CHAPTER 7

Investigation of the Hydraulic Diversity Created by Woody Debris in Agricultural Waterways

7.1 Introduction to Hydraulic Diversity Study (Goal 6)

The clearing and grading permit of King County has required large woody debris (LWD) be installed in King County agricultural drainage watercourses as mitigation for loss in in-channel cover and hydraulic diversity for native fauna as a result of dredging activities associated with routine agricultural watercourse maintenance (King County DDES, 2001). Goal 5 of this study addresses the preferential use of LWD by salmonid fishes (see Chapter 6) while this chapter addresses the effect of LWD on hydraulic diversity in two King County drainage watercourses since the effectiveness of LWD in providing hydraulic diversity in agricultural waterways has not been thoroughly investigated. This was accomplished through a combination of field observations and numerical modeling of the effects of LWD on the flow fields. High resolution turbulence measurements were made in the wake of installed LWD in two agricultural watercourses using an Acoustic Doppler Velocimeter. Limited hydraulic diversity was observed in the wake of the LWD. The observed region of influence depended on the investigated parameter and measured obstructions. However, the region of influence did not extend beyond 45 cm downstream from the installed LWD. Combinations of one-dimensional and three-dimensional hydrodynamic simulations were used to investigate the influence of LWD at a larger spatial scale and at higher discharges than the measured conditions. The numerical simulations indicated the presence of a limited velocity shelter less than 20 cm downstream of the LWD. Other flow metrics, including turbulent kinetic energy and vorticity, were also slightly influenced by the installed LWD. Bed surveys showed no scouring or sediment deposition from the installed LWD. Further, the incremental change in hydraulic properties was too small to cause noticeable changes in large scale flow characteristics (hydraulic roughness, mean flow velocity, and water surface elevation) and other related processes such as sediment transport. It was concluded that the installation of LWD in King County drainage watercourses does not effectively increase hydraulic diversity.

Although there is little published information on salmonid use of small watercourses associated with agricultural areas in King County's riverine floodplains and on the Enumclaw Plateau, waterways within these areas are known to be used by various salmonid species. As presented in Chapter 1, the overall objective of this entire study was to determine effective and economical means to maintain agricultural watercourses while protecting fish habitat as described in the Sampling and Analysis Plan developed by Washington State University and the University of Washington (2006) and approved by KCDNRP. In support of that mission, the goal of this specific chapter was to determine whether woody debris creates hydraulic diversity in agricultural lands. With the assistance of KCDNRP staff, the following research hypothesis was posed in relation to this study component:

Hydraulic parameters (e.g., pool depth, velocity, and turbulence) do not change due to the installation of large woody debris in configurations typically installed by KCDNRP staff.

7.2 Study Background

7.2.1 Problem Description

Agricultural drainage watercourses in King County support salmon production despite their highly modified condition. In addition, routine maintenance of these drainage ditches is important for sustaining agricultural practices. For this reason, engineering and dredging projects in King County are required to mitigate for losses of salmon habitat, even when motivated by more traditional concerns, such as agricultural drainage. This presents several challenges, as most habitat enhancement methods have been developed from the study of systems that are drastically different than the project sites.

One common technique for enhancing stream function is installed large woody debris (LWD). The functions and dynamics of LWD and debris jams in streams have been the subject of many studies (Harmon et al. 1986, Shield and Smith 1992, Abbe and Montgomery 1996, Lemly and Hilderbrand 2000). LWD provides several hydraulic functions important to salmon including forming pools (Bisson et al. 1987, Robinson and Beschta 1990, Lisle 1995), storing materials (Bilby and Likens 1980, Smith et al. 1993), and dissipating energy (Heede 1976, Gippel et al. 1996, Dudley et al. 1998). These functions often benefit fish by providing refuge and cover (Hicks et al. 1991) and increasing nutrient and organic matter retention (Raikow et al. 1995). In the past (through 2005), King County's clearing and grading permit sometimes required LWD be installed in agricultural drainage watercourses as mitigation for loss in in-channel cover and hydraulic diversity for native fauna as a result of dredging activities associated with routine agricultural watercourse maintenance (King County DDES, 2001).

Design considerations for installed LWD include spacing, size, and anchoring methods for the individual pieces of wood. Design methods are based largely on studies conducted in natural, undisturbed mountain streams (e.g. Nakamura and Swanson 1994, Montgomery et al. 1995). Great caution must be used when extending these design principles to drainage watercourses, as the processes forming and maintaining the channels (hydrodynamics and morphodynamics) are drastically different in these systems. The design procedure must account for local conditions including gradient, flood flow velocities, sediment transport characteristics, and channel morphology (Hilderbrand et al. 1997). Even in these settings, however, there have been significant differences in design complexity. As a result, the cost of LWD projects can vary by an order of magnitude ($12.90 vs. $164.50 per meter of channel length) due to differences in design complexity alone (Cederholm et al. 1997).

7.2.2 Large Woody Debris

An increase in anadromous and non-anadromous fishes after addition of LWD have been demonstrated through many studies and are often cited widely as justification for enhancement

projects (e.g. Bisson et al. 1987, Beechie and Sibley 1997). However, several published and unpublished studies have demonstrated no impact or even negative impacts of LWD on fish populations (e.g. Hall and Baker 1982). The effectiveness of LWD in providing the desired effects depends on many factors including velocity distributions and sediment transport characteristics of the stream, habitat connectivity, and watershed condition (Gippel 1995). For example, LWD will provide greater hydraulic diversity in streams with high velocity and bedload than lower gradient floodplain tributaries. Further, in heavily degraded watersheds the influence of basin disturbance on channel processes will often overwhelm any potential benefits of LWD, particularly when coupled with bank stabilization or armoring (Larson et al. 2001).

7.2.3 Hydraulic Diversity

Several studies have indicated that the availability of low-velocity habitat is an important factor in production of juvenile salmon (Pollock et al. 2004). Hydraulic diversity influences aquatic habitat in several ways including organism dispersal, habitat use, resource acquisition, and competitor/prey relationships (Hart and Finelli 1999). The installation of LWD can contribute to forming this habitat by providing a velocity refuge and creating pools in the LWD wake (Shields and Gippel 1995, Fischenich and Morrow 2000). In spite of the numerous studies, criteria dictating where and when LWD is appropriate are not widely available. Manga and Kirchner (2000) used simple theoretical models to estimate the partitioning of flow shear stress between woody debris and streambeds to investigate how changes in LWD would affect streams. However, as pointed out by Gippel et al. (1996), guidelines for LWD management still rely on a degree of intuitive judgment. As a result, their work proposed an eight step procedure for modeling the increase in water surface elevation and hydraulic efficiency cause by additional debris. Based on this modeling methodology, they concluded that for most lowland river situations, debris must block more than 10% of the cross-sectional flow areas to produce an afflux large enough to be detectable (Gippel et al. 1996). Interestingly, Dudley et al. (1998) reported an increase in Manning's roughness of 39 percent because of LWD although the percent channel blockage was not reported.

Hydraulic diversity is often described as the spatial distribution of velocity magnitude or three-dimensional velocity components. However, flow heterogeneity can also be described as the distribution of more advanced flow metrics, such as turbulent kinetic energy and eddy size, or through spatial gradients such as strain rate and vorticity (Crowder and Diplas 2002). The flow metrics used in this report are described in detail by Nikora and Goring (2000) and Crowder and Diplas (2002).

Hydraulic diversity can be measured and described using several methods. The flow field is most often measured with Price or Pygmy current meters. However, these instruments are not capable of measuring turbulent velocity fluctuations and are not accurate when used in shallow or slow flows (Fulford 2001). The recent development of acoustic instruments, such as the Acoustic Doppler Velocimeter (ADV), has improved our ability to measure detailed flow characteristics (Voulgaris and Trowbridge 1998).

In addition to field observations, the flow field can also be investigated using computational techniques. One-, two-, and three-dimensional numerical models have been developed to

simulate flow fields in natural and artificial streams (Duel et al. 2003). These models are based on the physical laws of conservation of mass, momentum, and energy. The governing equations are described in several reports (e.g. FLUENT 2005 and Lesser et al. 2004). The application of a model allows us to investigate flow features at higher spatial resolutions and broader spatial scales than allowed through flow observations alone. Further, models allow us to evaluate a wider range of flow rates (such as flood events), in which measurements are often unavailable.

7.2.4 Objective

The objective of this research was to evaluate the effectiveness of LWD, as installed in King County agricultural drainage watercourses, in providing hydraulic diversity. This objective was met through a combination of field measurements (in two watercourses), and hydrodynamic simulations under a range of flow rates.

7.3 Methods

7.3.1 Field Observations

ADV measurements were conducted in two King County drainage watercourses at the locations shown in Figure 7-1. The first watercourse was the Pickering property (B-2 downstream to A-2) at the 124th Street Complex (Site 1, see Figure 7-2 and Figure 7-3) and the second site was on the Nelson's Dairy property (B3 to B1) (Site 2, see Figure 7-4 and Figure 7-5).

These two study sites were selected from six potential reaches and were considered to be representative of LWD as installed by King County. In examining the potential locations, it was decided that one recently installed LWD site and one older LWD location would be used. The recently installed wood site (Pickering) permitted analysis of a recently cleaned ditch free of RCG while the older site (Nelson) allowed comparison of long-term effects for scour potential as well as sedimentation. Both reaches had free-flowing water.

At Site 1 (Pickering), data were collected upstream and in the observed wakes of a log and a root wad (Figure 7-6). At Site 2 (Nelson), data were collected upstream and in the wake of a log (Figure 7-7). Data were collected at approximately mid-water column (~10 cm below the water surface). A precise water depth was not measurable due to the extremely soft stream bed (deposited silts). A cross-section profile, consisting of 5 measurements, was collected upstream from each piece of LWD. A 5 by 5 grid with a spatial resolution of 0.15 m, for a total spatial extent of 0.36 m^2 (0.6 m x 0.6 m), was collected in the LWD wake. The ADV was positioned and secured with an aluminum sampling stand. A generalized schematic diagram of the study layout is presented in Figure 7-8. Data were collected for two minutes at each station at a 25Hz sampling frequency. In addition to the flow measurements, a detailed topographic survey was completed for both study reaches (Appendix 7-A).

The streamwise coordinate system was used in the data analysis. The data were rotated in post-processing to ensure that the mean transverse and vertical velocity components were zero for each cross-section (Wilczak et al. 2001). The data were rotated back to a standard Cartesian coordinate system for plotting. The data were filtered at a minimum signal to noise ratio of 15

and a minimum correlation value of 70 using WinADV (Wahl 2000). This eliminated about 5% of the data. The data were exported and processed using a custom developed FORTRAN code (Stone 2005). The FORTRAN program rotated the data and computed the flow field parameters including mean velocities, TKE (turbulent kinetic energy), and integral time scales (T).

7.3.2 Numerical Modeling

The stream flow field was modeled using the commercial computation fluid dynamics model FLUENT (2005). The FLUENT model performs two- and three-dimensional simulations of the flow field using a range of turbulence closure routines. For this study, a three-dimensional simulation of the log at Site 1 was conducted for the observed discharge and for the estimated bankfull discharge.

The computational mesh was developed using the GAMBIT software program (GAMBIT 2005). A structured-curvilinear mesh was constructed based on survey data. The computational range was approximately 15 m in the streamwise direction. This allowed the flow field to develop before reaching the obstruction and for the full obstruction wake to be observed. The width and depth varied with discharge and transverse location. The mean grid resolution was 5 cm, creating approximately 50,000 and 70,000 grid cells for the observed and bankfull discharges, respectively.

The boundary and initial conditions were determined using the one-dimensional open channel Hydrologic Engineering Center River Analysis System (HEC-RAS) model developed by the US Army Corps of Engineers (USACE 2006). HEC-RAS was used to determine the mean water column velocities and water surface elevations (Appendix 7-B). The bed and bank boundaries were set to a no-slip condition. The water surface boundary was set as symmetry. The upstream velocity profile was approximated using a power-law and the downstream outflow weighting factor was set to unity.

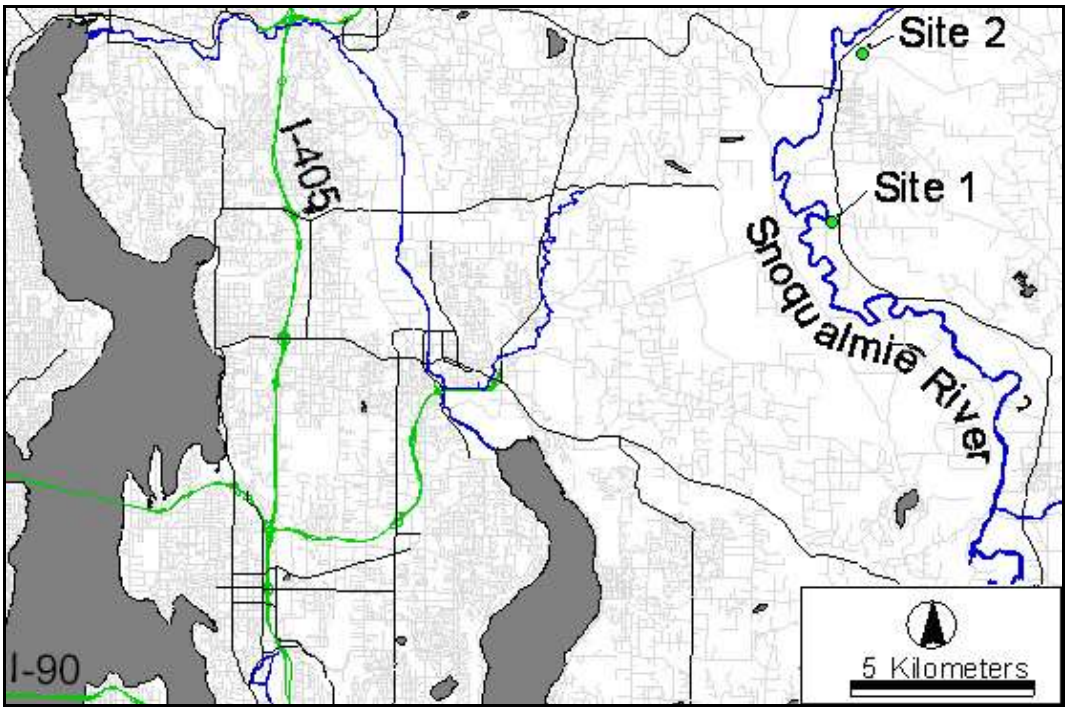

Figure 7-1. Map of the Seattle metropolitan region including the sampling sites near the Snoqualmie River

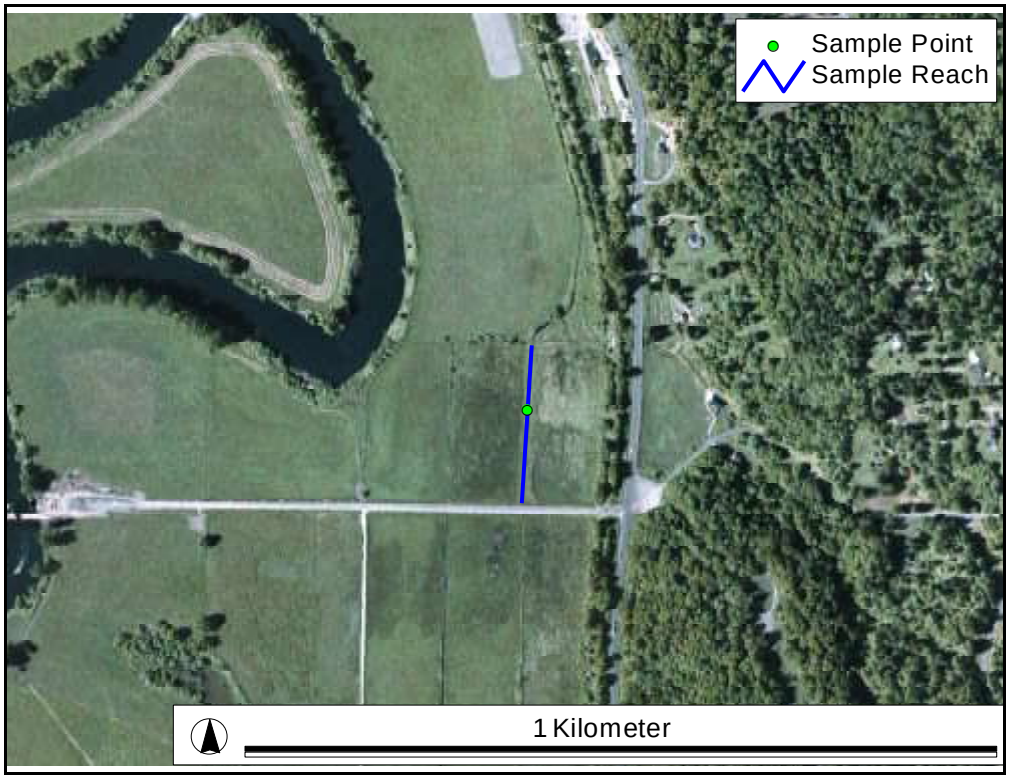

Figure 7-2. Aerial photograph of the Site 1 (Pickering) sampling reach and sampling point

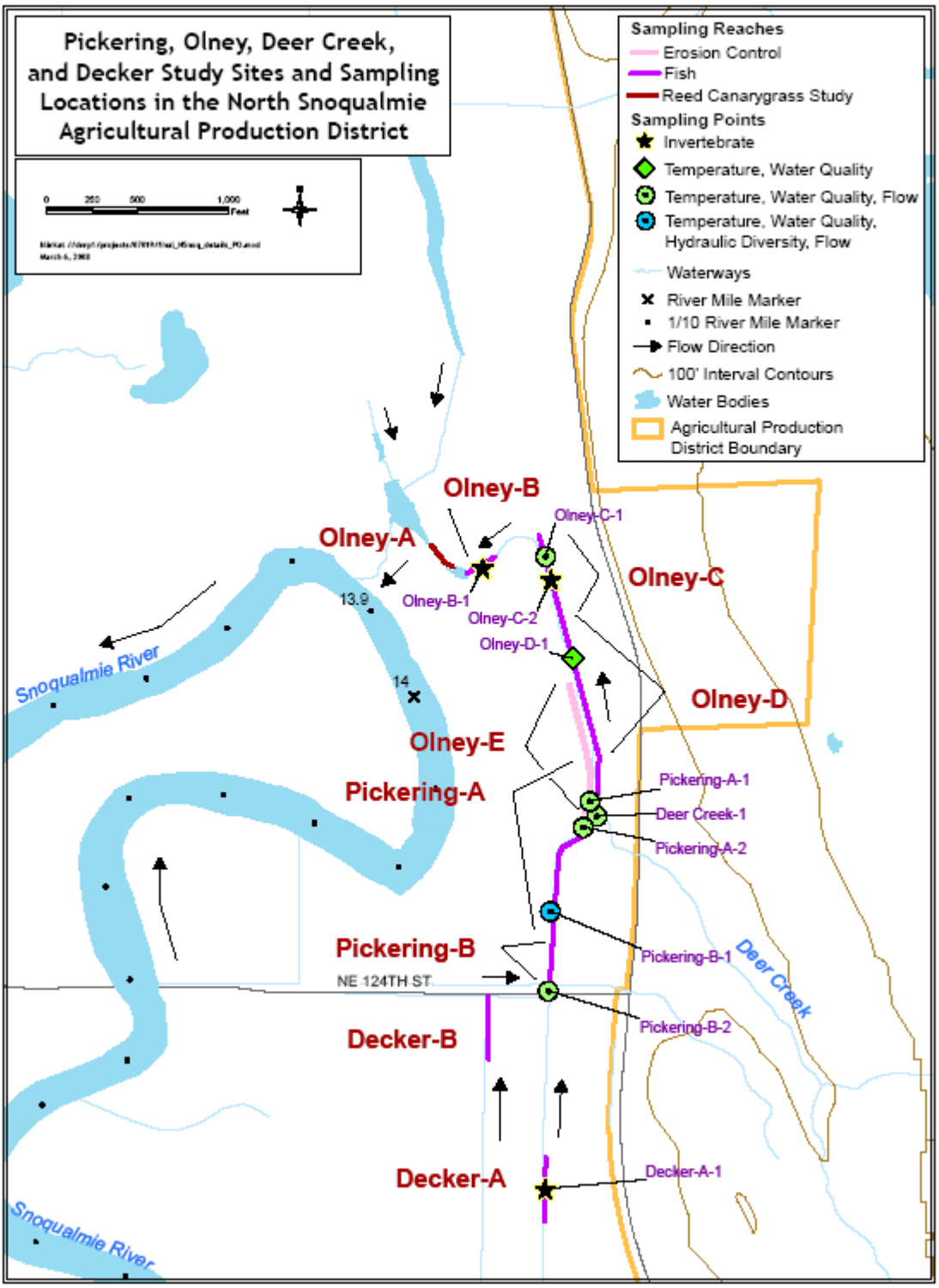

Figure 7-3. Site 1 (Pickering) sample location

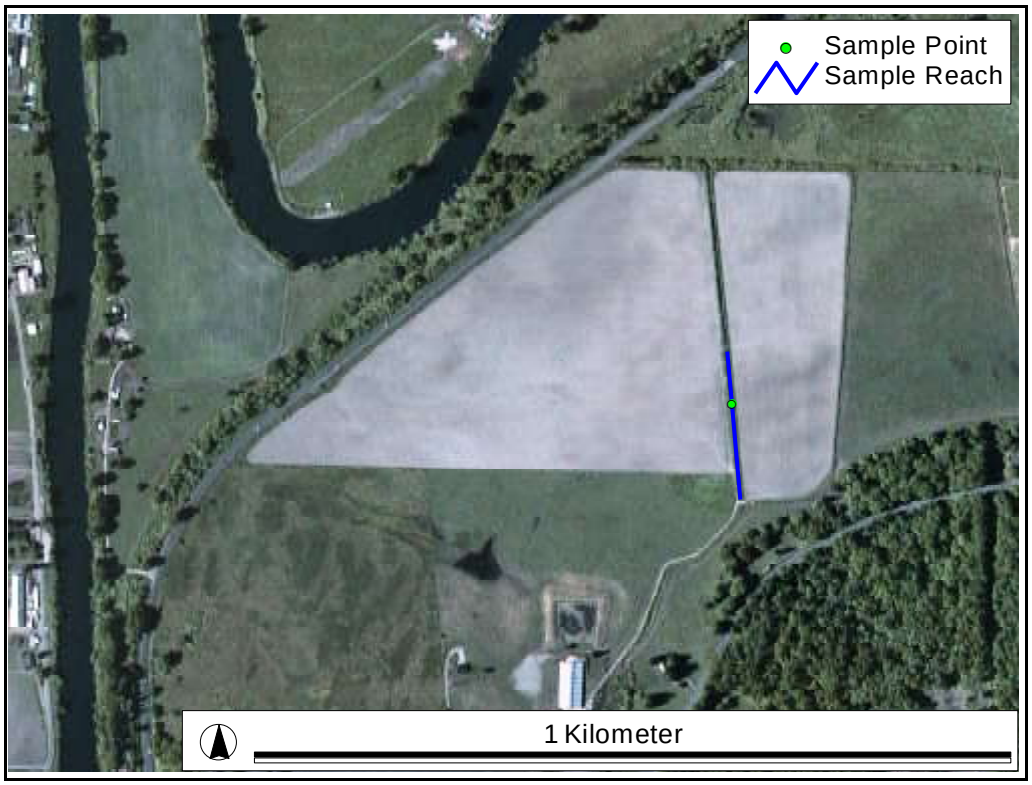

Figure 7-4. Aerial photograph of the Site 2 (Nelson) sampling reach and sampling point

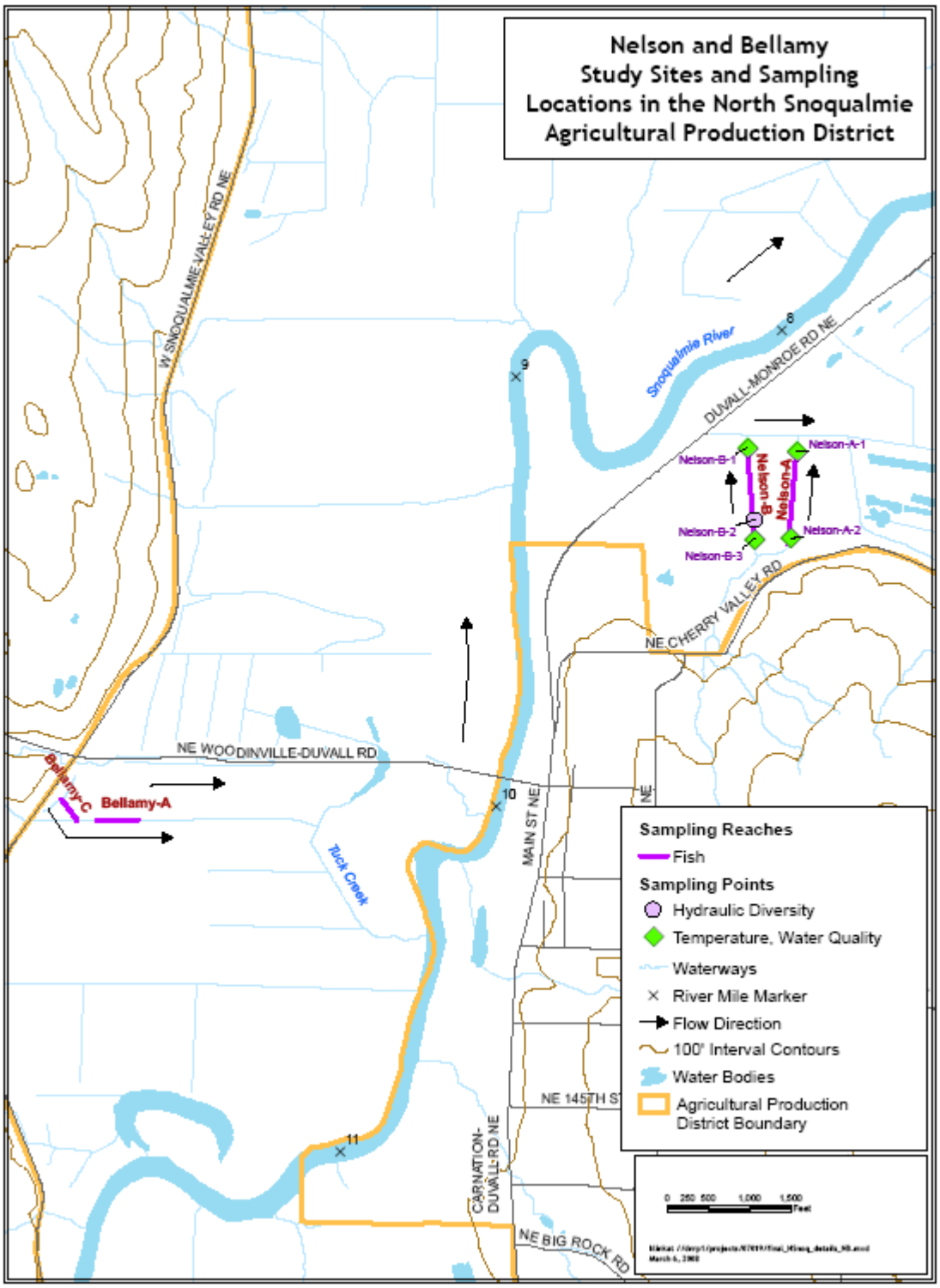

Figure 7-5. Site 2 (Nelson) sample location

Figure 7-6. ADV positioned in the wake of the LWD at Site 1 (Pickering)

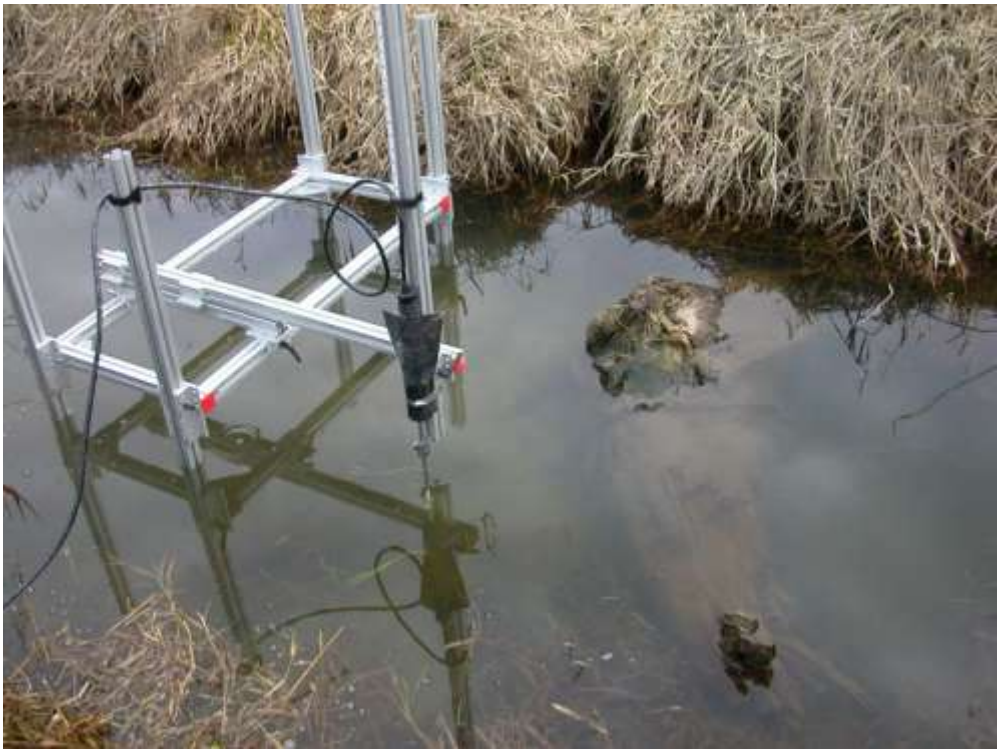

Figure 7-7. ADV positioned in the wake of the LWD at Site 2 (Nelson)

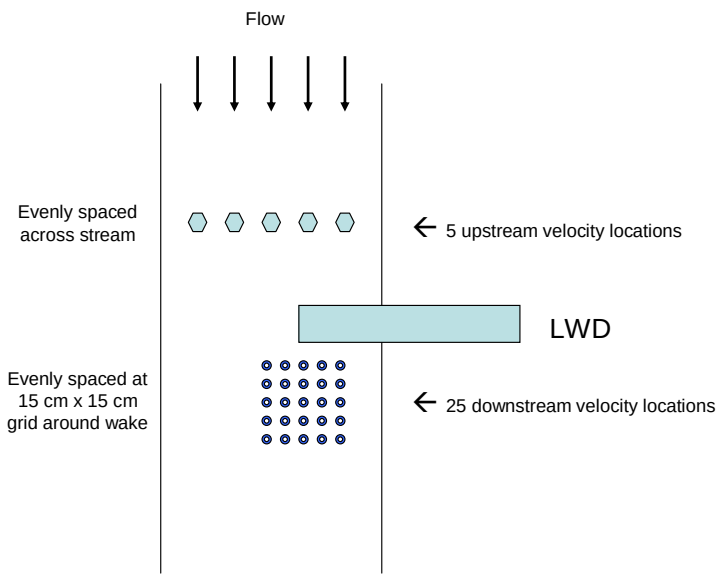

Figure 7-8. Schematic of velocity measurements

7.4 Results

7.4.1 Field Observations

Field data collection was completed at Site 1 on February 1, 2005 and at Site 2 on February 2, 2005. A wide range of hydraulic metrics were calculated from the field measurements. The full dataset has been provided to King County and is summarized in Appendix 7-C. This section is focused on measurable variables that are known to be good descriptors of hydraulic diversity: velocity magnitude, turbulent kinetic energy (TKE), and integral time scale (T).

Velocity magnitude observations for the log at Site 1 (Pickering) are shown in Figure 7-9. The mean velocity magnitude upstream from the LWD was 2.6 cm/s (1.02 inches/second). Velocity magnitudes this small are uncommon in natural streams and are near the level of detection for most velocity meters. The velocity observations were retarded slightly behind the log to a mean velocity of approximately 1 cm/s (0.39 in/s). However, the influence of the log on the velocity magnitude was diminished 15 cm (5.9 in) downstream and no longer observed at 30 cm (11.8 in). The velocity observations in the vicinity of the root wad at Site 1 (Pickering) are shown in Figure 7-10. The reduced velocity magnitude was again observed downstream of the debris: from an average of 2.5 cm/s (1.0 in/s) upstream to 0.18 cm/s (0.07 in/s) directly downstream from the log. The influenced region was slightly larger, extending to 45 cm downstream from the root wad. The velocity distribution for the log at Site 2 (Nelson) is shown in Figure 7-11. The observed velocities were reduced directly behind the log, but only for the left portion of the channel. It is important to note that the velocity variations between locations are relatively small. Velocity levels in natural streams are often in excess of 100 cm/s (39.4 in/s) (Stone 2005), particularly in small streams that are typically high gradient. Also, salmonid species typically show a preference for velocity levels from 15 cm/s to 115 cm/s (McMahon 1983). Further, these minor variations in velocity magnitude are much too small to influence scour and deposition of the cohesive watercourse banks and bed (Sanford and Maa 2001).

TKE observations for the log at Site 1 (Pickering) are shown in Figure 7-12. The mean TKE in the unobstructed region was 0.65 cm^2/s^2 (0.101 in^2/s^2). The TKE level was reduced directly behind the log to a mean TKE of 0.26 cm^2/s^2 (0.040 in^2/s^2). This can be attributed to the reduced velocity in this region. Beyond 15 cm (5.9 in) downstream from the log, TKE values approached similar levels to the unobstructed region. TKE values were slightly elevated near the bank at distances of 30 cm (11.8 in) and 60 cm (23.6 in) downstream from the log. This was likely caused by flow detachment around the log. The TKE distribution around the root wad at Site 1 (Pickering) is shown in Figure 7-13. Upstream of the root wad, the TKE was very similar to upstream from the log, with a mean TKE of 0.54 cm^2/s^2. The region of depressed TKE was slightly larger than the case of the log; extending approximately 0.5 m downstream from the root wad. This can be attributed to the smaller eddies formed around individual root structures, which were dissipated more readily than the larger eddies formed by the root structure. This point is supported by observations of the integral time scale, described below. The influence of the log on TKE distributions at Site 2 (Nelson) are shown in Figure 7-14. TKE levels were elevated directly behind the log from a background level of approximately 0.42 cm^2/s^2 to TKE values as high as 2.75 cm^2/s^2 just downstream of the log. The influence on the log was observed for a

distance of approximately 15 cm downstream. The elevated velocity just downstream from the log was likely caused by the shedding of vortices, which were quickly dissipated.

The LWD appeared to have only a minor influence on T distributions behind all three obstructions (Figure 7-15 (log at Site 1, Pickering), Figure 7-16 (root wad at Site 1, Pickering), and Figure 7-17 (log at Site 2, Nelson)). A close investigation of the T figures reveals some interesting characteristics of the turbulence structure downstream from the obstructions. The first thing to note in all three cases is that the background T (upstream from the obstructions) varied as much across each cross section as it did downstream from the obstructions. In the case of the log obstruction at Site 1 (Figure 7-15), no clear trends in the influence of the obstruction were observed. However, it is interesting to note that the integral time scale was overall reduced downstream of the root wad at Site 2 but overall increased downstream of the log. This is consistent with the above mentioned concept that the branching nature of the root wad served to break-down coherent structures and reduce eddy size while the log appeared to generate a vortex wake, increasing eddy size.

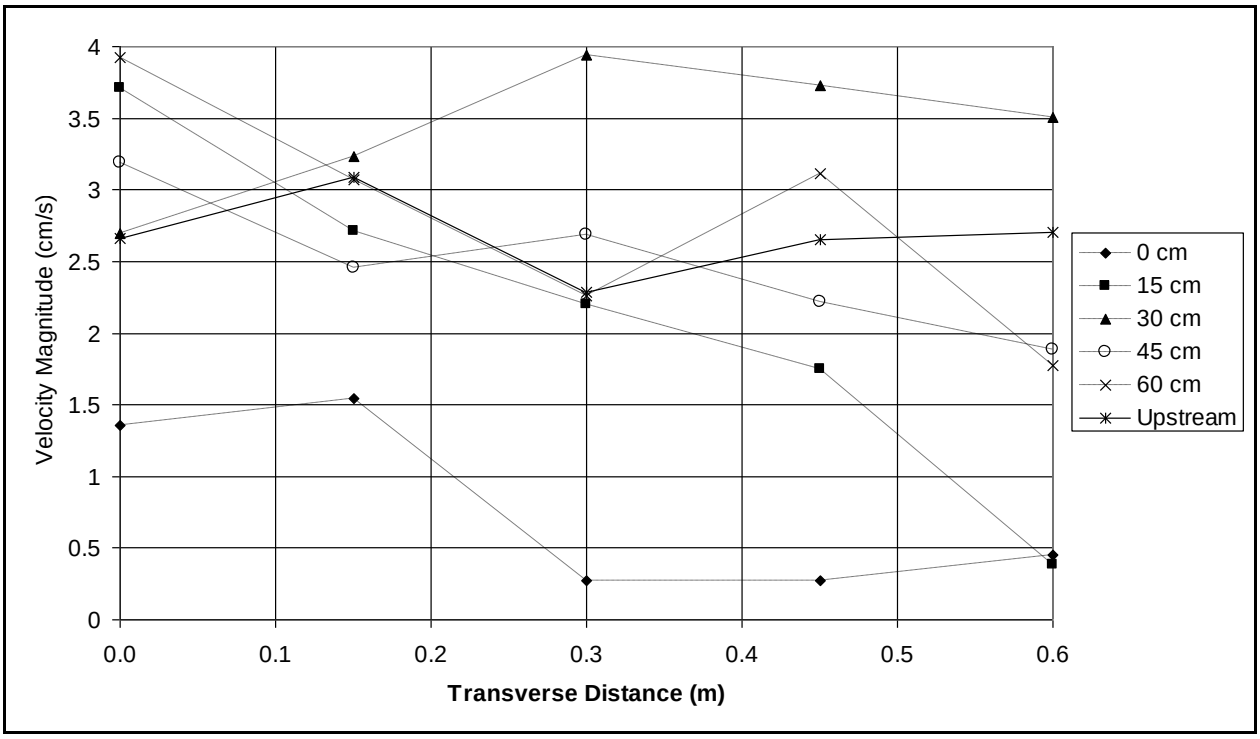

Figure 7-9. Velocity transects upstream and in the wake of the log obstructions at Site 1 (Pickering)

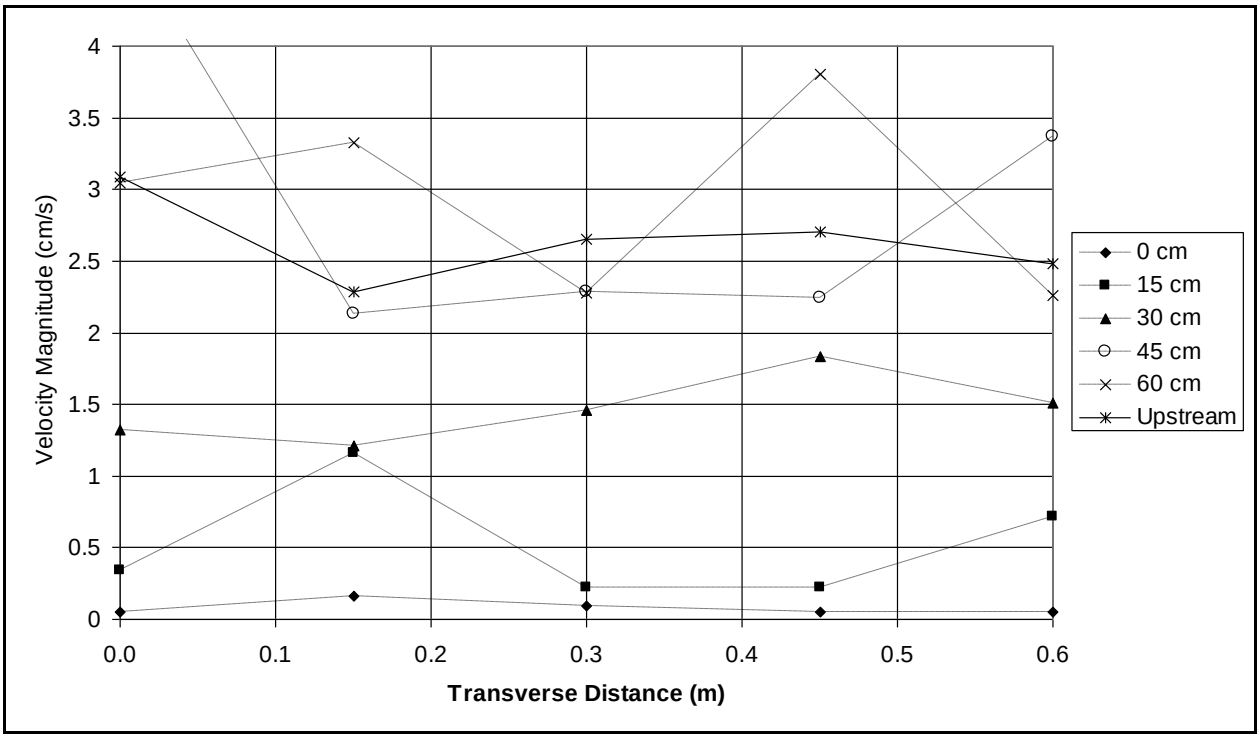

Figure 7-10. Velocity transects upstream and in the wake of the root wad obstructions at Site 1 (Pickering)

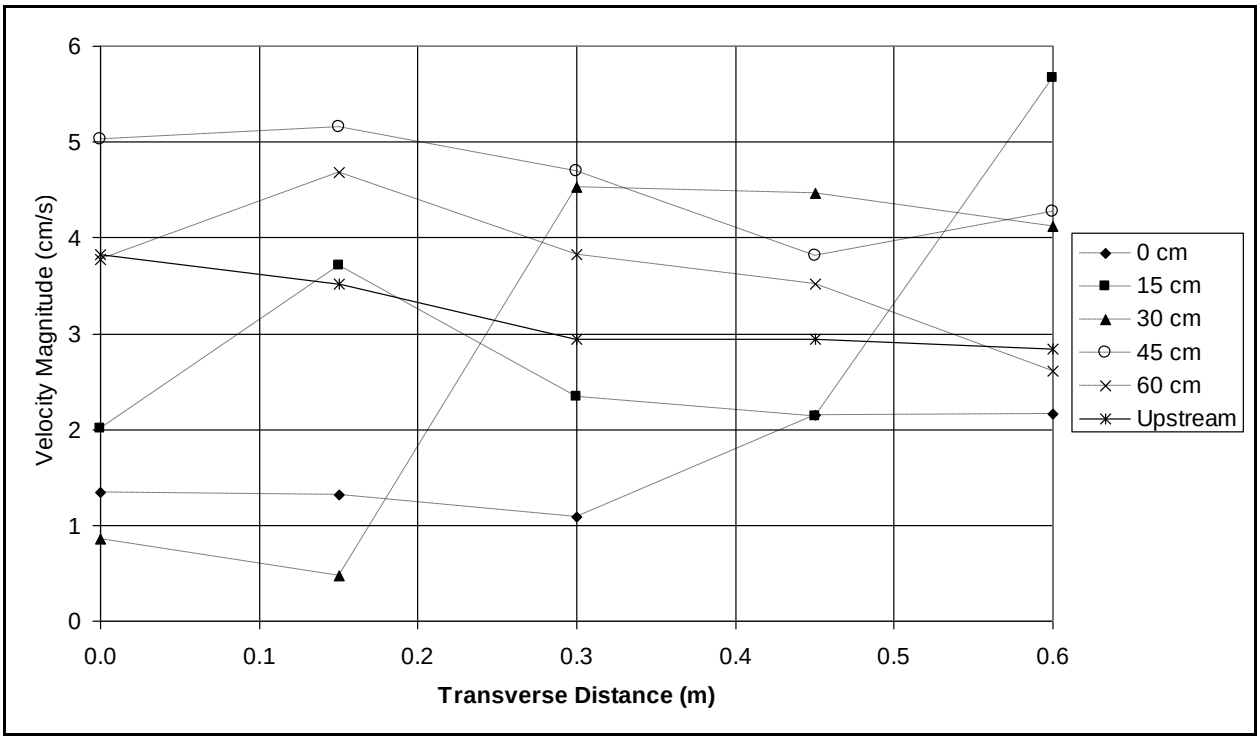

Figure 7-11. Velocity transects upstream and in the wake of the log obstructions at Site 2 (Nelson)

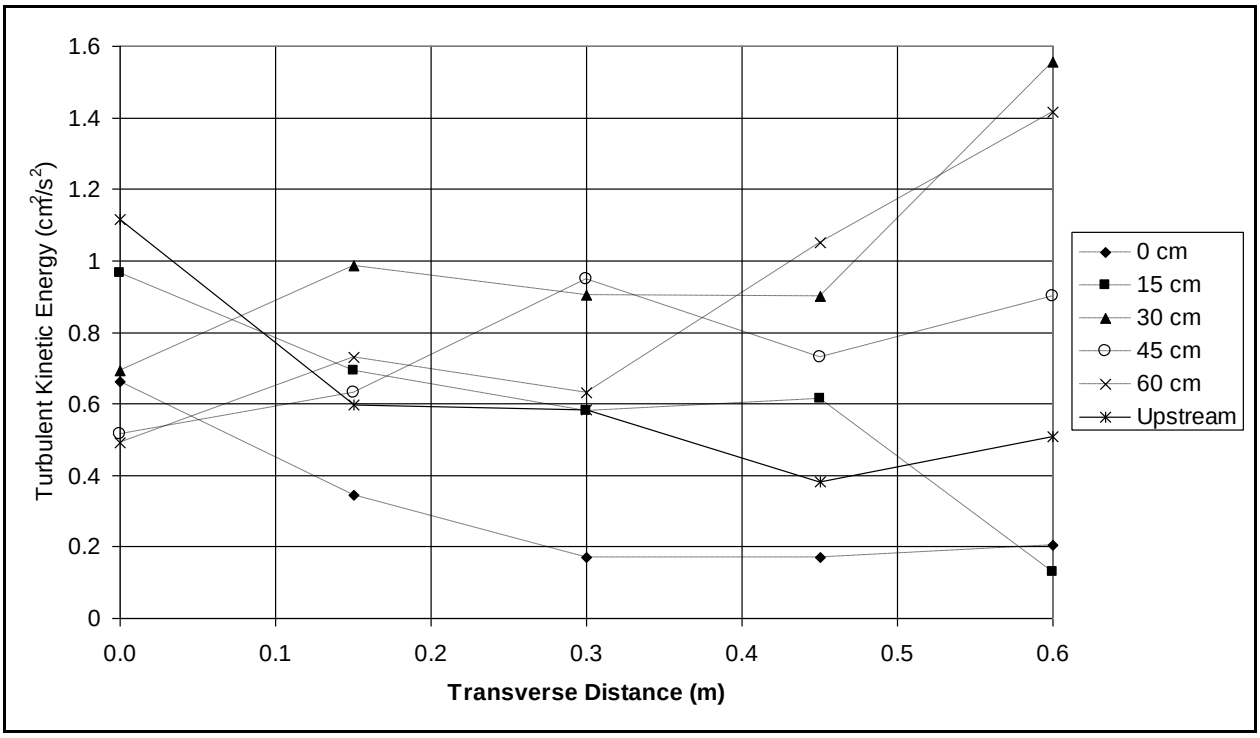

Figure 7-12. TKE transects upstream and in the wake of the log obstructions at Site 1 (Pickering)

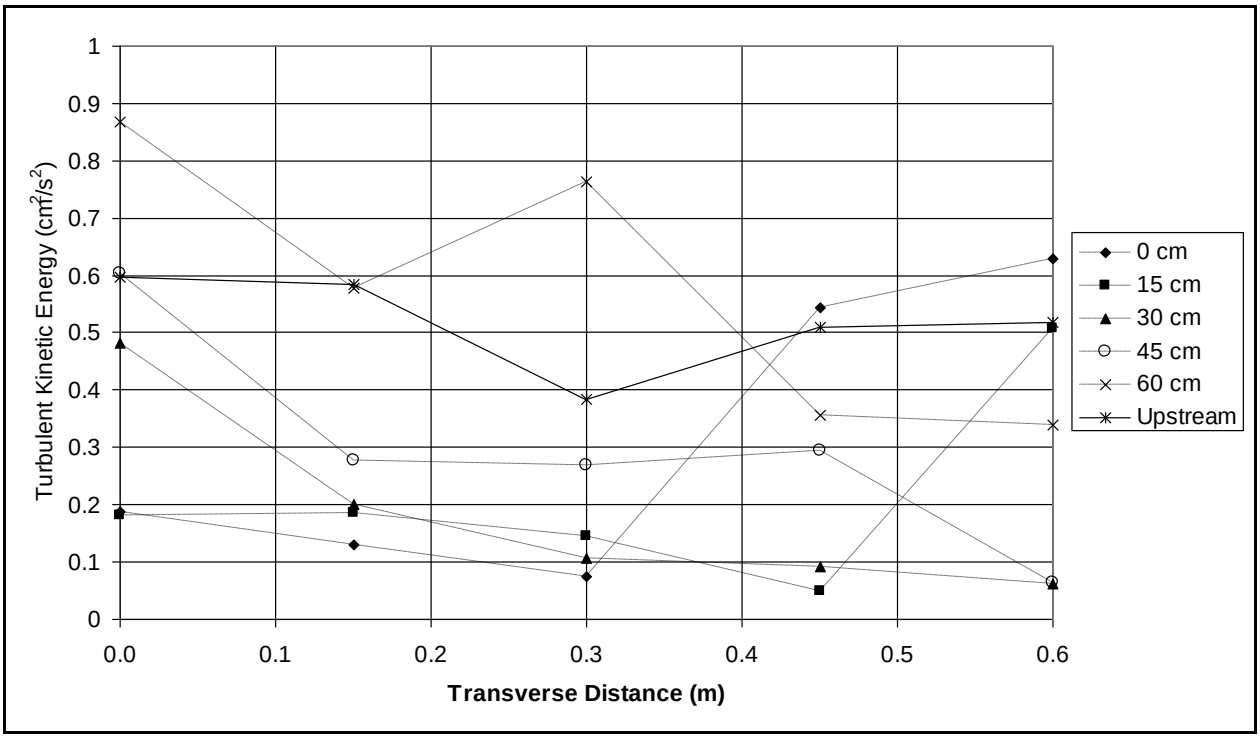

Figure 7-13. TKE transects upstream and in the wake of the root wad obstructions at Site 1 (Pickering)

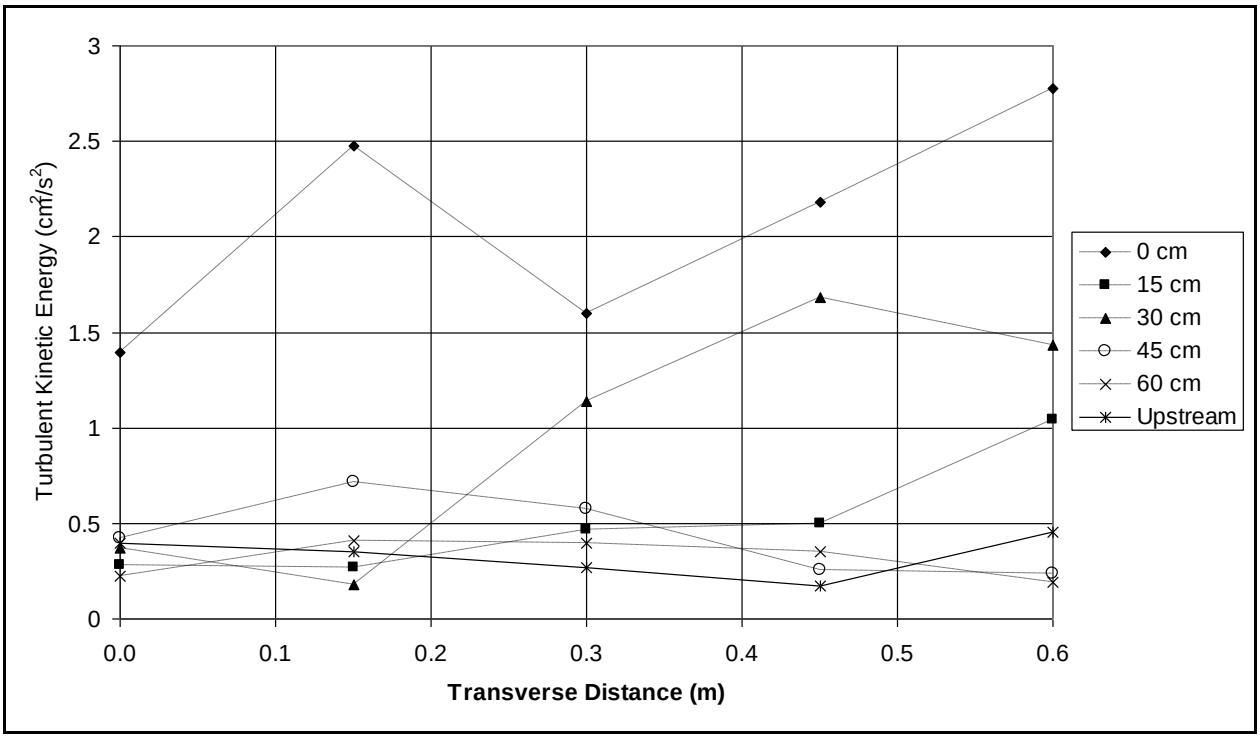

Figure 7-14. TKE transects upstream and in the wake of the log obstructions at Site 2 (Nelson)

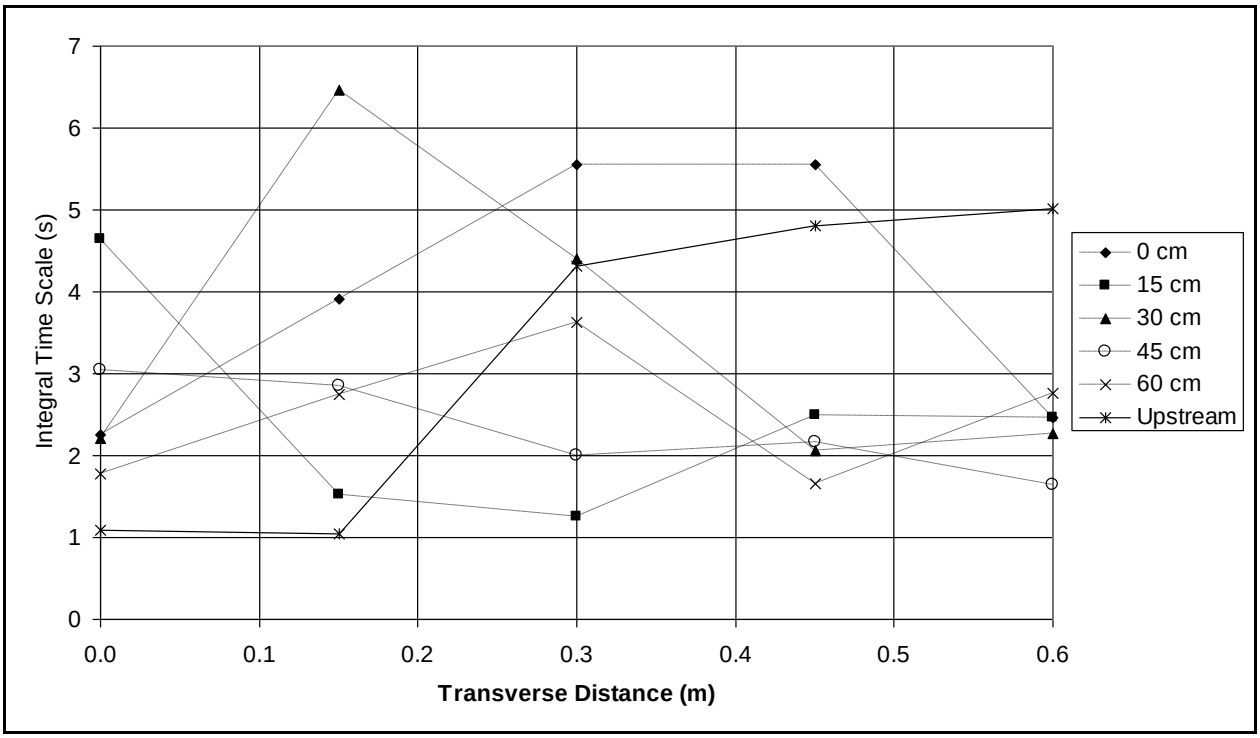

Figure 7-15. Integral time scale transects upstream and in the wake of the log obstructions at Site 1 (Pickering)

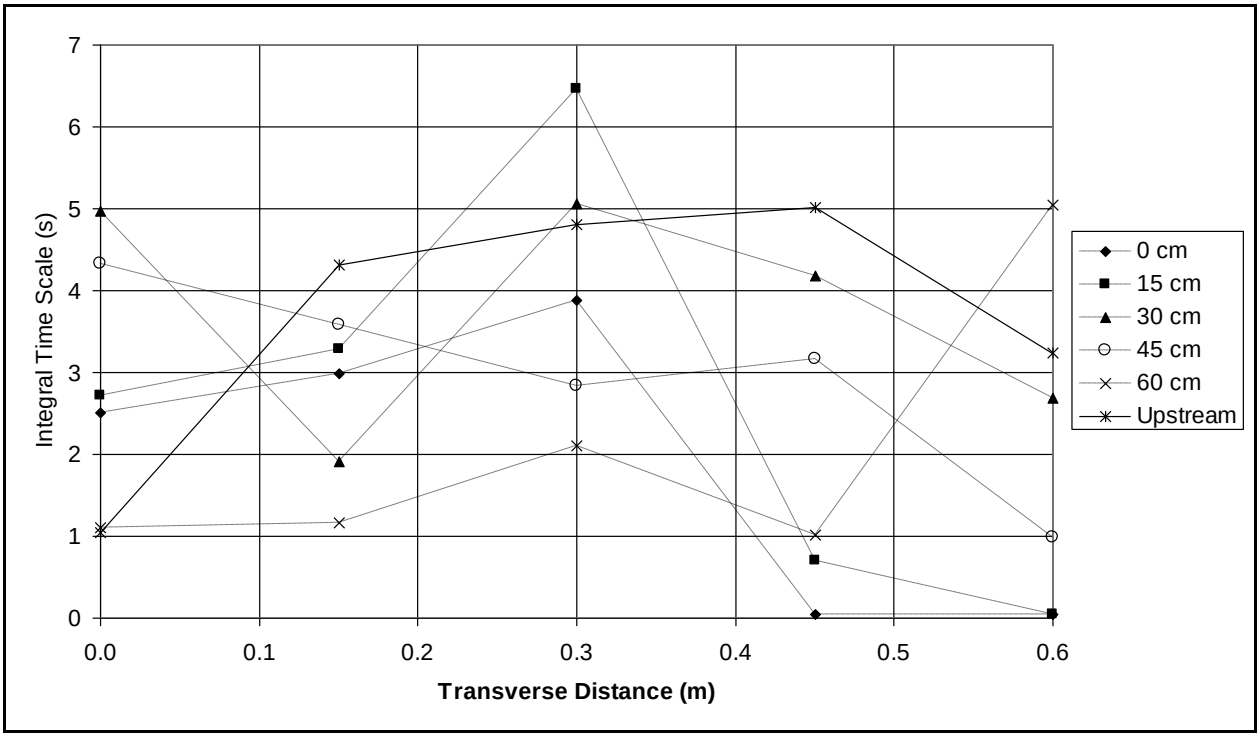

Figure 7-16. Integral time scale transects upstream and in the wake of the root wad obstructions at Site 1 (Pickering)

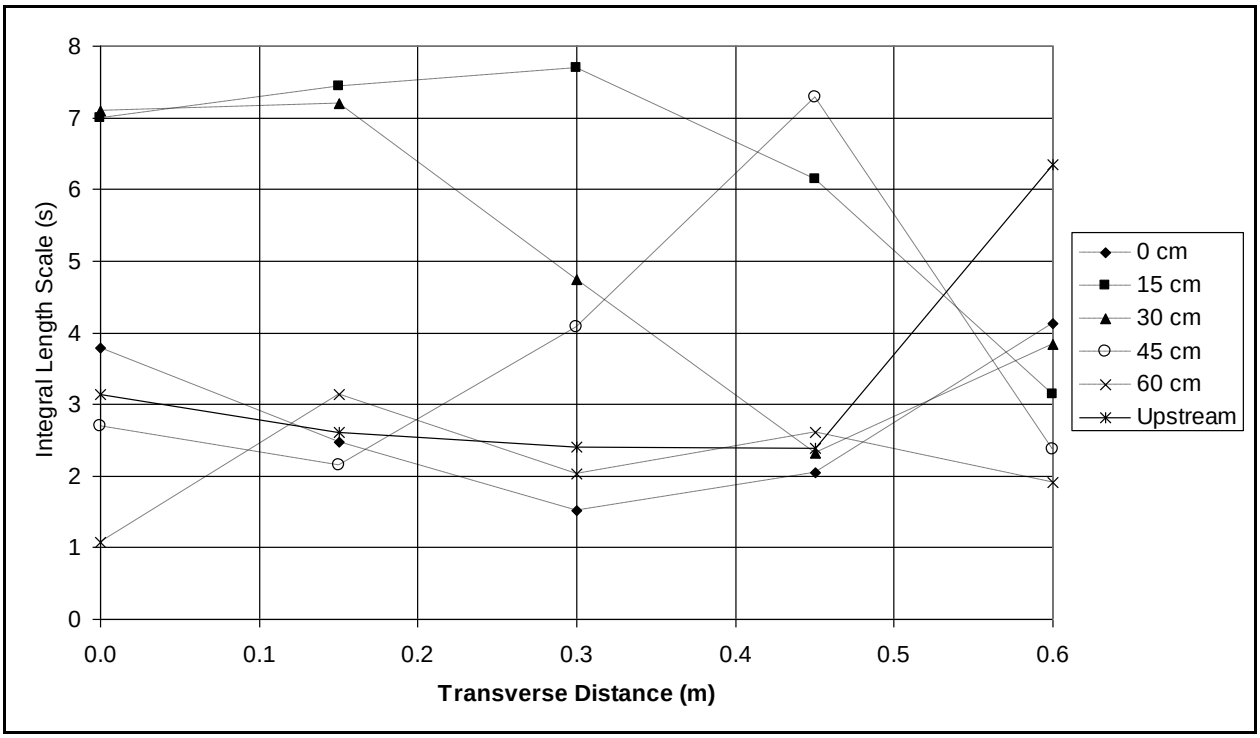

Figure 7-17. Integral time scale transects upstream and in the wake of the log obstruction at Site 2 (Nelson)

7.4.2 Numerical Simulation Results

The FLUENT simulation allowed the investigation of flow variables over a wider spatial extent than field measurements and for additional flow conditions. Further, numerical results can be analyzed for spatial variables, such as vorticity. However, the model only simulates time averaged flow, and therefore cannot be used to investigate integral time scale distributions.

The simulated velocities in the vicinity of the log were similar to observed values at Site 1 (Pickering), but with a smoother distribution (Figure 7-18). The velocity was depressed in the region surrounding the log and the obstruction forced the flow to accelerate around the log resulting in an elevated velocity along the left bank. As with the measured values, the extent of the influenced region was quite small and the relative influence was extremely small. This was due to the very low mean velocity in the channel. To see the impact of higher flow velocities, the velocity field for the estimated bankfull discharge is shown in Figure 7-19. The spatial distribution is very similar to the lower observed flow although the mean channel velocity was approximately twice as high (Figure 7-19). As a result, the influenced region was slightly larger and more pronounced. However, the influence of the log on the flow field was still very small.

Simulated TKE distributions for the observed and bankfull flow conditions were generated. For both observed and bankfull flow conditions, the model results showed a slight reduction in TKE near the obstructions (Figure 7-20 and Figure 7-21). This is due to the reduced velocity

fluctuations caused by local flow acceleration. As expected, the simulated influence of the log on TKE distributions was very small.

Vorticity is an excellent description of hydraulic diversity as it accounts for flow gradients in multiple directions (Crowder and Diplas 2002; Shields 2003). Vorticity distributions for the observed and bankfull flow conditions were generated by the FLUENT model. The simulation results indicate a high level of vorticity in the region near the LWD (Figure 7-22 and Figure 7-23). The vorticity magnitude was higher for the bankfull condition than the observed flow condition. However, as with other variables, only the region very close to the LWD (within approximately 20 cm) was influenced.

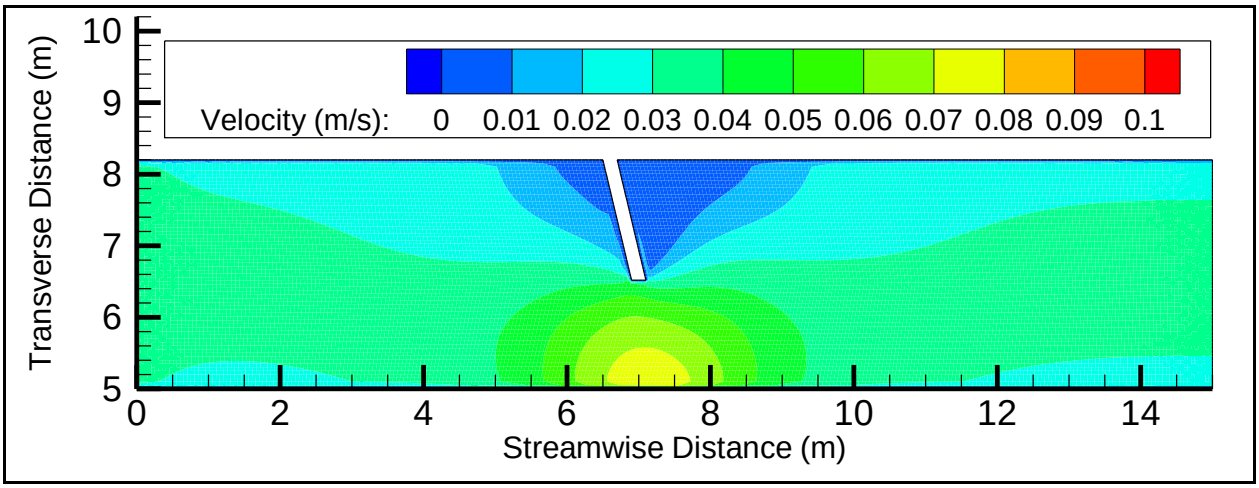

Figure 7-18. Numerically simulated velocity magnitude distributions around the log at Site 1 (Pickering) for the measured discharge

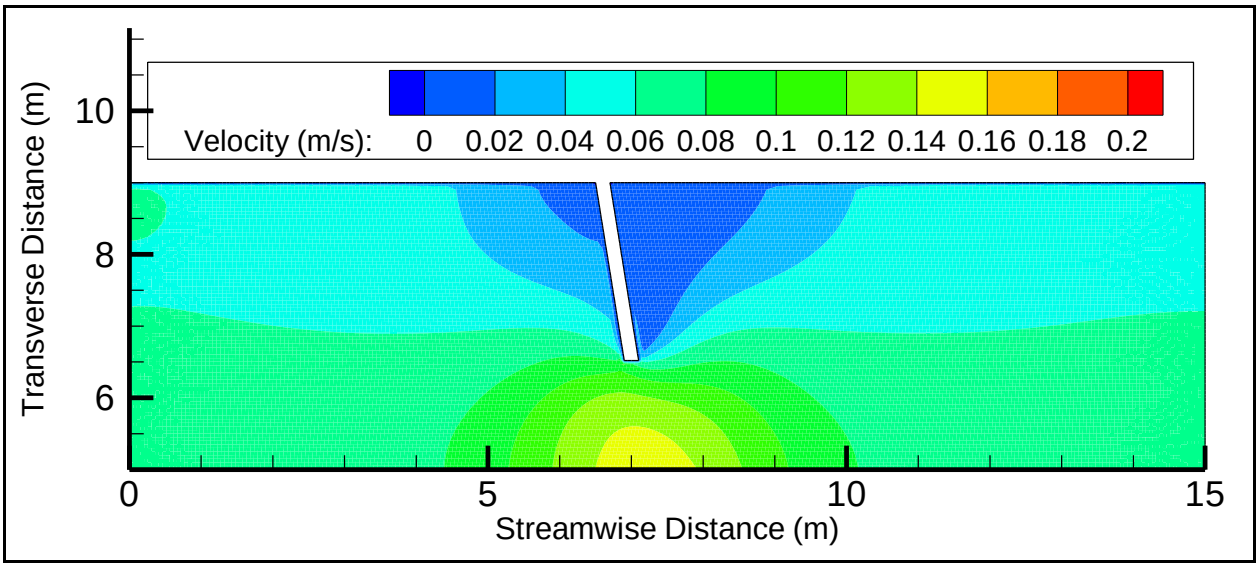

Figure 7-19. Numerically simulated velocity magnitude distributions around the log at Site 1 (Pickering) for bankfull discharge

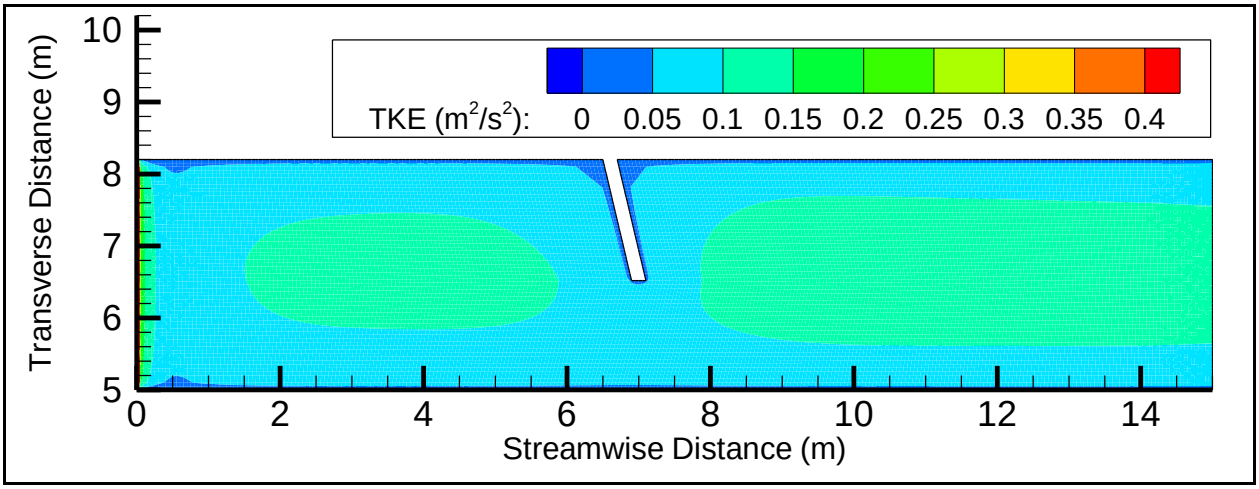

Figure 7-20. Numerically simulated TKE distributions around the log at Site 1 (Pickering) for the measured discharge

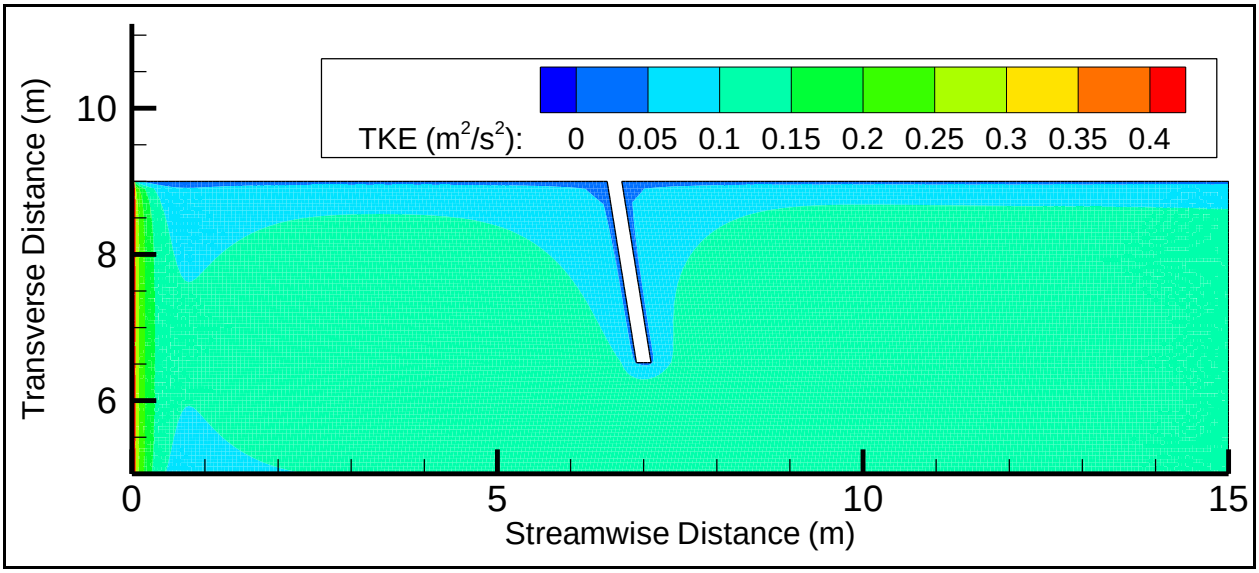

Figure 7-21. Numerically simulated TKE distributions around the log at Site 1 (Pickering) for bankfull discharge

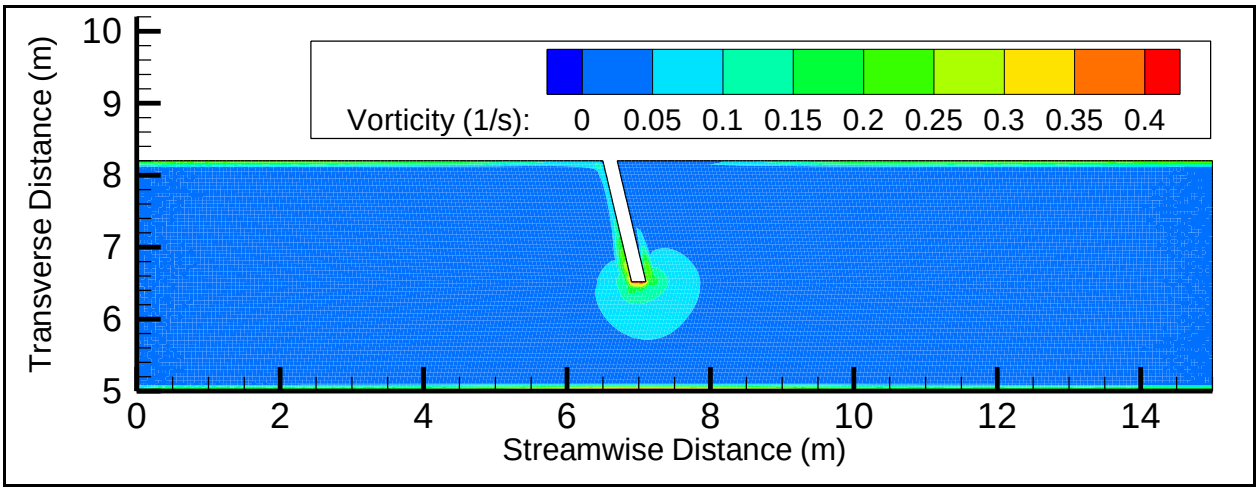

Figure 7-22. Numerically simulated vorticity distributions around the log at Site 1 (Pickering) for the measured discharge

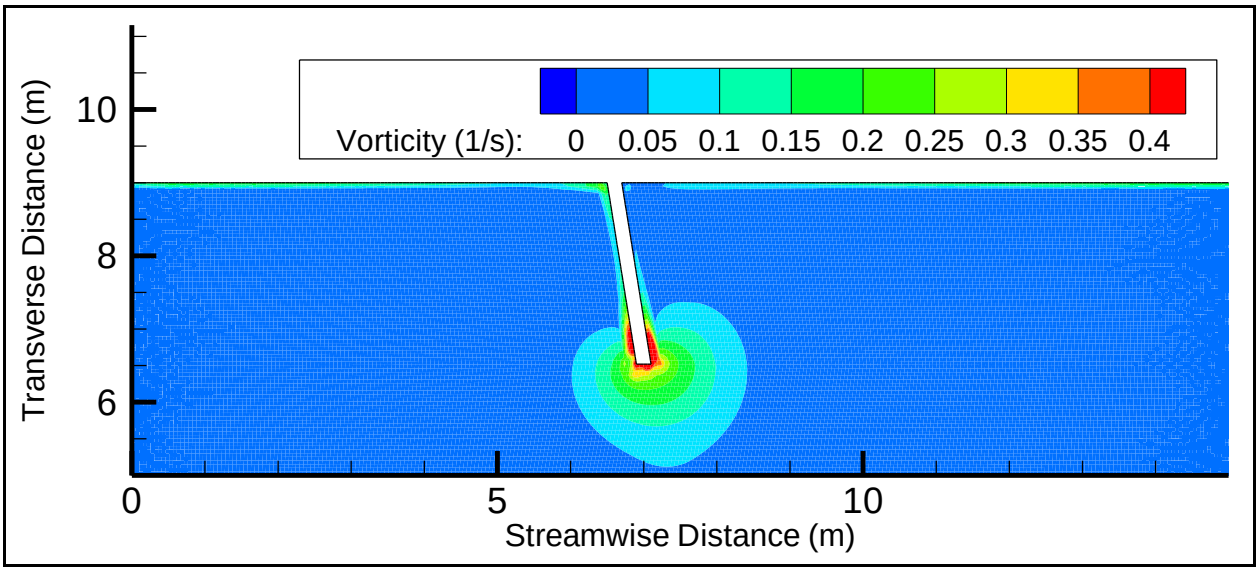

Figure 7-23. Numerically simulated vorticity distributions around the log at Site 1 (Pickering) for bankfull discharge

7.5 Discussion and Recommendations

The objective of this study was to investigate the effectiveness of installed LWD for providing hydraulic diversity in King County agricultural drainage ways. This objective was met through a combination of field observations and numerical simulations. It was found that installed LWD had a very minor influence on measured distributions of velocity magnitude, turbulent kinetic energy, and integral time scales. The observed region of influence depended on the investigated parameter and measured obstructions. However, the region of influence did not extend beyond 45 cm downstream from the installed LWD. The numerical simulation allowed for an investigation of flow parameters over a broader spatial extent and for higher flows than the observed value. The numerical simulation results agreed with measured values. For both the observed flow conditions, and the estimated bankfull discharge, the installed LWD was shown to have a slight influence on the local flow distribution. However, the magnitude and spatial extent of the influence was very small. It is concluded that the installed LWD does not effectively increase the hydraulic diversity of the drainage watercourses. Further, the incremental change in hydraulic properties was too small to cause noticeable changes in large scale flow characteristics (hydraulic roughness, mean flow velocity, and water surface elevation) and other related processes such as sediment transport.

At first, these results appear to contradict much of the previous research conducted salmonid bearing streams. However, a closer look reveals that the vast majority of studies conducted on LWD in the past have been conducted in drastically different conditions than those present in the study sites (e.g. Bisson et al. 1987, Beechie and Sibley 1997). In streams with higher levels of kinetic energy (high velocity and gradient), LWD is shown to create velocity shelters, scour holes, overhanging banks, and other hydraulic features desirable for salmonid habitat. However, these processes are dramatically altered in low energy channels, such as those studied here. Because background velocity and turbulence levels are remarkably low, the processes of flow separation, vortex wake formation, and bed and bank scouring are not facilitated by the installation of LWD. Rather the LWD slightly retards the flow over a very limited region and generates very low levels of turbulence in the wake (small eddies in the case of root wads and larger eddies in the presence of logs). Thus, the desired condition of increased hydraulic diversity is not achieved in this environment.

TKE is analogous to mean kinetic energy per unit mass associated with eddies in turbulent flow situations and therefore represents the level of turbulence activity. Kinetic energy has been shown to be a useful flow metric for evaluating hydraulic diversity, habitat quality, and fish movement (Stone and Hotchkiss 2007, Crowder and Diplas 2006, and Smith et al. 2006). In previous studies conducted in small streams, rivers, lakes, estuaries, and coastal environments, TKE values have been observed to range from approximately 10 cm^2/s^2 (1.55 in^2/s^2) in quiescent waters to more than 1000 cm^2/s^2 (155 in^2/s^2) in turbulent environments. A thorough literature review did not reveal any previous studies of turbulence in agricultural drainage ways or in open channels with similar characteristics.

As with velocity, it should be noted that the study site TKE levels were extremely low compared to those observed in natural streams. The mean TKE level in the study sites was approximately

0.50 cm^2/s^2. In contrast, mean TKE in gravel-bed rivers (grain size D_{50} = 50 mm) often exceeds 100 cm^2/s^2 (Tritico and Hotchkiss 2005) although TKE values vary widely as Wilcox and Wohl (2007) reported values consistently ranging from 80 to 400 cm^2/s^2 for step-pool channels (D_{50} = 78 mm), Cardinale et al. (2002) reported TKE values ranging from 25 to 60 cm^2/s^2 in free-flowing gravel-bed rivers (D_{50} = 55 mm) and Bouckaert and Davis (1998) found TKE values as low as 3 to 6 cm^2/s^2 in the wake region immediately downstream of large (D_{mean} >0.5 m) boulders. Unfortunately, comparable studies for low-gradient, agricultural waterways have not been conducted so it is not possible to determine if the results measured in this study are consistent with previous measurements. However, it is not unreasonable to observe such low turbulence levels in an environment with very low energy (low velocity and gradient).

There have been several questions raised concerning how LWD might impact sedimentation, how drain tiles might affect LWD placement criteria, and whether LWD would increase the need for maintenance. Since the impact of LWD on velocity and turbulence patterns in agricultural waterways is very limited, the expected impact on sedimentation would also be negligible. LWD has been installed at the Nelson site (Site 2) for a considerable length of time. We saw no evidence of sediment buildup or scour specifically associated with the LWD. Furthermore, since no excess deposition was noticed, it would seem that the impact on the rate of field drainage would be minimal and the issue surrounding drain tiles would be not to block or damage one when the wood is being installed. Arguably, one site does not adequately address every possible combination so the issue of sediment deposits around LWD has not been sufficiently investigated. Additional sites would most assuredly assist in making more definitive statements.

The goal of this task was to examine whether or not hydraulic parameters (e.g., pool depth, velocity, and turbulence) in agricultural waterways were impacted due to the installation of LWD in configurations typically installed by KCDNRP staff. Field measurements and model scenarios using much higher discharges clearly illustrated that the impact of LWD on pool depth, velocity and turbulence in these waterways is negligible. Therefore, King County should not require LWD in agricultural watercourses in order to increase hydraulic diversity. We are well aware of several studies documenting the benefits of LWD on stream and river hydraulics (Beschta and Robison 1990, Hicks et al. 1991, Abbe and Montgomery 1996); however, these studies did not focus on low gradient agricultural waterways with typical velocities much less than 0.1 m/s (0.33 ft/s). Moreover, even the few studies that addressed “low gradient” waterways (Beschta and Robison 1990, Gurnell and Sweet, 1998) referred to gradients higher (e.g., 1.3 ft/100 ft) than in most agricultural waterways. This is consistent with the findings of Keller and Tally (1979) who stated that the influence of LWD on channel form was less in low gradient streams than in high gradient waterways.

It is also important to note that this task did not include examining the ecological function of LWD in agricultural waterways. Numerous authors have investigated the benefits to channel complexity, cover, macroinvertebrate habitat, and birds (Reeves et al. 1991, Reeves et al. 1993, Spence et al. 1996); however these functions were not examined in our analysis.

According to KKDNRP staff, the large woody debris installed at the Pickering site (Site 1) cost approximately $600 per piece of LWD. This results in a cost to farmers in excess of $5,000 per 100 m of channel maintenance if both sides of the waterway are treated with LWD. Given an

impacted region of less than 0.5 m downstream from each installed piece of LWD, the unit cost of impacted habitat is more than $10 per cm of channel. The economics of such mitigation in terms of hydraulic parameters is not justified.

This study has several limitations that could be addressed through future studies. First, the influence of installed LWD was limited to hydraulic diversity. The influence of LWD on other stream processes, such as cover for fish and nutrient retention, was not addressed. However, the extremely low velocity and turbulence levels infer that there would be little or no effect on sediment scour and deposition and subsequently nutrient and carbon retention. Second, for logistical reasons, the study was restricted to two drainage watercourses and three pieces of LWD. The influence of LWD on hydraulic diversity may be more or less pronounced in other reaches and sites throughout King County. However, the study sites were selected from six potential reaches and were considered to be representative of LWD installed by King County.

7.6 References

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Appendix 7 - A – Survey Data

Table 7-A1. Site 1 (Pickering) survey data

Code	X	Y	Z
Pt 0	194.14	34.70	4.28
Pt 1	194.03	25.76	4.34
Culvert top	193.23	30.01	3.07
X1 Right Bank	185.54	37.49	3.80
X1 Right Side 1	185.48	32.89	2.40
X1 Right Side 2	185.55	31.66	2.22
X1 Right Toe	185.63	30.34	1.79
X1 Water Surface	185.64	30.10	2.21
X1 Right Toe	185.58	30.82	2.04
X1 Left Toe	185.77	29.42	1.99
X1 Left Toe	185.70	27.77	2.22
X1 Left Bank	185.71	22.83	3.50
X1 Left Floodplain	185.19	4.21	3.20
X1 Right Floodplain	185.79	53.58	3.22
Culvert right side	192.65	31.92	2.20
Culvert right entrance	193.16	31.11	2.23
Culvert left side	193.15	29.10	2.22
Culvert left entrance	192.34	28.44	2.23
Left top contraction	176.78	28.34	2.20
Left bank contraction	176.51	27.10	3.58
Left toe contraction	176.76	22.30	3.57
L. front cont	155.17	22.98	3.39
L. bank front cont	155.39	24.94	3.75
L. bank cont 2	155.25	27.34	3.28
L. front cont toe	155.05	28.34	2.22
Right cont top	152.53	36.57	3.78
Right cont bank	152.85	32.37	3.22
R. cont toe top	152.95	31.74	2.63
R. cont front toe	136.68	31.83	2.22
R. cont front bank	136.63	33.36	3.20
R. cont top	136.51	36.83	3.48
X2 right flood plain	91.56	49.96	3.06
X2 right bank	96.31	37.10	2.86
X2 right toe top	96.24	31.62	2.42
X2 right toe bed	96.26	31.21	2.26
X2 bed1	96.34	30.24	1.88
X2 bed2	96.12	29.40	1.80
X2 WS	96.25	29.70	2.21
X2 left toe	96.12	28.05	2.22
X2 left bank	95.99	22.88	2.79
X2 left flood plain	94.36	4.55	2.74
bridge east	3.21	30.91	3.48
bridge west	3.18	27.38	3.49
Pt 0	194.14	34.70	4.28
PT 1	194.06	25.77	4.33
EAST BRIDGE	3.22	30.65	3.45

code	X	Y	Z
X3RTOE	39.51	30.36	2.20
X3WS	39.54	28.62	1.99
X3LT	39.49	28.56	2.21
X3LSIDE	39.45	26.91	2.18
X3LSIDE	39.41	25.59	2.44
X3LB	39.47	22.71	2.81
X3LFP	37.89	6.20	2.66
SOU EXPAN L	29.33	23.09	3.00
SELTOP	29.24	25.13	3.02
SELFRONT	29.54	26.35	2.79
SELLOWER	29.88	25.31	2.20
SELTOE	29.67	28.04	1.92
SELWS	29.54	28.17	2.22
SERTOE	29.98	30.07	2.26
SERTOP	29.92	30.85	2.65
SERB	30.06	34.34	3.20
SERFP	30.30	37.15	2.91
SERTOE	32.99	30.40	2.21
SERB	32.98	30.82	2.68
SERFRONT	32.80	33.64	2.88
SERTOP	32.74	35.14	3.21
SERBANK	32.74	36.61	2.94
X4RFP	15.58	41.19	2.84
X4RB	14.24	32.41	3.01
X4RB2	14.27	30.52	2.62
X4RT	14.30	30.20	2.27
X4BED	14.01	28.82	2.02
X4WS	13.96	28.87	2.28
X4LT	14.00	27.64	2.24
X4LSIDE	13.87	26.73	2.35
X4LB	14.03	25.63	2.95
X4LFP	13.15	15.47	2.76
WS1	34.18	27.90	2.22
WS2	51.85	27.90	2.21
WS3	72.64	28.24	2.22
WS4	93.03	28.51	2.20
WS5	118.14	28.71	2.21
WS6	137.06	28.21	2.20
WS7	188.58	29.35	2.20
PT0	194.16	34.72	4.27
PT1	194.06	25.78	4.33
PT0	194.16	34.67	4.26
LOG UP	100.83	27.81	2.62
LOG DOWN	102.07	29.55	2.01
STANDDSL	103.55	28.58	2.03
SUSL	103.03	28.59	2.21

Table 7-A2. Site 2 (Nelson) survey data

code	X	Y	Z
PTO	211.45	10.99	3.83
PT1	218.27	16.61	3.80
WELL	2.59	-6.03	2.20
PT3	0.70	23.53	7.56
X1RFP	13.37	27.68	2.30
X1RB	12.62	17.91	2.42
X1RT	12.29	14.69	1.87
X1BED	12.10	14.47	1.51
X1BED	11.90	13.62	1.20
X1WS	11.94	13.51	1.61
X1LT	11.74	12.66	1.58
X1LB1	11.94	12.07	2.01
X1LB2	12.15	9.50	2.53
X1LFP	12.26	5.60	2.45
USRIGHT	8.68	18.13	2.51
ESLEFT	7.75	11.64	2.59
ESENTRANCE	9.48	12.75	1.60
USE 2	8.89	13.11	1.32
USE 3	9.43	14.87	1.50
X2RFP	111.10	30.51	1.81
X2RB	111.36	17.36	1.99
X2RB	111.31	16.01	2.01
X2RT	111.23	14.47	1.31
X2RT	111.10	13.20	0.82
X2LT	111.15	11.79	1.32
X2LB	111.12	11.52	1.65
X2LB	111.00	9.19	2.11
X2LTOPBANK	110.86	7.02	2.17
X2LFP	110.65	3.62	2.16
X3LFP	190.17	2.54	2.70
X3LB1	189.93	6.11	2.72
X3LB2	189.55	7.86	2.52
X3LT	189.76	10.09	1.34
X3BED	189.74	12.09	0.65
X3RT	189.53	13.73	1.29

code	X	Y	Z
X3RB	189.31	16.18	2.35
X3RFP	189.23	17.89	2.20
X3RFP	189.81	29.73	2.11
DSRT	210.89	15.24	2.79
DSRT	211.22	8.59	2.78
DSCONT.	210.14	10.66	1.27
DSCONT	210.62	11.99	0.88
DSCONT	210.59	11.47	1.03
DSCONT	210.61	12.54	0.96
DSCONT	209.80	13.13	1.22
DS	208.53	13.33	1.25
DS	210.72	12.01	2.10
WS1	210.41	11.92	1.36
WS2	187.10	13.11	1.34
WS3	159.43	13.11	1.35
WS4	122.39	13.94	1.35
WS5	86.33	13.36	1.35
WS6	55.27	13.55	1.37
WS7	22.25	13.13	1.51
PT0	211.45	10.99	3.84
PT1	218.28	16.66	3.78
ST FRONT	121.32	12.17	2.30
SRL	121.86	12.17	2.26
SRR	121.86	13.49	2.27
SFR	121.34	13.49	2.21
LOG1	120.41	13.83	0.18
L2	120.03	13.78	0.05
L3	120.72	13.12	0.28
L4	120.08	13.22	0.15
L5	119.97	12.16	0.27
L6	119.68	12.25	0.27
STANDLF	118.75	12.41	2.28
SLR	119.30	12.40	2.25
SRR	119.31	13.72	2.19
SRF	118.79	13.73	2.11

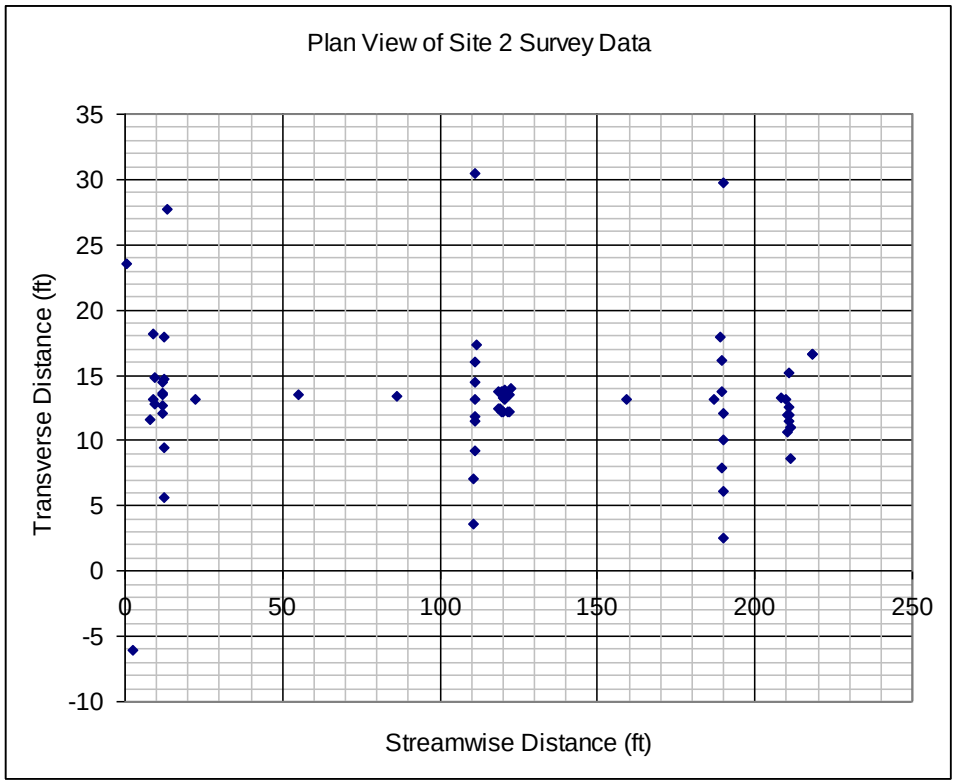

Figure 7-A24. Plan view of survey data from Site 2 (Nelson)

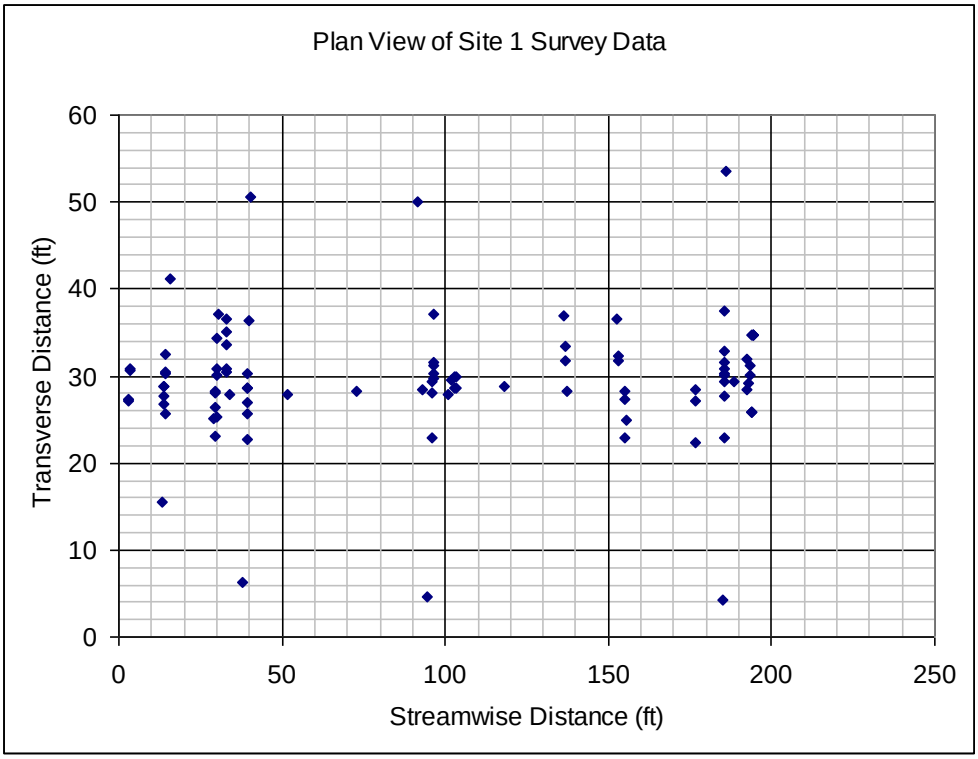

Figure 7-A25. Plan view of survey data from Site 1 (Pickering)

Appendix 7 - B – HEC-RAS Simulation

Table 7-B1. Hydraulic properties table from HEC-RAS simulation

River	Sta	Profile	Q	Total	Min	Ch	El	W.S.	Elev	Crit	W.S.
(m)	(m)	(m)	(cms)	(m/m)	(m/s)	(m2)	(m)				
192	PF	Measured	0.03	0.23	0.48	0.48	0.00049	0.07	0.35	2.83	0.07
192	PF	Bank Full	0.3	0.23	0.99	0.99	0.000273	0.12	2.42	6.26	0.06
167	PF	Measured	0.03	0.39	0.43	0.44	0.099583	0.32	0.08	3.84	0.7
167	PF	Bank Full	0.3	0.39	0.98	0.98	0.000093	0.07	5.17	27.93	0.03
117	PF	Measured	0.03	0.01	0.43	0.43	0.000045	0.03	0.74	3.03	0.02
117	PF	Bank Full	0.3	0.01	0.98	0.98	0.000084	0.06	4.95	23.65	0.03
17	PF	Measured	0.03	0	0.42	0.42	0.000079	0.04	0.68	3.77	0.03
17	PF	Bank Full	0.3	0	0.97	0.97	0.000078	0.07	4.16	8.4	0.03
12	PF	Measured	0.03	0	0.42	0.1	0.42	0.00008	0.04	0.67	3.76
12	PF	Bank Full	0.3	0	0.97	0.28	0.97	0.000078	0.07	4.15	8.39
6	Culvert										
5	PF	Measured	0.03	0	0.42	0.42	0.00008	0.04	0.67	3.76	0.03
5	PF	Bank Full	0.3	0	0.97	0.97	0.00008	0.07	4.12	8.36	0.03
0	PF	Measured	0.03	0	0.42	0.1	0.42	0.00008	0.04	0.67	3.76
0	PF	Bank Full	0.3	0	0.97	0.28	0.97	0.00008	0.07	4.12	8.36

Appendix 7 - C – Turbulence Data

Table 7-C1. Summary of turbulence data for Site

Site 1	X	Y	U Mean	V Mean	W Mean	Vel Mag	X TI	Y TI	Z TI	Ave TI	TKE	Time S	UU Cor	VV Cor	WW Cor	UV Cor	UW Cor	VW Cor	U Skew	V Skew	W Skew	U Kurt	V Kurt	W Kurt
log10001.rot	0	0.00	1.3373	0.2014	-0.1124	1.357043	0.7423	0.6664	0.5723	0.6603	0.6613	2.258427	0.551	0.444	0.3276	0.1056	-0.1583	-0.2147	0.2671	-0.092	0.1574	-0.1878	-0.1719	0.1865
log10002.rot	0	0.15	1.1429	0.9385	-0.4489	1.545482	0.5765	0.439	0.4075	0.4743	0.3456	3.909838	0.3323	0.1927	0.1661	0.0407	-0.0662	-0.0592	0.4011	0.8395	0.2043	0.3086	0.2605	0.5384
log10003.rot	0	0.30	-0.0766	0.2583	0.0483	0.273714	0.4086	0.3577	0.2213	0.3292	0.1719	5.554137	0.1669	0.128	0.049	-0.0379	0.007	-0.0288	-0.2238	0.8508	0.0823	-0.4841	0.7135	0.2643
log10004.rot	0	0.45	-0.0766	0.2583	0.0483	0.273714	0.4086	0.3577	0.2213	0.3292	0.1719	5.554137	0.1669	0.128	0.049	-0.0379	0.007	-0.0288	-0.2238	0.8508	0.0823	-0.4841	0.7135	0.2643
log10005.rot	0	0.60	-0.0663	0.3152	-0.32	0.454034	0.4865	0.3212	0.2578	0.3552	0.2032	2.461126	0.2367	0.1032	0.0665	0.0521	-0.0283	-0.0325	0.3342	-0.3844	-0.2545	-0.3436	-0.6569	0.0866
log10006.rot	0.15	0.00	3.6608	0.3933	-0.4289	3.706764	0.9463	0.6991	0.7387	0.7947	0.965	4.634603	0.8955	0.4888	0.5457	-0.2566	0.1358	-0.2026	-0.0166	0.0188	-0.2305	-0.4127	-0.3375	-0.2075
log10007.rot	0.15	0.15	2.6228	0.5937	-0.3386	2.710389	0.8146	0.6572	0.5354	0.6691	0.6911	1.524163	0.6636	0.4319	0.2867	-0.0538	-0.0411	-0.0987	0.3864	-0.2136	0.0717	-0.0352	-0.3425	0.0208
log10008.rot	0.15	0.30	2.1893	0.1014	-0.2074	2.201438	0.6942	0.6353	0.5256	0.6184	0.5809	1.250172	0.4819	0.4036	0.2763	-0.0407	-0.0739	-0.0905	0.0212	-0.3163	-0.1646	-0.106	-0.405	0.0193
log10009.rot	0.15	0.45	1.6354	0.5915	-0.1806	1.748434	0.7264	0.6743	0.4942	0.6317	0.6133	2.495876	0.5277	0.4547	0.2443	0.1316	-0.1258	-0.1156	0.0131	0.0785	0.2432	-0.3918	-0.5231	-0.0718
log10010.rot	0.15	0.60	0.3676	-0.0888	0.077	0.385933	0.3499	0.2412	0.275	0.2887	0.1281	2.461126	0.1224	0.0582	0.0756	-0.0077	-0.0137	-0.0425	0.2597	0.1542	-0.0513	-0.2882	0.1625	0.0241
log10011.rot	0.3	0.00	2.6863	0.09	0.1439	2.691657	0.7588	0.6651	0.6042	0.676	0.6916	2.207385	0.5757	0.4424	0.3651	-0.2182	-0.0178	-0.1919	0.1244	-0.733	0.4175	-0.2308	0.2207	-0.0798
log10012.rot	0.3	0.15	3.1581	-0.3554	0.5753	3.229686	0.986	0.7285	0.6851	0.7999	0.9861	6.467663	0.9723	0.5307	0.4693	-0.2958	0.0203	-0.0243	-0.1676	0.0602	-0.0726	-0.29	-0.2096	-0.2232
log10013.rot	0.3	0.30	3.8519	-0.7009	0.452	3.941154	0.891	0.8162	0.5906	0.766	0.9045	4.40762	0.7939	0.6662	0.3489	-0.2491	0.0009	-0.1257	0.0223	-0.5517	0.1748	-0.2401	-0.0456	-0.2397
log10014.rot	0.3	0.45	3.5672	-0.9145	0.5724	3.726777	0.9491	0.8104	0.4915	0.7503	0.8996	2.065859	0.9008	0.6567	0.2416	-0.1719	-0.0847	-0.0076	-0.1338	-0.2665	0.1786	-0.4584	0.3727	0.0631
log10015.rot	0.3	0.60	3.2934	-1.1886	0.2246	3.508518	1.2325	1.0354	0.7231	0.997	1.5571	2.273333	1.519	1.0722	0.5229	-0.2401	-0.445	0.1978	0.126	-0.1223	-0.0573	-0.4983	-0.5493	-0.5591
log10016.rot	0.45	0.00	3.1459	-0.1286	0.4937	3.186999	0.7531	0.5686	0.3781	0.5666	0.5167	3.045527	0.5671	0.3233	0.143	-0.1561	0.0039	-0.0456	0.3879	-0.2681	0.2417	-0.1061	-0.0114	0.3375
log10017.rot	0.45	0.15	2.4013	-0.3198	0.3877	2.453329	0.7901	0.6639	0.444	0.6326	0.631	2.855722	0.6242	0.4408	0.1971	-0.1342	-0.0641	-0.0477	0.161	-0.3103	0.5106	-0.3616	0.0058	0.2878
log10018.rot	0.45	0.30	2.6227	-0.2586	0.5373	2.689632	1.0146	0.7499	0.5504	0.7716	0.9473	2.000838	1.0293	0.5623	0.303	-0.1863	-0.0983	-0.006	0.3681	0.21	0.1995	-0.5985	0.3252	-0.1981
log10019.rot	0.45	0.45	1.9681	-0.738	0.7032	2.216428	0.7869	0.8007	0.4491	0.6789	0.7311	2.163473	0.6192	0.6412	0.2017	-0.215	0.0439	-0.1126	0.139	-0.8381	0.1226	0.1196	0.7632	-0.3548
log10020.rot	0.45	0.60	1.6755	-0.724	0.4722	1.885325	0.854	0.9045	0.5013	0.7533	0.8994	1.636202	0.7293	0.8181	0.2513	-0.1095	0.0182	-0.1507	-0.1902	-0.1942	0.2494	0.1158	-0.3447	-0.0827
log10021.rot	0.6	0.00	3.8553	-0.234	0.6747	3.920882	0.672	0.6328	0.3573	0.554	0.4898	1.777307	0.4515	0.4004	0.1276	-0.0687	-0.0171	0.0192	-0.176	-0.3048	0.011	0.2613	0.4169	-0.1275
log10022.rot	0.6	0.15	3.0103	-0.3417	0.4746	3.06658	0.9236	0.6954	0.3487	0.6559	0.729	2.741665	0.8529	0.4835	0.1216	-0.1268	-0.0508	-0.0164	0.2701	-0.2927	-0.3462	-0.3388	-0.0637	0.1105
log10023.rot	0.6	0.30	2.1304	-0.6011	0.4561	2.260078	0.6947	0.737	0.4854	0.639	0.6307	3.627206	0.4826	0.5432	0.2356	-0.0885	-0.019	-0.0959	0.3432	-0.3281	0.0974	-0.4244	0.0481	0.3344
log10024.rot	0.6	0.45	2.8669	-1.1543	0.3945	3.115631	0.9691	0.8715	0.6346	0.8251	1.0507	1.649955	0.9392	0.7595	0.4027	-0.2208	-0.1785	-0.1545	0.1864	0.0654	0.1377	-0.4408	-0.0736	-0.494
log10025.rot	0.6	0.60	1.6615	-0.4902	0.3937	1.776479	1.1838	1.0302	0.6081	0.9407	1.4162	2.754882	1.4014	1.0612	0.3698	-0.6475	-0.1777	-0.0569	0.0448	-0.2965	-0.0661	-0.7247	-0.341	-0.6026
root0001.rot	0	0.00	-0.0205	0.0388	-0.0297	0.052988	0.3579	0.4575	0.1893	0.3349	0.1866	2.510423	0.1281	0.2093	0.0358	-0.0209	0.007	-0.0266	0.2603	-0.2419	0.0406	-0.4153	-0.6579	0.8248
root0002.rot	0	0.15	0.0482	0.027	-0.1538	0.163422	0.3275	0.3565	0.1541	0.2794	0.129	2.984645	0.1072	0.1271	0.0237	0.029	-0.0009	-0.0151	0.2594	0.1154	-0.1479	-0.2216	-0.5903	0.3203
root0003.rot	0	0.30	0.0145	-0.0673	-0.0596	0.091059	0.2637	0.2552	0.1136	0.2108	0.0738	3.883944	0.0695	0.0651	0.0129	0.0199	0.0042	-0.0171	0.0532	0.1052	-0.0007	0.4061	0.5217	0.352
root0004.rot	0	0.45	-0.0489	-0.011	-0.0039	0.050273	0.7082	0.6875	0.3375	0.5777	0.544	0.043256	0.5016	0.4727	0.1139	0.0626	0.0229	-0.2021	0.0155	-0.085	0.0442	0.3794	0.5108	0.3849
root0005.rot	0	0.60	0.0518	0.0127	-0.0136	0.055041	0.8123	0.699	0.3311	0.6141	0.629	0.03751	0.6598	0.4886	0.1096	0.1876	-0.0594	-0.2081	0.0868	-0.0807	0.1807	0.6401	0.5792	0.488
root0006.rot	0.15	0.00	-0.3258	-0.0018	-0.0965	0.339796	0.4542	0.3375	0.2096	0.3338	0.1821	2.719667	0.2063	0.1139	0.0439	0.0518	0.0224	-0.0137	-0.1332	-0.2417	-0.2556	0.7522	0.4286	-0.3478
root0007.rot	0.15	0.15	0.987	0.587	-0.1737	1.161426	0.4054	0.3966	0.2256	0.3425	0.1863	3.281888	0.1643	0.1573	0.0509	0.024	0.0127	-0.0038	-0.6176	-0.3672	0.0674	0.2529	-0.1578	0.1539
root0008.rot	0.15	0.30	-0.055	-0.2165	-0.0159	0.223942	0.2895	0.3767	0.2546	0.3069	0.1453	6.464388	0.0838	0.1419	0.0648	-0.0243	0.0071	0.0124	0.0563	-0.4418	0.5171	-0.2841	0.3245	0.3914
root0009.rot	0.15	0.45	0.0607	0.1912	-0.0934	0.221281	0.205	0.197	0.1243	0.1754	0.0481	0.697898	0.042	0.0388	0.0154	-0.0011	0.0059	-0.0104	0.0693	0.3032	0.3247	0.296	0.2284	0.2289
root0010.rot	0.15	0.60	0.3165	0.5773	-0.2931	0.720663	0.5958	0.743	0.3317	0.5568	0.5085	0.04396	0.3549	0.5521	0.11	-0.0291	0.0692	-0.2113	-0.0212	0.0575	-0.004	0.874	0.6671	0.3687
root0011.rot	0.3	0.00	1.2002	0.5541	-0.0613	1.323354	0.643	0.6705	0.3152	0.5429	0.4812	4.963679	0.4135	0.4495	0.0994	0.1406	0.0089	-0.0463	-0.4801	-0.7399	-0.1015	-0.4347	-0.2341	1.7395
root0012.rot	0.3	0.15	0.8043	-0.8762	0.2119	1.208109	0.4271	0.3777	0.2751	0.3599	0.2003	1.913128	0.1824	0.1426	0.0757	0.0225	0.0177	0.0134	-0.2769	-0.0766	-0.1725	-0.1175	-0.3049	0.1941
root0013.rot	0.3	0.30	0.7917	-1.2108	0.1987	1.460242	0.3477	0.2644	0.1541	0.2554	0.1072	5.054659	0.1209	0.0699	0.0237	0.0174	0.0162	-0.0088	-0.0872	-0.4297	-0.2032	-0.3216	0.1538	0.2262
root0014.rot	0.3	0.45	1.6722	0.7446	0.1172	1.834235	0.2498	0.3218	0.1376	0.2364	0.0924	4.186107	0.0624	0.1035	0.0189	0.0303	-0.003	-0.0277	0.1642	-0.1955	-0.1203	0.8246	-0.4464	-0.0786
root0015.rot	0.3	0.60	1.4968	0.0797	0.1517	1.506577	0.2461	0.2174	0.119	0.1942	0.061	2.687627	0.0606	0.0473	0.0142	-0.0032	0.0047	-0.0166	-0.1117	0.237	0.1879	0.1893	0.3515	0.138
root0016.rot	0.45	0.00	4.6356	1.0297	0.7747	4.811365	0.8729	0.5669	0.3529	0.5975	0.6039	4.329483	0.7619	0.3214	0.1245	-0.0325	0.0316	-0.0565	-0.6426	0.129	-0.0192	0.8234	-0.1055	0.0604
root0017.rot	0.45	0.15	2.0831	0.4731	0.0017	2.136149	0.4875	0.4931	0.2718	0.4175	0.2773	3.582132	0.2376	0.2432	0.0739	0.0525	0.0284	-0.0013	-0.0286	-0.0291	0.0046	0.0152	-0.2308	-0.1219
root0018.rot	0.45	0.30	2.2808	0.0941	0.1454	2.287366	0.4789	0.4369	0.3406	0.4188	0.2681	2.832833	0.2293	0.1909	0.116	0.0569	0.0222	-0.0236	0.0969	0.2343	0.1112	-0.1464	-0.0902	-0.1632
root0019.rot	0.45	0.45	2.1616	0.5924	-0.1391	2.245618	0.5769	0.3827	0.3289	0.4295	0.2937	3.160686	0.3328	0.1464	0.1082	0.027	-0.0229	0.0033	0.1057	-0.271	-0.2832	-0.626	-0.2491	-0.0923
root0020.rot	0.45	0.60	3.2697	0.7792	0.1705	3.365585	0.2353	0.2209	0.151	0.2024	0.0635	0.979163	0.0554	0.0488	0.0228	-0.0084	0.0067	-0.0152	1.0234	0.4829	-0.0242	12.5773	0.4113	-0.5166
root0021.rot	0.6	0.00	2.9579	0.6917	0.1311	3.040528	0.9774	0.7369	0.4883	0.7342	0.8684	1.107531	0.9553	0.543	0.2385	-0.0695	0.0317	-0.0272	-0.4232	0.2171	0.1501	0.5439	-0.1886	-0.0722
root0022.rot	0.6	0.15	3.2786	0.3117	0.4911	3.329798	0.662	0.7239	0.4376	0.6078	0.5769	1.156831	0.4383	0.524	0.1915	0.0676	0.0896	0.0381	-0.1245	-0.0031	0.2018	-0.1712	0.0169	-0.2935
root0023.rot	0.6	0.30	2.1611	0.7259	0.0648	2.280676	0.7645	0.8527	0.4618	0.693	0.7624	2.106941	0.5845	0.7271	0.2133	0.0315	0.0192	0.0908	0.1092	0.2083	0.0561	-0.3297	-0.1767	0.1592
root0024.rot	0.6	0.45	3.7209	0.3352	0.7246	3.805588	0.571	0.4985	0.3737	0.4811	0.3571	1.010671	0.3261	0.2485	0.1397	0.0378	0.012	0.0418	-0.063	-0.1179	-0.4156	0.1034	0.0163	0.265
root0025.rot	0.6	0.60	2.1195	0.77	0.1515	2.260118	0.5537	0.5374	0.2869	0.4593	0.3388	5.043436	0.3066	0.2888	0.0823	0.1009	0.0197	0.0241	0.2711	0.1796	0.0663	0.0637	0.0409	-0.2505
log10001.rot	0	0.00	1.3244	-0.1544	0.1631	1.343308	0.5013	0.4358	0.354	0.4304	1.392	3.778628	0.2513	0.19	0.1253	0.0881	0.0442	0.0375	0.2102	0.377	-0.2808	0.4236	-0.0489	-0.1525
log10002.rot	0	0.15	1.2651	-0.3725	-0.08	1.321225	0.4969	0.426	0.3383	0.4204	2.4783	2.472975	0.2469	0.1815	0.1144	0.011	-0.0147	-0.0553	0.3077	0.6526	-0.1832	0.5838	0.6641	0.1847
log10003.rot	0	0.30	1.0484	-0.2516	-0.1007	1.08286	0.4615	0.5906	0.6059	0.5527	1.5966	1.518243	0.213	0.3488	0.3671	0.0867	-0.0601	-0.0767	0.2304	0.3099	-1.0675	0.273	-0.6756	1.2385
log10004.rot	0	0.45	2.1355	-0.1676	-0.1017	2.14448	0.5924	0.6987	0.4062	0.5657	2.1809	2.039881	0.3509	0.4882	0.165	-0.041	0.004	0.0316	-0.0325	0.2265	-0.2808	-0.1911	-0.4399	0.0066
log10005.rot	0	0.60	2.1281	0.2387	-0.2847	2.160287	0.9237	0.8799	0.6739	0.8259	2.7738	4.135463	0.8532	0.7743	0.4542	0.0511	-0.0169	0.1047	-0.0652	0.7177	0.2121	-0.2189	0.0406	-0.3017
log10006.rot	0.15	0.00	1.9785	0.1905	-0.294	2.009276	1.1344	1.0851	0.5653	0.9283	0.2833	6.993979	1.2868	1.1775	0.3196	0.5782	0.0082	0.0607	0.6768	0.3018	-0.058	0.0339	-0.7671	0.1874
log10007.rot	0.15	0.15	2.9128	-0.203	2.2876	3.709276	1.6467	1.003	1.1131	1.2543	0.2714	7.430659	2.7115	1.0061	1.239	0.2436	0.8182	0.2411	-0.4362	0.3075	-0.3681	-0.3634	0.2927	-0.095
log10008.rot	0.15	0.30	2.1885	0.8293	0.0232	2.340472	1.3389	0.8846	0.7861	1.0032	0.4644	7.696024	1.7928	0.7824	0.6179	-0.0047	-0.304	0.0124	0.2901	0.1318	0.1375	-0.522	0.1469	0.0604
log10009.rot	0.15	0.45	2.0969	-0.0209	0.4032	2.135415	1.3232	1.2266	1.0519	1.2006	0.502	6.148907	1.7508	1.5045	1.1065	0.0938	-0.1084	0.2481	0.0586	0.2939	-0.1364	-0.5629	-0.0023	-0.5932
log10010.rot	0.15	0.60	4.3923	-0.8982	3.4767	5.673315	1.6478	1.0226	1.3367	1.3357	1.0408	3.140224	2.7152	1.0458	1.7867	0.2206	0.9417	0.0706	-0.381	0.0406	-0.7686	-0.0433	-0.1635	-0.0949
log10011.rot	0.3	0.00	0.4624	-0.5712	-0.4517	0.862622	0.5497	0.5684	0.3334	0.4838	0.3682	7.089049	0.3022	0.3231	0.1111	0.0371	0.0259	0.0265	0.1491	0.2027	-0.0431	0.1321	-0.4516	1.4825
log10012.rot	0.3	0.15	-0.024	-0.3334	-0.3439	0.479582	0.2918	0.4467	0.2706	0.3363	0.1789	7.201289	0.0851	0.1995	0.0732	0.0137	-0.0222	-0.0063	-0.1081	-0.08	-0.4595	-0.0395	-0.9448	1.1251
log10013.rot	0.3	0.30	4.5113	0.0753	-0.4339	4.532744	0.9928	0.8273	0.7803	0.8668	1.1394	4.747065	0.9857	0.6844	0.6088	0.416	0.1309	0.2554	-0.4506	-0.1826	-0.2605	-0.2105	0.0004	0.1932
log10014.rot	0.3	0.45	4.4594	0.0304	-0.0534	4.459823	1.2369	1.0367	0.8726	1.0487	1.6831	2.327341	1.53	1.0747	0.7614	0.5402	-0.4456	-0.0066	0.2289	-0.1272	-0.0683	-0.7748	-0.1174	-0.4891
log10015.rot	0.3	0.60	4.1085	0.2578	-0.1905	4.120986	1.1735	0.926	0.7918	0.9638	1.4308	3.832603	1.3772	0.8575	0.627	0.4106	-0.0901	0.178	0.0286	-0.2112	0.3423	-0.6862	0.24	-0.0905
log10016.rot	0.45	0.00	5.0239	0.0274	-0.0097	5.023984	0.596	0.5651	0.4059	0.5224	0.4197	2.69777	0.3553	0.3193	0.1648	-0.0749	-0.0421	-0.0025	0.249	-0.008	-0.2491	-0.1365	0.2437	-0.081
log10017.rot	0.45	0.15	5.1553	0.158	-0.09	5.158506	0.7437	0.7058	0.6135	0.6876	0.7138	2.154106	0.553	0.4981	0.3764	-0.0042	-0.1249	0.0672	-0.03	-0.1236	0.0612	-0.1498	0.0311	0.0492
log10018.rot	0.45	0.30	4.6858	0.187	-0.0105	4.689542	0.7151	0.6457	0.4719	0.6109	0.5755	4.07355	0.5114	0.417	0.2227	-0.1023	0.0128	-0.0254	0.0315	-0.2882	-0.1704	-0.2769	-0.0852	-0.0259
log10019.rot	0.45	0.45	3.7871	-0.3653	0.1959	3.809717	0.5443	0.3794	0.2784	0.4007	0.2588	7.284831	0.2962	0.144	0.0775	-0.0701	-0.038	-0.0008	0.1218	0.2578	0.478	-0.6578	0.3574	0.5442
log10020.rot	0.45	0.60	4.2507	-0.3615	0.1255	4.26789	0.4366	0.3778	0.3669	0.3938	0.234	2.374294	0.1906	0.1427	0.1346	0.0118	-0.0509	0.0091	-0.1802	-0.2549	-0.0893	0.1003	0.3978	0.1189
log10021.rot	0.6	0.00	3.7633	-0.1699	0.2589	3.776019	0.3837	0.4378	0.331	0.3842	0.2242	1.077197	0.1472	0.1917	0.1096	-0.0069	-0.0177	0.0182	0.0139	-0.2895	0.1117	0.0997	0.5042	-0.2661
log10022.rot	0.6	0.15	4.6721	0.1609	0.2077	4.679481	0.5946	0.5658	0.382	0.5141	0.4098	3.143803	0.3535	0.3202	0.1459	-0.0516	-0.0028	-0.0079	0.2513	-0.1599	-0.1203	0.2056	-0.4098	0.1383
log10023.rot	0.6	0.30	3.8115	-0.0173	0.3683	3.829292	0.5741	0.5616	0.3841	0.5066	0.3963	2.031976	0.3296	0.3154	0.1476	-0.122	0.0108	0.0524	0.2572	-0.2103	0.0142	-0.0374	-0.4538	-0.2924
log10024.rot	0.6	0.45	3.5088	-0.0196	0.2971	3.52141	0.5076	0.5818	0.3369	0.4754	0.3548	2.613317	0.2576	0.3385	0.1135	-0.0994	-0.0201	0.0341	0.3232	-0.1635	-0.2169	-0.0986	-0.3524	-0.1715
log10025.rot	0.6	0.60	2.5785	0.2905	0.2494	2.606771	0.4078	0.3841	0.2539	0.3486	0.1892	1.904731	0.1663	0.1476	0.0645	-0.0229	-0.0316	0.0344	0.2727	-0.1026	-0.0564	-0.1229	0.1167	0.1473

Table 7-C2. Summary of turbulence data for Site 1

input	X	Y	U Mean	V Mean	W Mean	Vel Mag	X TI	Y TI	Z TI	Ave TI	TKE	Time S	UU Cor	VV Cor	WW Cor	UV Cor	UW Cor	VW Cor	U Skew	V Skew	W Skew	U Kurt	V Kurt	W Kurt
unob0001.rot	0	0.00	4.5113	0.0753	-0.4339	4.532744	0.9928	0.8273	0.7803	0.8668	1.1394	4.747065	0.9857	0.6844	0.6088	0.416	0.1309	0.2554	-0.4506	-0.1826	-0.2605	-0.2105	0.0004	0.1932
unob0002.rot	0	0.15	4.4594	0.0304	-0.0534	4.459823	1.2369	1.0367	0.8726	1.0487	1.6831	7.201289	1.53	1.0747	0.7614	0.5402	-0.4456	-0.0066	0.2289	-0.1272	-0.0683	-0.7748	-0.1174	-0.4891
unob0003.rot	0	0.30	4.1085	0.2578	-0.1905	4.120986	1.1735	0.926	0.7918	0.9638	1.4308	3.832603	1.3772	0.8575	0.627	0.4106	-0.0901	0.178	0.0286	-0.2112	0.3423	-0.6862	0.24	-0.0905
unob0004.rot	0	0.45	5.0239	0.0274	-0.0097	5.023984	0.596	0.5651	0.4059	0.5224	0.4197	2.69777	0.3553	0.3193	0.1648	-0.0749	-0.0421	-0.0025	0.249	-0.008	-0.2491	-0.1365	0.2437	-0.081
unob0005.rot	0	0.60	5.1553	0.158	-0.09	5.158506	0.7437	0.7058	0.6135	0.6876	0.7138	2.154106	0.553	0.4981	0.3764	-0.0042	-0.1249	0.0672	-0.03	-0.1236	0.0612	-0.1498	0.0311	0.0492
unob0006.rot	0.15	0.00	4.6858	0.187	-0.0105	4.689542	0.7151	0.6457	0.4719	0.6109	0.5755	4.07355	0.5114	0.417	0.2227	-0.1023	0.0128	-0.0254	0.0315	-0.2882	-0.1704	-0.2769	-0.0852	-0.0259
unob0007.rot	0.15	0.15	3.7871	-0.3653	0.1959	3.809717	0.5443	0.3794	0.2784	0.4007	0.2588	7.284831	0.2962	0.144	0.0775	-0.0701	-0.038	-0.0008	0.1218	0.2578	0.478	-0.6578	0.3574	0.5442
unob0008.rot	0.15	0.30	4.2507	-0.3615	0.1255	4.26789	0.4366	0.3778	0.3669	0.3938	0.234	2.374294	0.1906	0.1427	0.1346	0.0118	-0.0509	0.0091	-0.1802	-0.2549	-0.0893	0.1003	0.3978	0.1189
unob0009.rot	0.15	0.45	3.7633	-0.1699	0.2589	3.776019	0.3837	0.4378	0.331	0.3842	0.2242	1.077197	0.1472	0.1917	0.1096	-0.0069	-0.0177	0.0182	0.0139	-0.2895	0.1117	0.0997	0.5042	-0.2661
unob0010.rot	0.15	0.60	4.6721	0.1609	0.2077	4.679481	0.5946	0.5658	0.382	0.5141	0.4098	2.031976	0.3535	0.3202	0.1459	-0.0516	-0.0028	-0.0079	0.2513	-0.1599	-0.1203	0.2056	-0.4098	0.1383
unob0011.rot	0.3	0.00	3.8115	-0.0173	0.3683	3.829292	0.5741	0.5616	0.3841	0.5066	0.3963	3.143803	0.3296	0.3154	0.1476	-0.122	0.0108	0.0524	0.2572	-0.2103	0.0142	-0.0374	-0.4538	-0.2924
unob0012.rot	0.3	0.15	3.5088	-0.0196	0.2971	3.52141	0.5076	0.5818	0.3369	0.4754	0.3548	2.613317	0.2576	0.3385	0.1135	-0.0994	-0.0201	0.0341	0.3232	-0.1635	-0.2169	-0.0986	-0.3524	-0.1715
unob0013.rot	0.3	0.30	2.9078	0.1143	0.4362	2.942556	0.4687	0.3974	0.3934	0.4198	0.2662	2.408839	0.2197	0.1579	0.1548	-0.0122	-0.0503	0.0196	0.2435	-0.3533	-0.0327	0.0989	0.0628	-0.2915
unob0014.rot	0.3	0.45	2.9186	0.2071	0.2463	2.936287	0.4134	0.3336	0.2604	0.3358	0.175	2.384758	0.1709	0.1113	0.0678	-0.0442	-0.0419	0.0465	0.1543	-0.0019	-0.162	0.163	-0.04	0.1302
unob0015.rot	0.3	0.60	2.8267	-0.0137	0.2826	2.840824	0.6735	0.5464	0.3906	0.5369	0.4524	6.347699	0.4536	0.2986	0.1526	-0.0438	-0.1352	0.0672	-0.1578	-0.4067	-0.4041	-0.513	0.4606	-0.0565
unob0016.rot	0.45	0.00	2.037	0.2776	0.3151	2.079836	0.8372	0.4294	0.311	0.5259	0.491	9.168377	0.7009	0.1844	0.0967	-0.1292	-0.0014	0.0264	-0.5604	-0.3506	0.2447	-0.5308	0.0434	0.3084
unob0017.rot	0.45	0.15	2.5785	0.2905	0.2494	2.606771	0.4078	0.3841	0.2539	0.3486	0.1892	1.904731	0.1663	0.1476	0.0645	-0.0229	-0.0316	0.0344	0.2727	-0.1026	-0.0564	-0.1229	0.1167	0.1473
unob0018.rot	0.45	0.30	1.8111	0.3914	0.2374	1.868057	0.7309	0.4282	0.3719	0.5103	0.428	5.209497	0.5342	0.1833	0.1383	-0.0779	-0.1264	0.0637	0.3382	-0.1438	0.2945	-0.1733	0.0778	-0.3464
unob0019.rot	0.45	0.45	1.3226	0.3202	0.2372	1.381326	0.5712	0.4135	0.2702	0.4183	0.2851	6.639335	0.3262	0.1709	0.073	-0.0148	-0.0573	-0.0059	-0.0244	-0.0222	-0.2213	-0.7686	0.433	0.0932
unob0020.rot	0.45	0.60	1.0624	0.2249	0.1541	1.096823	0.5129	0.3671	0.1574	0.3458	0.2113	6.639335	0.2631	0.1348	0.0248	0.0323	-0.0085	0.0196	1.1167	-0.4015	0.2727	1.1586	-0.1678	-0.4334
unob0021.rot	0.6	0.00	0.8144	0.2645	0.1712	0.873222	0.3508	0.3191	0.26	0.31	0.1463	2.525507	0.1231	0.1019	0.0676	0.0173	-0.013	-0.0033	0.6749	-0.0945	-0.6541	0.4648	0.3255	-0.2347
unob0022.rot	0.6	0.15	0.575	0	0.1739	0.600721	0.5277	0.3682	0.2718	0.3892	0.2439	9.902772	0.2784	0.1356	0.0739	-0.1125	-0.0554	0.0436	0.2206	-0.001	0.3506	-0.3711	-0.1302	-0.6827
unob0023.rot	0.6	0.30	0.5109	0.166	-0.0398	0.538664	0.4169	0.2906	0.3546	0.3541	0.192	7.141275	0.1738	0.0845	0.1258	-0.0057	0.0056	0.0362	0.6991	-0.0119	0.2762	-0.232	-0.3304	-0.5005
unob0024.rot	0.6	0.45	-0.5176	-0.2787	-0.1943	0.619141	0.2792	0.3687	0.1668	0.2715	0.1208	2.042273	0.0779	0.1359	0.0278	-0.0136	-0.0016	0.0391	0.1324	-0.2565	-0.9031	-0.1423	0.0878	2.1474
wood0001.rot	0	0.60	1.3244	-0.1544	0.1631	1.343308	0.5013	0.4358	0.354	0.4304	0.2833	3.778628	0.2513	0.19	0.1253	0.0881	0.0442	0.0375	0.2102	0.377	-0.2808	0.4236	-0.0489	-0.1525
wood0002.rot	0	0.00	1.2651	-0.3725	-0.08	1.321225	0.4969	0.426	0.3383	0.4204	0.2714	2.472975	0.2469	0.1815	0.1144	0.011	-0.0147	-0.0553	0.3077	0.6526	-0.1832	0.5838	0.6641	0.1847
wood0003.rot	0	0.15	1.0484	-0.2516	-0.1007	1.08286	0.4615	0.5906	0.6059	0.5527	0.4644	1.518243	0.213	0.3488	0.3671	0.0867	-0.0601	-0.0767	0.2304	0.3099	-1.0675	0.273	-0.6756	1.2385
wood0005.rot	0	0.45	2.1355	-0.1676	-0.1017	2.14448	0.5924	0.6987	0.4062	0.5657	0.502	2.039881	0.3509	0.4882	0.165	-0.041	0.004	0.0316	-0.0325	0.2265	-0.2808	-0.1911	-0.4399	0.0066
wood0006.rot	0	0.60	2.1281	0.2387	-0.2847	2.160287	0.9237	0.8799	0.6739	0.8259	1.0408	4.135463	0.8532	0.7743	0.4542	0.0511	-0.0169	0.1047	-0.0652	0.7177	0.2121	-0.2189	0.0406	-0.3017
wood0007.rot	0.15	0.00	1.9785	0.1905	-0.294	2.009276	1.1344	1.0851	0.5653	0.9283	1.392	6.993979	1.2868	1.1775	0.3196	0.5782	0.0082	0.0607	0.6768	0.3018	-0.058	0.0339	-0.7671	0.1874
wood0008.rot	0.15	0.15	2.9128	-0.203	2.2876	3.709276	1.6467	1.003	1.1131	1.2543	2.4783	7.430659	2.7115	1.0061	1.239	0.2436	0.8182	0.2411	-0.4362	0.3075	-0.3681	-0.3634	0.2927	-0.095
wood0009.rot	0.15	0.30	2.1885	0.8293	0.0232	2.340472	1.3389	0.8846	0.7861	1.0032	1.5966	7.696024	1.7928	0.7824	0.6179	-0.0047	-0.304	0.0124	0.2901	0.1318	0.1375	-0.522	0.1469	0.0604
wood0010.rot	0.15	0.45	2.0969	-0.0209	0.4032	2.135415	1.3232	1.2266	1.0519	1.2006	2.1809	6.148907	1.7508	1.5045	1.1065	0.0938	-0.1084	0.2481	0.0586	0.2939	-0.1364	-0.5629	-0.0023	-0.5932
wood0011.rot	0.15	0.60	4.3923	-0.8982	3.4767	5.673315	1.6478	1.0226	1.3367	1.3357	2.7738	3.140224	2.7152	1.0458	1.7867	0.2206	0.9417	0.0706	-0.381	0.0406	-0.7686	-0.0433	-0.1635	-0.0949
wood0012.rot	0.3	0.00	0.4624	-0.5712	-0.4517	0.862622	0.5497	0.5684	0.3334	0.4838	0.3682	7.089049	0.3022	0.3231	0.1111	0.0371	0.0259	0.0265	0.1491	0.2027	-0.0431	0.1321	-0.4516	1.4825
wood0013.rot	0.3	0.15	-0.024	-0.3334	-0.3439	0.479582	0.2918	0.4467	0.2706	0.3363	0.1789	2.327341	0.0851	0.1995	0.0732	0.0137	-0.0222	-0.0063	-0.1081	-0.08	-0.4595	-0.0395	-0.9448	1.1251