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River morphology, sediments and fish habitats

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ABSTRACT The viability, preservation and rehabilitation of fish habitats have become a focal point of impact assessment and monitoring. Salmon, trout and walleye have specific ecological requirements that are dependent on basin and channel morphology, sedimentology, sedimentation processes and hydrological regimen. Hydraulic processes, because of their known relationship to aggradation and degradation, clearly affect the distribution of fish habitats. Planning, management and impact assessment will have to be based on specific data not routinely assessed. These data include frequency and magnitude of fluid discharges, timing of discharges and entrainment of bed material, packing and size distribution of bed material, mode of transport of particles, and hydraulic geometry of the channel. All are important additions to programs that include already the concentration of suspended solids. The purpose of this report is to review the data requirements for a management base, and to give examples of data acquisition from a field program developed in Ontario, Canada to meet new initiatives and regulations at Federal and Provincial levels.

INTRODUCTION

Human activities associated with navigation, hydroelectric power generation, water supply, waste management and urban development have had a major impact on many river systems, primarily due to alteration of regional or local hydrological conditions. With few exceptions river management has been based on design discharge criteria established to meet human interests. The consequences of human actions and associated management objectives are typically manifest through initial loss of habitats and population diversity (Imhof et al., 1990, 1991), followed by larger-scale, accelerated, and perhaps longer-term geomorphological adjustments of the river system towards some new equilibrium state.

The current dilemma is that data bases for proactive assessment are lacking, along with strategic frameworks and methodologies for data acquisition and utilization. This situation, coupled with proposed management initiatives, has created an opportunity to formulate a conceptual framework and strategy for the systematic assessment of physical habitat structure and dynamics. A program was initiated based on a geomorphological perspective and has included an empirical assessment of 35 cross-sections of two headwater tributaries of the Credit River, Ontario (Fig. 1). These tributaries, Black and Silver Creeks, and a portion of the West Credit River (totalling 32.5 km. in length), are situated within a rapidly urbanizing region and support primary spawning habitat for salmonid species (Fisheries Potential of the Credit River, Credit Valley Conservation Authority 1:50000, 1989). The preservation and rehabilitation of these habitats is a priority and constitutes a relevant basis for assessment. The purpose of this paper is to provide a review of the framework, approach, and data needs for assessment, and ultimately for management.

ASSESSMENT FRAMEWORK AND APPROACH

Assuming that a natural drainage basin exists in some state of dynamic equilibrium, and barring natural catastrophic events, human activities will constitute the primary impact source. Planning is based on site-specific objectives and rarely embraces the whole watershed in a holistic manner (Imhof et al., 1991). Predicting impacts from individual developments is a fortuitous exercise when cumulative effects cannot be established. This is in spite of established watershed storm water management planning and policy. Rather than predicting the extent and direction of impacts the management strategy must seek to maximize benefits including the preservation of valuable habitats and the realization of socioeconomic interests. Ecological status, dynamics and tolerances associated with fish habitats must serve as references for determining design and management criteria.

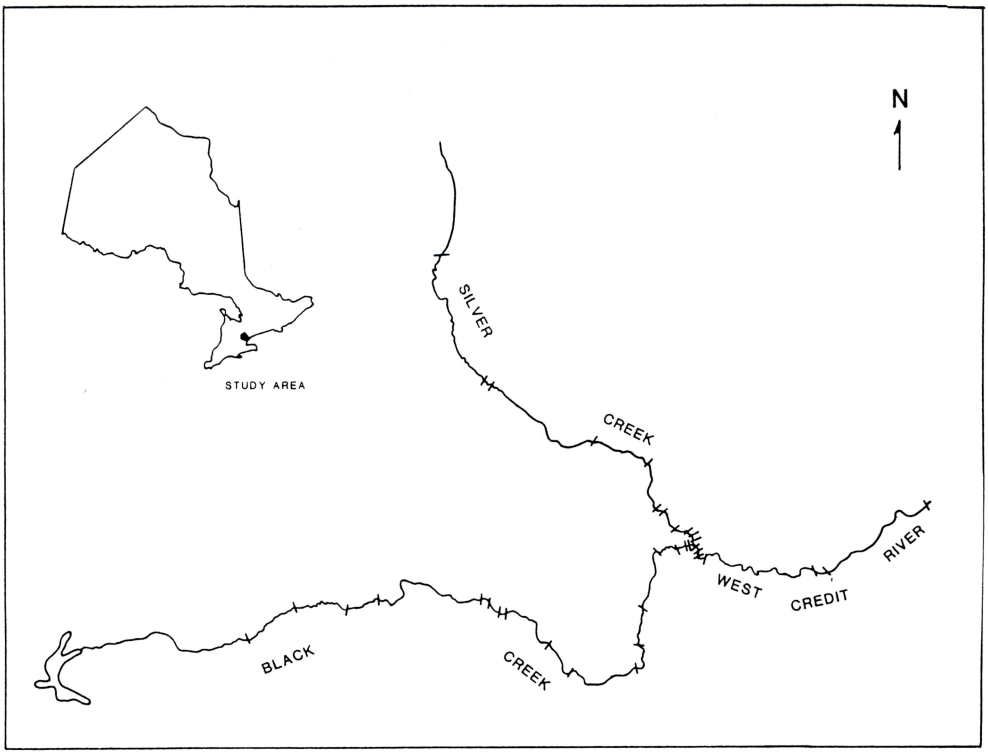

FIG. 1 The Credit River study area and sample locations.

FLUID AND SEDIMENT DYNAMICS

Bilby (1984) and Heede and Rinne (1989) have documented the importance of vegetation cover in providing both shade for fish and in mediating water temperatures. As well, vegetation and woody debris can influence in-channel riffle-pool sequences and associated habitats. Empirical evidence from the Credit River shows that vegetation (either exposed at the bank or in-channel) is a preeminent agent for change in channel morphology. Exposed bank vegetation takes two forms, tree trunks which become the actual bank material as the original bank recedes due to natural erosive processes, and roots which may originate from either trees or smaller species of plant (i.e. ferns) and are also exposed due to erosion of the bank.

Exposed tree trunks at regular intervals can create a 'w' shape in the bank in the downstream direction. As fluid flows along the channel and comes in contact with a protruding trunk, it separates from the regular flow pattern. The resultant zone of turbulence downstream has the ability, when the fluid is moving at critical speeds, to erode the bank. The amount of turbulence (and subsequent erosive power) during flow separation depends on the initial fluid velocity, the amount of protrusion into the flow by the trunk and the nature of the material to be eroded.

Exposed bank roots can have a dual effect. At times when roots are young and occur at high density in the soil, they act as a stabilizing agent, preventing erosion. This is evident where undercut banks occur (provided a layer of cohesive material is not present). This is also true of exposed tree roots, but only when the distance from root to bank is minimal. On the other hand, larger exposed tree roots have the same effect as large particles on the bed--they intensify turbulence which then acts as an erosive agent on the bank and bed of the channel at that point. Whenever there is evidence of erosion due to bank vegetation in shallow, riffle areas, there is also degradation of the bed in the immediate downstream area.

In-channel vegetation can have drastic effects on channel morphology. Where trees have fallen into the channel, a new fluid pathway is created. This can result in degradation of the bed in particular locations. At the downstream side of fallen trees there can also occur aggradation of bed material in the form of mid-channel bars. Vegetation 'jams' can occur behind these fallen trees, where floating detritus jams up until enough energy is available to remove it. On Silver Creek one jam was noticed to cover the width of the channel for a distance of 10 metres upstream.

TABLE 1 Width, depth, discharge and suspended sediment concentration for 35 cross sections of Black and Silver Creeks and the West Credit River under base flow conditions.

SECTION	WIDTH m.	MEAN DEPTH m.	DISCHARGE $m^3 sec^{-1}$	SUSP. SED. CONC. $mg L^{-1}$
BC1	5.55	.163	1.719	2.34
BC2	4.4	.204	1.413	7.27
BC4	4.4	.137	1.825	2.26
BC5	6.15	.364	0.988	2.25
BC6	5.55	.225	0.887	11.44
BC7	6.53	.207	1.823	23.02
BC8	6.33	.115	1.956	2.42
BC9	7.66	.324	0.885	5.01
BC10	8.25	.219	1.489	11.22
BC11	6.28	.137	0.939	50.27
BC12	5	.139	0.649	2.23
BC13	7.8	.138	1.076	8.94
BC14	5.18	.148	0.948	2.56
BC17	5.05	.154	0.775	2.24
BC18	4.7	.100	0.958	15.78
BC19	2.46	.145	0.436	13.18
BC20	4.35	.236	0.484	9.06
SC1	4.61	.253	0.677	2.46
SC2	7.05	.055	0.777	7.06
SC3	3.54	.697	0.465	13.04
SC4	3.03	.153	0.490	2.59
SC5	6.05	.075	0.637	37.33
SC6	4.7	.172	0.525	2.54
SC7	6.4	.429	0.582	7.33
SC8	4.05	.150	0.601	2.25
SC9	6.7	.185	0.489	4.64
SC10	5.6	.260	0.280	13.82
SC11	4.8	.336	0.239	19.03
WC1	6.92	.257	1.307	5.13
WC2	8.02	.095	1.146	4.79
WC3A	7.38	.193	1.341	13.02
WC3B	6.08	.296	1.226	26.87
WC4	5.85	.12	1.895	2.27
WC5	5.41	.165	1.884	37.21
WC6	8.47	.149	1.736	12.48

Heede and Rinne (1989) indicated that hydrodynamic conditions within the channel were of ecological significance. Roughness as indicated by Manning and Darcy-Weisbach equations can be too general, and in view of the influences of vegetative matter along channel banks and within channels more specific roughness indices have to be defined, especially for gravel-bed streams. Specific ecological implications of flow regime criteria relative to fish habitats have to be defined beyond the context of resistance to flow and bedform mechanics.

One of the most significant aspects of hydrodynamic conditions from a fish habitat perspective is the way which geomorphological conditions can change over short distances. Within any fluvial system it is expected there can be a certain amount of variability. When that fluvial system is under the influence of man's activities, variability can be significant. Table 1 gives an indication of that variability through the 35 cross-sections in the Credit River study under base flow conditions.

Channel width and mean depth can be altered simply through the nature of the bank material at a location. On Silver Creek an outcrop of cohesive clay in the bank had the dramatic effect of decreasing channel width and increasing depth, yet less than 100 metres downstream that cohesive material was not present, and the channel returned to a broader profile (Fig. 2, Fig. 3). This kind of effect is shown in the variation of width to depth ratios through the 35 sample cross-sections (Table 2).

Variability is not limited to width and depth relationships. Under base flow conditions considerable fluctuation in discharge, suspended sediment concentration and bed material are evident. Study of a culvert draining a construction site in the basin showed that sediment concentrations input into

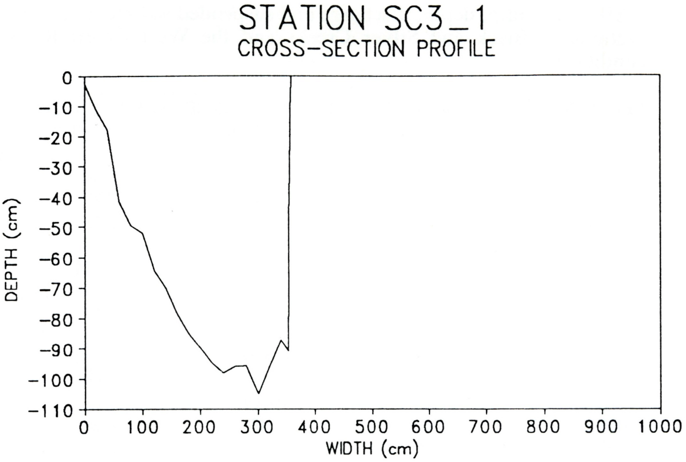

FIG. 2 Channel profile under the influence of a cohesive clay outcrop on Silver Creek.

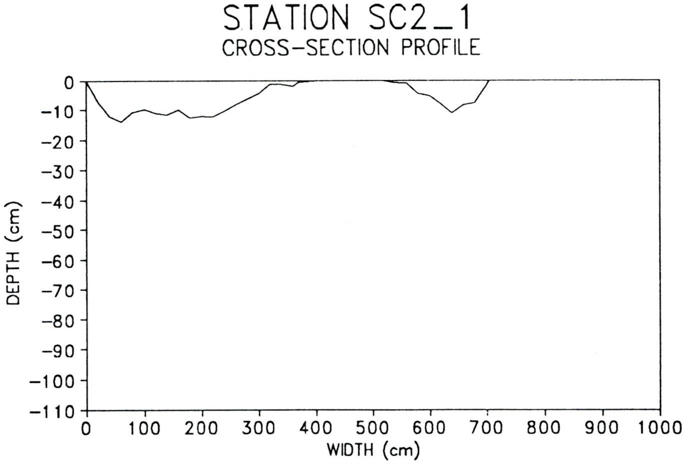

FIG. 3 Channel profile 100 m downstream from Fig. 2, where the cohesive outcrop no longer influences channel profile.

the system from these areas can be quite high, one sample indicating >200 mg L^{-1} min^{-1} contribution from a misty rain lasting less than 2 hours.

The effect of high suspended sediment concentrations manifests itself through physiological changes to fish. Herbert and Merkins (1961) and Herbert et al. (1961) showed that concentrations of suspended solids in the form of diatomaceous earth and china clay wastes of 270 mg L^{-1} or greater were harmful to trout, effectively causing thickening of respiratory epithelium cells and fusing adjacent laminae, in essence suffocating the fish.

Salmonids require relatively specific bed material textures and structures that allow for spawning and the availability for food. Fig. 4 is a particle size curve from an area of Silver Creek where trout spawning had occurred in the fall of 1991. Variability of bed material particle size distribution throughout the study area effectively cut down the amount of spawning beds available for the fish. Fig. 5 shows a bed sample with a high proportion of particles in the coarse end of the curve. This material is too coarse for spawning, as the eggs would either be entrained by the fluid flow through the gravel or be subject to predation. It is consistent with good feeding and resting habitat, as the larger particles provide shelter from flow. Fig. 6 shows how the activities of man can be deleterious to salmonid habitat. The bed sample at this location consists primarily of sand sized particles which may have been introduced to the creek

TABLE 2 Width to depth ratios for all cross sections showing change in the downstream direction.

STATION	RATIO	STATION	RATIO
WC1_1	26.926	BC1_1	33.966
WC2_1	88.534	BC2_1	21.558
WC3A_1	38.14	BC4_1	62.35
WC3B_1	20.519	BC5_1	16.859
WC4_1	48.75	BC6_1	24.568
WC5_1	32.63	BC7_1	35.531
WC6_1	56.731	BC8_1	54.948
SC1_1	18.166	BC9_1	23.602
SC2_1	126.27	BC10_1	37.568
SC3_1	5.073	BC11_1	45.54
SC4_1	19.788	BC12_1	35.765
SC5_1	80.1	BC13_1	56.358
SC6_1	27.243	BC14_1	34.861
SC7_1	14.914	BC17_1	32.722
SC8_1	26.837	BC18_1	46.831
SC9_1	36.159	BC19_1	16.873
SC10_1	21.501	BC20_1	18.394
SC11_1	14.277		

Note: for West Credit stations, the low station number indicates the upstream site, for Black and Silver Creeks the high station number indicates the upstream site.

from sand and gravel mining operations nearby, resulting in destruction of the habitat. It is no longer good spawning habitat, nor is it likely to be used as feeding habitat due to the likelihood of increased suspended sediment transport through this area.

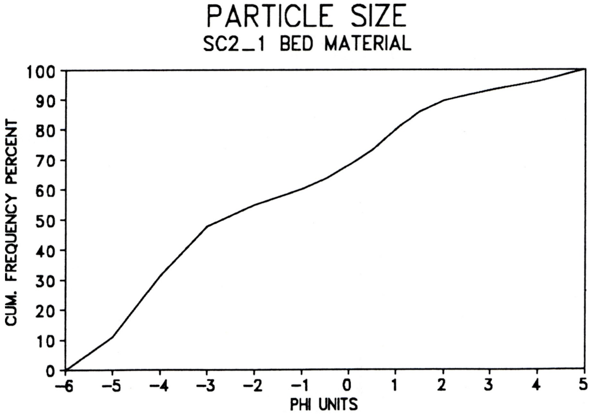

FIG. 4 Particle size curve from a known spawning bed.

The introduction of fines into the interstices of spawning gravel has been shown to decrease the flow of dissolved oxygen to the egg, resulting in smothering incubating eggs and fry (Milhous, 1982; Chapman, 1988). Chapman also showed that fines in spawning gravel can create a cementing of the bed, through which the fry cannot travel up to the flow. As well the accumulation of fine sediment can cause an ecological shift by limiting macroinvertebrate species used as food, and by providing conditions that are attractive to bottom dwelling fishes.

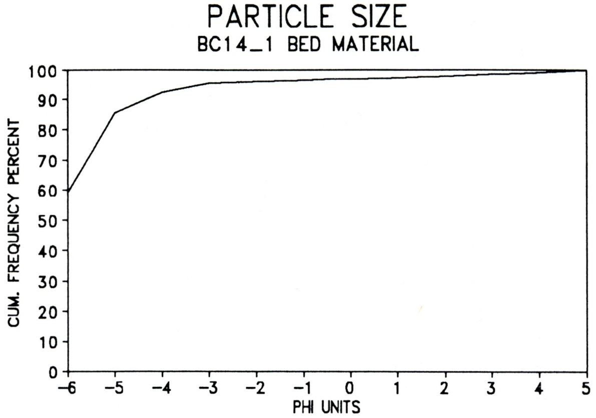

FIG. 5 Bed material from a section showing the high proportion of coarse material. This is consistent with good feeding and hiding habitat.

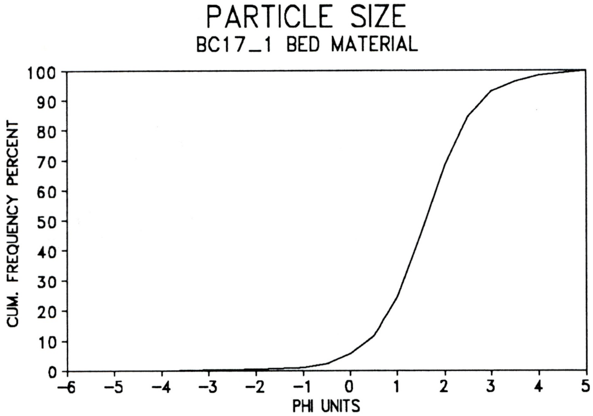

FIG. 6 Bed material particle size curve showing the potential effect of sand and gravel mining operations in the vicinity. This is poor habitat for salmonids.

Bed material transport is vitally important since frequent high magnitude flow events can result in bed scour and sediment entrainment below the base of redds constructed for eggs and fry. The goal, as indicated by Milhous (1982), is to manage flow conditions to flush fines from the surface and interstices, and to provide textural and structural characteristics that correspond closely with natural habitats.

The stability of the bed is dependent on the particle sizes as well as the structural attributes of the pavement (Church, 1978; Komar, 1987; Wilcock and Southard, 1989). The structural characteristics or attitude (Church, 1978) of the surface pavement can substantially affect the critical conditions for entrainment. Intuitively a tight interlocking pavement would be resistant to entrainment and would inhibit redd construction, while an underloose structure would facilitate entrainment for flows less than predicted from normal structural conditions.

While bed stability is important from a structural perspective, from the management perspective the timing of flow events is of utmost importance. It has been observed in the Credit River basin that a gravel bar (consisting of particles up to and including 8 centimetres on the intermediate axis) was completely displaced and deposited downstream after a single short duration storm event in July, 1991. If that gravel bar were a spawning bed, the destruction to the spawn would be enormous. This establishes the need to design management criteria with the knowledge that fluvial systems are dynamic in nature, and management should include methods which could deal with the mistiming of events.

CONCLUDING REMARKS

Recent initiatives in Canada have drawn attention to the need for watershed planning and management to reconcile human and ecological needs and objectives. Integration of these objectives at the planning stage will hopefully reduce the dependence on reactive environmental assessment processes. Achieving the overall watershed management objectives will require specific information on habitat status and dynamics to establish baseline management criteria. The hydrological attributes of the watershed affect the geomorphological attributes of the drainage network, the channel and hydrodynamic conditions which control the physical viability and dynamics of fish habitats. A geomorphological approach represents a relevant foundation for assessment of the physical habitat and provides a useful framework for addressing key processes and responses both at the watershed and sediment-habitat interface levels.

Empirical study is required to define functional relationships including sedimentation processes which directly affect habitat quality. A number of significant issues require resolution, including the definition of the functional relationship between vegetation cover and debris in controlling bank stability, roughness and flow vectors within the channel. Field evidence, including the distribution of fish populations, indicates the probable significance of these features.

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