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MOVEMENT AND SUMMER HABITAT OF BROWN TROUT (*SALMO TRUTTA*) BELOW A PULSED DISCHARGE HYDROELECTRIC GENERATING STATION

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ABSTRACT

Radiotelemetry was used to investigate detailed movement and summer habitat of brown trout *Salmo trutta* (size range 157–488 mm TL, $n = 18$) in the Kananaskis River, Alberta. Flows in the Kananaskis River respond to pulsed daily discharge from an upstream hydroelectric generating facility (range 0.15–25 $m^3 s^{-1}$). Wetted area available for brown trout doubled during periods of high flow. Fluctuating river levels did not appear to influence the degree to which brown trout moved within the study site. However, there was evidence that brown trout used cover and pools more as discharge increased. During high flow conditions, brown trout used similar depths (63 cm), and significantly lower surface water velocities than during low flow conditions. Brown trout also moved closer to shore into interstitial spaces among woody debris and root complexes during high flow. Pool habitats were used most often compared with all other habitat types combined. Pools with large woody debris accounted for 75% of all habitat observations. Woody debris was used more often than all other cover types. Results of the study indicate that the effects of river regulation on brown trout appear to have been moderated by woody debris in pools and along river banks, which provided refuge from high water velocities during periods of high flow.

KEY WORDS: pool habitats; *Salmo trutta*; summer habitat

INTRODUCTION

River regulation and specifically hydro-peaking limit the quality and quantity of habitat available for use by resident fishes (Reiser *et al*., 1989; Valentin *et al*., 1994). Disturbance and instability associated with fluctuating river levels results in dynamic environmental conditions that fish must adapt to if they are to persist (Power *et al*., 1988; Dudgeon, 1991). River depth, velocities, temperature, turbidity and other water chemistry variables are altered by pulsed reservoir discharges associated with on-demand hydroelectric power generation. Downstream from hydroelectric dams, fish may shift between temporarily suitable habitats to compensate for periodic reductions in the quality or availability of habitat (Kraft, 1972). Depending on the frequency and intensity of water level fluctuation, movement from one suitable habitat type to another may be an energetically adaptive strategy to facilitate survival in regulated rivers. Understanding the effects of flow regulation on habitat use (Nestler *et al*., 1989; Pert and Erman, 1994), fish distributions (Pert and Erman, 1994), community structure (Bain *et al*., 1988; Valentin *et al*., 1994) and behaviour, requires detailed observation and analysis to implement suitable flow regimes that are consistent with the concepts of sustainable development.

Previous attempts to examine the influence of flow on salmonids have been restricted to snorkelling observations (Rincón and Lobón-Cervia, 1993; Pert and Erman, 1994) and electrofishing (Heggenes, 1988a; Valentin *et al*., 1994). Turbidity, water depth, water velocity and debris can compromise the accuracy and reliability of these methods. Furthermore, none of these methods can account for the influence of flow regulation on diel activity. Recent reductions in the size and weight of radio transmitters

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permit the behavioural response of fish in rivers to be continuously monitored over 24 h periods with minimal influences of depth, flow and debris. Telemetry has been used in a number of published reports to study brown trout in unregulated rivers (Clapp *et al.*, 1990; Meyers *et al.*, 1992; Young, 1994, 1995). Both Clapp *et al.* (1990) and Young (1995) indicated that radio-tagged brown trout recovered quickly from surgery and did not behave differently than untagged fish.

In unregulated rivers, telemetry has been used to illustrate the importance of structure, in particular, woody debris and areas of low water velocity (i.e. pools) to adult brown trout (Clapp *et al.*, 1990; Young, 1995). The degree to which daily changes in water flow from a peaking, or pulsed-discharge hydroelectric generating station influence movement and habitat use by brown trout is not known. The objective of the present study was to examine the daily movement and changes in habitat use by brown trout relative to flow regulation using radio telemetry.

MATERIALS AND METHODS

Study site and flow regimes

The Kananaskis River is located in south-western Alberta, Canada (50°37′–51°01′N; 115°08′–115°08′W; Figure 1). It flows 84 km northward from the most upstream reservoir, Upper Kananaskis Lake, through Lower Kananaskis Lake and Barrier Lake to the Bow River. The Kananaskis River has been impounded three times since 1936. Barrier Lake was created when the Kananaskis River was dammed in 1947 to reduce the effects of ice jams created by fluctuating flows from Upper Kananaskis Reservoir, which was constructed in 1942. In 1955, Lower Kananaskis Lake was created, and since then, the daily discharge for approximately 40 km downstream to Barrier Lake has fluctuated in response to generation flows released from the Pocaterra Hydroelectric Generating Station. Daily but somewhat irregularly timed periods of high discharge (>48 m^3 s^{-1}) have caused marked fluctuations in river levels (Nelson, 1965). Fish species present in the study area included brown trout, brook trout (*Salvelinus fontinalis*), mountain whitefish (*Prosopium williamsoni*) and cutthroat trout (*Oncorhynchus clarki*).

The present study was conducted between the inlet to Barrier Lake and 1 km upstream from the Nakiska Bridge (sections 1–4, Figure 1). This region was chosen based on accessibility, and prior observations that revealed sufficient numbers of brown trout for the execution of this study. During extensive electrofishing surveys in the area upstream from the Nakiska Bridge, only juvenile brown trout were observed (mean length 62 mm TL, $n = 10$; Paul, Marion Environmental, personal communication). Coincident with the present study, comparisons were made between brown trout areal biomass in channelized versus unchannelized sections of the Kananaskis River. There was a twofold increase in brown trout biomass in unchannelized areas of the river with woody debris (95% confidence interval: 0.16–0.23 kg ha^{-1}) compared with channelized sections (95% confidence interval: 0.07–0.16 kg ha^{-1}; Paul, Marion Environmental, personal communication). In addition to electrofishing catch-depletion population estimates, habitat availability models (weighted usable area (WUA) and wetted area) were available for the study site.

Instream flow incremental methodology (IFIM) models (Bovee, 1982; Orth and Maughan, 1986) permitted comparisons to be made between habitat availability and river discharge. The Kananaskis River study used a new two-dimensional hydrodynamic model (River2D) to simulate river flows and fish habitat (Ghanem *et al.*, 1996). The model was calibrated with flow measurements and riverbed topography at two segments of the Kananaskis River—one just downstream of the Nakiska Bridge (Figure 1) and one upstream from the study area. These calibrations demonstrated that the model was capable of simulating realistically complex features of the river, such as flows around gravel bars and multi-channel (braided) sections, and flows at rapids and within pools (Courtney *et al.*, 1998). Depths and velocities from the hydrodynamic model were used to estimate wetted area and WUA using preference curves developed from fish observations in the Kananaskis River (Courtney *et al.*, 1998). Information from these models allowed us to compare areas that were used by brown trout during high and low flow conditions and to illustrate the degree to which habitat availability changed on a daily basis.

Radio-tagging

Brown trout were caught by back-pack electrofishing (Smith-Root Type VII) from 27 July–2 August 1996. Micro-radiotags (Lotek Engineering Ltd., 0.75 g in air, 0.5 g in water, $12 \times 5 \times 7$ mm) with unique frequencies (148.200–149.200 MHz) were surgically implanted into 18 brown trout (size range 157–488 mm TL, mean 332 ± 28 mm).

Brown trout were initially anaesthetized in 10 L of river water with a 50 mL L^{-1} clove oil/ethanol mixture (0.5 mL clove-oil (Anderson *et al.*, 1997) emulsified in 4.5 mL ETOH). After anaesthesia was induced (i.e. after regular opercular movement had ceased), total length (mm) and weight (g) were recorded. Fish were then placed dorsal side down into foam padding in which slits had been cut to provide support during surgery. Head and gills were submerged in 8 L of aerated river water with a maintenance concentration of 25 mL L^{-1} clove oil/ETOH anaesthetic. A 1 cm incision was made posterior to the left pelvic fin. Using an 18 G hypodermic needle, a small puncture was made, anterior and slightly lateral to the urogenital pore, through the body wall. A 150 mm spinal tap needle with a blunt tip was then inserted into the puncture, through the body cavity, and out of the incision. The 30 cm antenna of the transmitter was then inserted into the tip of the needle, which was subsequently withdrawn, leaving the antenna threaded through the puncture near the vent. The transmitter was inserted into the

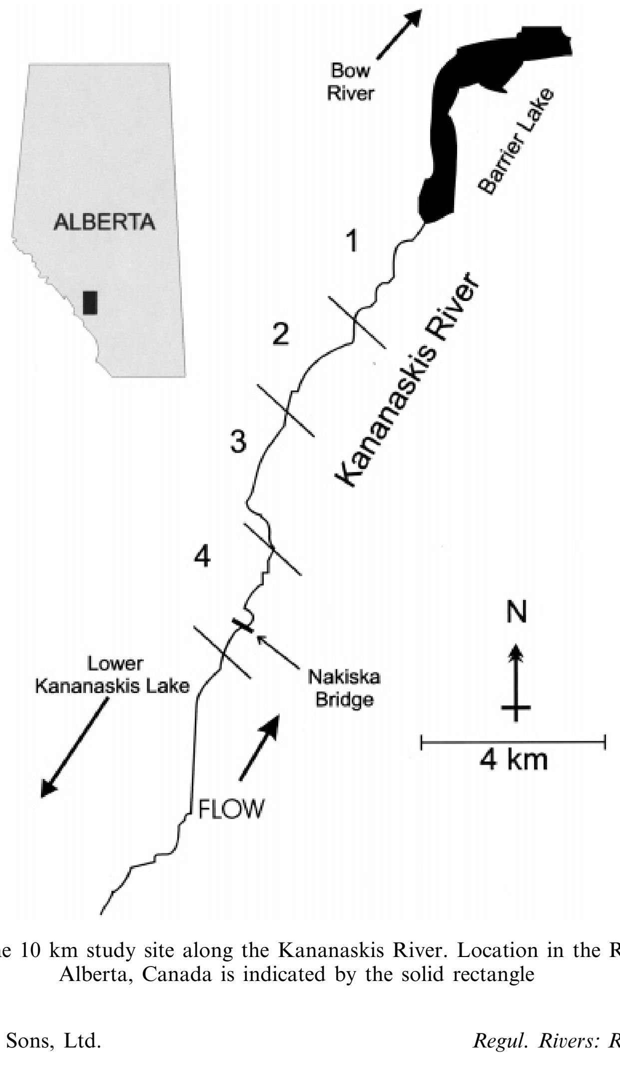

Figure 1. The four sections of the 10 km study site along the Kananaskis River. Location in the Rocky Mountains of southwest Alberta, Canada is indicated by the solid rectangle

body cavity and the incision was closed with one or two sutures of Ethicon 1-0 non-absorbable braided silk. Surgery and recovery required < 10 min. Pilot experiments in which tagged and untagged fish were observed for several days revealed no physical or behavioural impacts of the transmitters. Visual observations suggested that there were no obvious behavioural differences among fish before or after they were tagged and clove oil anaesthetic has been shown to have negligible post-surgical effects on the swimming behaviour of small salmonids (Anderson *et al.*, 1997). After the procedure, fish were released within 1 h at the site of capture. We began collecting data from the positions of radio-tagged fish the day after surgery, thereby allowing each fish approximately 24 h to recover in their natural habitat.

Tracking and habitat characteristics

Fish movements were monitored using a sequential scanning receiver (Lotek Eng. Inc. SRX_400) and a hand-held H-antenna from 29 July 1996 to 16 August 1996. Tracking was conducted manually on foot, over 24 h periods and we attempted to locate each fish every day and night for the duration of the study period. Fish movements and general habitat use (e.g. pool, riffle or run) were determined to within 100 m^2. Micro-habitat characteristics were determined from fish positions that were usually located to within < 1 m^2 by observers who carefully waded the river and walked along the banks during daylight hours. At each fish location, river status (i.e. high or low flow) and fish movements relative to previous positions were recorded. To describe displacements, daily positions of fish were plotted on scale maps. Maximum displacement was calculated as the difference between the furthest upstream position and furthest downstream position of each fish. When possible, tracking was conducted in Barrier Lake by boat and helicopter and to a distance of 20 km upstream from the Nakiska Bridge, by vehicle, to establish positions of any lost transmitters and to avoid underestimates of movement (Gowan *et al.*, 1994).

Primary habitats used by fish included pools, riffles and runs as described in Bisson *et al.* (1982). Several micro-habitat variables were examined from the positions of fish within these habitat types during both high flow and low flow conditions. Water velocities were measured at three points; 10 cm below the surface, at 0.6 depth (average velocity) and 10 cm above the river bed (bottom velocity) with a Sigma PVM flowmeter and a Marsh McBirney Model 511 M flowmeter. Velocities were recorded as 10 s averages to the nearest $cm\,s^{-1}$. Water depths were measured using a calibrated rod and water temperatures were measured with a pocket thermometer. Distances to nearest shoreline or nearest vegetation-bearing island and distances to nearest available cover were measured to within 0.1 m. Substrate use was recorded according to a modified Wentworth scale (Cummins, 1962) as silt and sand (< 2 mm), gravel (2–16 mm), pebble (17–64 mm), cobble (65–256 mm) and boulder (> 256 mm). Overhead and instream cover use was also documented. Fish were determined to be using cover if they were located < 0.5 m from any cover type. Cover types were divided into four categories that included undercut banks, overhanging vegetation, woody debris, and root complexes. Roots were considered to be distinct from woody debris if they were anchored to the stream bed or river bank. Undercut banks were classified as cover if the distance between the water surface and the underside of the bank was less than 25 cm. Overhanging vegetation was defined as living plants within 25 cm of the river surface.

Size-dependent differences in movement patterns (Clapp *et al.*, 1990) and behaviour (Bachman, 1984) of brown trout may exist. We therefore separated our radio-tagged fish into two size groups for comparison. However, *post hoc* analyses indicated no significant differences in either movement or habitat use when data from fish < 200 mm TL ($n = 5$) were compared with data from fish > 200 mm TL ($n = 13$). Although this may simply have been a result of inadequate sample sizes, data from all 18 radio-tagged brown trout were subsequently pooled and analysed together. Differences between depths, water velocities, and distances to nearest shoreline at positions of radio-tagged fish during high and low flows were assessed with Mann–Whitney U-tests ($\alpha = 0.05$) because data were non-normal (Lilliefors test, $\alpha = 0.05$). Log-likelihood ratio tests ($\alpha = 0.05$, Zar, 1984) were used to examine differences in primary habitat, cover and substrate used by brown trout during high flow and low flow conditions. Micro-habitat characteristics were considered independent since fish were never located in exactly the same position for more than one micro-habitat survey. Fish locations in consecutive days were not considered to be

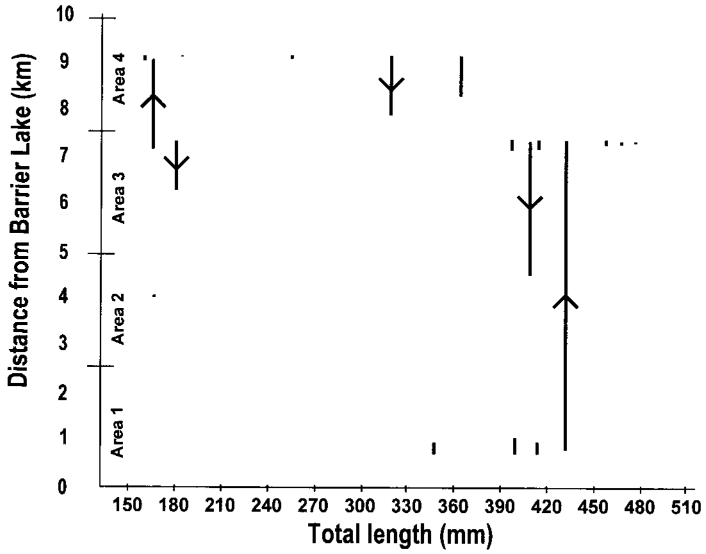

Figure 2. Movement of radio-tagged brown trout ($n = 18$) within the study site as a function of fish size. Vertical lines indicate regions of the river that were occupied by each fish over the duration of the study. Arrows indicate the net direction of movement when large-scale displacement occurred (> 1000 m)

statistically independent. For this reason, movement data were examined from a displacement perspective to determine whether river discharge or time of day affected fish positions.

RESULTS

Discharge-dependent habitat characteristics

During the study period, discharge from the upstream generating station varied between 0.15 $m^3 s^{-1}$ and 25 $m^3 s^{-1}$ on a daily basis (Drury, Trans Alta Utilities, personal communication). Groundwater inputs and runoff augmented flows within the Kananaskis River. At the study site, located 30–40 km downstream from the generating station, mean river depth increased by approximately 30 cm during high flow conditions. It was not possible to collect habitat availability data, particularly during high flow conditions when vast reaches of the river were considered unsafe. We therefore relied on results from independently generated models from within the study site, to determine that (1) predicted wetted area doubled between low and high discharge, which varied between 3 and 50 $m^3 s^{-1}$ (Christison, University of Alberta, personal communication) and (2) WUA increased by a factor of 1.5 for juvenile brown trout (< 250 mm TL) and by 1.9 for adult brown trout as discharge increased from minimum to maximum values (Hardy, Utah State University, personal communication). Mean water temperature during the investigation was 9.0 ± 0.3°C and there were no significant differences between mean water temperatures in areas used by brown trout during high and low flow conditions (t-test, $p > 0.05$).

Fish movements

Fish movements were variable and consisted of upstream, downstream and lateral movements within complex areas of the river. Several individuals remained sedentary during both high and low flows while others showed a high degree of mobility. For example, one large fish (436 mm TL) moved 7000 m upstream from section 1 to section 3 (Figure 1) of the study site within 2 days (Figure 2). Similarly, a slightly smaller individual was observed to move downstream from section 3 to section 2 in 1 day. Maximum displacements ranged between 5 and 7000 m (mean 917 ± 404 m, Figure 2) and displacement patterns appeared to be independent of fish size. Fish were not displaced downstream by high discharge flows and there appeared to be no differences in movement among brown trout between day and night. Daily movements were localized (i.e. < 10 m) and generally involved lateral shifts towards the expanded shoreline during high flow conditions, and movements in the opposite direction as flows diminished.

Habitat use

Surface water velocities in areas where brown trout were located during high flow were significantly lower than surface water velocities in areas used during periods of low flow ($p = 0.0003$, Table I). Similarly, average and bottom water velocities in the same areas during high flow conditions were lower than water velocities in areas used during low flow, but the relationships were not significantly different.

Water depths in areas used by brown trout did not differ significantly during periods of high flow (0.63 ± 0.04 m) or low flow (0.67 ± 0.02 m, $p = 0.4406$, Table I). During high flow periods, river width increased and brown trout moved nearer to the expanded river bank so that the measured distances to nearest shoreline did not differ significantly between extremes in flow (e.g. during high flow, distance to shore was 1.4 ± 0.19 m, and during low flow, distance to shore was 2.97 ± 0.41 m, $p = 0.6207$).

There appeared to be no major shifts in the types of habitats used during low flow or high flow periods in the Kananaskis River. Brown trout were, however, associated with cover for 231 of 233 combined observations (99%) during both high and low flow conditions. Woody debris was the most frequently used cover type during periods of low and high flow (Table I). During periods of high flow, brown trout were also more frequently associated with root complexes than during low flow. Pools were the most frequently used habitat type (75–80% of observations), followed by runs (20–25% of observations).

During periods of low flow, brown trout used all four classes of available substrate (Table I). Gravel was the least used substrate type, and during periods of high flow, no fish were observed to use it. Instead, during high flow, there appeared to be an increase in the degree to which sandy and silty areas were used.

DISCUSSION

This study demonstrated that the variable flows of water in the Kananaskis River, as a result of the peaking operation of the Pocaterra Hydroelectric Generating Station, appeared to have minimal influence

Table I. Mean (± 1 S.E.) surface, average and bottom water velocities (m s^{-1}), depths (m), and distances to nearest shoreline (m) from positions of brown trout during periods of low and high flow[a]

	Low flow	High flow
Surface velocity	0.16 ± 0.02 ($n = 94$)*	0.10 ± 0.04 ($n = 24$)*
Average velocity	0.19 ± 0.02 ($n = 94$)	0.13 ± 0.04 ($n = 24$)
Bottom velocity	0.15 ± 0.02 ($n = 94$)	0.12 ± 0.04 ($n = 24$)
Depth	0.67 ± 0.02 ($n = 94$)	0.63 ± 0.04 ($n = 25$)
Distance to shore	2.97 ± 0.41 ($n = 94$)	1.4 ± 0.19 ($n = 25$)
Overhanging vegetation	9.8 ($n = 112$)	5.0 ($n = 121$)
Woody debris	72.3 ($n = 112$)	69.4 ($n = 121$)
Root complex	9.8 ($n = 112$)	17.4 ($n = 121$)
Undercut bank	8.0 ($n = 112$)	8.3 ($n = 121$)
Sand/silt	40.2 ($n = 112$)	45.7 ($n = 127$)
Gravel	5.4 ($n = 112$)	0 ($n = 127$)
Pebble	23.2 ($n = 112$)	21.3 ($n = 127$)
Cobble	31.2 ($n = 112$)	33.1 ($n = 127$)

[a] Cover and substrate types used by fish during low and high flow conditions are shown as frequencies of occurrence (%). Numbers of observations are included in parentheses.
* Indicates significant discharge-dependent differences among variables.

on the movement of brown trout. These results were consistent with other studies that suggested radio-tagged brown trout were generally sedentary in unregulated rivers (Clapp *et al*., 1990; Meyers *et al*., 1992; Young, 1994, 1995). Our results did, however, indicate that brown trout modified their use of habitat as river levels fluctuated.

During periods of high discharge, brown trout moved closer to shore into slower velocity areas provided by dense cover. Root complexes were used more often during high flows, largely as a result of small-scale movements towards the river bank where roots were more common. In addition, distances to the nearest shoreline and the water depth where most fish were located were relatively constant and independent of flow. With underwater observations, Pert and Erman (1994) found that rainbow trout used shallower water during lower discharges and slightly deeper water during higher discharges.

All fish in the Kananaskis River used cover (to within 0.1 m) on all but two occasions. Woody debris was used more often than all other types of cover. Brown trout used root complexes and woody debris during high flow, and predominantly woody debris during low flow. Other researchers have identified cover types used by brown trout (Shirvell and Dungey, 1983; Heggenes, 1988a; Young, 1995) and their findings were similar to those reported here. Meyers *et al*. (1992) found large brown trout under banks with dense overhanging vegetation during the day. Most fish in the present study used woody debris as cover during both the day and night.

Brown trout were often located in highly braided areas of the river with numerous side channels that offered substantial cover. Channelized areas with no instream or overhead cover were present upstream from section 4 of the study reach (Figure 1) and in these areas, no adult brown trout were observed. Angermeier and Karr (1984) observed similar relationships between woody debris, channelization and fish habitat in an unregulated warmwater stream. In regulated river systems, removal of woody debris may be especially harmful if it is used as critical habitat during extremely low or high flow conditions and if it creates habitat by contributing to pool formation (Benke *et al*., 1985; Richmond and Fausch, 1995).

Brown trout used pools more and runs less during high flow compared with low flow but the differences were not significant. Pools were the most commonly used primary habitat type. Other researchers have reported that brown trout frequently occupy pools in unregulated rivers (Jenkins, 1969; Nyman, 1970). During low flow conditions in regulated rivers, pools are good foraging sites since they concentrate drifting invertebrates (Benke *et al*., 1985). Pools also provide sufficient depth and cover to obscure fish from avian predators. When discharge increases, pools are effective velocity refuges, particularly for small fish.

Brown trout used slower surface water velocities during high flow compared with low flow, but average and bottom water velocities did not differ. In contrast, Pert and Erman (1994) found that rainbow trout used higher mean water velocities (16–37 cm s^{-1}) as discharge increased. These values are within range of the mean water velocities used by brown trout in the Kananaskis River. Bachman (1984) and Fausch (1984) reported that focal water velocities between 10 and 30 cm s^{-1} were considered favourable based on concepts of energetic cost minimization. As expected, strong correlations between low surface velocities and dense cover were apparent. The use of lower surface water velocities by brown trout during high flows may be explained by lateral movements deep into cover to avoid unnecessary energy expenditures in areas with high water velocities. This strategy (1) reduces cumulative energetic impacts associated with maintaining positions in high flows and (2) minimizes the likelihood of catastrophic impacts resulting from loss of position (i.e. downstream displacement by high flows). High flows in the Kananaskis River did not displace brown trout downstream. Similar findings have been reported for brown trout in a Norwegian river that delivered pulsed discharges that were up to 100 times greater than during low flow conditions (Heggenes, 1988a).

In the Kananaskis River, brown trout used depths between 43 cm and 86 cm with no significant differences between low flow and high flow conditions. These depths are very similar to those used by brown trout in Europe (e.g. 46–53 cm, Heggenes, 1988b). Other studies report that brown trout used mean depths between 20 and 62 cm (Horton and Cochnauer, 1978). Similarly, Shirvell and Dungey (1983) found the mean water depth used by large brown trout (32–55 cm TL) was 65 cm. Others have found brown trout using depths up to 115 cm (Heggenes, 1988a).

Substrate types used by brown trout did not vary with discharge. However, sand/silt was used less, albeit not significantly, during low flow because of small-scale movements into higher velocity areas as river levels decreased. Pert and Erman (1994) also found no correlation between substrate types used by rainbow trout and river flow. Substrates used by brown trout in the Kananaskis River were generally finer (i.e. silt/sand versus pebble and cobble) than those reported from unregulated systems due to differential deposition of these materials into pools and beneath instream overhead cover where most fish were located. Brown trout that were found within interstitial spaces among woody debris and root complexes used low velocity areas that allowed sand and silt to settle.

To summarize, daily pulsed-discharge appeared to have only minimal effects on the movement and types of habitat used by brown trout in the Kananaskis River. Pools, woody debris and roots were frequently used habitat and cover types for brown trout because they provided regions with reduced water velocities, particularly during periods of high flow. Brown trout appeared to seek velocity refuges during high discharge by shifting location to areas closer to shore and deeper into cover. This was demonstrated as fish maintained the same depth and position relative to the shoreline during both high flow and low flow.

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