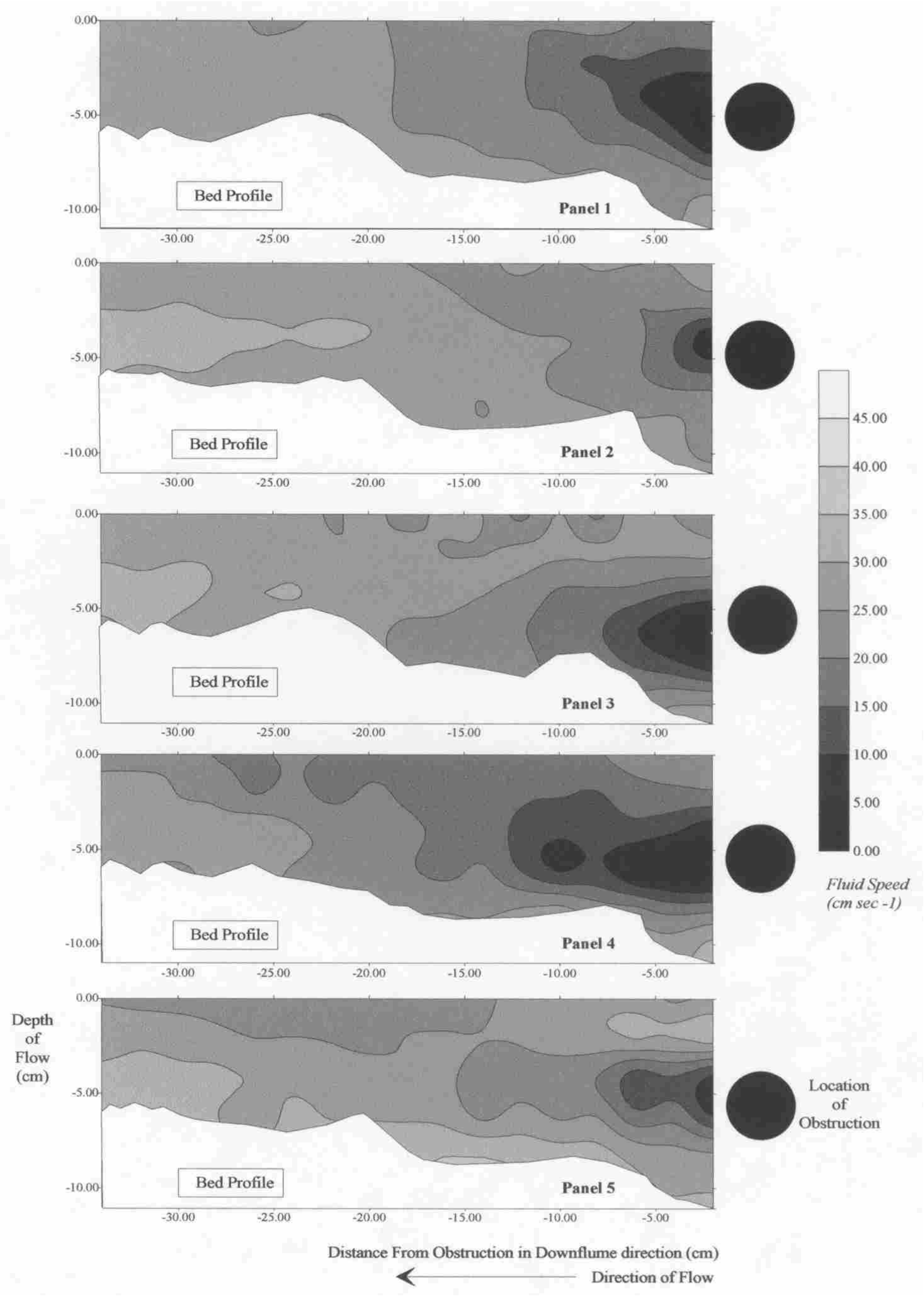

Figure 4: Diagram of fluid speed patterns in the downflume direction for stage condition 2 (70 percent obstructed). The panels represent transects downflume as indicated in Figure 1. Flow is from right to left.

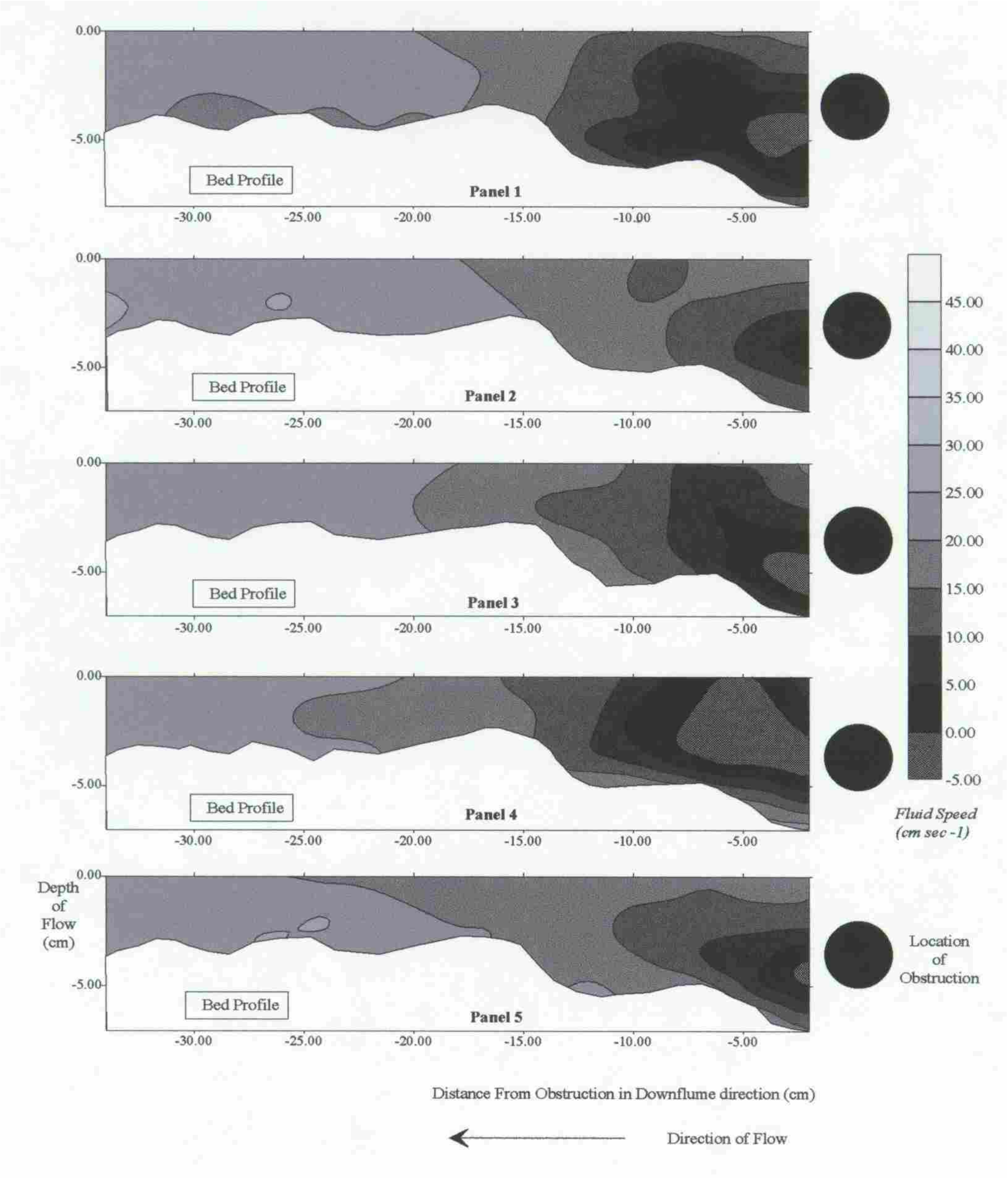

Figure 5: Diagram of fluid speed patterns in the downflume direction for stage condition 3 (97 percent obstructed). The panels represent transects downflume as indicated in Figure 1. Flow is from right to left.

Table 3 Maximum Downflume Extent of Altered Speeds for Runs 1-3, Panels 1-5 and Depths 0-60mm[a]

Stage Condition	Depth (mm)	Panel					Mean
		1	2	3	4	5	
Stage Condition 1	0	15.33	11.52	15.33	11.90	8.09	12.43
50% Obstructed	10	17.23	13.42	13.80	9.61	7.33	12.27
	20	18.38	14.95	12.66	6.95	17.61	14.10
	30	16.85	13.42	11.14	3.52	19.14	12.81
	40	14.57	5.04	11.52	0.00	0.00	6.23
	50	11.52	0.00	8.85	0.00	0.00	4.07
	60	0.00	0.00	0.00	0.00	0.00	0.00
Stage Condition 2	0	16.09	14.95	10.76	18.38	24.46	16.93
70% Obstructed	10	17.24	12.29	13.04	17.24	19.90	15.94
	20	15.71	12.29	14.95	17.61	18.00	15.71
	30	16.47	11.90	18.38	18.00	15.71	16.09
	40	8.09	18.00	18.00	12.29	8.09	12.89
	50	5.04	8.09	17.61	5.81	5.42	8.39
	60	0.0	4.29	18.00	0.00	0.00	4.46
Stage Condition 3	0	12.67	14.57	15.33	15.71	16.85	15.03
97% Obstructed	10	13.04	13.42	16.47	14.57	14.95	14.49
	20	13.42	12.66	13.80	15.33	14.95	14.03
	30	14.19	12.28	12.66	14.57	14.57	13.65
	40	14.57	17.61	12.28	7.71	7.71	11.98
	50	12.28	23.71	9.23	3.52	6.19	10.99
	60	8.85	0.00	6.57	0.00	3.90	3.86

[a] The values in each cell are in centimetres downflume from the obstruction. Results for each condition represent values averaged over the series of experiments, variation between series within each run were less than 0.7 percent of the mean value.

underpassing the obstruction at panels 2, 4 and 5. If flow were influenced equally across the cross-section of the obstruction, then the resulting wake diagram as seen in Figure 6 would approximate that of the classic horseshoe vortex, which is common around cylindrical bridge piers (Gill, 1972; Melville, 1975; Breusers et al., 1977; Baker, 1980; Kothyari et al., 1992). At 30mm depth in Figure 6, it appears that the flow through the free end is extending the zone, rather than suppressing it, and the absence of any disturbed zone at the underside indicates the effect of the bed on shooting flow (as previously described).

Under stage condition 2 (70 percent obstructed, Figure 7: side view) the influence of the bed is evident for panels 1, 4 and 5, where velocities at the underside (60mm from the surface of the obstruction) are never slower than the mean value for the transect: that is, there is no slowing of fluid as a direct result of the obstruction. Only in panels 2 and 3 is the bed effect negated. The plan view for condition 2 (Figure 7) shows that the disturbed zone varies considerably with depth, from broad at the surface to almost non-existent at the underside.

Under stage condition 3 (97 percent obstructed, Figure 8) shape goes from one extreme to the other. In panel 1 the boundary is shaped as would be expected given the nature of the two surfaces that bound it (deformable air and more resistant sediment). On the other hand, panel 5 shows that the boundary is highly irregular in shape.

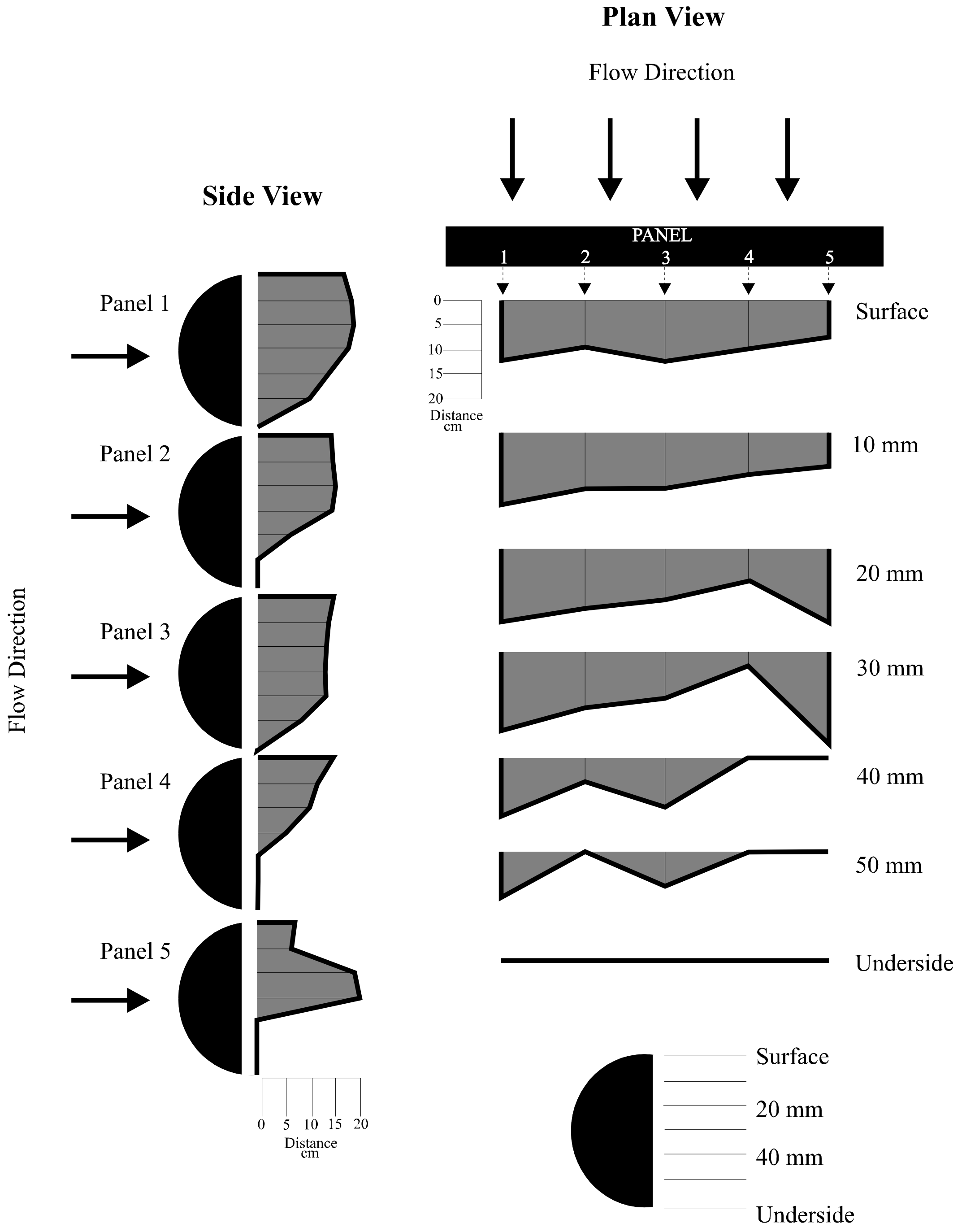

Figure 6: Diagram showing the downflume extent of the disturbed zones under stage condition 1 (50 percent obstructed). The zone is shown in cross-section at the panels (side view) and in the downflume direction through the water column at each transect (plan view). The obstruction shape is simplified in both plan and cross-section view. The lightly shaded zones are where speeds are slowed as a result of the obstruction, the farther from the obstruction this zone extends the more effect the obstruction has on speeds.

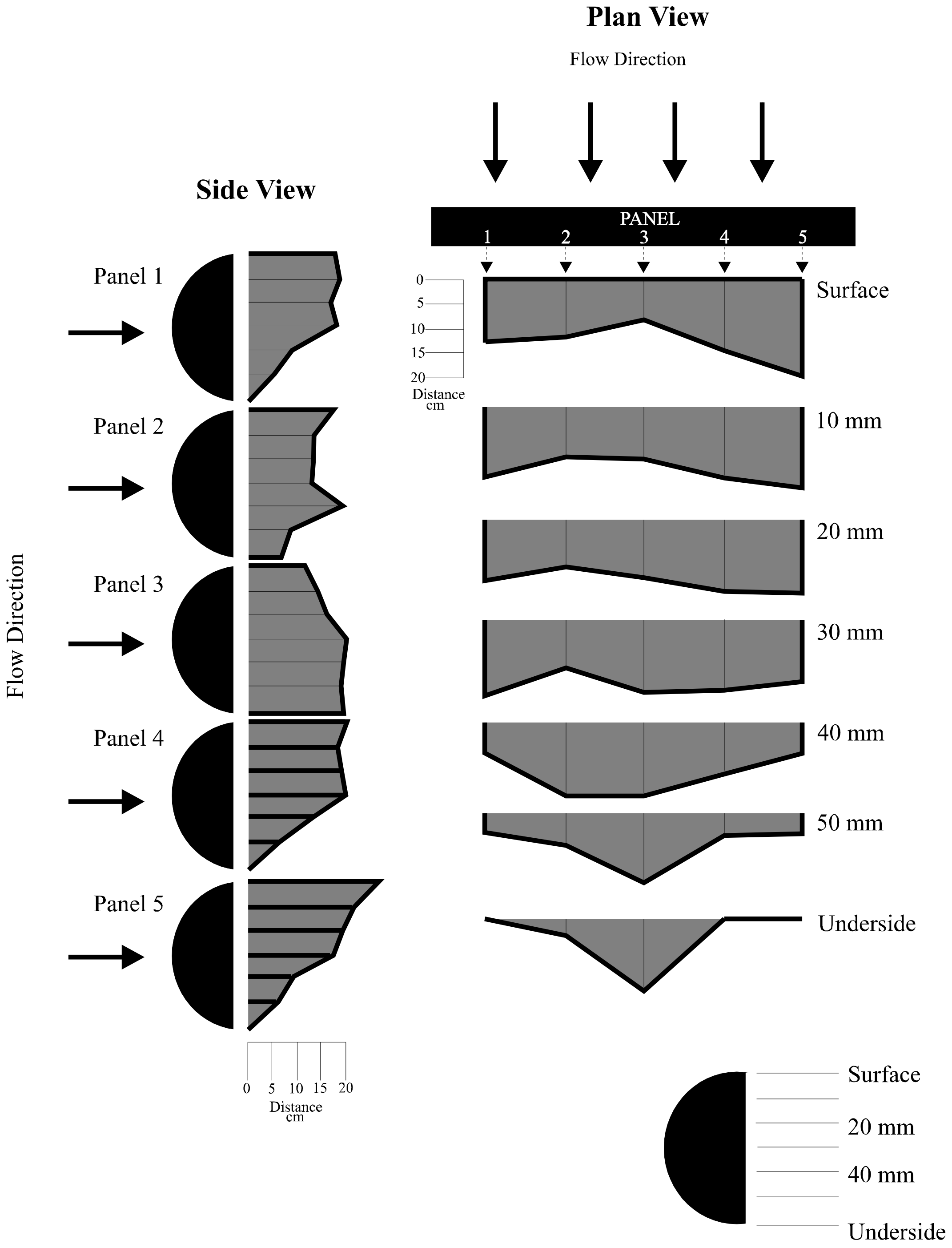

Figure 7: Diagram showing the downflume extent of the disturbed zones under stage condition 2 (70 percent obstructed). The zone is shown in cross-section at the panels (side view) and in the downflume direction through the water column at each transect (plan view). The obstruction shape is simplified in both plan and cross-section view. The lightly shaded zones are where speeds are slowed as a result of the obstruction, the farther from the obstruction this zone extends the more effect the obstruction has on speeds.

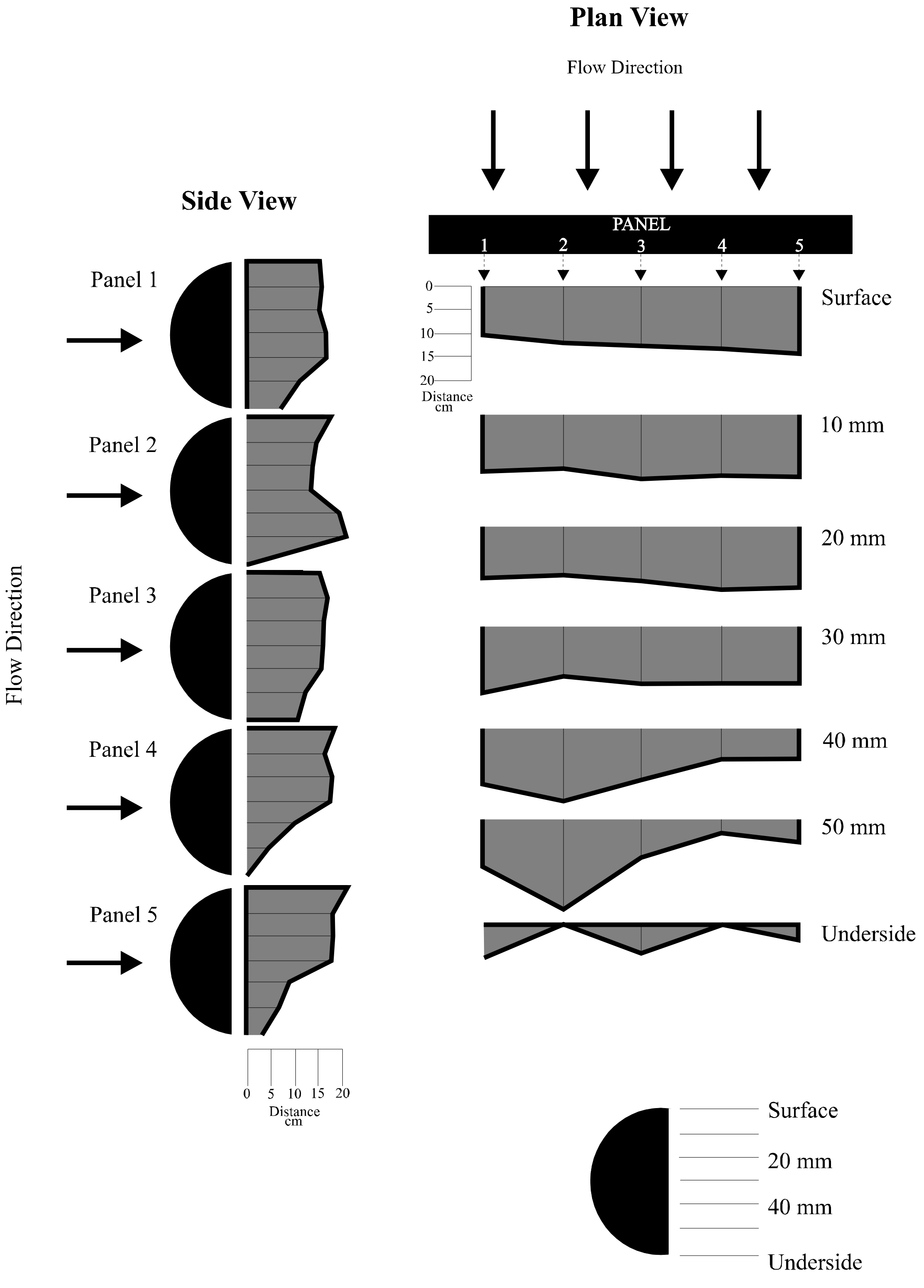

Figure 8: Diagram showing the downflume extent of the disturbed zones under stage condition 3 (97 percent obstructed). The zone is shown in cross-section at the panels (side view) and in the downflume direction through the water column at each transect (plan view). The obstruction shape is simplified in both plan and cross-section view. The lightly shaded zones are where speeds are slowed as a result of the obstruction, the farther from the obstruction this zone extends the more effect the obstruction has on speeds.

Discussion

As the percent obstructed flow decreases there is a corresponding change in mean flow velocity upstream of the obstruction, which has the effect of each canceling the other out. This highlights the stability of the size of the influence zone. Results indicate that as stage changes, the extent of the influence zone is only moderately altered. This is an important result for management of woody debris in streams as aquatic habitat. This also implies that assessment of the influence zone of woody debris may be conducted at any stage, though it is preferable to determine these influences at low stage as that is generally the prevailing condition in streams for the majority of time.

Bed Morphology

Bed scour patterns for the three conditions were relatively consistent in shape regardless of the obstruction ratio. The only difference was seen in the size of the scour pool (Table 2), which was expected. There was a tendency for the scour pattern to extend in the downflow direction across the entire obstruction with tails at the open (unsecured) end and also at the secured end. The tail at the secured end is attributed to the effects of the clamping mechanism holding the log in place, whereas the tail at the open end is attributed to pinched flow accelerating through the site and deflecting off the wall of the flume. These results differ from those found by Owusu (1984), who found with perpendicular obstructions that scour was localized at the open end and extended downstream. Although the downflow component is consistent with these results, the scour pool was not localized at the open end.

The relationship between maximum depth of scour and average flow depth for cylinders lying flat on the bed has been investigated by Cherry and Beschta (1989), who arrived at a dimensionless value of 2.00 for Ds/H (see Table 2 for definition of the term). The range of values for Ds/H in this study are much below that of Cherry and Beschta (Table 2), but it appears that the value of 2.00 actually represents H/Ds (5.36/2.68, see Table 1, p. 1035) in their study. If the value for Ds/H were calculated using their values, the ratio would be 0.5, which closely approximates that for condition 1 in this study.

Flow Patterns

Fluid velocity patterns through the obstruction site are influenced by the nature of the obstruction and the percentage of flow that is obstructed. The distance that flow is affected away from the obstruction varies little under each condition (2.45 L_D to 3.09 L_D, an actual channel distance of only 41mm: Table 4). There appears to be a lack of symmetry in the influence zone across the series of experiments, which may be a function of the rough boundary. Clearly the rapid accelerating flow from the underside of the obstruction plays a major role in the size and shape of the influence zone. Where flow accelerates quickly, the zone is small along the 60mm plane, and where flow is slower through the underside, the zone is larger. There appears to be little difference in the shape of the influence zones between conditions 2 and 3; in side view (Figures 7, 8) they appear very similar. The patterns shown in condition 1 (Figure 6) are different enough that they cannot be classed with the others. From the data in Table 3, it is clear that there is no relationship between percent obstructed and the size of the zone, except that generally as percent obstructed increases the patterns become more fragmented, especially at the underside. The zone of disturbance appears to decrease in areal extent at 97 percent obstructed, which is an expected result (as flow depth decreases relative to the diameter of the obstruction the influence of that obstruction decreases), and there is little difference between the 50 percent and 70 percent obstructed zones.

This work shows that for this particular orientation of obstruction and these obstruction ratios, there is a minimum distance that flow is disturbed, as outlined by the extent of the influence zone in Figures 6-8. Beyond that point there is little information on flow patterns. Since fallen trees enter streams at orientations between 0 and 180 degrees (Cherry and Beschta, 1989: Figure 3, p. 1035), this work is only a starting point in studying flow patterns and scour around fallen trees in streams.

Table 4 Spatial Dimensions of Influence Zones

Stage Condition	Flume L_D[a]	Range
1: 50% obstructed	2.52	2.49-2.57
2: 70% obstructed	3.06	3.00-3.09
3: 97% obstructed	2.48	2.45-2.49

[a] dimensionless relationship between downflume length of influence as a function of obstruction diameter

Fluid approaching from upflume has three possible routes once it encounters the obstruction: it can either go over, under or be deflected around to the side (Beebe, 1997). In well-armoured gravel or bedrock channels the passing under option is limited by the resistance of the bed, and when the shearing stresses created by pinched, accelerated flow are below the shearing strength of the bed, little scour results. In these instances the bulk of flow either passes over or goes around the obstruction. With passing over there is the potential for scour by plunging flow, and the resulting scour pool would be highly concentrated and deep. In a looser, cohesionless sand bed the passing undershear stresses may easily surpass the entrainment threshold of bed material, and scour occurs immediately upon obstruction. At the point where the time-averaged stress|strength ratio = 1, the scour pool stabilizes and remains so until that ratio is disturbed. Under these bed conditions (where a stable scour pool is formed) flow can pass over or under the obstruction with relative ease, and in doing so simulates flow around cylindrical piers (with the exception that orientations are shifted by 90 degrees). The tendency then is to assume that the fluid will behave as it would around a cylindrical pier, but in reality that is not the case.

Ecological Implications

This research has potential implications for aquatic habitat. The ability to determine the effect of woody debris in streams enables stream managers to better assess their streams. It is clearly understood that woody debris provides a number of benefits for aquatic organisms (shade, shelter, food), but too much debris may be detrimental to the ability of the stream to route fluid and sediment through the system (Beebe, 1997). Laboratory studies, such as the one carried out here, give preliminary dimensions to obstructed flow which may be compared to stream situations. These experiments have shown that a cross-stream obstruction creates a scour pool that is relatively consistent over a range of flow depths (an indication of stability), and that fluid is slowed behind such obstructions for a distance downstream which may be expressed in terms of the number of obstruction diameters (Table 4). This is important because it creates a slackwater area, of determinable distance, available for use by aquatic organisms in the earlier life stages (for example young-of-the-year salmonids). But, the implications for aquatic systems are more far-reaching than this.

In general terms, channels that are hydraulically rough (by having natural impediments to flow) are most likely to be characterized by the trapping and retention of organic matter, material that is a major food source for aquatic organisms (Sedell and Beschta, 1991). This, coupled with increased habitat diversity that results from fallen trees in streams, provides a new and productive habitat for fish which may not have existed previously (Bilby and Likens, 1980). A complex habitat provides rearing space for small fish (including a diversity of substrates for food organisms) and hiding places from which large fish can prey on smaller species (Sedell and Beschta, 1991). The introduction of woody debris into channels has also resulted in greater habitat diversity for macroinvertebrates (Marzolf, 1978), resulting in increased populations and species diversity. These species are a potential food source for fish.

Conclusions

These experiments show that cross-stream positioned woody debris has a direct influence on flow and bed characteristics which are relatively consistent for similar stage conditions. It can be concluded therefore that positioning of woody debris in streams, or allowing existing woody debris to remain in place, may have positive implications for stream ecology. Specifically, a number of direct conclusions may be drawn from these experiments: 1) scour pool shape was relatively similar over the three sets of stage conditions. Of note is the fact that the shape of the scour pool where maximum depths were recorded paralleled the position of the log; 2) the location of the maximum point of scour occurred near the fixed end of the obstruction rather than the free end, indicating that scour may be greater where the obstruction is more stable; 3) Ds/H ratios indicate that, for these configurations, the maximum depth of scour will range between 47 and 88 percent of the pre-obstructed flow depth under sand bed conditions; 4) the downflume extent of the influence zone varies considerably within conditions (between depths) and between conditions. There was no obvious relationship between the size of these zones and the percent of flow obstructed; 5) flow underpassing the obstruction appears to exert the greatest control on the shape of the influence zone; 6) more research is needed on varying orientations and dip (see Cherry and Beschta, 1989) using pieces of woody debris in place of cylinders to determine more fully if a predictable relationship can be found.

Results show that there are distinct zones behind obstructions in flow whereby vortex generation and flow separation occurs. Technological limitations prevented further investigations into the spatial variability of these phenomenon at this scale. It is important that these factors be investigated in detail at the field scale due to their obvious relevance to aquatic habitat. Additionally, it is important to investigate the role that fluctuations in discharge plays in bed morphological changes and alterations to fluid patterns (combining to represent influence zones).

Acknowledgements

The author would like to acknowledge Dr. Rick Cheel of Brock University, who provided time in the flume for this study; Mr. Jim Dozois, who assisted with data collection; and Dr. Houston Saunderson and three anonymous reviewers whose comments have made this a much better manuscript.

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