Morphological and Habitat Classification of the Lower Fraser River Gravel-Bed Reach

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Executive Summary

We present a hierarchical classification of riverine habitats for the gravel reach of Fraser River. The classification links morpho-sedimentary characteristics of distinct habitat types, as determined by air photo interpretation and detailed ground surveys, with ecological attributes of the habitats as determined by field sampling for fish and benthic invertebrates. Emphasis has been placed on delineating habitat types with respect to juvenile fish species, both resident and anadromous, known to use the gravel reach for rearing.

The classification provides three levels of increasing detail on the morphological, sedimentary, hydraulic, and ecological properties of the channel. Each level has a particular applicability to planning and management. The classification is seasonally sensitive, because both flow conditions and the habitat available for fish use change as discharge changes.

At the highest hierarchical level, we divide the river into a select number of sub-reaches, each of which presents a distinct array of aquatic environments. Taking note of these distinctions is believed to be important in strategic planning for fish and fisheries management.

At the intermediate level, we identify major pool-bar-riffle units along the river. The scale of these units is approximately 2.6 km, or 4.4 channel widths. The intermediate level is expected to guide field studies and operational management of fisheries along the river. Information for these two levels is gained from map and air photo analyses. Given the rate at which sedimentation processes alter river form, the intermediate units may require revision every decade or so.

At the finest level of classification, we identify habitat types around individual bars. Field surveys are required to identify these units with reasonable accuracy. Each habitat type is characterised by relatively homogeneous morphologic and hydraulic properties and is bounded by a change in gradient of depth and flow. Our classification consists of 12 habitat types and a typical pool-bar-riffle consists of 30-50 units. Units associated with large morphological features may occupy areas exceeding 5,000 m^2 whereas smaller units occupy 100 to 500 m^2. Because bars change from year to year, it may be necessary to review this classification level classification frequently.

During the past year, detailed surveys were conducted at two sites to identify micro-topography that characterises habitat types. Intensive sampling of surface sediments, which form the substrate of the habitat, has been carried out at these sites as well. Several major morpho-sedimentary units were identified that reflect differences in genesis and sedimentary characteristics. These units are believed to be common to most bar-island complexes in the gravel reach, and a provisional typology of morpho-sedimentary units for the gravel reach is proposed.

We conducted sampling of fishes and benthic invertebrates at 13 sites over 2 summers and the intervening winter, and distinct ecological patterns of habitat use are emerging. Low-velocity habitats, particularly open nooks, are recognised for rearing value to small juvenile fish. Species diversity and catch per unit effort (CPUE) are generally high. High-velocity habitats favour a narrow range of species, including several salmonids. Eddy pools, which develop in the lee of riffles have the highest species diversity of all habitat types.

Since water levels change dramatically between freshet and winter, the location of these units also changes. In some cases, habitat units may seasonally disappear. For this reason, our habitat classification is repeated for the three sites at freshet, winter low flow, and two intermediate water levels to demonstrate seasonal habitat changes.

The results of the topographical, sedimentary, and ecological sampling will provide the basis to identify habitat units and predict fish use around other bars along the gravel reach in the future. We have still to learn how patterns of habitat use by fish change as the river channel changes, but we expect that they will consistently follow the modification of the river morphology and sediments around the bars.

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Acknowledgements

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1.0 Background

Classification frameworks are useful tools for resource management and scientific research as they enable the ordering, comparison, synthesis, and inventory of biophysical data. There is no shortage of stream and riparian classification systems available, particularly for the Pacific Northwest where conflicts between forestry and fisheries management have prompted the need for an increased level of stream and riparian protection. As management tools, classification systems can consolidate and summarise large amounts of information in a format that reduces variability and emphasises patterns of significance. In this way, they provide a common language with which resource managers can communicate results and make decisions. As research tools, they help to structure the design of a project including site selection and field sampling, as well as to ensure consistency in long-term monitoring programs.

It is clear that no one stream classification is adequate for all situations. Biophysical differences between watersheds, differences of channel scale within a river basin, and differences in the purpose of the classification require that diverse systems exist. Hierarchical classifications are a means of eliminating some redundancy between systems. By incorporating multiple levels of detail, they allow choice as to the degree of resolution required for the specific objectives. Furthermore, they provide a consistent means for either combining or splitting data if the objectives change or comparisons across studies are made.

The majority of habitat classifications are both hierarchical and geophysically based, following the premise that channel form is governed by river boundary adjustments to stream flow and sediment regimes. Together, hydrological and geomorphic processes structure the landscape and, subsequently, provide the foundation for biotic assemblages. Some examples of geophysically-based classifications applied in the Pacific Northwest are the stream hydroriparian ecosystem classification (Clayoquot Sound Scientific Panel 1995); Channel Assessment Procedure (Province of BC 1996a); Riparian Management Areas classification (S1 – S6, Province of BC 1996b); and the Rosgen classification (Rosgen 1985, 1994).

A broader, ecosystem approach was taken by MacKenzie and Banner (1995) in an attempt to classify wetland and riparian areas throughout British Columbia. Their Wetland Riparian Ecosystem Classification (WREC) integrates climate, landscape features, vegetation, and hydrologic information on a regional scale to provide a useful tool for resource managers. R.U. Kistritz Consultants Ltd. (1996) adapted the WREC system to develop a Salmon Habitat Classification System (SHCS) for aquatic, riparian, and wetland habitat of the lower Fraser River. The classification was developed for the Department of Fisheries and Oceans (DFO) and the Fraser River Action Plan (FRAP), and is based on air photo interpretation and limited ground surveys.

The purpose of the SHCS was to provide a simple, yet effective and ecologically defensible habitat management classification system. It was designed to be of sufficient scope so that it could be applied in other regions of the province and within other jurisdictions. The SHCS is hierarchical, at the highest level differentiating aquatic, riparian, and wetland "realms", subsequently identifying large-scale features ("forms") within each realm, and further classifying riparian and wetland realms at three finer levels of detail. Rating criteria were added to the classification to characterise specific habitat attributes for juvenile trout and salmon. Following a habitat inventory of Fraser River from Kanaka Creek to Hope, habitat units were evaluated based on a rating system for their salmon rearing value.

The lack of ground truthing and field surveys incorporated into the SHCS has limited its application. While many anomalies and errors in the classification were resolved through a validation process, there remain inconsistencies between the assigned classification and expected habitat value for many polygons along the river. Moreover, the expected value of a habitat for juvenile salmon rearing was based not on empirical data but on the judgement of several fisheries scientists upon examination of air photographs. Without an empirical basis, the SHCS lacks the necessary confidence for resource managers to make decisions that impact aquatic habitat along Fraser River. The "salmon-centric" focus of the SHCS also limits its applicability by neglecting non-anadromous fish species residing in the reach, which serve an important function in the river ecosystem. The habitat needs of many of these species differ from those of salmon.

2.0 Statement of Purpose

We present a hierarchical classification of riverine habitats for the gravel reach of the lower Fraser River. Our classification links morpho-sedimentary characteristics of the reach, as determined by air photo interpretation and detailed ground surveys, with ecological attributes as determined by field sampling for fish and benthic invertebrates. Habitat types are delineated primarily on the basis of patterns of habitat use by juvenile fish, both resident and anadromous, known to occupy the gravel reach. There remains uncertainty about habitat use by adult fishes due to gear limitations for fish sampling. For this reason, adult fishes, including migratory salmon, are not given direct consideration in the classification.

The classification consists of three levels of increasing detail on the morphological, sedimentary, and ecological properties along the gravel reach of Fraser River. At the highest level, the river is divided into a small number of sub-reaches, each of which presents a distinct array of aquatic environments. These distinctions are believed to be important in strategic planning for fish and fishery management. The intermediate level identifies major pool-bar-riffle units along the river, within which habitat units are identified. The intermediate level is expected to support field studies and the operational management of fisheries along the river. Information for these two levels is gained from map and air photo analyses. At the finest level of classification, habitat types are characterised around individual bars in the gravel reach. Field surveys have provided the information necessary to identify these units with accuracy.

The study reach extends from Hope to the downstream end of Sumas Mountain, about 5 km upstream from Mission (Figure 1). Attention is focused on the reach between Laidlaw and Sumas Mountain (river km 150 – 90) where gravel deposition occurs. Field activities have been concentrated in the 20-km reach between Chilliwack Mountain and lower Herrling Island (see

Figure 2).

The work required to produce the habitat classification was requested of the Geography Department, University of British Columbia, by the Department of Fisheries and Oceans. The following six work tasks were requested, each contributing to the final classification framework.

1. *Acquisition of large-scale air photography (1:12,000) of the gravel reach from the confluence of the Sumas River to mid-Herrling Island. This area is to match the area covered by the ecological field studies.*
2. *Development of a hierarchy of habitat classification units for linking the physical characteristics of the river with habitat values observed in ecological fieldwork. This hierarchy will allow habitat values to be assessed at various scales, form the entire gravel reach to individual bars. The coarser scale habitat units will be able to be interpreted from existing medium scale (1:50,000) air photography, whereas finer scale habitat units will require larger-scale (1:12,000) air photography. The classification will be stage-sensitive, so that information about habitat values will be preserved from high to low water.*
3. *Constructing detailed maps of form and sedimentation patterns using large-scale air photography, and applying results of field ecology studies to delineate candidate habitat units on these maps. Detailed maps will be carried out at the 12 sites that have been selected for detailed ecological sampling, and will include historically mined and unmined sites.*
4. *Interpretation of habitat classification units using the large-scale and medium-scale air photography.*

5. *Making detailed measurements of particle size, fabric and shape at a subset of sites, by examining internal stratigraphy (at cut banks and any other exposed sections, and by ground penetrating radar (GPR) surveys). These measurements will be carried out before and after the 2000 freshet period.*

Figure 1. Location map of the lower Fraser River. The reach of focus in this report, from Mission to Hope, is highlighted.

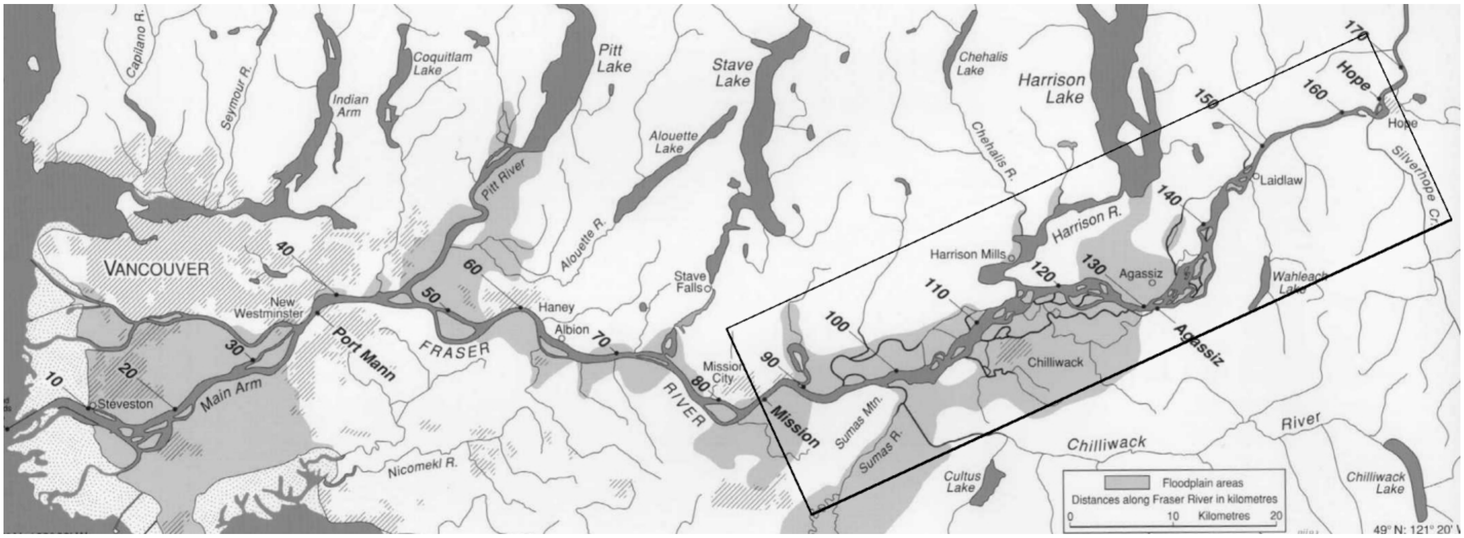


Figure 2**.** Location map of the thirteen sites along the gravel reach, Fraser river, where intensive sampling for fish, benthic invertebrates, surface and subsurface sediments, and micro-topography have occurred. Seven sites have been subjected to gravel removal (G), and six have no known previous gravel removal (N). The sites (listed from the downstream end) are: Wellington Bar (N), Queens Bar (N), Lower Minto Bar (G), Calamity Bar (N), Minto Bar (G), Harrison Bar (G), Upper Minto Bar (N), Foster Bar (G), Carey Bar (N), Hamilton Bar (G), Big Bar (N), Powerline Island (G), and Lower Herrling Bar (G).

6. *Field checking and revising habitat characterisations: collating habitat characterisations with hydraulic and morphological measurements made in the field during sampling of fish and benthic invertebrates.*

The air photography (task 1) was acquired in March 2000 and copies have been delivered to DFO. Of the remaining, ambitious tasks, (2) has been achieved and is described in this report. Items (3), (5) and (6) have been completed for three sites. We have not completed all 12 ecological study sites because of the great labour involved in obtaining the field measurements of the physical environment. This work continues.

Item (4) requires, first, that the field-based characterisations be in place and that correlation between physical and ecological parameters be achieved. It also requires that information about the physical habitat be available on a stage-specific basis at the other sites (and, ultimately, for all sites along the river). The physical-ecological correlation has been established, on the basis of the three completed sites, but the physical information on a stage-specific basis is not yet available for the other sites, and probably will require a 2-D hydraulic flow model to resolve. We have acquired stage-specific information by field survey and interpolation for the sites described in this report, and we are beginning to work with 2-D flow models as part of the larger Fraser River Gravel Reach Study. In the meantime, we can proceed to test our ability to identify habitat by air photo interpretation by using the winter-stage photography to interpret winter-stage conditions. Our first opportunity to test such interpretations will be in winter 2001, upcoming.

3.0 Study Area Overview

Fraser River drains 250,000 km^2 of south-western British Columbia. Much of the river system is steep and, consequently, significant amounts of sediment are mobilised and transported from the upper basin. Where the river emerges from Fraser Canyon, it encounters a rapidly declining gradient that forces the deposition of much of this coarse sediment load. Significant quantities of sand and gravel are deposited in the channel zone between Hope and Mission to form, on a large scale, a partially confined alluvial fan. On a local scale, the gravel deposits force the channel to flow around them, leading to a pattern of multiple, wandering channels that shift with bar growth and bank erosion.

Gravel accumulates in bars that occur within the channel zone. Bars shift during annual freshet as material from one location is entrained and transported while material from another location is deposited. The sequence of sediment erosion and renewal around bars results in frequent changes in morphology and bar configuration at a local scale. It also maintains fish habitat of high quality and supports benthic invertebrate production because the sediment is episodically reworked and cleaned.

Some gravel deposits build to the point that they have slack water across the top even in flood. Then sand becomes deposited, vegetation becomes established, and the bar surface builds up to form an island. Islands are stable relative to gravel bars, and may persist for centuries and support mature forests before they are eventually attacked by the river again. The longevity of many islands is an indicator of the slow pace of large-scale change along the river. Where erosional attack occurs, cut banks are steep or vertical and the water is deep and fast immediately offshore. Along these banks, “scour holes” may exceed 25 m in depth.

The channel has developed a wandering plan-form (Neill 1973; Desloges and Church 1989) to route itself around the gravel bar deposits and islands. The range of channel sizes provides varied combinations of velocity, depth, and substrate that together support a diverse assemblage of fish species. Back-channels and off-channel embayments provide rearing habitat for many species including some salmonids, and vegetated bank edges along the channels provide extensive riparian habitat where cover, terrestrial insects, nutrients and micro-habitat features are found. Vegetation along the river banks is also thought to play an important role in bank stabilisation.

The wandering pattern of multiple channels through the reach ensures a complex and diverse array of habitats is available for different fish species throughout the year. Studies currently underway at the Department of Geography, UBC, are attempting to characterise these habitats with respect to their physical morphology and the life stages of the various fish species that they support. These studies are also designed to identify the physical processes involved in the development and maintenance of these habitats through time. Physical and biological sampling has taken place at thirteen sites along the gravel reach between Chilliwack Mountain and Herrling Island (Figure 2). Each site consists of a group of connected gravel bars and vegetated islands that are, in most cases, intersected by seasonally-active secondary channels. Seven of the sites have a history of gravel extraction, five of which have been subject to gravel removals within the past 5 years.

Spatially intensive sampling for fishes and benthic invertebrates has taken place at the thirteen sites over 2 summer seasons and the intervening winter and spring. Sampling effort has been stratified across representative units of twelve distinct habitat types found in the gravel reach. A sub-set of these sites has been subjected to detailed morpho-sedimentary analyses. The three sites, Harrison Bar, Calamity Bar, and Queens Bar have been surveyed to identify micro-topography that characterises each habitat type. The sites were first surveyed at low flow in the fall/winter of 1999-00, prior to the removal of 70,500 m^3 of gravel by bar scalping from Harrison Bar. Re-surveying of the sites took place in September 2000, after freshet.

4.0 Methods

4.1 Aerial Photograph Mapping and Water Level Simulations

Large-scale aerial photographs of the gravel reach were flown by Selkirk Remote Sensing at low water conditions in March 2000. The 1:10,000 scale black-and-white stereo photos cover an area extending from Chilliwack Mountain to the upstream end of Herrling Island. From these photos, detailed morphologic maps were produced for Queens Bar, Calamity Bar, and Harrison Bar. Individual habitat and sedimentological units have been subsequently superimposed on these maps in a Geographic Information System (GIS).

The exposed gravel bars, channel banks, and channel islands were digitised from air photos of each site using an analytic stereoplotter. The stereoplotter is a photogrammetric instrument that mathematically relates two-dimensional coordinates on each photo pair to three-dimensional ground coordinates of the same features. In effect, any point on the ground can be digitised and its real-world coordinates (northing, easting, and elevation above mean sea level) will be recorded. The actual ground location of the site maps is based on the UTM projection, NAD83 datum, which is consistent with the Provincial level TRIM mapping program. The absolute accuracy of any given mapped point (i.e. its positional error with respect to its true location) is roughly 2 m root mean square (rms). However, relative accuracy (i.e. the distance between two points) for any stereo pair is 30 cm rms or less.

All digitised features were imported into Arc/Info GIS for editing and coding. The final maps consist of closed polygons representing vegetated surfaces (islands and floodplain), exposed bar gravels (unvegetated), ponded areas on the bars, and the water surface in the adjacent channel. A second set of base maps was produced by scanning aerial photographs of each site. Within the GIS, scanned images were geo-referenced by selecting a number of well distributed points and assigning northing and easting coordinates as determined with the stereoplotter. Once the initial registration was complete, each photograph was rectified, a process whereby image coordinates are uniformly rotated, translated, and scaled to the map coordinates. The rectified photographs were used as base maps for locating sample sites and habitat and sedimentologic information (see Figure 3-8).

The morphological site maps only depict habitat conditions for the water level at which the photographs were flown. As water level changes, the exposed area of bar surface changes in accordance with bar topography and the steepness of the water surface slope. The effect of changing flow levels on the distribution of habitat units around a bar was examined using a GIS-based procedure to simulate different water levels. The procedure initially involved producing a three-dimensional topographic surface for each bar complex.

Topographic field surveys of the bars (refer to Section 4.3) were imported into the GIS as a series of discrete points. The points, while scaled identical to the base maps, need to be rotated and translated until they visually aligned with the base map. Similarly, the survey elevation datum was adjusted to the true datum by comparing relative heights to locations of known elevation. Because the spatial coverage of field surveys was limited, topographic data from separate, earlier, surveys were included to produce complete surface models. These data were obtained from (1) a survey by laser altimetry of bar, island, and floodplain surfaces completed in March 1999 and (2) a hydrographic survey of the gravel reach completed in summer 1999. The data were combined into a single file and edited to remove those points overlapping the more detailed survey data. A topographic surface grid for each bar was produced using the TOPOGRID command in Arc/Info. The TOPOGRID command produces hydrologically correct digital elevation models and has been found to produce a realistic bed surface model for the entire gravel reach of Fraser River (Church et al. 2000).

With the completion of each surface model, different water levels can be simulated in the GIS by assigning an elevation to the water level. Any cell above the elevation specified (i.e. floodplain, island and some bar surfaces) will remain exposed while lower elevation cells are inundated. This simple example, however, does not account for channel gradient; the inundated area at the downstream end of a bar will be overestimated because the water surface is lower in elevation (a difference of greater than 0.5 m for Queens Bar). To account for the effect of gradient, an approximate water surface model for each site was produced. Gradient was estimated from an available map of the flood profile along the gravel reach (Ministry of Environment, Lands and Parks 1998) and water surface elevation equalled the product of slope and the horizontal distance along each site. Elevations were represented as a point-coverage and converted to a surface using a TIN model, which was then converted to a grid surface matching the interpolated cell size and orientation of the original TOPOGRID surface. The two surfaces together created the adjusted water surface model, which was then used to ‘fill’ the channel represented in the original model.

The relation between discharge and the map elevation datum was required in order to represent the bar area inundated for a given flow. A single relation for all sites was not realistic because the flow/elevation relation differs due to changes in channel geometry and gradient. Staff gauge data are a reliable source for these relations, however, none were available. An alternative approach was adopted based on hydraulic geometry, which relates channel width, depth, and velocity of flow to discharge based on power function relations. The relation between channel width and flow was obtained from mapped historical sequences of the sites that were previously produced at the Department of Geography for various dates between 1928 and 1999. River discharge was related to water area for each site as $A=xQ^n$, where Q represents flow and x and n are constants. A similar relation was established for area and height above datum from the adjusted water slope model by specifying an elevation and calculating the total area covered by water.

Both equations have the same form, hence, they were combined and reduced to the form $h=xQ^n$. Any flow then can be specified and the corresponding height above datum calculated. Cells less than this value will be inundated at the specified flow. Maps depicting Queens Bar, Calamity Bar, and Harrison Bar at one actual and three simulated water levels are presented in Sections 8.3 - 8.5.

Figure 3. Wolman sample sites on Queens Bar. Airphoto taken March 10, 2000.

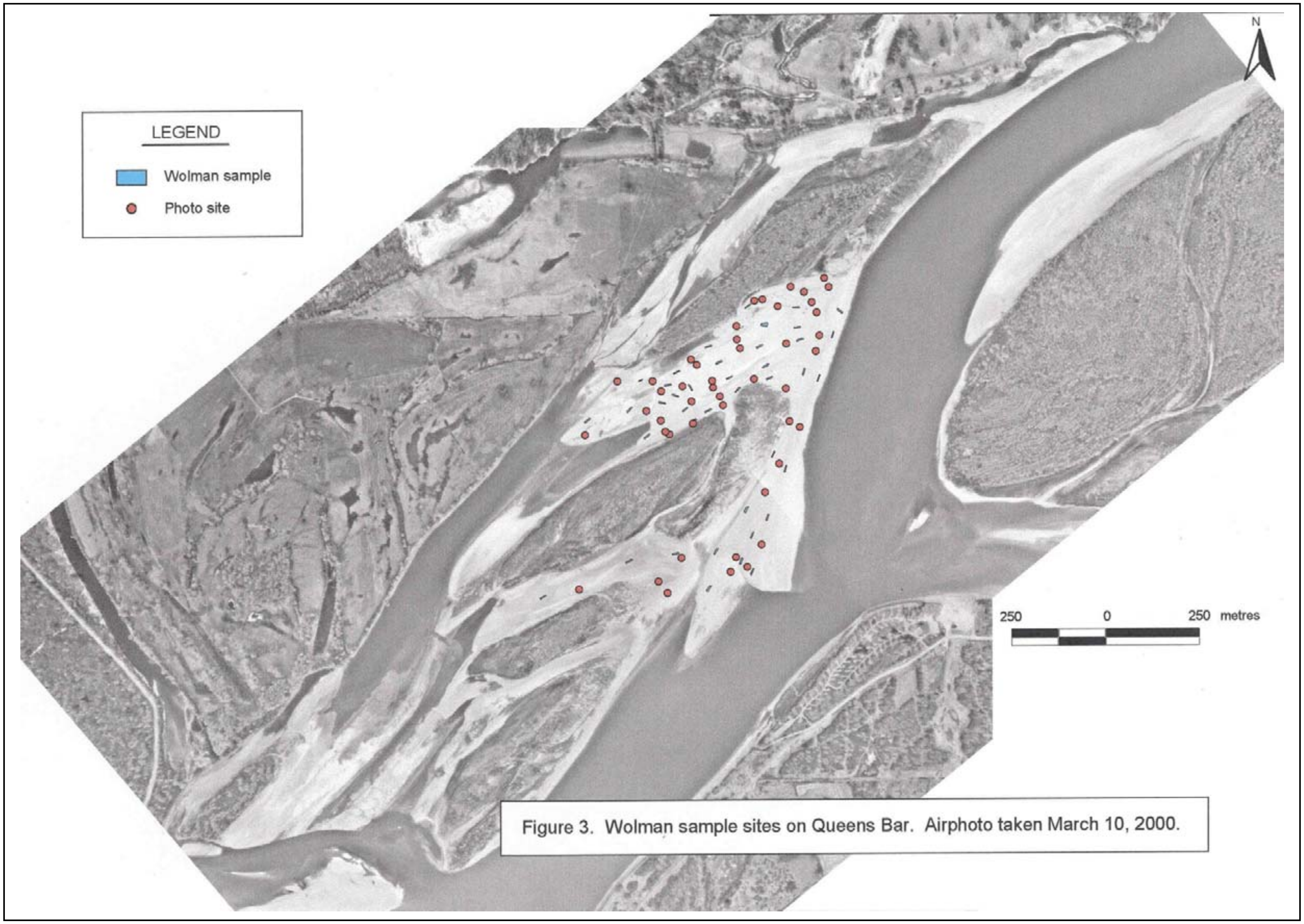


Figure 4. Fish and benthic sample sites on Queens Bar - July 1999 to September 2000. Airphoto taken March 10, 2000.

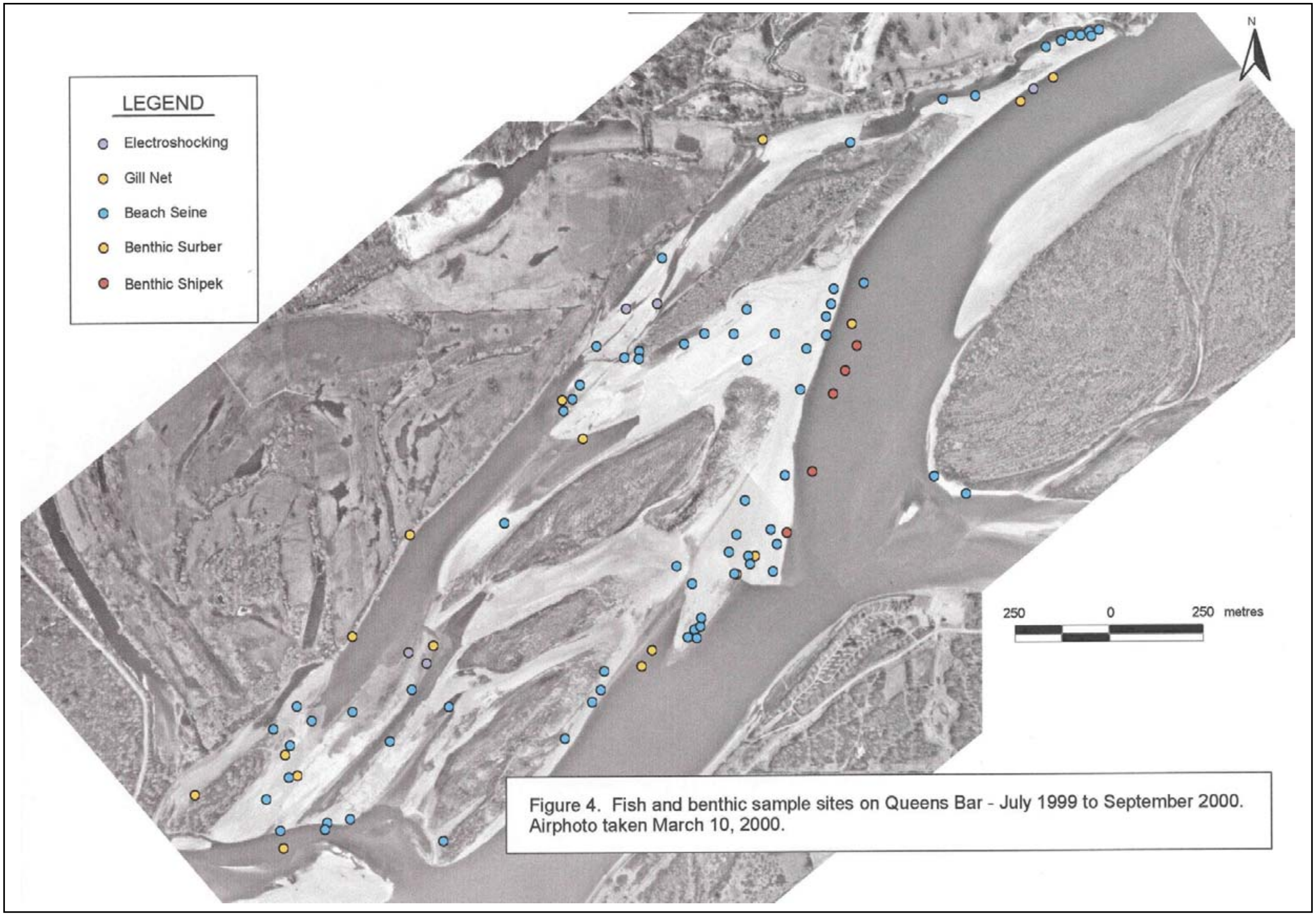


Figure 4. Fish and benthic sample sites on Queens Bar - July 1999 to September 2000. Airphoto taken March 10, 2000.

Figure 5. Wolman sample sites on Calamity Bar. Airphoto taken March 10, 2000.

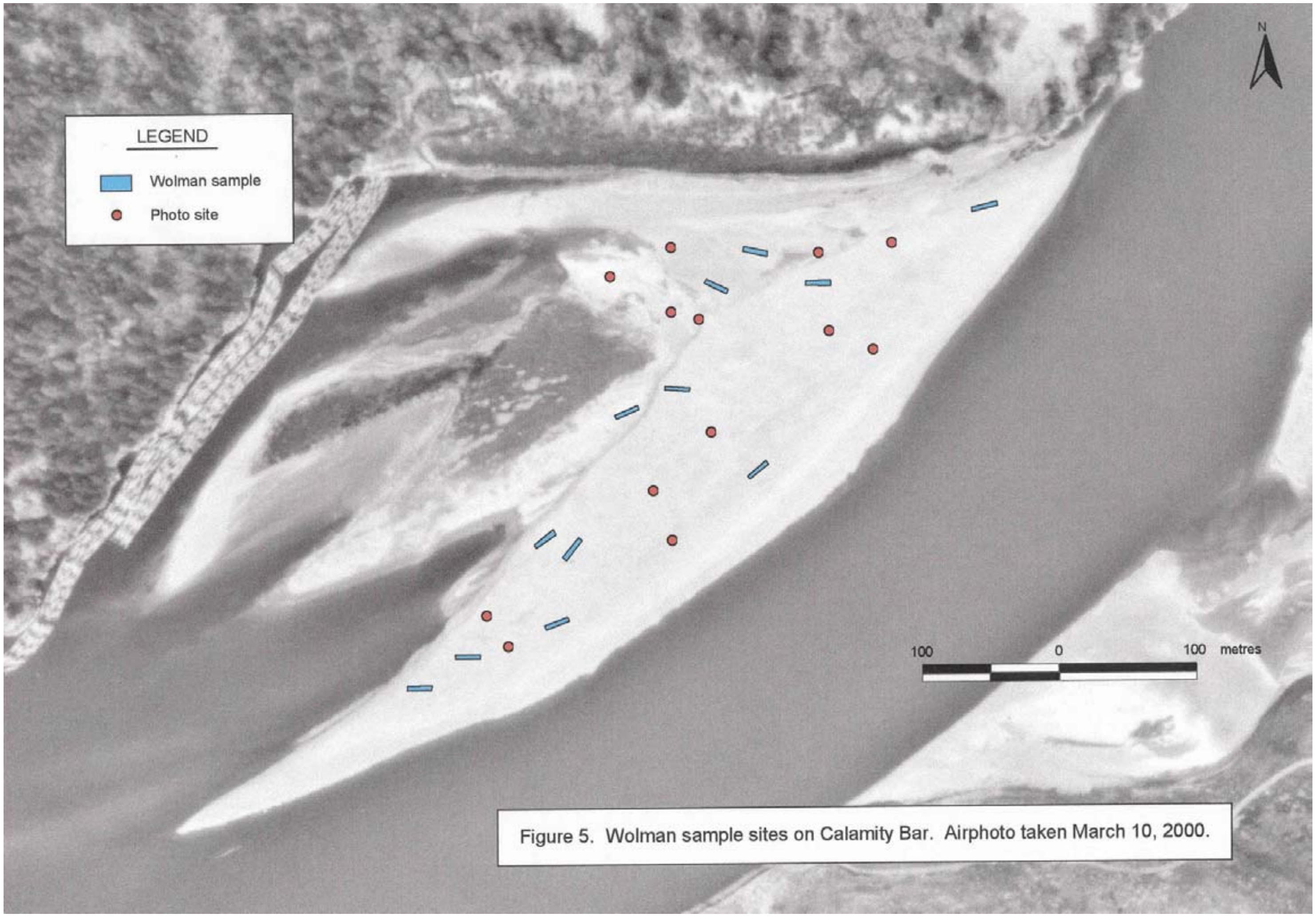


Figure 5. Wolman sample sites on Calamity Bar. Airphoto taken March 10, 2000.

Figure 6. Fish and benthic sample sites on Calamity Bar - July 1999 to September 2000. Airphoto taken March 10, 2000.

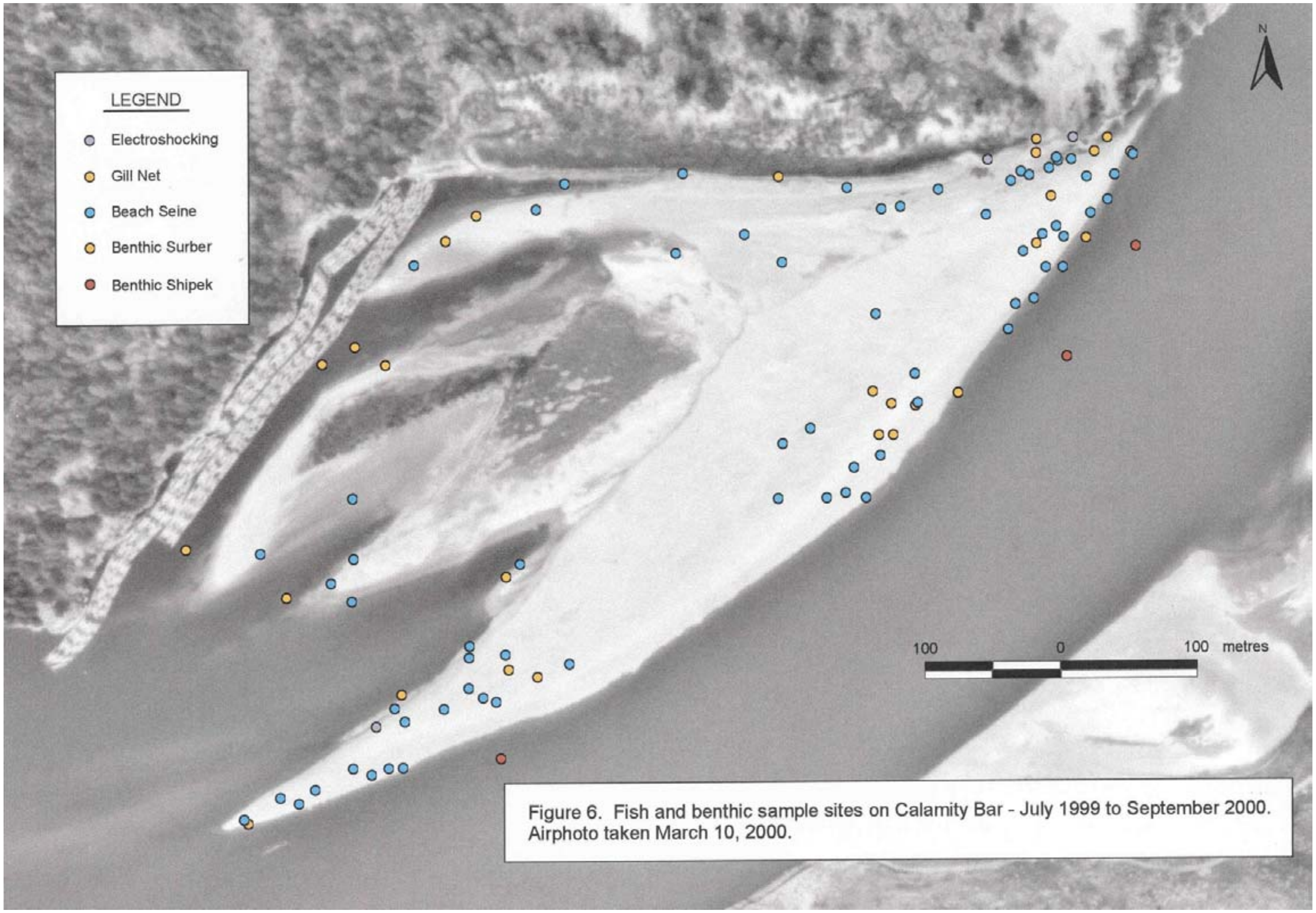


Figure 6. Fish and benthic sample sites on Calamity Bar - July 1999 to September 2000. Airphoto taken March 10, 2000.

Figure 7. Wolman sample sites on Harrison Bar. Airphoto taken March 10, 2000.

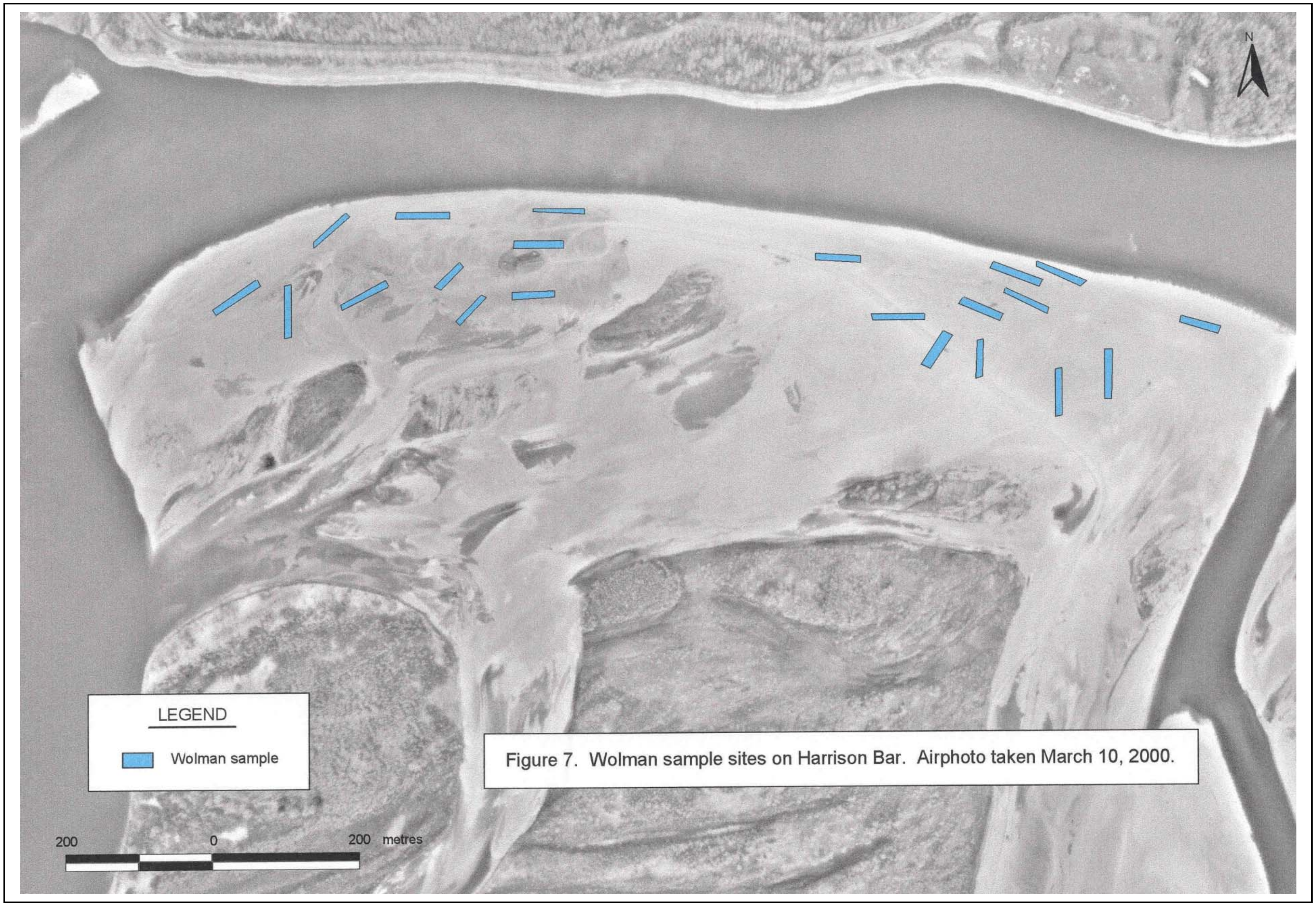
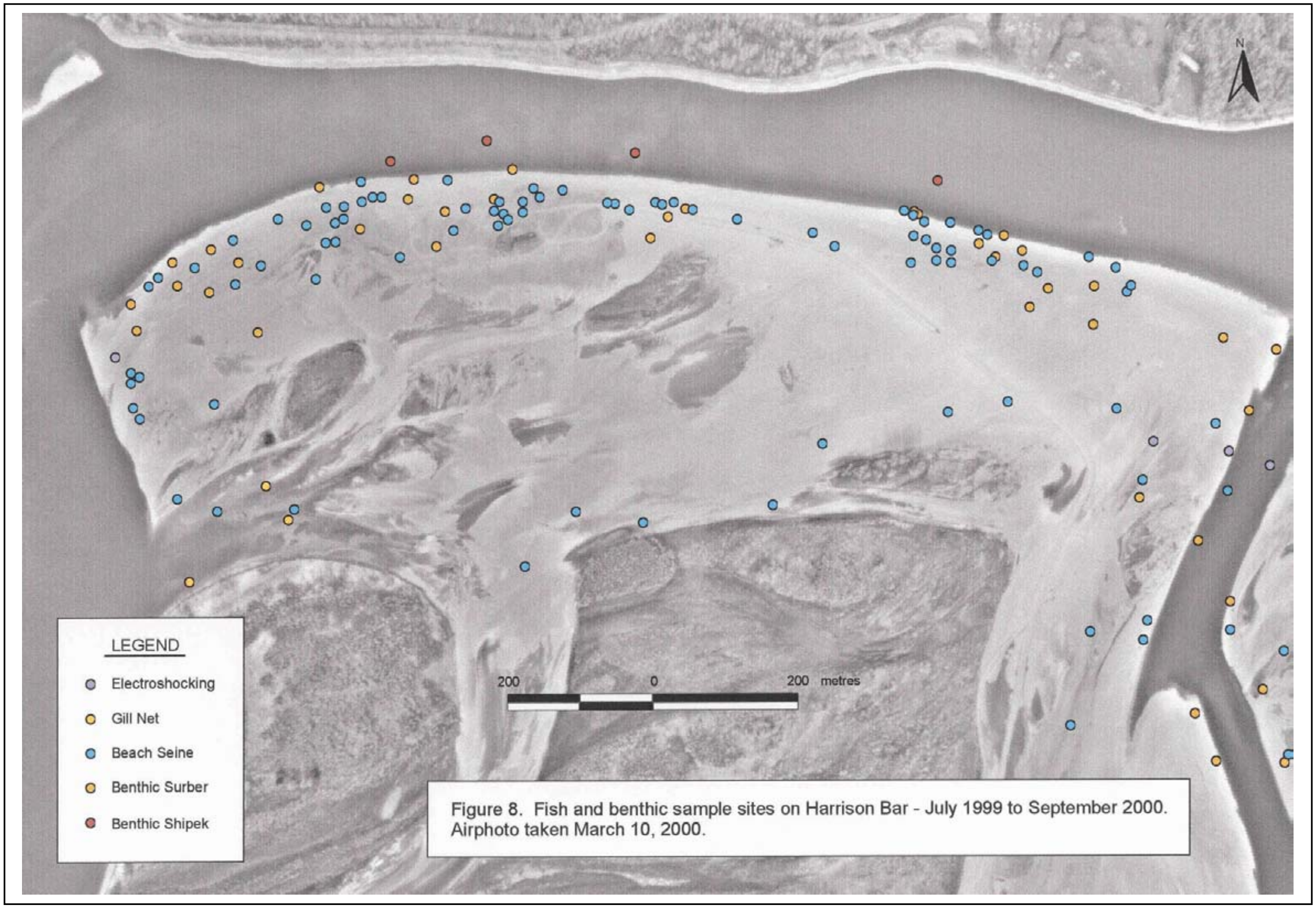


Figure 8. Fish and benthic sample sites on Harrison Bar - July 1999 to September 2000. Airphoto taken March 10, 2000.



4.2 Field Sample Site Locations

The locations of surface sediment samples and sites of fish and benthic invertebrates collection on Queens Bar are shown in Figure 3 and Figure 4, respectively. Sample locations on Calamity and Harrison Bars are presented in Figure 5 – Figure 8. All sediment samples were collected during periods of low flow in between February and April 2000, and in September 2000. Fish and invertebrate sampling was carried out on a seasonal basis between July 1999 and September 2000. At each site, attempts were made to distribute sampling efforts over the entire site and also stratify effort across the various habitat types.

4.3 Topographic Surveys

Detailed morphological surveys were conducted across the main platform of Calamity and the central portion of Queens in April 2000. A new survey of Harrison was conducted in September 2000. Surveys were carried out using a Leica total station equipped with a coaxial, infrared EDM, automatic target recognition, motorised target tracking, and remote control facilities. The instrument allowed rapid collection of precise measurements (nominally, ± 5” (seconds) on angles and ± 3mm on slope distances) over large areas. Control networks were established on each bar and, in the case of Harrison, tied to a pair of pre-existing control points. Exposed gravel surfaces were surveyed at a density that varied with the intricacy of the surface topography but averaged approximately one point per $100m^2$ (yielding 3300, 1950, and 1400 positions on Queens, Calamity, and Harrison respectively). All notable breaks of slope were included and from each survey the bar-surface morphology associated with accretionary sediment units and erosional channel complexes was resolved. It was not possible to continue the survey into areas of deep water and dense vegetation, hence the main channel and bar-top island topography were excluded.

4.4 Sediment Sampling

The unconsolidated sediments that dominate the substrate of gravel-bed rivers are notoriously heterogeneous. Texture varies in space, with depth, and through time to produce a changing mosaic of textural patches at a variety of scales. Here, our intention was to characterise the spatial patterns of textural variation across large areas of the three bars chosen for detailed study. A limited number of subsurface sediments were collected, but field efforts focused on sampling surface materials because it is this layer that spawning and rearing fish encounter, that macroinvertebrates live, and that defines boundary hydraulic roughness. In addition, it is the surface sediment that is visible to a practitioner charged with identifying habitat units.

Field reconnaissance in September 1999 revealed three bed-surface types within the gravel reach. “Clean gravels” have little or no fine material present. “Sandy gravels” are those with the coarse gravel framework partially obscured by a thin, discontinuous veneer of sand. “Blanket sands” are those where the gravel framework is buried beneath a sequence of sandy deposits. Clean and sandy gravels dominate the active portions of the reach. Within annually inundated areas, blanket sands are limited to areas of low hydraulic stress, although there is prolific deposition of overbank sands on islands.

The proportion of fine material on the surface is of ecological interest because it affects primary production, modifies the architecture of macroinvertebrate habitat and, in part, determines the spawning quality of the bed. The coarser, framework fraction is equally important because it determines the ultimate stability of the bed at a particular place and it is this material that dominates the surface layer when discharge rises sufficiently to flush away patches of fine material. In sandy gravels it then becomes important to appreciate not only the proportion of sand present (considered here as material less than 4mm in diameter), but also the grain-size distribution of the partially covered gravel underneath. A composite grain-size distribution that incorporates both size fractions is of relatively little value. Sampling was, therefore, designed to provide information about both fractions.

Two sampling methods were used during low flow periods between February and April 2000. "Wolman" samples obtained a robust characterisation of the entire grain size distribution at 41 sites on Queens, 12 sites on Calamity and 11 sites on Harrison (eight before and three after gravel removal). Additional samples were collected after the freshet from 21 sites on Queens and 10 sites on Harrison. Each sample consists of between 360 and 400 stones picked from the intersections of a grid laid out on the bar surface. Grid spacing must exceed twice the diameter of the largest particle present and, in most cases, a grid spacing of 0.75m was adopted. Individual stones were sorted using hand templates into standard grain-size categories (<4, 4-8, 8-11, 11-16, 16-22, 22-32, 32-45, 45-64, 64-90, 90-128, 128-180mm) from which cumulative percentage curves were constructed. Wolman sampling does not provide information about the distribution of sizes in the sand fraction (i.e. material finer than 4mm) but it does give an accurate assessment of the overall proportion of the surface area that is covered with sand-sized material. In line with the argument made above, frequency distributions were truncated at 4mm to yield a frequency curve for only the gravel fraction. A number of descriptive parameters were then determined including, median size (D_{50}), sorting coefficient (σ), and two distribution percentiles that indicate the size of the coarse (D_{95}) and fine (D_5) material present (see Appendix C).

Wolman sampling is time consuming hence a complementary photographic method, which allows rapid data collection over large areas, was also used to estimate grain-size parameters. The technique is based on simple geometrical arguments, which suggest that there is an inverse relation between the size of the particles that occur on a surface and the number of those particles present per unit area. At 83 sites where Wolman data were collected (including 30 sites on nine other bars along the gravel-reach) a hand-held 35mm camera was used to obtain a vertical photograph of a 0.5 x 0.5m quadrat laid down within the Wolman sampling grid. In the office, the clasts visible within each quadrat were counted and the proportions of the area covered in sand and obscured by shadow were measured.

By plotting grain-size data from the truncated Wolman samples against the counts obtained from the photographs (after correction for areas obscured by shadow and sand), simple relations are apparent between count per m^2 and D_5, D_{50} and D_{95}. Note that by correcting for sand cover and utilising truncated Wolman samples, one obtains percentiles for the coarse gravel framework as specified above. Linear regression on log-transformed variates yields calibration functions that can then be applied to counts obtained from other sites. This calibration provides a means of rapidly obtaining percentile estimates in the field, although the counting process remains time-consuming in the office.

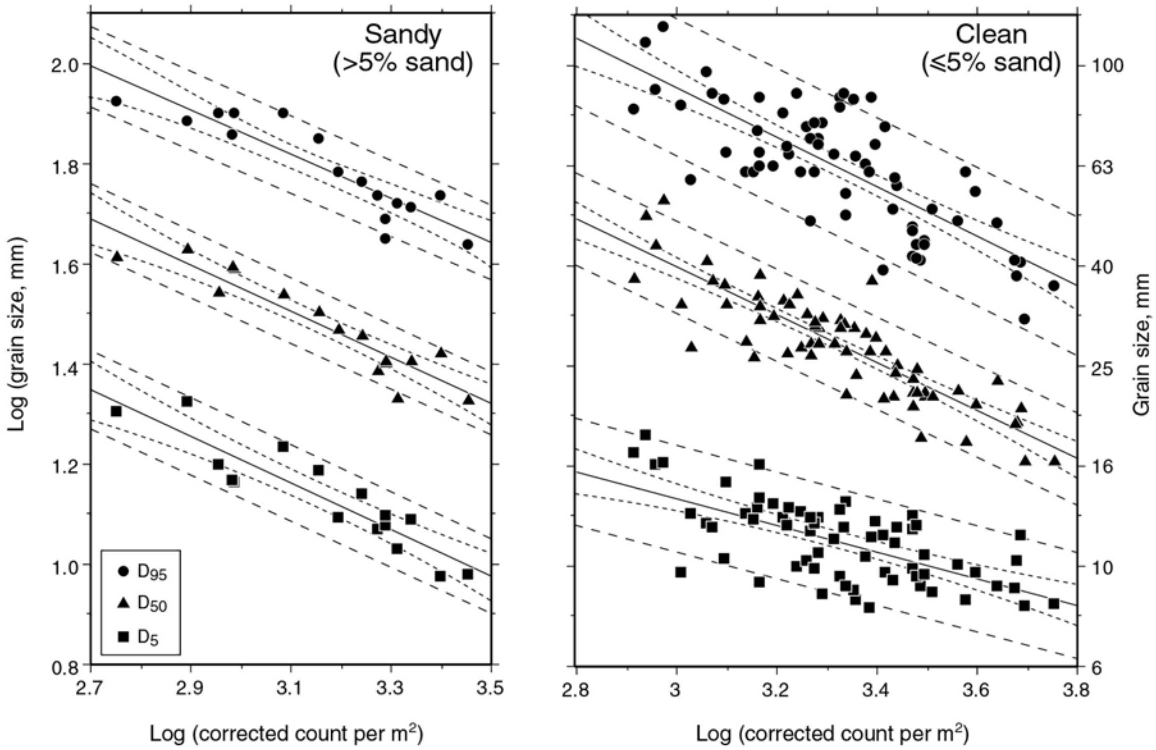
Analysis indicates that, despite correction for sand cover, two sets of calibration functions are appropriate for the gravel reach of Fraser River (Table 1, Figure 9): one set for sites characterised by clean gravels ($\leq$ 5% sand) and one set for sandy sites (> 5% sand). The errors associated with individual predictions are not trivial such that care need be exercised in interpreting results from this method. Nevertheless, it provides a feasible means of obtaining useful information over large areas. Photo-based estimates of percentage sand cover and framework grain-sizes were obtained at 13 sites on Calamity and 46 sites on Queens.

Table 1. Calibration equations for the photographic sampling method.

	R^2	Significance (α)	RMS residual	Prediction limits (α = 0.05) on mean estimates at $C = 10^{3.1}$ (sandy) and $C = 10^{3.5}$ (clean)
Sandy gravels $D_5 = 400\ C^{-0.46}$	0.83	< 0.0001	0.043	+3, -2mm
$D_{50} = 869\ C^{-0.46}$	0.87	< 0.0001	0.037	+5, -4mm
$D_{95} = 1500\ C^{-0.44}$	0.82	< 0.0001	0.043	+13, -10mm

Clean gravels $D_5 = 85.7\ C^{-0.27}$	0.43	< 0.0001	0.062	+3, -2mm
$D_{50} = 1052\ C^{-0.48}$	0.75	< 0.0001	0.055	+5, -5mm
$D_{95} = 2723\ C^{-0.49}$	0.60	< 0.0001	0.081	+19, -14mm

Figure 9. Calibration relations for the photographic sampling method.



4.5 Fish Sampling

Patterns of habitat use by juvenile fish species have been examined using a variety of techniques: beach seine, gillnet, minnow trapping, and electro-shocking. Beach seining provides the most reliable and consistent catch data, and is also the most versatile collection method for different habitats. Its major limitation is that sampling extends only to depths of less than 1.2 m, the maximum depth one can safely beach seine with chest waders. In most cases, a beach seine with dimensions 12.5 m x 2 m and a mesh size of 19mm was used.

Gillnetting was restricted to habitats of deep, standing water away from the main channel to minimise the risk of intercepting migratory adult salmon. The small mesh sizes (2.5, 4, 7 cm) in each of three, 15 x 2.5 m panels also helped to reduce this risk. As a consequence, the habitats sampled by gillnet were distinct from those sampled by beach seine. Minnow traps were set along river banks over a range of depths and velocities where both beach seining and gillnetting were not feasible. The traps were baited with salmon roe and, consequently, do not provide representative data of fish species composition. For this reason, they were not widely used. The use of electro-shocking was also limited because high turbidity interferes with fish collection. Only riffle habitat to water depths <60 cm were electro-shocked. In these conditions, beach seining was not practical.

The sampling schedule coincided with the major phases of the discharge hydrograph. Winter sampling at low flow took place in February 2000. Spring sampling on the rising limb of the hydrograph took place in March and April 2000. Limited sampling at peak flow occurred in July 1999 and 2000. Summer sampling on the declining limb of the hydrograph took place in August and September 1999 and 2000.

A significant amount of sampling effort was devoted to fish sampling over the course of the study. Efforts were stratified across three channel types and twelve habitat types (refer to Section 5.3). A total of 675 beach seines were conducted, together extending along more than 25 km of bar edge and bank line, and covering 240,000 m^2 of channel area. Three hundred hours of gillnetting were carried out in deep, low velocity habitats, with an average gillnet set lasting approximately 4 hours. A total of 385 overnight sets using minnow traps along deep, low velocity bank edges accounted for more than 9,100 hours of sampling time. Also, 2,300 m^2 of shallow, riffle habitat were sampled by electro-shocking in late summer 1999.

Together, more than 42,000 fish were identified and counted in the gravel reach of Fraser River. Of these, 21,000 were measured for fork length and 9,900 were weighed and measured. Twenty-four species of fish were identified, including ten salmonid species, white sturgeon (red-listed in British Columbia) and 4 blue-listed species (mountain sucker, coastal cutthroat trout, bull trout, and Dolly Varden) (http://www.elp.gov.bc.ca/rib/wis/cdc/vertebrates.htm). A complete species list is provided in Appendix A.

Observations and measurements of the physical habitat were made at all fish collection sites, with the level of detail depending on the sampling technique used. Water velocity and depth were measured at nine points within beach seine areas using a wading rod and Marsh-McBirney velocity meter. The surface sediment was visually classified for degree of embeddedness and the percentage representation of major grain size classes. The slope angle of the bar edge was estimated and the presence and type of nearby riparian vegetation were noted. Water temperature at the mid-point of the seine area was measured and a detailed sketch map of the local bar configuration and flow patterns was made at all sampling locations. Factors possibly influencing fish distributions such as the presence of large woody debris, algal growth and fine sediment draped over the surface substrate were also noted.

Once collected, all fish were identified to species and counted. A minimum of 15 fishes representing non-anadromous species and all anadromous fishes were measured for fork length and, weather permitting, weighed as well.

Approximately 3% (533 fish in 1999 and 595 in 2000) of fishes representing most species were sacrificed to examine the stomach contents and determine the dietary selection of different species. These data are not yet available, but will be linked with macroinvertebrate data as a means of determining habitat utilisation by fish (see below). Collecting stomach contents of a particular species from multiple locations and dates also allows testing for site-specific, habitat-specific, and season-specific differences in foraging patterns.

4.6 Benthic Invertebrate Sampling

Macroinvertebrates were collected from most sites in spring and autumn 1999, winter 2000, and summer 2000. A Surber net (500-μm mesh, 0.09 m^2) collected samples at approximately 25 cm water depth and in habitat types with flow. By collecting invertebrates from near-shore locations, the data can be linked spatially with fish stomach data from beach seining. An alternative method was used in May and August 1999, to collect benthic samples from 1.5 m water depth. The Shipek Grab had been used successfully in a previous study on the Fraser River (Rempel et al. 1999, 2000) for sampling in deep water. Use of the Shipek for this project, however, has not continued because the Surber net is easier to use and its samples are more spatially related to fish stomach samples. Due to the extensive time required for benthic sample processing, results are not complete; therefore only preliminary comments are made in this report.

This past September, drift samples were collected from the water surface and adjacent to the river bed in deep water habitats. Samples were taken from (1) secondary channels in immediate proximity to riparian vegetation, and (2) the main channel at sites with no riparian influence. The contrasting site conditions were selected to evaluate the contribution of terrestrial insects from bank-edge vegetation because large proportions of terrestrial insects have been observed in the stomachs of several fish species. The drift samples are not yet analysed, however, a significantly greater volume of invertebrate biomass (both terrestrial and aquatic) was observed in drift samples as compared to late summer Surber samples.

5.0 Classification Overview

5.1 Level One – Reach Scale Classification

The morphology of alluvial rivers -- ones flowing through their own sedimentary deposits -- is governed principally by the flow, the quantity and calibre of sediment delivered to the channel, and the topographic setting. Flow determines the scale of the river. The size of the sediment load in the river and its concentration (quantity per unit flow) determine the morphological form of the channel and channel pattern, hence the character of the aquatic habitat. The topographic setting includes the gradient available to the river, hence its ability to transport the sediment.

The gravel-bed reach of Fraser River does not have a large variation in flow. The principal tributary is Harrison River, which has, in any case, a highly regulated flow regime because of the large lake upstream. The gradient of Fraser River, however, declines steadily through the reach as a consequence of long-continued deposition of the gravel portion of the river load as it approaches the end of its course. Consequently, the competence of the river (the ability to transport sediment of a given size) also declines, and there is a downstream decline in the size of material comprising the bed and banks of the river. This declining competence determines the wandering morphology of the channel as the river is forced to flow around its own deposits.

Within the gravel reach, variations in morphological style are discernible, governed by the variation in reach gradient and the trend of the sediment budget (which determines the rate of sediment exchange and net aggradation rate in the sub-reach). These variations have been identified and located by examination of the following information sources:

- NTS topographic maps at 1:50 000 scale (sheets 92G/1; 92H/4; 92H/5; 92H/6: information from 1988-89);
- air photographs flown 20 March, 1999 at a nominal scale of 1:40 000 (15BC99001/1-37);
- sediment budget information as summarised in Church et al. (2000).

Trends in river gradient, observed morphology, and sediment transport have been collated in 5 sub-reaches of individually identifiable morphological character. This lends them a distinctive distribution of habitats (though not individually unique habitats) which probably influences the fish assemblages dominantly found in each sub-reach. The characteristics of these reaches will remain unchanged for many decades (simply in view of the cumulatively very large volume of resident sediment that will have to be moved to effect a definitive change in each sub-reach), hence these sub-reaches are suitable for strategic management planning within the gravel-bed reach.

5.2 Level Two – Pool-Bar-Riffle Classification

Within each sub-reach the river is organised into a sequence of pool-bar-riffle units. These units correspond with the characteristic step-length for gravel displacement, once mobilised, in the river. Such units are also characteristic of the organisation of all gravel-transporting channels. In Fraser River, the average width of such units is 700 metres -- that is, about 1.4 times the apparent equilibrium width of the principal channel (which is about 500 m). The number of units recognised along the study reach is 31, for an average unit length along the river of 2.6 km.

A unit consists, basically, of a riffle, superimposed bar, and adjacent/downstream pool. Some units are more complex; sometimes more than one unit is identified on a single, extended riffle; and sometimes the riffle is entirely coincident with the bar and is not separately identified. Around each such unit, a variety of fluvial sedimentary features and habitats is found (see section 5.3), but they are replicated from unit to unit, only changing their relative frequency as one moves from sub-reach to sub-reach along the river. The size of these units, and the fact that they are the largest identifiable units within which the full range of local habitats may be found, makes them suitable for operational management along the river, and appropriate as planning units for scientific studies of river sedimentation and ecology.

The units have been identified from the air photography of March 1999, at 1:40,000 nominal scale and photography at 1:10,000 nominal scale (SRS 6164/1-92, flown on 10 March, 2000). Both sets are low-flow photos commissioned for this project. To some degree, the unit division is arbitrary since individual, very large features of the river (e.g., Herrling Island) are multi-unit complexes with a long history of development, which must be divided for practical purposes. In addition, the classification must cover the entire river, so deep-water boundaries between adjacent units are locally rather arbitrarily drawn. True boundaries, which would be defined by the thalweg (deepest part) of the river shift in many places from year to year, making defined boundaries somewhat inexact in any case.

Erosion and sedimentation changes the features around bars in most years. Occasionally, an avulsion within the channel zone causes a substantial reorganisation of channels and bars locally. Hence, these units are somewhat changeable. In practice, the major bars remain identifiable for many decades (mostly, they have well-established names), so that this level of the classification will remain useful, with some year-to-year practical adjustment, for a decade or more, and may then require redefinition only locally.

5.3 Level Three – Habitat Classification

Within pool-bar-riffle units, the finest level of classification identifies three *channel* types and twelve *habitat* types on the basis of morphological and hydraulic differences, and differences in the spatial distribution of fish species.

The types of aquatic habitats in large rivers, as well as their extent and distribution have been inadequately described, and the fish assemblages they support have remained equally uncertain. Consequently, it was originally unknown how differently, if at all, habitats should be defined for large rivers in contrast to small streams. Recognising and delineating habitat types along the gravel reach of Fraser River was therefore an iterative process, using a combination of both air photograph interpretation and field surveys. Air photographs were examined initially to identify morphologically homogeneous areas around bars. Fish sampling served to validate and refine the boundaries of these habitats and identify spatial differences in the distribution of species. Together, physical characteristics and empirically-derived ecological patterns formed the basis for the classification system.

River habitats were first classified according to *channel type* (Table 2). This level of classification distinguished seasonally active channels (summer) from perennial channels (main and side) and recognised differences in channel size (Figure 10). Generalisations about the calibre of bed material and the frequency of bed load transport, as well as flow conveyance capacity, can be made at this level of classification. The amount of main and side channel area at the thirteen study sites is generally similar, however, the number of summer channels tends to vary between sites. Several summer channels are depicted in Figure 11.

Table 2. Level *I* of the habitat classification: channel type classification for the gravel reach of Fraser River.

CHANNEL TYPE	DESCRIPTION
Main	Channel conveys flow throughout year and includes the thalweg. Bed material consists mostly of "clean gravels", containing a low proportion of fine sediment. The surface material is subject to bed load transport during freshet.
Side	Channel conveys substantial discharge during freshet but may have little or no flow during winter. Wetted habitats at the upper and lower end of the channel persist year-round. Orientation is usually parallel to the main channel. Bed material contains a low to moderate amount of fine sediment (i.e., "sandy gravels") at the upstream end and a moderate to high amount at the downstream end (i.e., "blanket sands"). Minor bed load transport during freshet.
Summer	Channel is seasonally inundated during freshet only and is often oriented diagonal to the main channel and intersecting the bar top. Bed surface elevation is high relative to the main channel and the bed material contains a high proportion of fine sediment (i.e., "sandy gravels" and "blanket sands"). Fine gravel may be transported; heavy sand load.

Figure 10. Photograph taken from Cheam Mountain in September 1999 of a portion of the gravel reach at Agassiz. Lower Herrling Island, Powerline Island, Hamilton Bar, and Big Bar are shown. The three channel types are indicated and boundaries of several pool-bar-riffle units (Level 2) are shown. Direction of flow is from bottom-left to top-right.

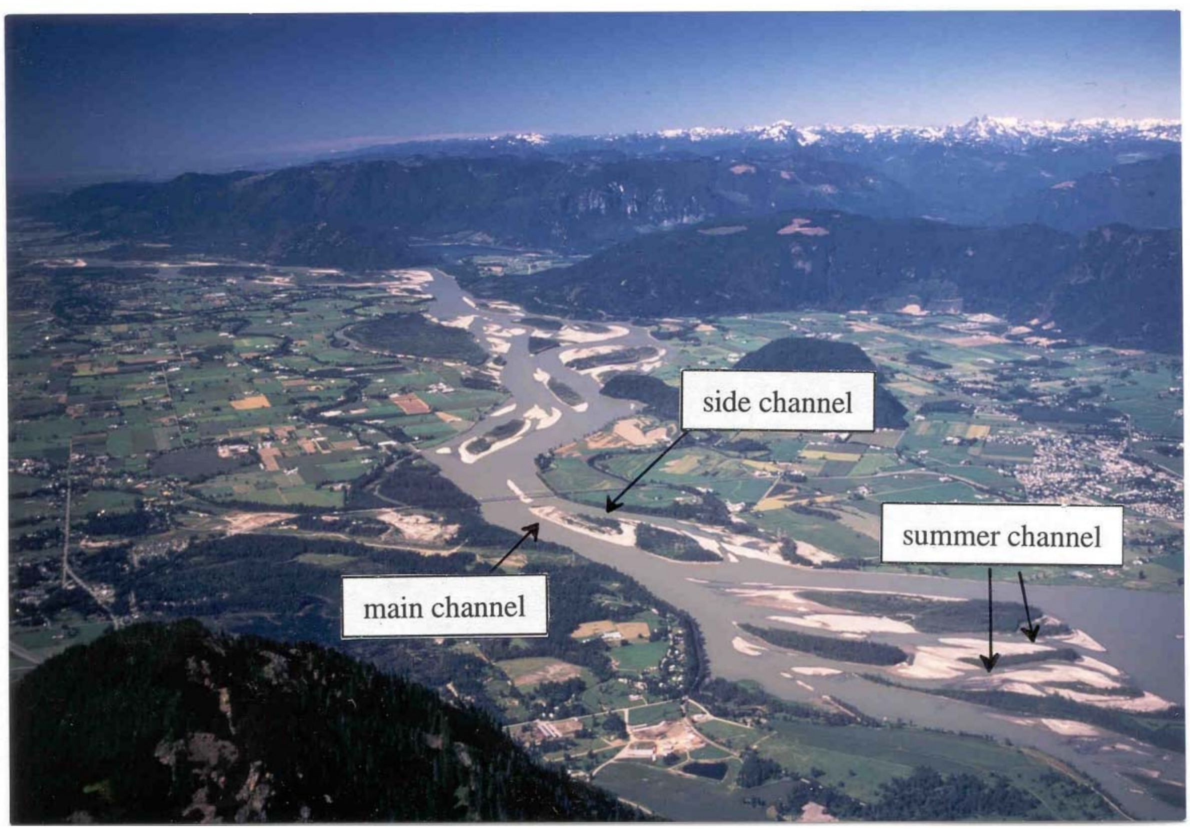
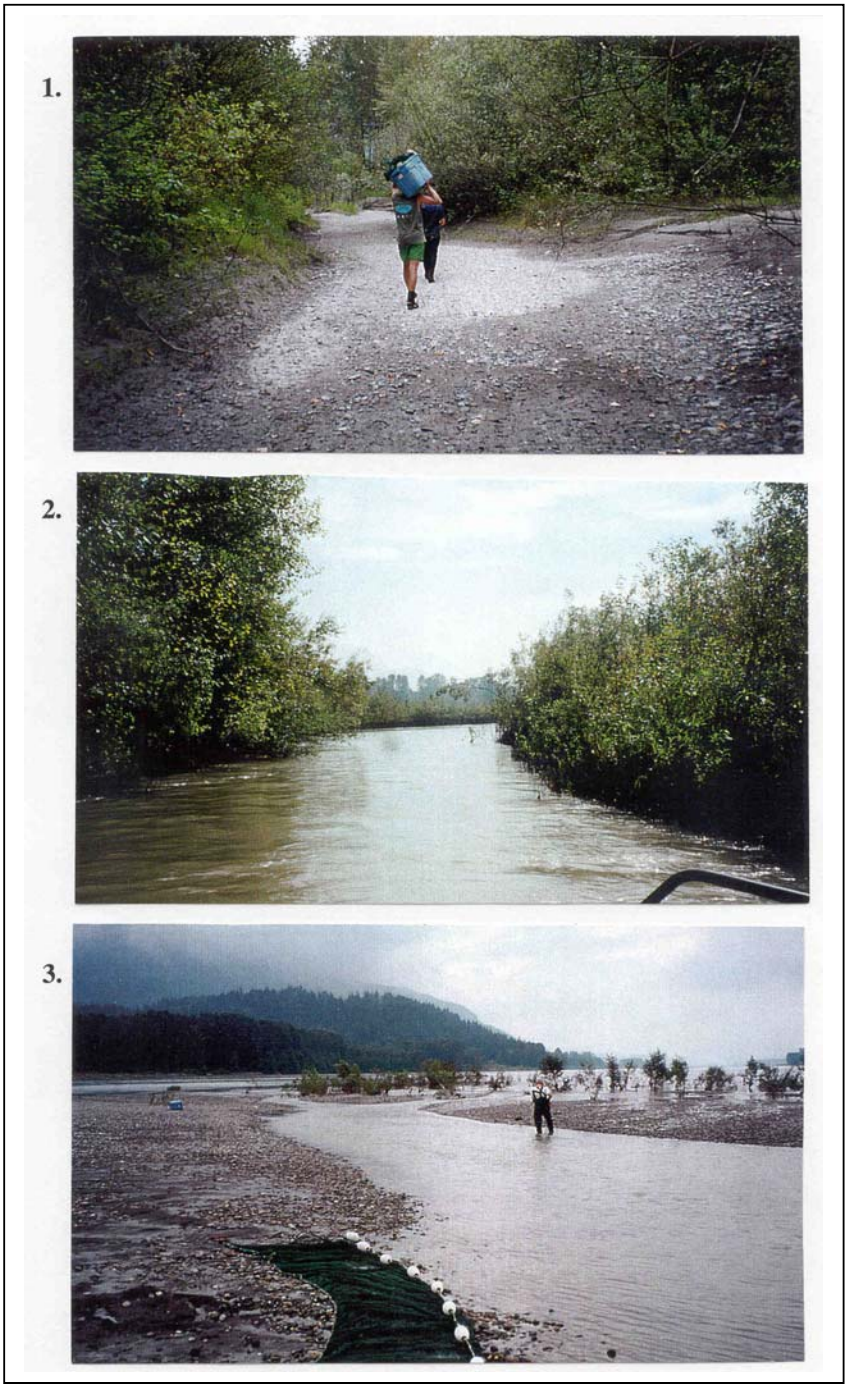


Figure 11. Examples of summer channels, which are seasonally inundated during freshet and are typically oriented diagonal to the main channel. **(1)** Dry channel in September 2000 on Foster Bar; **(2)** Heavily vegetated channel near Lower Minto Bar in July 1999 (water depth 2 m); **(3)** Non-vegetated channel on Harrison Bar, July 2000 (water depth 0.5 m).

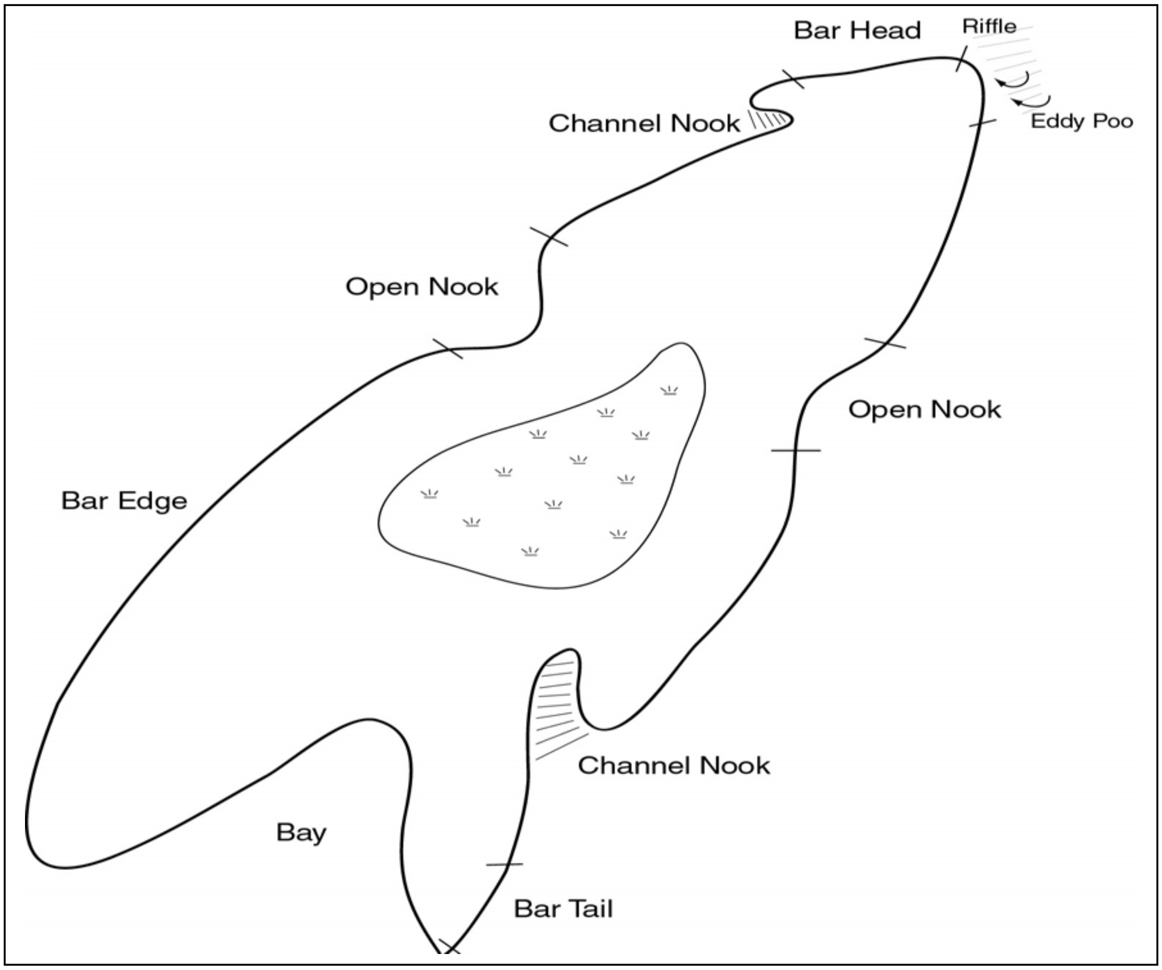


Twelve *habitat types*, defined in Table 3, were classified as physically and ecologically distinct in the gravel reach. All habitats have a likelihood of occurring in each type of channel and at each site. The habitats differ with respect to morphological, sedimentary, and hydraulic characteristics and, consequently, different collection techniques were used for fish sampling. A comprehensive description of the physical and ecological attributes of these habitats is presented in Section 8.1. Photographs of these habitat types and examples of the typical surface sediment texture are provided in Appendix B. Because several habitats have not been identified in previous stream and river habitat classifications, a sketch illustration is also included for clarification (Figure 12). The thalweg was deliberately omitted from the classification because sampling limitations made it impossible to determine whether or not it represents rearing habitat for juvenile fishes.

Table 3. Level *II* of the habitat classification for the gravel reach of Fraser River.

HABITAT TYPE	DEFINITION
Bar Head	Upstream end of a gravel bar. Surface substrate is characteristically coarse and there is negligible riparian influence except possibly at high discharge. Flow velocity is usually high (erosional) but can be a back eddy (depositional) depending on the orientation of the current.
Bar Tail	Downstream end of a gravel bar, usually with moderate to low flow velocity and negligible riparian influence. The habitat is often depositional and surface substrate consists of smaller cobbles and gravels, often of uniform size and sometimes embedded with fine sediment.
Bar Edge	Any length of bar edge not occurring at the head or tail of a bar that is oriented parallel to the flow and subject to constant and consistent flow forces. A range of velocities and substrate types is possible. Riparian influence is variable.
Riffle	High-gradient area of shallow, fast water flowing over well-sorted, coarse substrate that often has granular structures and is stable. The flow is rough.
Eddy Pool	Area bounded by fast, rough water that creates a back eddy in the lee of the flow. Common on the inside edge of riffles and at the most upstream end of some bar head habitats. Bank slope is invariably steep and the substrate is often embedded gravel and cobble.
Open Nook	Shallow indentation along a bar edge of reduced velocity that is openly connected to the channel with no sedimentary barrier (unlike channel nook). An ephemeral habitat that often disappears with a relatively small change in water level.
Channel Nook	Dead-end channel of standing water and concave geometry with the deepest water at the mid-point of a cross-section. The channel conveys flow at higher discharge. Substrate material usually consists of sand/silt and embedded gravel.
Bay	Semi-enclosed area with no flow velocity and of fine bed material (sand/silt). Occurring on the lee side of large sediment accretions that are deposited in the shape of a crescent-dune. In-stream large woody debris may occur and the degree of riparian influence is variable.
Cut Bank	Naturally eroding bank that is steeply sloped or near vertical. Dense riparian vegetation is often, but not invariably present. Large woody debris is common. Flow conditions are variable and the substrate usually consists of fine sediment.
Rock Bank	Natural bank consisting of bedrock material that is invariably steep. The water is deep immediately offshore and currents are either fast or form a back eddy.
Artificial Bank	Bank that is invariably steep and consisting of unnatural material, usually rip rap or rubble rock. The water is usually deep and fast immediately offshore.
Open Water	Open area with no direct influence from bank or bar edge features or riparian vegetation. Velocity and substrate characteristics are variable. In-stream large woody debris may occur.

Figure 12. Sketch illustrating several common habitat types in the gravel reach of Fraser River.



6.0 Reach-Scale Classification (Level One)

The 5 reaches identified in level 1 of the classification are presented in Table 4 (also refer to Figure 13).

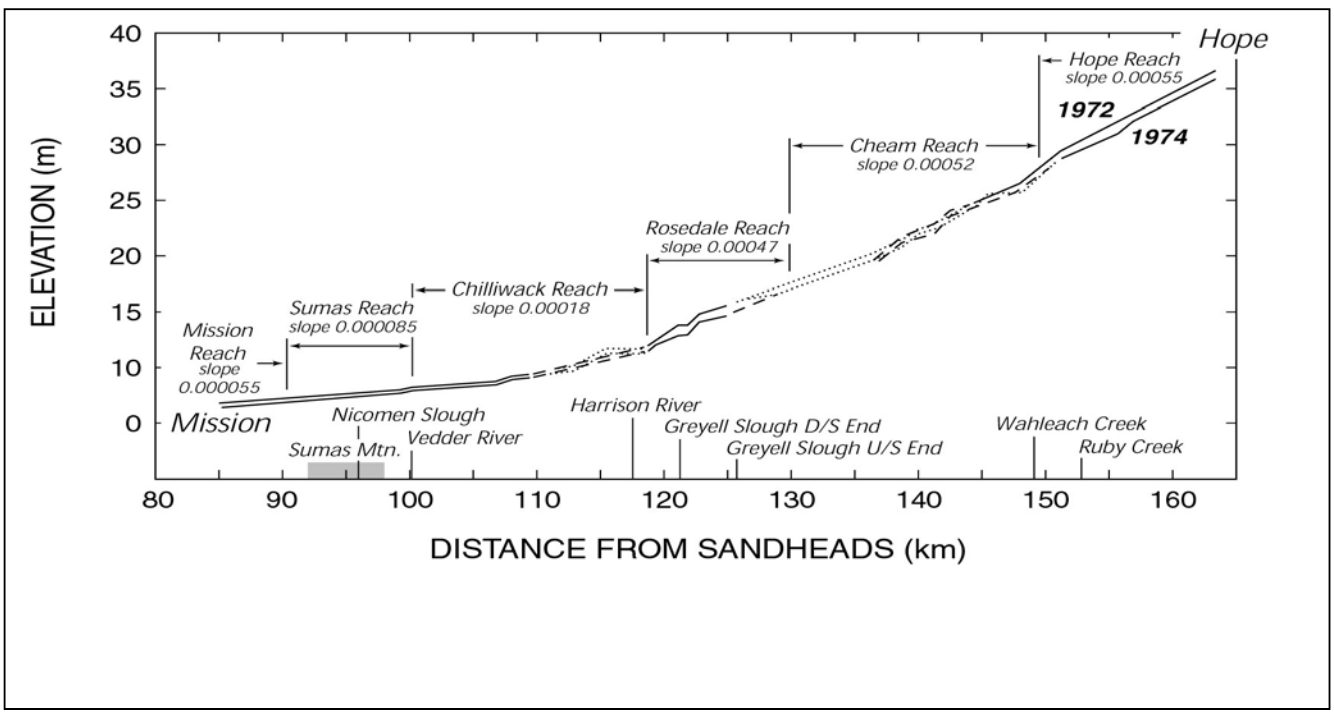
Hope Reach is largely confined by the valley walls and by debris from ancient landslides. The river flows in a nearly straight, single-thread channel that is essentially stable. There are few sedimentary accumulations along the channel, but there is substantial sediment deposition at Hope, where the 130^o bend in the river contributes significant additional resistance to flow causing slackening of the current. Downstream there is a sequence of alternate lateral bars with about 6.3w_s spacing (w_s being the surface width of the channel), which is exactly the classical riffle-pool spacing for large gravel-bed rivers. These bars have been stable for many years. However, occasional gravel scalping from them shows that sediment, once removed, is replaced (Kellerhals et al., 1987).

Table 4 . Level One Classification of Fraser River gravel-bed reach; morphologically homogeneous sub-reaches. Information in italics is estimated only.

Name	Downstream Limit	River km	Mean Gradient	Mean Grain Size (mm)	Discharge at MAF (m^3s^{-1})[1]	Mean Gravel Transport (tonnes a^{-1})[2]	Aggradation Tendency	Major Features
Hope	u/s Wahleach Cr.	149-165	0.00055		8766	*400 000*	*stable*	single-thread cobble-gravel channel with stable lateral bars
Cheam	Rosedale-Agassiz Bridge	130-149	0.00052	50	8766	400 000	mild degradation	major islands with surrounding bars; single dominant channel
Rosedale	Harrison R.	118-130	0.00047	40	8766	250 000	strong aggradation	island-bar complexes; channel commonly divided; laterally unstable
Chilliwack	Vedder R.	100-118	0.00018	26	9790	20 000	strong aggradation	channel bars with subordinate islands
Sumas mainly	Matsqui Bend	89-100	0.000085	16 - sand	9790	0	*degrading*	single-thread, gravel-sand transition; bars submerged

1. Based on gauges at Hope (first three reaches) and Mission (last two reaches). MAF = mean annual flood.
2. Transport is mean for the period 1952-1999, estimated at the downstream end of the reach.

Figure 13. Water surface profile of the gravel reach, Mission to Hope, Fraser River (from McLean et al. 1999).



The Hope Reach is stable and the morphology is relatively monotonous. The stability is related to the degree of confinement. The gravel load delivered from Fraser Canyon and Coquihalla River is transported through the reach. Major eddies off the bar tails are apt to be fish holding areas and seasonally slack water along bar edges probably is also important. The locally complex morphology at Hope and immediately downstream represents the most diverse area for habitat in the reach.

In Cheam Reach, the river ceases to be confined. This sub-reach is essentially as steep as Hope Reach, so that bed material transported into the reach is apt to move through it. However, the channel becomes more sinuous as it swings around a series of islands. The main channel remains obvious, except where it bifurcates about Spring Bar (?). As a result of the sinuosity, sediment deposition is encouraged on bars around the head and flanks of the islands, and there is compensating erosion from the channel banks along both the floodplain and islands.

The reach is mildly degrading through most of its length, with compensating aggradation on Tranmer Bar and at the lower end of Herrling Island (upstream from the severe natural constriction of the channel at the Agassiz-Rosedale Bridge). Sediments are cobble-gravels in the channel, with gravels on the bars and major sand sheets on lower Herrling Island. The reach is dominated by the series of major islands, around and behind which there is a substantial length of perennial and seasonal secondary channels. These channels constitute important rearing areas for fish, while some have been cut off or are regulated at the entrance.

Rosedale Reach extends from the channel constriction at the Agassiz-Rosedale Bridge to the contemporary constriction at the mouth of Harrison River. At this point, the main channel currently is forced to turn sharply against Harrison Knob. The gradient is lower than reaches upstream by only about 10 per cent. Rosedale reach has been the site of major aggradation during the past half-century. Early in the period, the major area of gravel accumulation was off Greyell Island but, within the past two decades, it has progressed to the area immediately upstream of the Harrison confluence. The river is partly confined on the north side (left upstream bank) by high, rocky ground, but the channel has no constraint inside the set back dykes on the south side (except that introduced in the form of revetments). Consequently, the aggradation has produced a split and braided channel with low sinuosity and substantial lateral instability in this reach. Sediments are similar to those upstream. At several places in the reach, there is substantial potential for avulsion of the main channel within the channel zone.

Bar and island complexes with perennial and seasonal back channels occur throughout Rosedale reach, with frequent re-entrainment and renewal of bar gravels. Consequently, the reach presents a wide range of diverse habitat opportunities that change and are renewed frequently. Additionally, the south bank floodplain has a substantial number of "sloughs" – in many cases back channels that have been cut off or regulated by head gates at the main dyke.

Chilliwack Reach is much less steep than those upstream. At the upstream end of the reach, river channel changes about 35 years ago created a major island demarcated by Minto Channel. The reach is otherwise dominated by gravel bars built around island cores. However, the islands are relatively less dominant in this reach than they are upstream. The gravel is finer in this reach (D_{50} of subsurface material < 20mm, versus D_{50} > 20mm upstream), and the bar gravels are relatively more mobile. This creates notably shallow points at Chilliwack Rock and near the downstream extremity of the reach. Aggradation in the reach is strong (but has been partially offset by major gravel removals in the past from Minto channel).

The bars through Chilliwack reach provide variable hydraulic conditions and rapidly renewed shallow water habitat. There are major secondary channels and "bays" on the back (shoreward) sides of the bars. Shefford Slough, immediately downstream from the end of Minto Channel, is a back channel area that has been isolated from the river at its upstream end by channel works. Continuing sedimentation near the upstream end of the reach suggests that this sub-reach may become an even stronger focus of aggradation in the next two decades.

Sumas Reach, with a gradient half that of Chilliwack Reach, is transitional from gravel to sand. The D_{50} of the subsurface riverbed material in this reach declines to 8-10mm and the proportion of sand in the bed rapidly increases from the 20-30% figure found everywhere upstream. The river bars are mostly submerged, so there is a single-thread channel, now mainly confined within dykes (except at Strawberry Island) or by Sumas Mountain. Sedimentary trends in this reach are complex. There is apparently significant erosion upstream of Matsqui Bend and aggradation through the bend. To some degree, replacement of sand with gravel may be occurring.

Sumas reach is much less varied than those upstream, with little morphological variety except around Strawberry Island and the entrances to Nicomen and Hatzic loughs. The substrate is radically different in this reach as well, with fine gravel veneers giving way to sand. Correspondingly, habitat variability is also reduced, but there remain possibilities along the remaining natural shores.

7.0 Pool-Bar-Riffle Classification (Level Two)

A pool-bar-riffle unit consists, basically, of a riffle, superimposed bar, and adjacent/downstream pool. The typical configuration of a unit is illustrated in Figure 14and an example is given in Figure 15.

Figure 14. A typical pool-bar-riffle unit in the gravel reach of Fraser River.

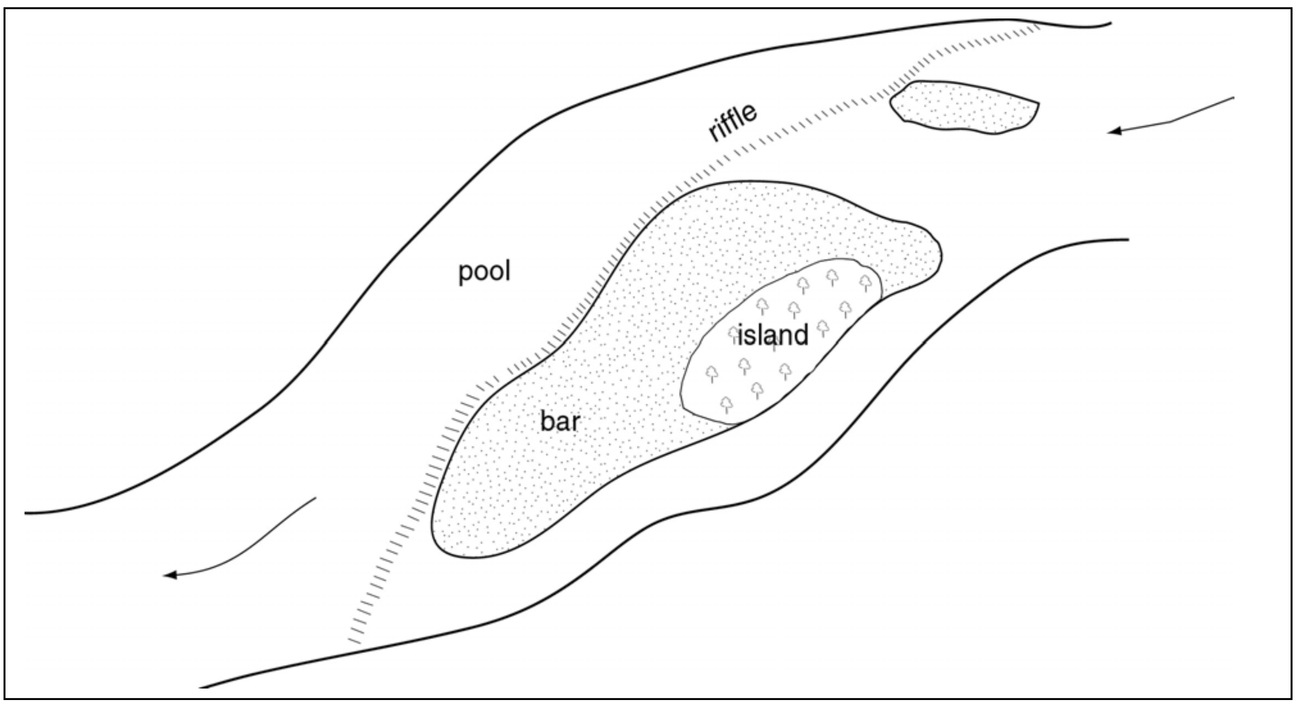
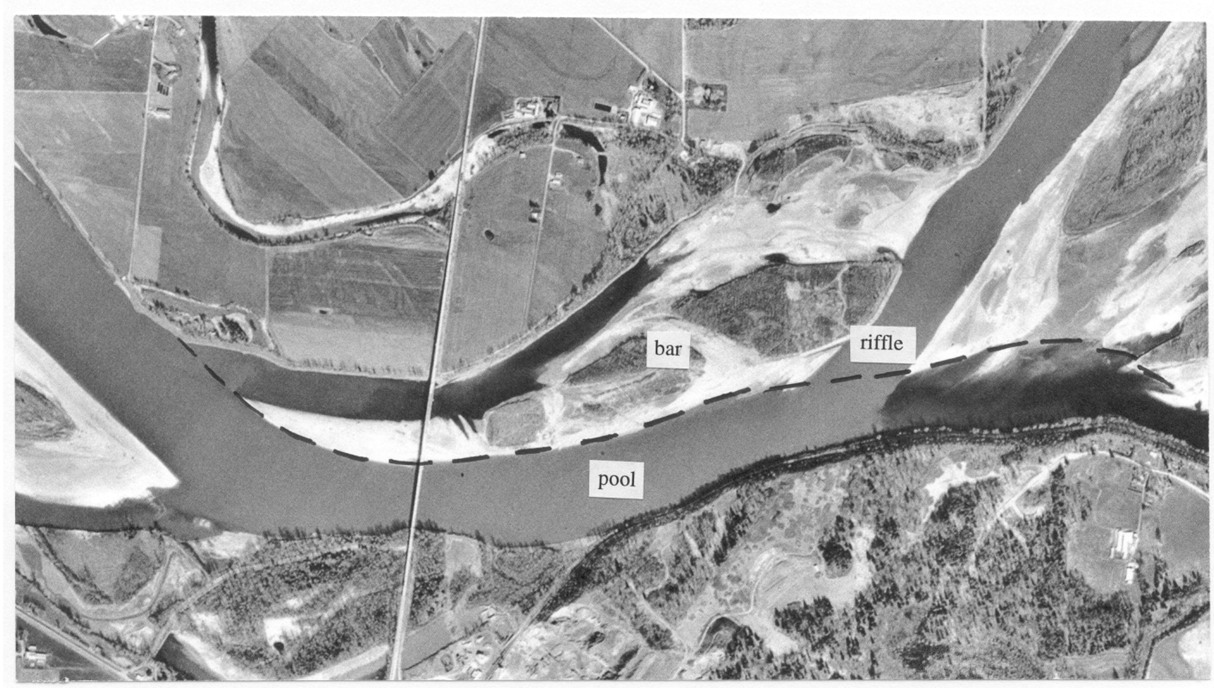


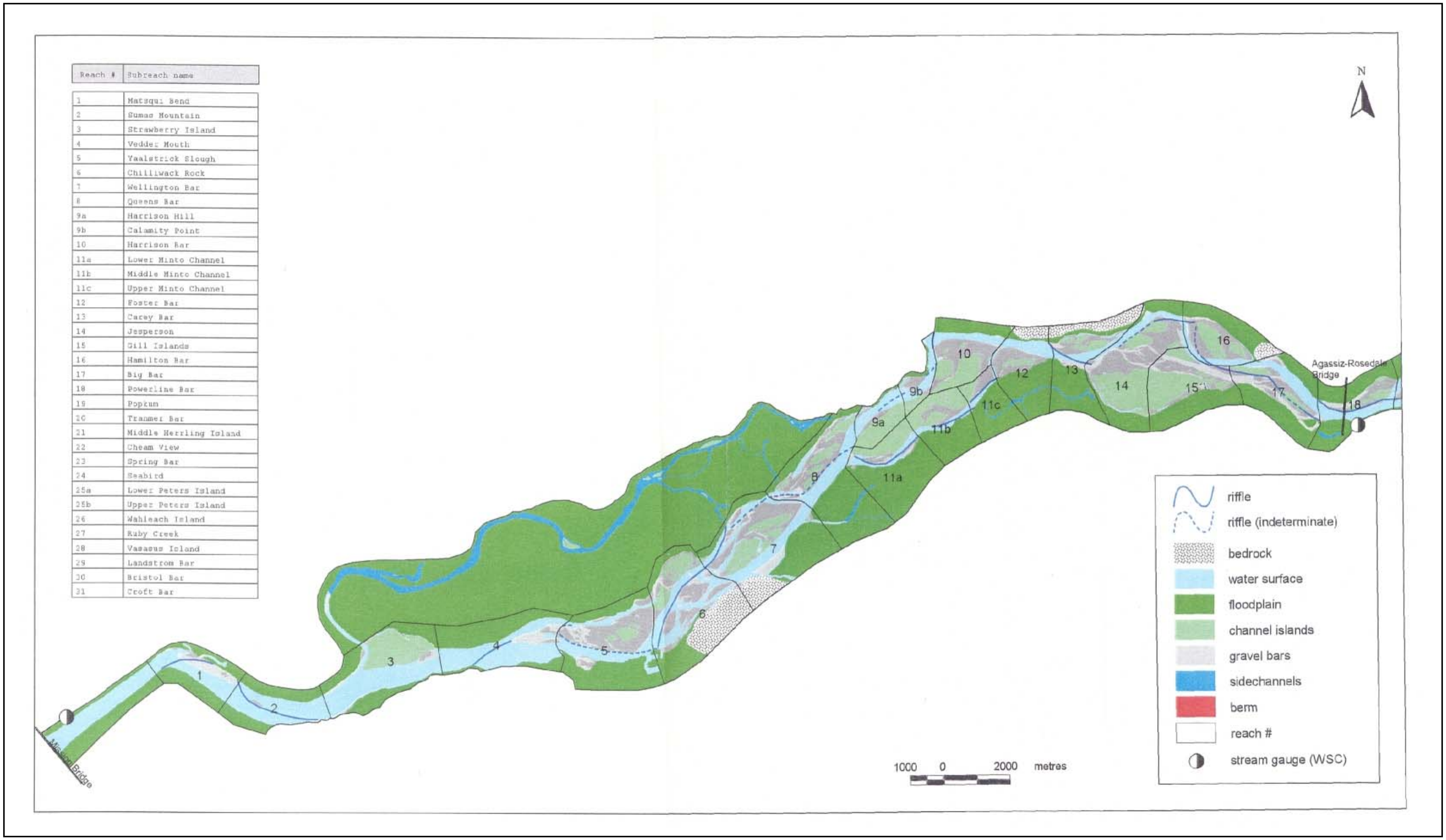
Figure 15. Riffle-bar-pool unit at Powerline Island (Rosedale-Agassiz Bridge; river km 130). The riffle is a long, right-diagonal feature upon which the “bar” extends (Powerline Island). The upper end of the riffle has been overrun by Lower Herrling Island bars. The extreme elongation of the riffle, which runs for some distance essentially parallel with the channel, is not unusual in lower Fraser River. Scale of photo approximately 1:10,000 (enlarged from 15BCB99001-15).



Level two sub-reaches are listed in Table 5 and displayed in Figure 16. Table 5 gives sub-reach areas of water, bar, and island, and unit length and width. Areas are calculated at low flow (i.e., ca 700 m^3/s), so that water areas represent the main, deep channel and limited shallow water area. Bar area is the area of unvegetated, seasonally exposed channel bed. This area mainly constitutes intermediate and shallow water area during freshet. Islands are vegetated areas within the channel zone, which mainly remain emergent except in high freshets. Channel width is calculated as the mean width of water + bar, excluding island surfaces.

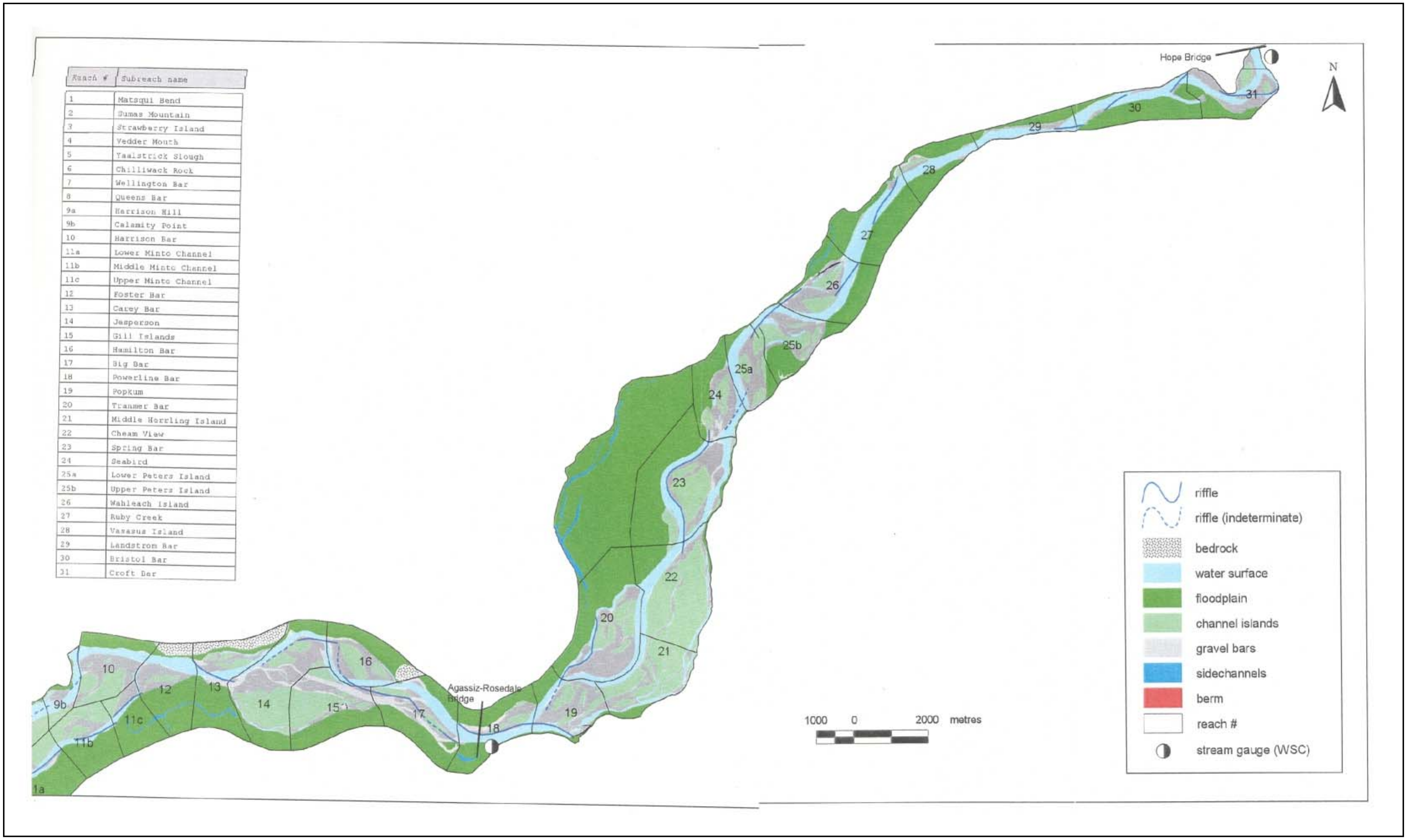
Sub-reaches 1 through 4 make up the Sumas reach (Level One). Sub-reaches 1 (Matsqui Bend) and 2 (Sumas Mountain) lie in the gravel-sand transition. The most notable channel features are a large bar composed mainly of sand on the right bank upstream of Matsqui Bend, and a medial bar with gravel veneer on the long riffle in subreach 2. Both bars have limited exposure at low flow and neither presents significant topographic complexity. Sub-reaches 3 (Strawberry Island) and 4 (Vedder mouth) immediately upstream present similarly simple topography in the main channel. However, significant variability is represented by the mouth of Nicomen Slough, the channels around Strawberry Island, and the downstream continuation of the last major gravel bar complex in the river, adjacent to Vedder River mouth. In Sumas reach, 83.5% of the combined water + bar area is wetted channel at low flow. The sole significant islands in the reach, at Strawberry Island, represent an isolated piece of Nicomen Island rather than main channel islands.

Figure 16. Level Two sub-reaches in the gravel-bed reach of Fraser River.



Reach #	Subreach name
1	Matsqui Bend
2	Sumas Mountain
3	Strawberry Island
4	Vedder Mouth
5	Yaalstrick Slough
6	Chilliwack Rock
7	Wellington Bar
8	Queens Bar
9a	Harrison Hill
9b	Calamity Point
10	Harrison Bar
11a	Lower Minto Channel
11b	Middle Minto Channel
11c	Upper Minto Channel
12	Foster Bar
13	Carey Bar
14	Jesperson
15	Gill Islands
16	Hamilton Bar
17	Big Bar
18	Powerline Bar
19	Popkum
20	Tranmer Bar
21	Middle Herrling Island
22	Cheam View
23	Spring Bar
24	Seabird
25a	Lower Peters Island
25b	Upper Peters Island
26	Wahleach Island
27	Ruby Creek
28	Vasasus Island
29	Landstrom Bar
30	Bristol Bar
31	Croft Bar

Figure 16 continued,



Reach #	Subreach name
1	Matsqui Bend
2	Sumas Mountain
3	Strawberry Island
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11b	Middle Minto Channel
11c	Upper Minto Channel
12	Foster Bar
13	Carey Bar
14	Jesperson
15	Gill Islands
16	Hamilton Bar
17	Big Bar
18	Powerline Bar
19	Popkum
20	Tranmer Bar
21	Middle Herrling Island
22	Cheam View
23	Spring Bar
24	Seabird
25a	Lower Peters Island
25b	Upper Peters Island
26	Wahleach Island
27	Ruby Creek
28	Vasasus Island
29	Landstrom Bar
30	Bristol Bar
31	Croft Bar

Table 5. Attributes of pool-bar-riffle sub-reaches in lower Fraser River.

REACH NO.	REACH NAME	WATER SURFACE (m^2)	BAR SURFACE (m^2)	ISLAND SUFACE (m^2)	UNIT LENGTH (m)	UNIT WIDTH (m)
1	Matsqui Bend	1213820	597304		2662	680
2	Sumas Mountain	2052029	84635		3115	686
3	Strawberry Island	2358156	492996	1489512	3677	775
4	Vedder Mouth	2692033	473280		3504	903
5	Yaalstrick Slough	1378493	2414917	226975	3110	1220
6	Chilliwack Rock	1558072	1981732	668485	2718	1303
7	Wellington Bar	1822592	2213577	1012307	3273	1233
8	Queens Bar	1213943	1461902	542619	2652	1009
9a	Harrison Hill	553518	223374	885175	1765	440
9b	Harrison Knob	571485	271487	184240	2157	391
10	Harrison Bar	508472	1204031	970942	2144	799
11a	Lower Minto Channel	411264	395031	725566	2435	331
11b	Middle Minto Channel	283746	452814	916162	1843	400
11c	Upper Minto Channel	146620	304781	182866	1173	385
12	Foster Bar	528684	804594	130408	1566	851
13	Carey Bar	468651	790289	276078	2082	605
14	Jesperson	544912	2311756	1934397	2212	1292
15	Gill Island	89170	1338319	1521870	2513	568
16	Hamilton Bar	405184	1073095	567353	2774	533
17	Big Bar	683517	1430895	334585	2614	809
18	Powerline Bar	668422	770153	206388	2354	611
19	Lower Herrling Island	631003	1626305	521103	2561	881
20	Tranmer Bar	971651	2226377	878789	4571	700
21	Middle Herrling Island	886998	1231391	3746925	4352	487
22	Cheam View	696436	697629	2130024	1819	766
23	Spring Bar	1354470	1579372	1514575	3990	735
24	Seabird	414418	1117190	359624	1835	835
25a	Lower Peters Island	667700	851366	470134	2120	717
25b	Upper Peters Island	433614	1110075	663860	2136	723
26	Wahleach Island	761153	1176447	529708	2091	927
27	Ruby Creek	1093709	217354	19682	2988	439
28	Vasasus Island	590340	305572	61122	2413	371
29	Landstrom Bar	688058	304380		3176	312
30	Bristol Bar	1054449	314670		3680	372
31	Croft Bar	698301	1216698	196548	2731	701

Chilliwack reach (Level One) includes sub-reaches 5 through 9, and unit 11 is classified with this reach as well. Sub-reach 5 (Yaalstrick Slough) represents the most distal major gravel accumulation on the river, downstream from Yaalstrick Island. Sub-reach 6 (Chilliwack Rock), opposite Yaalstrick Island, is a zone of active sedimentation on an exaggeratedly long left-diagonal riffle over which the river divides into several shallow channels. The channels are notably unstable in this unit. Units 7 (Wellington Bar) and 8 (Queens Bar) complete this long riffle, but a reverse-oriented riffle has developed over it along upper Wellington and Queens bars. Both of these bars include significant island units within the main channel and thus present diverse habitat opportunities. In sub-reach 9 (Harrison Hill/Calamity Point), the main channel is severely constricted where it flows around Harrison Hill. It includes two minor riffles with left and right bank lateral bars. Sub-reach 11 (Minto Channel) is subdivided into three sub-units, determined by major riffle positions along Minto Channel. Minto Channel drains a significant portion of summer flow past Harrison Bar and re-enters the main channel opposite Queens Bar. In winter, flow through the channel is small and mainly of hyporheic origin, but it remains wet year-round. Excluding Minto Channel, 45.3% of the water + bar area in Chilliwack reach is wetted channel at low flow, indicating a large proportion of seasonal potential habitat.

Rosedale reach includes units 10 and 12 through 17. This reach is substantially steeper than the downstream ones and channel islands are relatively more prominent. Sub-reach 10 (Harrison Bar) is immediately upstream of Harrison River confluence. The effect of the confluence and of the sharp bend around Harrison Hill have determined the aggradation here. The bar is a relatively simple platform on the north side of what is now the major island group that we call Minto Island. The bar surface is contiguous with Upper Minto Channel and the division between the two is arbitrary. Sub-reach 12 (Foster Bar) is also a part of this gravel accumulation, but is divided from Harrison Bar by Upper Minto channel. It is also a relatively simple lateral bar accumulation. Unit 13 (Carey Bar) includes Carey Point, where there has been major erosion in recent decades. The right-bank bar opposite Carey Point -- which we call Carey Bar -- has developed in the same period and now consists of a complex of young islands and open bar with good seasonal habitat opportunities. Sub-reach 14 (Jesperson) covers a large area of complex bars on the north side of Greyell Island, and half of the major island. Unit 16 (Gill Island) covers the upstream half of the same bar-island complex. The division between them is arbitrary; the decision to establish two units was made mainly on the basis of the enormous size of the area of bars and secondary channels north of Greyell Island. Unit 16 (Hamilton Bar) lies opposite, across the channel from Gill Island, rather than upstream. The occurrence of the two units opposite each other emphasises the complexity of this area, which presents a wide variety of habitat opportunities year-round. Sub-reach 17 (Big Bar) lies upstream astride a long, right-diagonal riffle that extends to Hamilton Bar. The main channel flows to the right of Big Bar, but a perennial side channel follows the left bank. In Rosedale reach, 26.5% of the water + bar area is wetted at low flow, reflecting the large areas of bar surface in the Harrison-Foster and Jesperson-Gill Island units.

Cheam reach includes units 18 through 26. In this reach, channel islands dominate the morphology, presenting significant year-round habitat opportunities. Sub-reach 18 (Powerline Island) straddles the boundary between Cheam and Rosedale reaches. In recent years, a bar developing downstream from Powerline Island has increased complexity in this sub-reach. In the past, secondary channels on the right bank have been more active. Sub-reach 19 (Lower Herrling) is a large complex of bars that has undergone substantial recent aggradation, with the main channel confined to the right bank. Immediately upstream, sub-reach 20 (Tranmer Bar) is a similar island-bar complex on the right bank that has developed in recent years. Both units offer extensive seasonal habitat opportunities at times of higher flow, although the downstream end of Tranmer Bar, being younger and unvegetated, is less stable. Opposite Tranmer Bar, sub-reach 21 (Middle Herrling Island) presents a more stable complex of islands and back channels, with perennial waters offering high quality habitat opportunities. Unit 22 (Cheam View) -- the upper end of Herrling Island -- is similar in character to Unit 21, but the density of back channels is much lower. Unit 23 (Spring Bar) is a medial island-bar complex with deep water on all sides. Unit 24 (Seabird) is a right-bank island-bar complex near the upstream end of Seabird Island proper. Sub-reach 25 (Peters Island) is subdivided into upper and lower sub-units largely because of the overall size and complexity of the unit. However, it presents the same morphological characteristics as other units in the Cheam reach. Unit 26 (Wahleach Island) is a right-bank island-bar complex, similar in character to Seabird and Tranmer. In this reach, 37.7% of water + bar area is permanently wetted. There is also a high incidence of side and back-channels.

In Hope reach, the river is largely confined to a single channel, with minor side channels. Hence, it is morphologically much simpler than reaches downstream, except Sumas reach which has, however, very different sediments. Hope reach includes sub-reaches 27 through 31. Unit 27 (Ruby Creek) contains a submerged riffle anchored to the right bank at Ruby Creek. Unit 28 (Vasasus Island) includes a right-bank island and small back-channel immediately upstream from Ruby Creek. Unit 29 (Landstrom Bar) is a simple right diagonal riffle-lateral bar unit. Unit 30 (Bristol Bar) contains two riffles, but very limited sediment accumulation. Unit 31 (Croft Bar) includes Hope Bend and substantial bar areas around the bend. This presents the most complex morphology and most varied habitat opportunities of any unit in this reach. In the reach, 63.6% of water + bar area is permanently wetted.

8.0 Habitat Classification (Level 3)

8.1 Habitat Type Characterisation

Observations and measurements made at all fish sampling locations during the study provide the basis for describing habitat characteristics (Table 6). Within most habitats, sampling was conducted over the range of physical conditions occurring along the river. Hence, a high level of confidence is assigned to the physical characterisation provided (indicated by **bold** type). However, some habitats (i.e., cut bank, rock bank, rip rap, open water) have areas with extreme velocity ranges that could not be sampled. For these habitats, both the conditions of sampling and the maximum observable conditions are given. A lower confidence level for the assigned attributes of these habitats is indicated by normal type. It is unknown whether juvenile fish rear in areas of extremely high velocity.

Associated ecological attributes for each habitat type, based on fish sampling data from 2 summers and the intervening winter and spring, are also given (Table 6). In determining both the physical and ecological attributes, greater importance was assigned to data derived from beach seining because observations were more reliably made along the shoreline than in deep water where gillnets and minnow traps were set. The assigned attributes also emphasise conditions during summer months on the declining limb of the hydrograph when the majority of field sampling took place. The locations of habitat units changed for winter and spring sampling, and in some cases their characteristics also changed, but to a lesser extent. Definitions for some of the attributes in Table 4 are as follows:

1. **Bank Shape:**
   Steep: linear profile, steep angle
   Deep: concave profile, steep angle
   Flat: linear profile, low angle
   Shallow: concave profile, low angle

2. **Flow Type:**
   Tranquil: little vertical mixing, smooth surface
   Rough (turbulent): irregular flow path, vertical mixing
   Back Eddy: reverse orientation of flow in the upstream direction
   Standing: no velocity

3. **Velocity Range (cm/s):** the average of 9 measurements in a beach seine area classified according to the following flow classes:
   0 – 5 cm/s
   6 – 25 cm/s
   26 – 50 cm/s
   51 – 80 cm/s
   > 80 cm/s

4. **Riparian Vegetation:** *None*: no vegetation within 25 m of sample site
   Willow: most advanced stage is willow
   Alder: most advanced stage is alder
   Forest: thick vegetation of mixed stages present

5. **Position on Bar:** *Upper*: upper 1/3 portion of bar
   Mid: middle 1/3 portion of bar
   Lower: lower 1/3 portion of bar

6. **Dominant Substrate:** *Silt*: < 63 μm
   Sand: 63 μm – 2 mm
   Gravel: 2 mm – 64 mm
   Cobble: > 64 mm

7. **Substrate Type:** *Clean*: gravels have little or no fine material present
   Sandy: gravels partially obscured by a thin, discontinuous veneer of sand
   Blanket: gravels buried beneath a sequence of sandy deposits

8. **Fish Species Diversity:** *Low*: < 0.02 fish/m^2 (seine), < 0.006 fish/m^2/hour (gillnet)
   Moderate: 0.02 – 0.03 fish/m^2 (s), 0.006 – 0.008 fish/m^2/hr (g)
   High: > 0.03 fish /m^2 (s), > 0.008 fish/m^2/hr (g)

9. **Fish Size Range (g):** fish size expressed as weight (g) because body morphometry varies for each species

10. **CPUE:** "Catch Per Unit Effort", defined as the number of fish/m^2 (seine) or fish/m^2/hr (gillnet). CPUE is given for all species (n=24), for salmonids only (n=10) and for 3 species separately (i.e., juvenile chinook, mountain sucker, largescale sucker) to demonstrate species-specific differences in habitat associations.

11. **Aquatic Insect Production**: *Low*: qualitative estimate based on experience
    Moderate: qualitative estimate based on experience
    High: qualitative estimate based on experience

12. **Terrestrial Insect Input:** *Low*: qualitative estimate based on experience
    Moderate: qualitative estimate based on experience
    High: qualitative estimate based on experience

Table 6. Physical and ecological attributes for 12 habitat types in the gravel reach of Fraser River. Information is derived mainly from beach seining and secondarily from gillnetting. Entries in **bold** have a high level of confidence that they characterise the most commonly occurring conditions of habitat types in the gravel reach. Non-bold entries have less confidence because of a low sample size. Entries in *italics* indicate velocity conditions that could not be sampled.

HABITAT TYPE	FISH SAMPLING METHOD	NUMBER OF SAMPLING SETS	BANK SHAPE	BANK SLOPE	FLOW TYPE	VELOCITY RANGE (cm/s)	RIPARIAN VEGETATION	POSITION ON BAR	CHANNEL TYPE	DOMINANT SUBSTRATE CLASS	SUBSTRATE TYPE	FISH SPECIES DIVERSITY	FISH SIZE RANGE (g)	MEAN CPUE ± SE (ALL SPECIES)	MEAN CPUE ± SE (SALMONIDS ONLY)	MEAN CPUE ± SE (JUVENILE CHINOOK ONLY)	MEAN CPUE ± SE (JUVENILE MOUNTAIN SUCKER ONLY)	MEAN CPUE ± SE (JUVENILE LARGESCALE SUCKER ONLY)	AQUATIC INSECT PRODUCTION	TERRESTRIAL INSECT INPUT
Bar Head	seine	s: 117	**flat**	**< 5°**	**tranquil**	**26 – 80**	**none**	**upper**	**main side**	**cobble**	**clean**	**low**	**2 – 10**	**s: 0.11 ± .02**	**0.05 ± .016**	**0.03 ± .005**	**0.006 ± .001**	**0.001 ± .003**	**high**	low
Bar Tail	seine	s: 86	**flat**	**< 5°**	**tranquil**	**26 – 50**	**none willow**	**lower**	**main side**	**gravel**	**clean or sandy**	**moderate**	**2 – 5**	**s: 0.17 ± .02**	**0.03 ± 0.005**	**0.02 ± .004**	**0.01 ± .003**	**0.009 ± .004**	**high**	low
Bar Edge – Steep	seine trap	s: 28 t: 17	**steep**	**> 5°**	**tranquil**	**6 - 80**	**none**	**mid lower**	**main side**	**gravel**	**clean or sandy**	**moderate**	**2 – 5**	**s: 0.27 ± .1**	**0.02 ± .005**	**0.01 ± .004**	**.002 ± .0007**	**0.002 ± .0009**	moderate	low
Bar Edge – Flat	seine	s: 227	**flat**	**< 5°**	**tranquil**	**26 – 50**	**none willow**	**upper mid** **lower**	**main side summer**	**cobble gravel**	**clean or sandy**	**low**	**2 – 10**	**s: 0.10 ± .01**	**0.03 ± .005**	**0.02 ± .002**	**0.007 ± .001**	**0.003 ± .0006**	**high**	low
Riffle	seine electro- shocking	s: 6 e: 20	**flat**	**< 5°**	**rough**	**50 - >80**	**none**	**upper mid lower**	**side summer**	**cobble gravel**	**clean**	**moderate**	**2 – 5**	**s: 0.15 ± .06**	**0.02 ± .009**	**0.02 ± .009**	**0**	**0**	**high**	low
Eddy Pool	seine	s: 41	**steep**	**> 2.5°**	**back eddy**	**0 – 25**	**none**	**upper mid**	**main side summer**	**gravel sand**	**sandy**	**high**	**2 – 10**	**s: 0.25 ± .05**	**0.08 ± .04**	**0.03 ± .009**	**0.002 ± .0008**	**0.01 ± .006**	moderate	low
Open Nook	seine	s: 67	**flat**	**< 2.5°**	**tranquil standing**	**0 – 25**	**none willow**	**upper mid lower**	**main side**	**cobble gravel sand**	**clean or sandy**	**high**	**0 – 5**	**s: 0.75 ± .19**	**0.03 ± .006**	**0.01 ± .004**	**0.006 ± .002**	**0.18 ± .07**	**moderate**	low
Channel Nook	seine trap	s: 47 t: 17	**shallow or deep**	**variable**	**standing**	**0 – 5**	**none willow**	**upper mid** **lower**	**main side summer**	**gravel sand**	**sandy or blanket**	**high**	**0 – 5**	**s: 0.38 ± .09**	**0.08 ± .03**	**0.03 ± .01**	**0.005 ± .003**	**0.008 ± .002**	moderate	low
Bay	seine gillnet trap	s: 54 g: 25 t: 38	**shallow or deep**	**variable**	**standing**	**0 – 5**	variable	**mid lower**	**side** main	**sand**	**blanket**	**moderate**	**1 – 10**	**s: 0.33 ± .09 g: 0.05± .02**	**0.09 ± .04**	**0.04 ± .02**	**0.003 ± .001**	**0.01 ± .004**	moderate	low to moderate
Cut Bank	gillnet trap	g: 6 t: 73	**steep**	**> 15°**	**tranquil standing** *back eddy*	0 – 25 26 - >80*	variable	**upper mid lower**	**side** main	gravel sand	sandy or blanket	moderate	10 – 50	g: 0.03 ± .02	insufficient data	insufficient data	insufficient data	insufficient data	low	high
Rock Bank	gillnet trap	g: 0 t: 25	**steep**	**>15°**	tranquil standing *back eddy*	0 – 5 6 - >80*	variable	**upper mid lower**	**side** main	cobble sand	insufficient data	no data	no data	no data	insufficient data	insufficient data	insufficient data	insufficient data	low	high
Rip Rap	gillnet trap	g: 2 t: 56	**steep**	**> 5°**	**standing** *tranquil*	0 – 25 26 - >80*	none willow	**upper mid lower**	**side** main	rubble sand	insufficient data	low	15 – 30	g: 0.04 ± .04	insufficient data	insufficient data	insufficient data	insufficient data	low	low to moderate
Open Water	gillnet trap	g: 3 t: 58	**flat**	**n/a**	**standing tranquil**	0 – 50 51 - >80*	**none**	**upper mid lower**	**side summer** main	cobble gravel sand	variable	low	10 - 30	g: 0.003 ± 0.001	insufficient data	insufficient data	insufficient data	insufficient data	low	low

The majority of bar head habitats along the gravel reach have a low to moderate bank slope and no riparian vegetation. Water velocity ranges from 26 to 80 cm/s and the flow is commonly tranquil. Where the orientation of flow at bar heads is diagonal, an eddy pool habitat is created at the most upstream end of the bar. In these cases, the extent of bar edge along which back eddy flow was detected was classified as an eddy pool and bar head habitat was assigned to any remaining length of bar edge conforming to the definition. Bar heads are most common in the upstream portion of sites and along main and side channels. The dominant substrate class is cobble. Fish diversity was low relative to other habitats, generally consisting of species known to reside in fast flowing water such as juvenile chinook, mountain sucker, and leopard dace. While the CPUE for all species was low compared to most habitats, it was relatively high when only salmonid species were considered.

Bar tails have low to moderately sloped bar edges and have a slower velocity range than bar heads. Riparian vegetation is uncommon at low water levels, however, bar tail units are occasionally found in the proximity of willow vegetation during freshet. Most bar tails are positioned in the lower-most third of sites. Surface substrate consists of mostly gravel, generally smaller than for bar heads. Fish species diversity was moderate, with lower velocities possibly favouring a wider range of species than bar heads. Previous sampling indicates that insect production is high in both bar head and bar tail habitats, with mayflies, stoneflies, and caddisflies being common. The input of terrestrial insects should be low due to the lack of riparian vegetation.

Bar edge habitat is divided into sub-classes based on bank steepness because the fish species associated with steep banks ($> 5^o$) were found to differ from those along flat banks ($< 5^o$). Steep bar edges have a wide range in velocity, little riparian influence, and typically gravel substrate (16 – 64mm). They occur in the upper, middle, and lower portions of a site with equal frequency and are mostly found along main and side channels. The bed elevation of summer channels is generally high such that steep banks are uncommon. Fish species diversity was moderate and the CPUE was relatively high.

Flat-sloped bar edges have a narrower velocity range (26- 50 cm/s) and are common in all channel types and in all portions of a site. Both fish species diversity and the CPUE for flat bar edges was low compared to other habitats. Insect production is believed to be higher on flat banks as compared to steep banks because the photic zone is limited along steep banks and water depth is negatively associated with aquatic insect density (Rempel et al. 1999).

Riffles consistently occur in areas with a low bank slope. They have rough flow, high velocity, and occur in all portions of a bar with equal frequency. They are most common in side and summer channels, however, they can also occur at the upper-most ends of bar heads and lower-most areas of bar tails. The location and extent of riffle habitat is highly stage-dependent while the surface substrate is consistently coarse. Both species diversity and CPUE were moderate in riffles, with longnose dace, coastrange sculpin, and leopard dace being common. Insect production, particularly mayflies, stoneflies, and caddisflies, is known to be high in riffles based on sampling experience.

Eddy pools are particularly distinct both in their physical and ecological characteristics. Bank slope is variable, but more commonly high, and the flow character is consistently a back eddy created in the lee side of a fast-flowing riffle. They are most common in the upper and middle portions of bars and in all channel types. Due to the back eddy character of the flow, surface sediment is gravel and cobble heavily embedded by sand. Fish species diversity in eddy pools was highest of all habitat types, with juvenile chinook and redside shiner being most common. Aquatic insect production in eddy pools is uncertain, but back eddy flow patterns likely concentrate drifting insects and organic matter.

Open nooks are invariably flat with a low bank slope and low velocity. They occur extensively across all sites and are most common along main and side channel bar edges. They are less common in summer channels due to narrow channel width and the short duration of flow conveyance. A wide range of surface sediment sizes is observed. Fish diversity was high and CPUE was highest of all habitats because of the high densities of small fish (<35mm) consistently found in open nooks. These habitats apparently provide important rearing habitat for young fishes, particularly slow-water species such as largescale sucker and peamouth chub.

Channel nooks are distinguished by a concave geometry, reflecting their flow conveyance potential. Water velocity is negligible and channel nooks are widespread around bars and in all channel types. Fish size was positively related to water depth in channel nooks and both species diversity and CPUE were high. Salmonids, particularly juvenile chum, were found in high densities in channel nooks in the spring. The amount of insect production is expected to be moderate and terrestrial insect inputs are expected to vary with the degree of riparian influence.

Bays are large-scale features usually associated with accreting sediment features in the lower portion of bars. Riparian vegetation is variable, with willow growth being common around the perimeter. The substrate is consistently sand. Fish size was related to water depth and both species diversity and CPUE were high. Salmonids, including juvenile chinook, sockeye and chum were common (depending on time of year). Other commonly occurring species were peamouth chub and northern pikeminnow. Insect production in bays is expected to be moderate and chironomids are likely common.

Cut banks, rock banks, and artificial banks are consistently steep and a range of velocities and flow types are possible. Such banks are widespread through the gravel reach, however, their associated ecological attributes are uncertain. Efforts will be made over the next year to modify sampling techniques in order to survey the fish species associated with these habitats.

Open water habitat has been assessed to a limited degree using gillnets and minnow traps. Catch rates for both methods were consistently low, as was species diversity. The lack of cover in open water habitat may not favour fish rearing, however, the lack of sampling data leaves this hypothesis untested.

Figure 17 summarises the CPUE for several groups of fish species to faciliate habitat-specific comparisons. These data are based on catches by beach seine only. Open nooks have the highest CPUE when all species are considered, but have a relatively low CPUE when only salmonids or chinook alone are considered. Habitat associations of salmonids generally reflect differences among the species, with chum (early spring only) and sockeye being common in slow-water habitats and chinook, trout, and char species being common in fast-water areas.

Juvenile chinook were found in all habitat types, with highest CPUE in bays, eddy pools, and bar heads. Mountain sucker were most common in bar tail habitat and also bar heads and along bar edges. They were uncommon in slow velocity habitats such as eddy pools, bays, open nooks and channel nooks. In contrast, the CPUE of largescale sucker was significantly higher in open nooks than in all other habitats. High densities of small largescale sucker (< 35mm, < 5 g) were common through the summer and early fall in both 1999 and 2000.

The distribution of fish by weight classes among habitat types is presented in figure 18. All species (n=24) collected by all sampling methods are included. The product of average water depth * mean velocity is plotted on the secondary axis as an index of flow circulation for each habitat. Slow-water habitat types (eddy pool, bay, open nook, channel nook) have a higher proportion of small fish than do fast-water habitats. Eddy pools show the widest range in fish weight, while the dominant weight class of bar edge, bar head, and bar tail habitats is somewhat larger, 2.1 – 10 g.

Figure 17. Catch per unit effort (#/m^2) for several groups of fish species based on beach seine collections from July 1999 and September 2000.

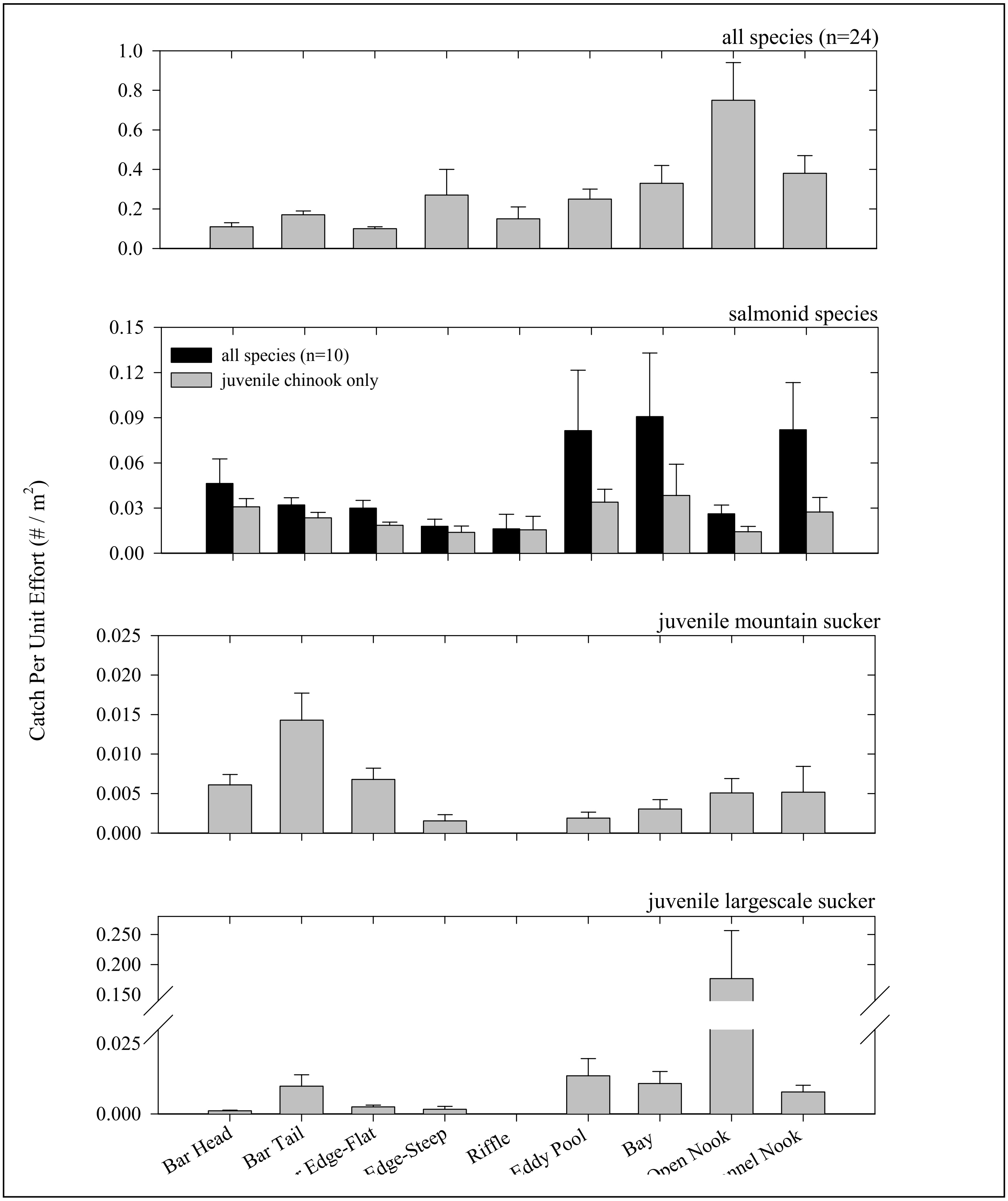
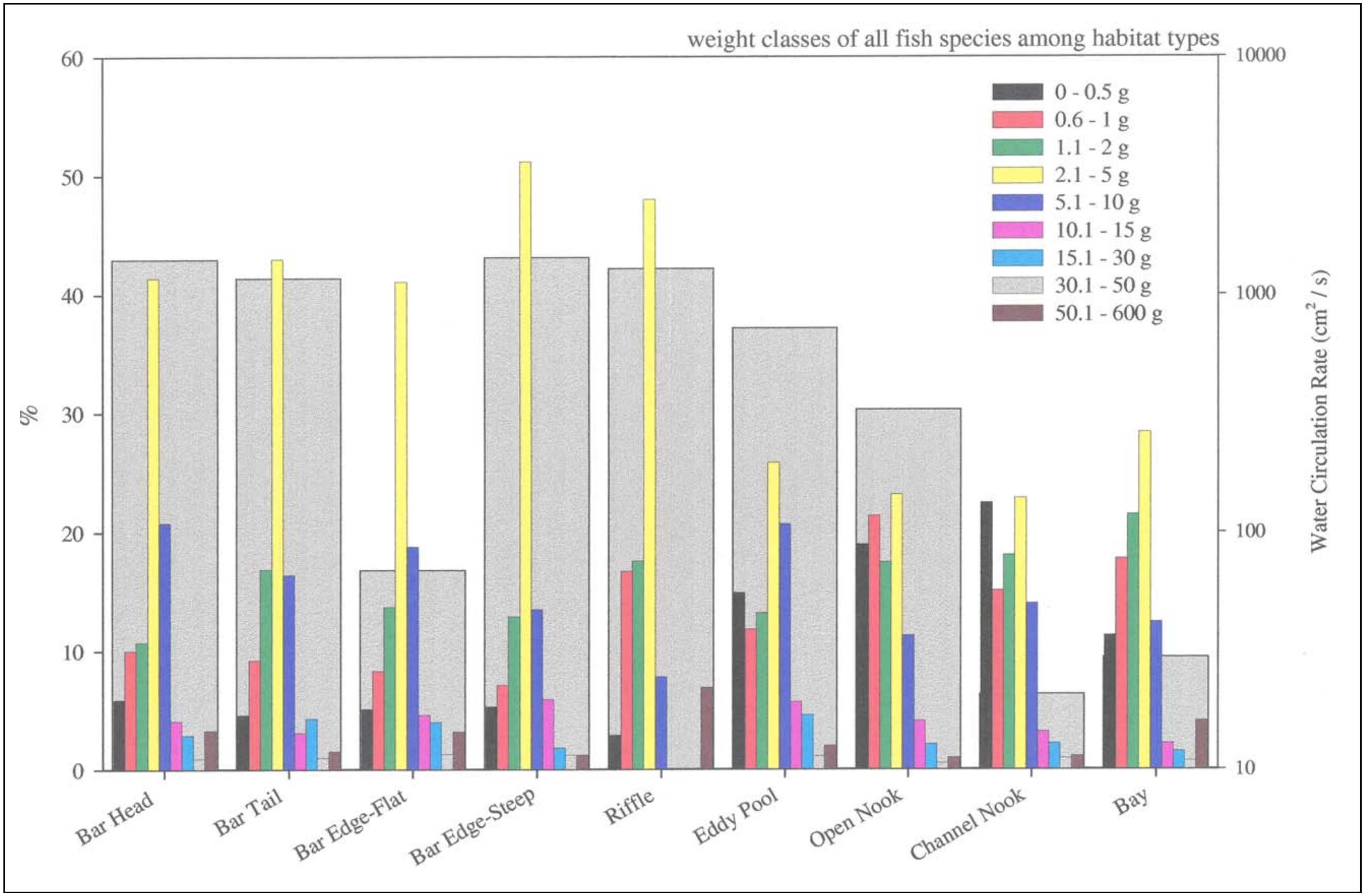


Figure 18. Weight classes of all fish species (n=24) among habitat types in the gravel reach of Fraser River.



8.2 Sediment Characterisation

The areas of Queens and Calamity bars chosen for detailed study can be divided into a number of morphological-sedimentary units (Figure 19a, Figure 20a) that reflect differences in genesis and sedimentary characteristics (Figure 19b-d, Figure 20b-d). These units provide a useful means of describing the geomorphology and sedimentology of the bar surfaces (below), but they should not be confused with the habitat classification units considered in above and in subsequent sections. In some cases, however, the boundaries of each unit type roughly coincide.

Observations throughout the gravel reach indicate that morpho-sedimentary units like those identified on Queens and Calamity bars are common to most bar-island complexes. With additional work at other sites, these descriptions can be developed into a typology of morpho-sedimentary units. A provisional typology would include the following elements:

- Large accretionary wedges attached laterally to existing bar surfaces, e.g. units H and I on Queens and units A and B on Calamity.
- Chute-lobe couplets of erosion and deposition in summer and side channels, e.g. units A and B on Queens, and E and F on Calamity.
- Stable, low-lying platforms prone to burial e.g. units C and K on Queens and, to a lesser extent, unit D on Calamity.
- Bar-tail sand-blanket complexes, e.g. units G and H on Calamity
- High accretionary platforms advancing over existing bar topography, e.g. units F and D on Queens
- Areas of high local complexity associated with chute-lobe development at a local scale, e.g. unit E on Queens.

8.2.1 Queens Bar

Unit A is a wide, low-lying summer channel that connects the main channel and primary side-channel during high flows. Hyporheic flow through the upper section maintains a large ephemeral pool in the deepest, downstream section after direct connectivity is lost. The upper section grades laterally into Unit E and upstream into the main channel, but is bounded on its left-hand edge by a steep 1-2 m high erosional scarp. The bed material in this upper portion is clean, coarse ($80 < D_{95} < 100$ mm), exceptionally well-imbricated and rigid underfoot. Scattered fine patches persist, possibly reflecting the passage of sand sheets out of the main channel during recession of the summer freshet. Downstream, the gravels are a little finer ($D_{95} \approx 80$ mm) and less well-imbricated, and the rigid armour gives way to slightly looser material. To the right, unit A is bounded by a steep erosional scarp and to the left and downstream it grades into unit B.

Unit B is a depositional feature that is building in response to sediment movement through unit A. Bedload moving through the summer channel is deposited in a complex splay of superimposed accretionary lobes where flow becomes unconstrained downstream of unit D. Elevations here are higher than in the summer channel and it is unit B that dams the post-freshet pool. The downstream limit of the unit is marked by a steep, loose avalanche face (> 2 m high) that is actively prograding into a deep, backwater pool. Gravels fine rapidly across unit B (D_{95} drops from 81 mm at w7 to 55 mm at w9) and are very clean, with virtually no sand. To the right, smaller avalanche faces of varying crispness mark the termini of two or three extensive, flat-topped lobes that wrap around the downstream end of unit D and consist of equally clean, but finer gravel ($D_{95} \approx 60$mm). To the left, material is being pushed out of the summer channel towards the vegetated island, building a berm that has begun to spill into the currently sandy channel separating the two islands in the centre of the study area.

Figure 19. Morphological-sedimentary units on Queens Bar. (b-d) Percentage sand cover, surface gravel D50, and surface gravel D95 at Wolman and photographic sample sites. Note that D50 and D95 are calculated for the gravel framework (sediment > 4 mm).

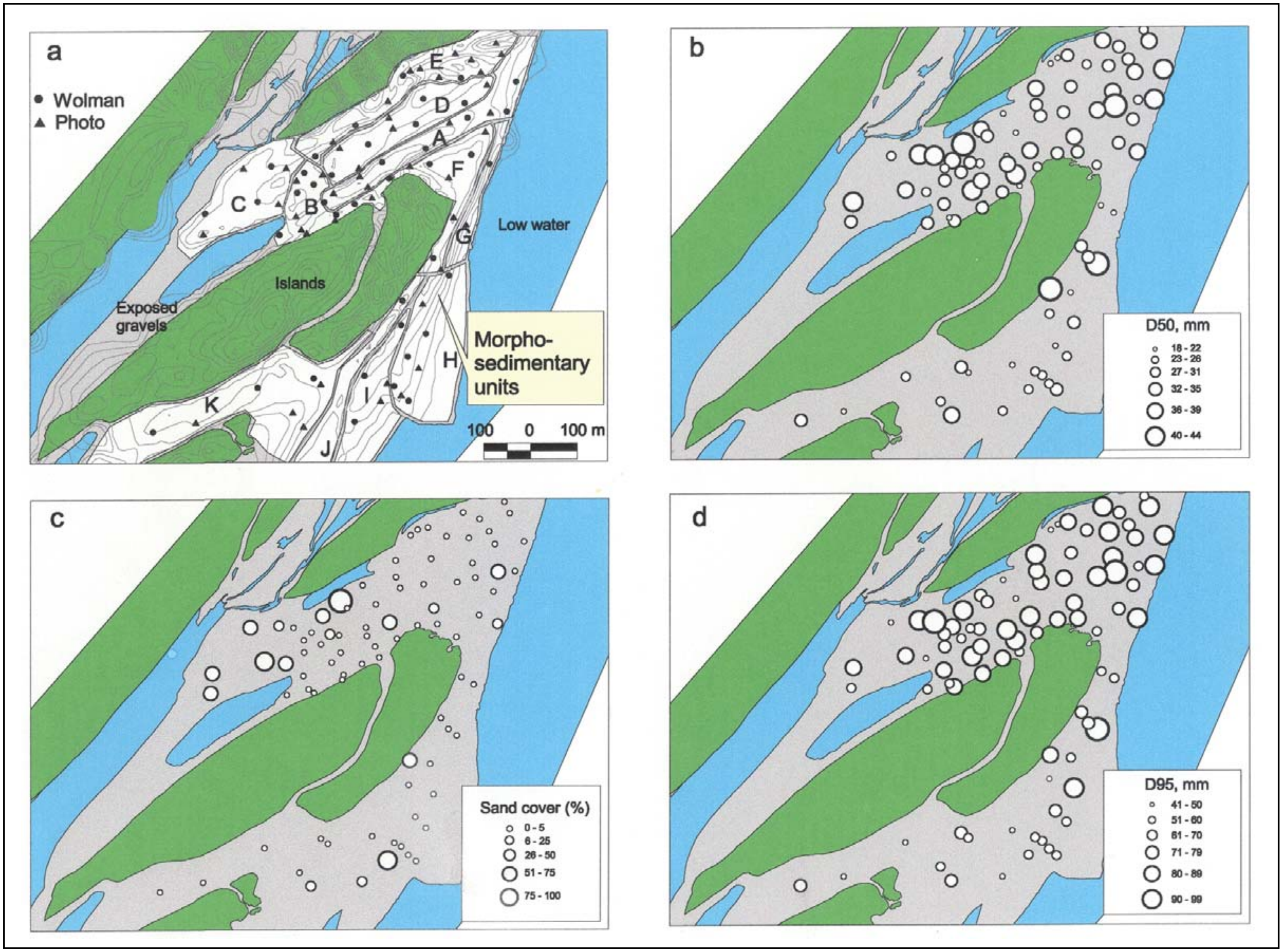
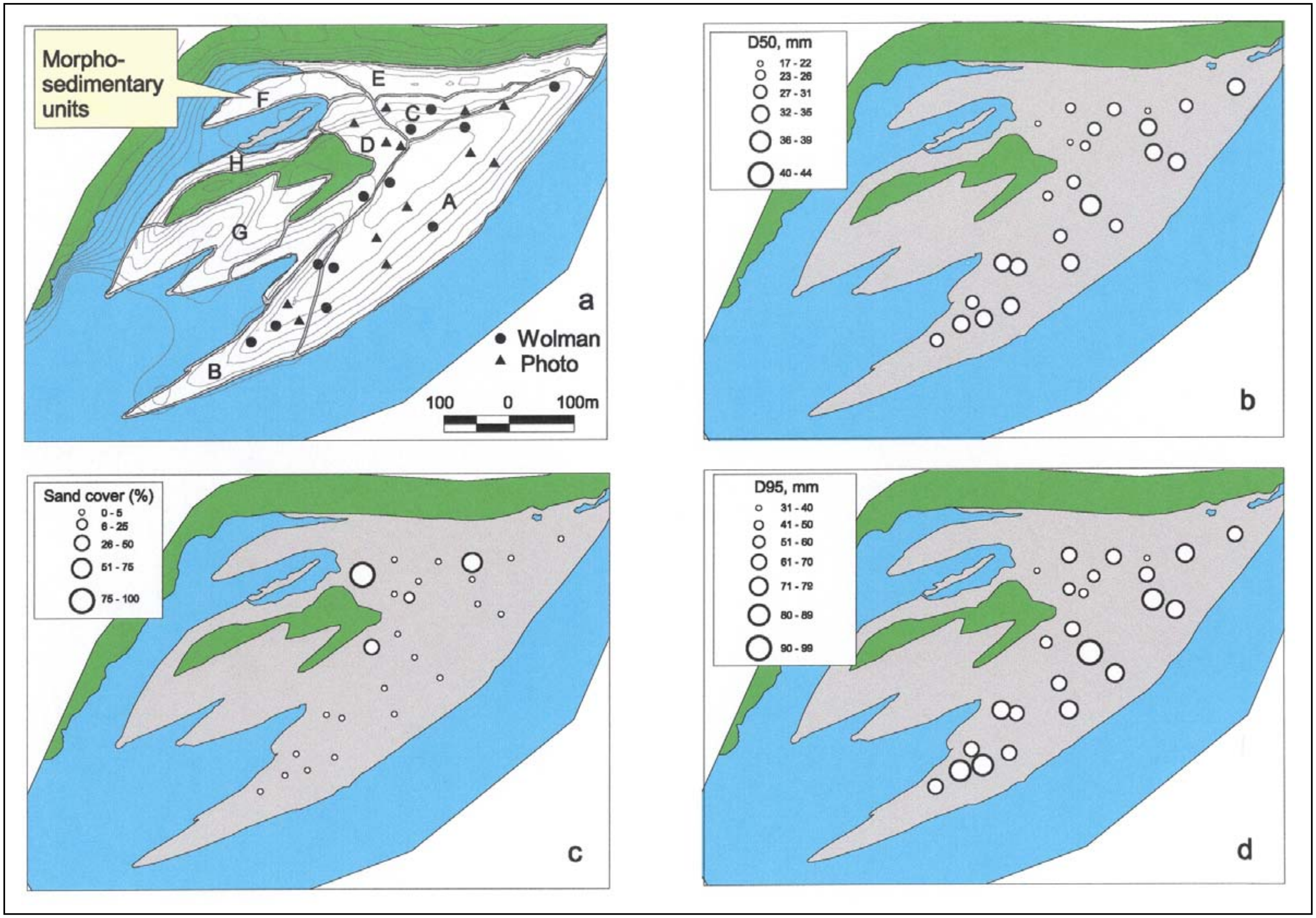


Figure 20. Morphological-sedimentary units on Calamity Bar. (b-d) Percentage sand cover, surface gravel D50, and surface gravel D95 at Wolman and photographic sample sites. Note that D50 and D95 are calculated for the gravel framework (sediment > 4 mm).



Chute (unit A) and lobe (unit B) features occur at various scales throughout the gravel reach. Indeed, they might be regarded as the fundamental building blocks of the complex topography that characterises areas undergoing active aggradation. They provide a variety of habitats at various flow stages and annual processes of sediment reworking within these features are largely responsible for the creation, modification and destruction of small-scale habitat units within the bar-island complexes.

Unit C is a flat, low-lying area of mixed gravels ($50 < D_{95} < 80$ mm) characterised by discontinuous sand cover, silty drapes and shallow, ephemeral pools. A purple-grey patina on exposed gravels indicates that the deposit is old and relatively stable. It is probably the bed of the original through-channel and, as has happened upstream, it is being buried beneath mobile material from units B and E.

Unit D is an elevated, flat-topped depositional feature that dips gently toward the main channel from a steep avalanche face (up to 3 m high) that marks the boundary with units B and E. This avalanche face has developed in response to the progressive deposition of gravel sheets that move out of the main channel at the highest flows. The left-hand edge is erosional, suggesting that the unit is a source of sediment that flow-through unit A is depositing in unit B. It consists of well-sorted, clean gravels that fine downstream (D_{95} drops from 70-90 mm to 50-60 mm). The surface is very loose at the avalanche face, but becomes increasingly well-structured upstream, grading into the coarse and imbricated material of unit A. There was notable deposition of sandy material across the surface from the 2000 freshet, but cover remains thin and very patchy. In itself, the unit is of relatively little ecological importance because of its high elevation and infrequent inundation. However, it forms the right and left banks of two important summer channel habitats (units A and E respectively).

Unit E is a second summer channel bounded on the right by a vegetated island at the height of the floodplain, and on the left, by the avalanche face of unit D. Deep water remains here for long periods and it provides connected backwater habitat before and after the freshet. In its lower section the unit consists of coarse ($D_{95} \approx 84$ mm), stable gravels that are strongly structured and heavily embedded. Sand cover varies between 40 and 80%, and the surface is similar to much of unit C. In contrast, the middle and upstream sections are particularly complex, consisting of several chute (upper) and lobe (middle) couplets. The gravels are locally well-sorted and extremely clean, reflecting the high-energy environment. Two wide, flat-bottomed incisions through what formerly would have been an upstream continuation of unit D, connect the unit to Fraser River. A third incision, slightly upstream of the detailed survey area, developed during the 2000 freshet. Coarse, imbricated gravels in the base of the upper section chutes, are replaced by much finer, loose materials in the lobes that are deposited downstream. Thus, D_{95} drops from 85 mm in the base of one chute (sample w22) to 48 mm in one of several lobes in the middle section (sample w21). The topographic, hydraulic, and sedimentological diversity of this unit, along with its connectivity and clean gravels, make it off-channel habitat of high quality.

Unit F is a flat-topped depositional unit at the same elevation as unit D. It is also, in several respects, similar to it. The unit consists of a wide platform that dips gently back into unit A upstream and terminates in a high, steep avalanche face downstream. This face is steadily advancing, burying a sandy island populated by young alder and willow beneath 1-2 m of clean gravel. On the right, the unit A summer channel is actively recruiting material from this wedge, and on the left it grades into unit G. The advancing wedge of gravel is wrapped around the head of the island so that berms with inward facing avalanche faces continue for some distance down either side of the vegetated area. The surface materials are well-sorted and of moderate size ($D_{95} \approx 70$ mm) and sand content is low (between 0 and 2%). Like unit D, this large accretionary wedge, with an upper surface 0.5 to 2 m above the previous high level, is indicative of rapid aggradation in the reach and is the product of significant bedload transport at high stages. It may have grown significantly during the 1999 freshet, but the 2000 freshet inundated the unit without adding to or reworking the sediment within it.

Unit G is a bar-edge beach that drops from the high level of unit F into the main channel. The gravels are clean and moderately coarse ($50 < D_{95} < 80$ mm) with some evidence of coarsening from higher to lower elevations. The unit is of ecological value throughout the year and in the upstream section, where the lateral slope eases and grades into unit A, pink salmon redds were abundant in spring 2000. Material was trimmed from this beach during the 2000 freshet, creating deeper water offshore.

H and I are two large depositional units that grade upstream into units F and G and laterally grade into one another. Unit I is the older of the two and lies inside unit H. From a common high point where units F, G, and H merge, unit H dips laterally and longitudinally toward the main channel. Its downstream limit is marked by an avalanche face that drops steeply into a deep eddy pool where there is significant sand deposition. Aerial photographs flown in March 2000 indicate that this unit was deposited during the 1999 freshet and that it extends diagonally back across Fraser River to the apex of Minto Island. This deposition is of some concern as it is likely to cause bank erosion at Island 22. Unit I represents an earlier phase of aggradation with similar morphological characteristics. The downstream portion of unit I lies below the level of H, and a low, discontinuous avalanche face marks the limit of progression of H over I. Upstream, the two units join seamlessly and share a common, high (2-3 m) avalanche face that faces away from the main channel. This runs downstream for approximately 500 m parallel to the island, continuing across the entrance to a major summer channel (unit K). Stalled gravel sheets, one or two grain-diameters thick, occur on the surface of both units. Unit H and the upper portion of Unit I are very clean, with little sand cover. However, the lowest portion of unit I, downstream of the interface with unit H and adjacent to the eddy pool, consists of sandy gravels where sand cover is as high as 75%. Gravels on this low-lying tongue are fine ($D_{95} \approx 50$ mm). Coarse materials in the upper portion of Unit H ($D_{95} \approx$ 97 mm) give way to finer materials downstream so that the D_{95} decreases from 97mm at w31 (in the area where G and H merge) to ≈ 55 mm across the lower portions of H.

Unit J is a backwater area confined between the high avalanche face of units H and I, and the vegetated island to its right. Downstream of the island the unit grades into unit K on the right. To receive water from upstream, stage must exceed the height of units F and H, which only occurs at the highest flows. However, it is connected to the main channel for long periods at its downstream end. Low-energy deposition is prevalent and the entire unit is characterised by high quantities of sand that form thick layers in the base of the cut. Apart from on the avalanche face, gravels are infrequently exposed, and only one muddy Wolman sample was collected (w39). Sand cover was 50% and the underlying gravels are moderately coarse ($D_{95} = 77$ mm).

Unit K is a low-lying, old through-channel, which carries water during freshet, but which is not geomorphologically active. The same purple-grey patina that is apparent in unit C covers most of the bed material and the surface is very stable. The gravels are clean, not particularly coarse ($44 < D_{95} < 70$ mm), and frequently covered by a silty drape. Stalled accretionary lobes that grade upstream into unit J terminate at smooth, reworked avalanche faces where the channel bends to the left. Downstream of these, the unit is characterised by a simple trapezoidal cross-sectional geometry that is in stark contrast to the complexity apparent in the upstream channel (units A to E). While this simple trough is inundated throughout the freshet and retains pools for some time, it presents little topographic or hydraulic complexity and may be of lower habitat quality as a result. The lack of active sediment transport through this unit is probably a consequence of the longitudinal growth of units H and I across its upstream entrance. These form a high barrier which isolates the channel from Fraser River, essentially starving it of fresh bedload material.

8.2.2 Calamity Bar

Unit A is an extensive accretionary wedge that dips gently upstream and toward the main thalweg. It terminates adjacent to unit D in a high (1-2 m) avalanche face. A lower avalanche face (0.5-1 m high) marks the boundary with unit C. Downstream, A grades almost imperceptibly into unit B, which appears to be a slightly older element of the same depositional phase. The boundary between A and B is marked by a low, sometimes indistinct continuation of the main avalanche face that sweeps back from the boundary with unit D extending as a low gravel sheet into the main channel. The main, inner avalanche face continues along the inner edge of B and only peters out at the tip of the unit. Both units are composed of clean gravels and at most sites, sand cover is zero. The coarsest materials occur in the centre of unit A (D_{95} = 90 mm) but otherwise there are no clear grain-size trends. Indeed, the gravels are well-sorted with the majority of the surface characterised by D_{95} in the range 60-70 mm. Together, units A and B provide a long, shallow bar-edge beach of clean, homogeneous gravel adjacent to the main Fraser channel. By deflecting flow away from the older bar complex which they have partially buried (units D, G and H) they also create the sheltered bay that dominates the lower part of the site.

Unit C lies below the level of unit A and above the main side channel E. It is an older depositional unit that terminates downstream in a low avalanche face and grades upstream and to the right, into unit E. This surface presumably extends back beneath unit A. There is some topographic complexity, with generally coarser material at slightly higher elevations toward the downstream end of the unit. Thus, D_{95} increases from 38 mm upstream to ≈ 60 mm downstream and sand cover in the upper portion is as high as 70%.

Like units G and H, unit D is part of an older bar-island complex that has been partially over-ridden by units A and C. It is a crescent-shaped, low-lying channel contained by the avalanche faces of A and C upstream and the high, vegetated bar top downstream. At high flow, water in this channel separates the older downstream parts of the complex from the recent accretionary wedges upstream, probably carrying water from E and C along the face of A to the main downstream bay. From its apex where C, A and D meet, the two arms of unit D act as quiet backwaters at lower flow. Sand cover is high (30 - 80%) and the gravels are small ($35 < D_{95} < 55$ mm).

Unit E, the upper portion of the side channel that runs the entire length of Calamity, is contained on the right by the floodplain and bedrock of Calamity Point, and on the left by units A and C. The bed consists of clean, coarse gravels though direct sampling was not possible because of inundation throughout the April and September sampling periods. Areas at the interface with unit E exhibit sand cover. The channel is noticeably steep and has a simple, trapezoidal cross section with little morphological complexity, although there is some outcropping bedrock in the upper entrance.

Unit F is a low-lying bar of fine gravels that extends into deep water of the lower side channel. At low flow it contains a shallow bay to the left, but drops away steeply to the right and downstream. At moderate to high flows it is entirely inundated. This unit is the depositional lobe associated with bedload transport through the upper portion of the side channel (unit E).

Unit G is a sandy beach that drops gently from the vegetated upper levels of the central island into the bay that dominates the lower part of the site. A thick blanket of sand results in gravels being exposed in only a few high positions; in most places they are not seen at all. Sand deposition in this area has probably been accelerated by the extension of unit A/B to form the low-energy, backwater bay.

Unit H is also dominated by thick blanket sands. In the lower section, where flow down the side channel from E is constrained between the island and the opposing bedrock bank, the sands have been cut away to produce a steep, and often vertical sand cliff 1-2 m high. The angle eases to a more gentle grade where the channel is less confined upstream and some fine gravels are exposed.

8.2.3 Harrison Bar

Sediment data were collected from two areas of Harrison bar: the "removal area", where approximately 70,500 m^3 of gravel was removed between February 26th and March 17th 2000, and a "control area" unaffected by scalping operations. The removal area was located on the downstream portion of the main bar platform and had a relatively simple morphology prior to scalping. It consisted of two flat, open areas ($38 < D_{95} < 45$ mm), separated from each other by a summer channel, each of which dipped moderately steeply over coarse gravel beaches ($81 < D_{95} < 102$ mm) into the main channel. These areas were separated from the low islands that run down the centre of the bar by a second summer channel containing complex chute and lobe features. Morphology in the control area on the upper part of the bar was equally straightforward: a large flat-topped area dipping gently to the main summer channel on its left and more steeply to the main channel on its right. These observations are based on site observations and topographic maps produced by Tunbridge and Tunbridge Surveyors, Chilliwack, under contract to Steelhead Aggregates and the City of Chilliwack.

Grain sizes in the control and removal areas were similar, with D_{95} on the upper surface of approximately 46 mm and on the steeper beach face of approximately 98-103 mm. Prior to removal, sand content was high on both the removal (11%) and control (18%) surfaces. Indeed, reconnaissance in September 1999 suggested that the extensive and topographically simple gravel surfaces, away from the coarse beach, were unusually sandy relative to many sites within the gravel reach.

Scalping operations essentially removed the steep beach face from the upper removal area, producing a low gradient slope running without interruption from the low water edge to a high point adjacent to the summer channel in front of the central islands. In the lower portion of the removal area scalping created a flat, low-lying basin separated from the main channel by a low berm. After the removal and prior to freshet, the bed surface was found to be more sandy than before (average cover 32%), with finer overall gravel distributions (average D_{50} dropped from 26 mm to 13 mm after removal). This fining reflects disruption of the surface layer to expose finer bulk materials beneath. One sample was collected from the haul road that was constructed through the control area. Sand content was very low (< 1%) and grain sizes were fine (D_{50} = 6 mm, D_{95} = 25 mm).

After freshet, sand cover in both areas was significantly lower, averaging 0% in the removal area and 1% in the control area. It should be noted, however, that the exact sites sampled before freshet were not revisited afterwards. Still, a significant amount of sandy material appears to have been entrained from across the entire bar surface. The quantity entrained from the removal area must have been higher than that from the control section, suggesting that sand transport rates are limited only by sand availability, even in a moderate freshet. D_{95} values in the control area remained similar to those before, except for the road surface where some coarsening was observed (although this was patchy). In the removal area, the gravel fractions coarsened slightly during the freshet and, in places, were again similar to the surface prior to removal (e.g. sites 18, 19 and 20). However, recovery was not so apparent in other areas: at site 21, D_{95} was 52 mm, compared with the pre-freshet value of 102 mm at site 1 nearby.

8.3 Queens Bar Habitat Classification

Habitat units are delineated for Queens Bar according to habitat type and bank slope for four water levels (Figure 21 - Figure 24). These water levels were chosen to reflect conditions at winter low flow, summer high flow, and two intermediate levels typically encountered during summer and autumn fish sampling episodes. Estimates of discharge at Hope are assigned to each of the water levels, however, values should be read as only approximate.

The lowest water level (Figure 21) represents approximately 700 m^3/s discharge at Hope when low-level air photography was flown in March 2000. An extensive network of channel nook habitat remains wet through the winter along the NE bank, although much of it becomes isolated from the main channel. Much of this nook habitat is reasonably deep (>1.5 m) but it is unknown whether fish (either deliberately or accidentally) use it for over-wintering. Bar edge habitat along the main channel has a variable bank slope, with the large accretionary wedge (unit H, Figure 19a) having a gentle slope (<5^o) and the erosional edge (unit G, Figure 19a) being steep. Little of the bank and bar edge habitat is vegetated at low flow and the amount of bay habitat connected to the main channel is small.

Figure 21. Habitat classification of Queens Bar at ~700 m^3/s.

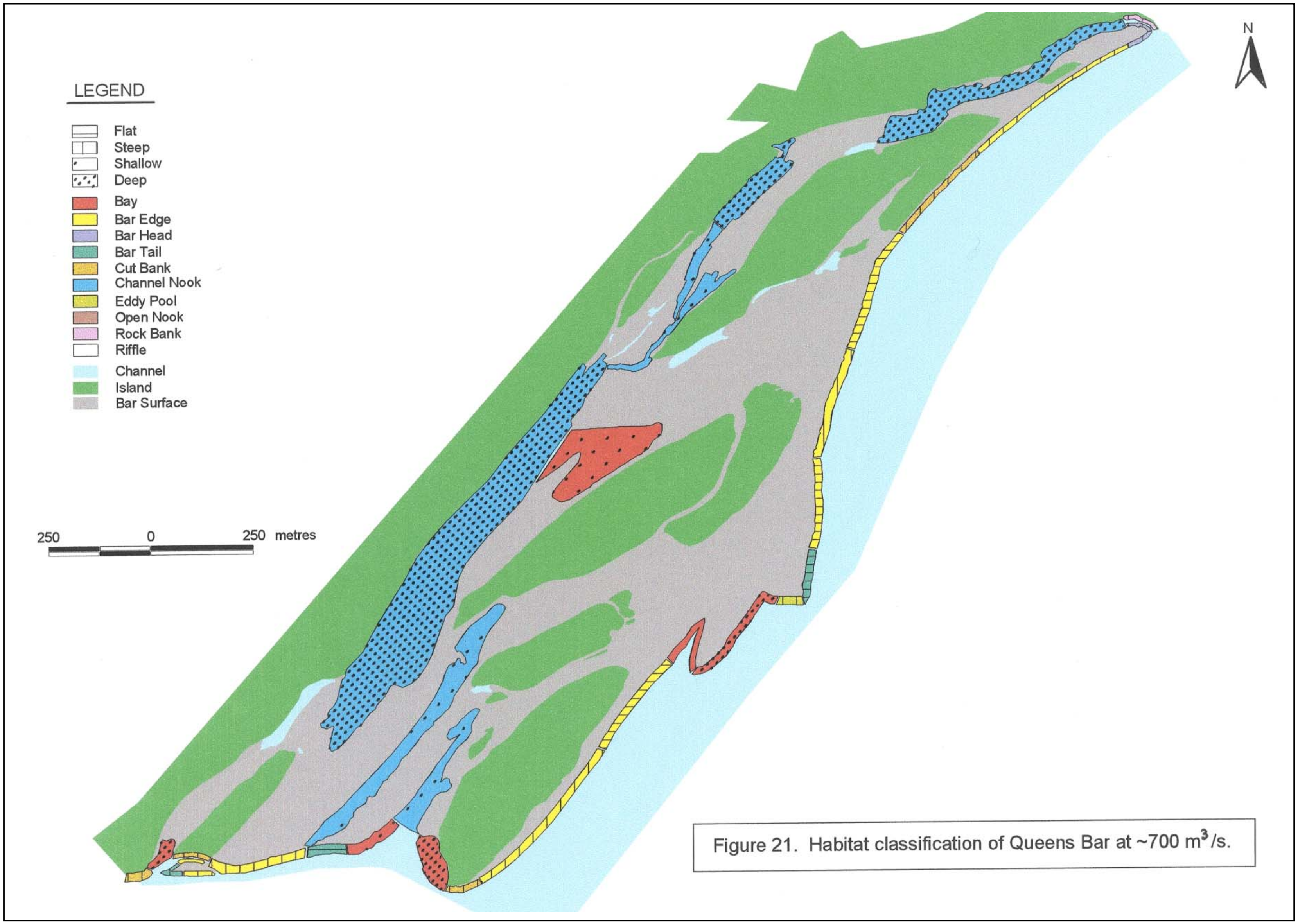


Figure 22. Habitat classification for Queens Bar at ~1500 m^3/s.

Figure 23. Habitat classification for Queens Bar at ~3000 m^3/s.

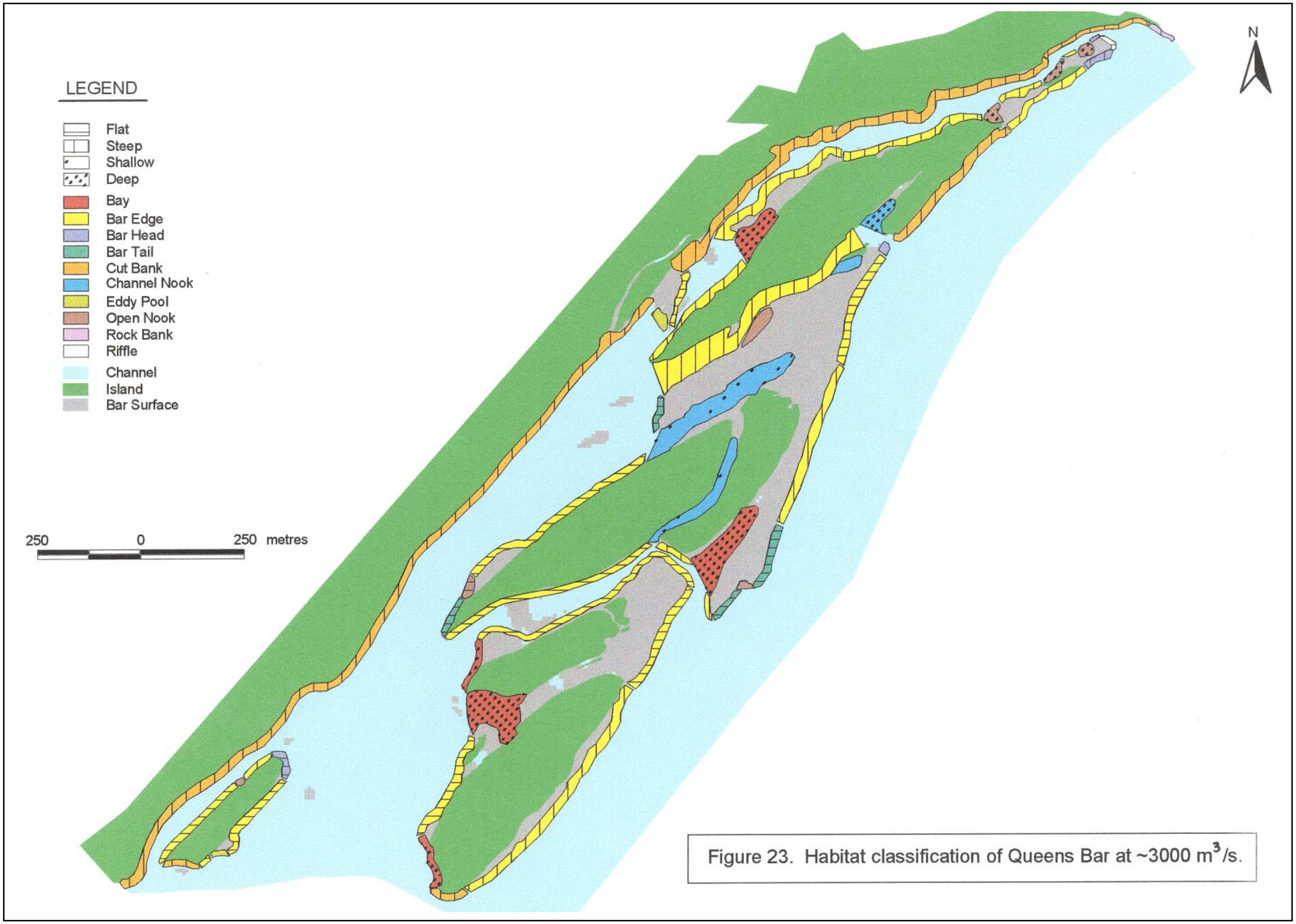


Figure 24. Habitat classification for Queens Bar at ~6000 m^3/s.

Figure 24. Habitat classification of Queens Bar at ~6000 m^3/s.

Non-isolated slow-water habitats (i.e., bays, open nooks, channel nooks) are uncommon at low winter flow and, in contrast to most other bars in the gravel reach, steep bar edges at higher flows remain steep even during winter months.

The greatest amount of habitat unit diversity exists at intermediate water levels on Queens Bar (Figure 22, Figure 23). Open nooks, eddy pools, and bays are common and an increasing amount of bankline is vegetated. Presumably, these water levels provide habitat conditions most conducive for juvenile fish rearing. The greatest range of water depth, velocity, and substrate conditions are available to suit the habitat preferences of fish species at all life stages. As well, the greatest total length of wetted bank and bar edge is exposed. The major side channel along the NE bank of Queens Bar becomes flow-through at discharges exceeding ~1500 m^3/s, roughly between mid-April and late September. Summer channels are generally dry except during the peak period of freshet, however, water encroachment at their lower and upper ends creates bay and channel nook habitat (Figure 23, corresponding to August conditions).

At high flow, summer channels are active, most gravel bar surfaces are completely inundated, and the total length of exposed bank and bar edge is low (Figure 24). Much of the wetted bankline is vegetated and islands appear as isolated units with mostly steep-sloped cut banks. Low-velocity habitats such as open nooks and bays are uncommon as much of the active channel zone is inundated and in flood.

8.4 Calamity Bar Habitat Classification

The distribution of habitat units around Calamity is shown in Figure 25-Figure 28 for the same flow conditions as Queens Bar, above. The large accretionary wedge (unit A, Figure 20a) that covers much of the main platform of Calamity Bar represents gently sloping bar edge habitat for much of the year (Figure 25, Figure 26, Figure 27). This habitat unit appears to be of high rearing quality for a variety of species, in particular juvenile chinook that were caught consistently and in high numbers in August and September 1999. A large area of deep-water bay and channel nook habitat at the bar's lower end represents over-wintering and summer rearing habitat of high quality as well. Fish sampling by beach seine and gillnet yielded a consistently high CPUE throughout the year. This bay area corresponds with the bar tail complex (units G and H) identified in Figure 20a.

The side channel along the north bank of Calamity Bar is flow-through for much of the freshet and has relatively steep-sloped bank and bar edges. An eddy pool off the bar head persists for much of the period that the side channel conveys flow (Figure 26, Figure 27). An indentation along the upper side channel bar edge offers open nook habitat for much of the freshet period as well (Figure 26, Figure 27). As at Queens Bar, intermediate water levels offer the greatest variety of habitat units and the greatest total length of bar and bank edge along which fish rear and invertebrates are produced.

Calamity Bar has only one summer channel that flows along the boundaries of units C and D, and E and F (Figure 20a). The channel conveys flow for only a short period in late spring and summer, however an extensive area of open nook at the channel's mouth persists through the summer months (Figure 27). The ephemeral and shallow character of the summer channel limits its rearing value for fish.

At high flow, the entire gravel bar surface is inundated and only an isolated island of willow and alder remains (Figure 28). A small amount of bay area may persist at the lower end of the bar, however, the input of water from Harrison River immediate upstream contributes to high-velocity conditions across much of Calamity Bar at peak flow.

Figure 25. Habitat classification for Calamity Bar at ~700 m^3/s.

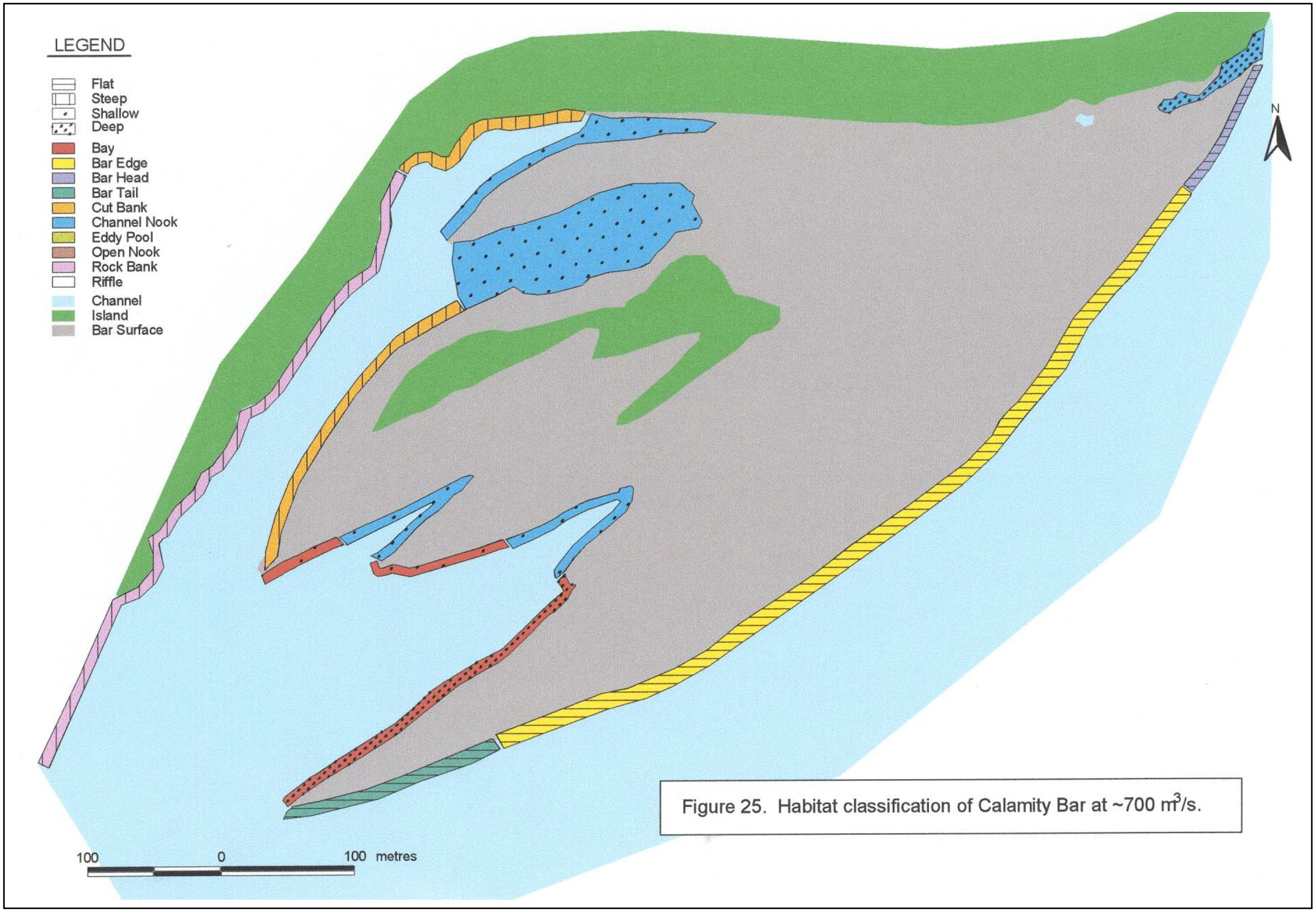


Figure 26. Habitat classification for Calamity Bar at ~1500 m^3/s.

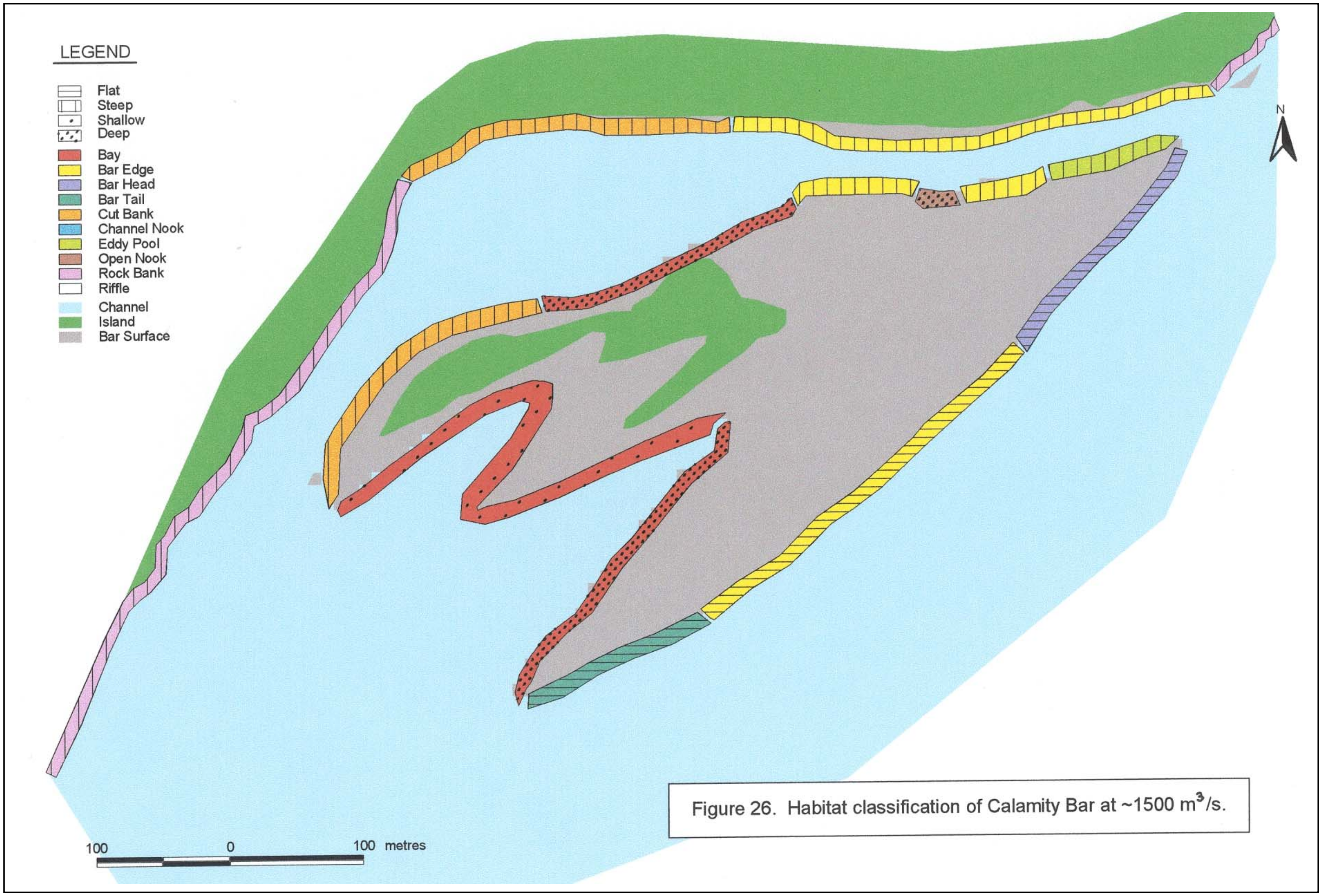


Figure 26. Habitat classification of Calamity Bar at ~1500 m^3/s.

Figure 27. Habitat classification for Calamity Bar at ~3000 m^3/s.

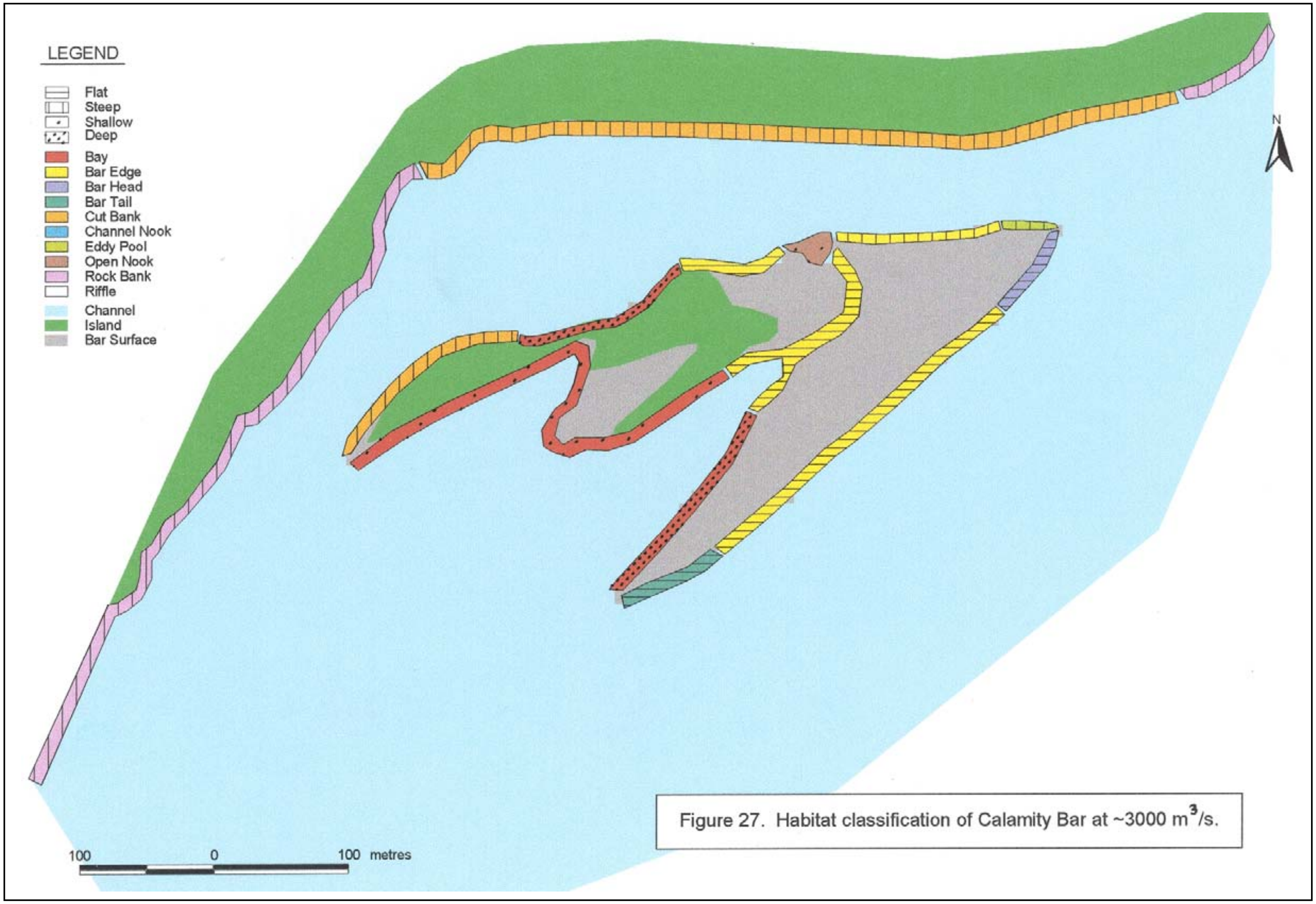


Figure 28. Habitat classification for Calamity Bar at ~6000 m^3/s.

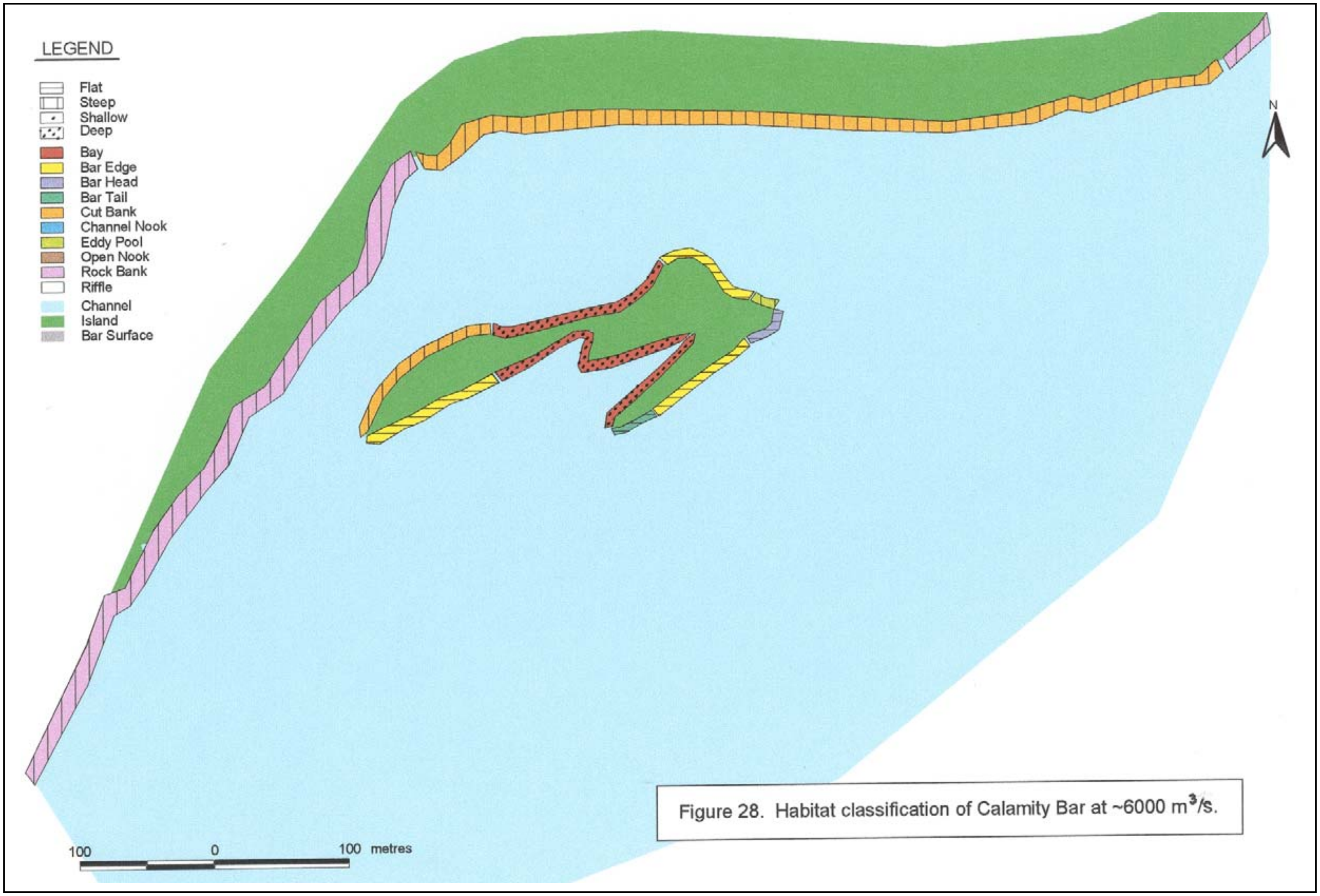


Figure 29. Habitat classification for Harrison Bar at ~700 m^3/s.

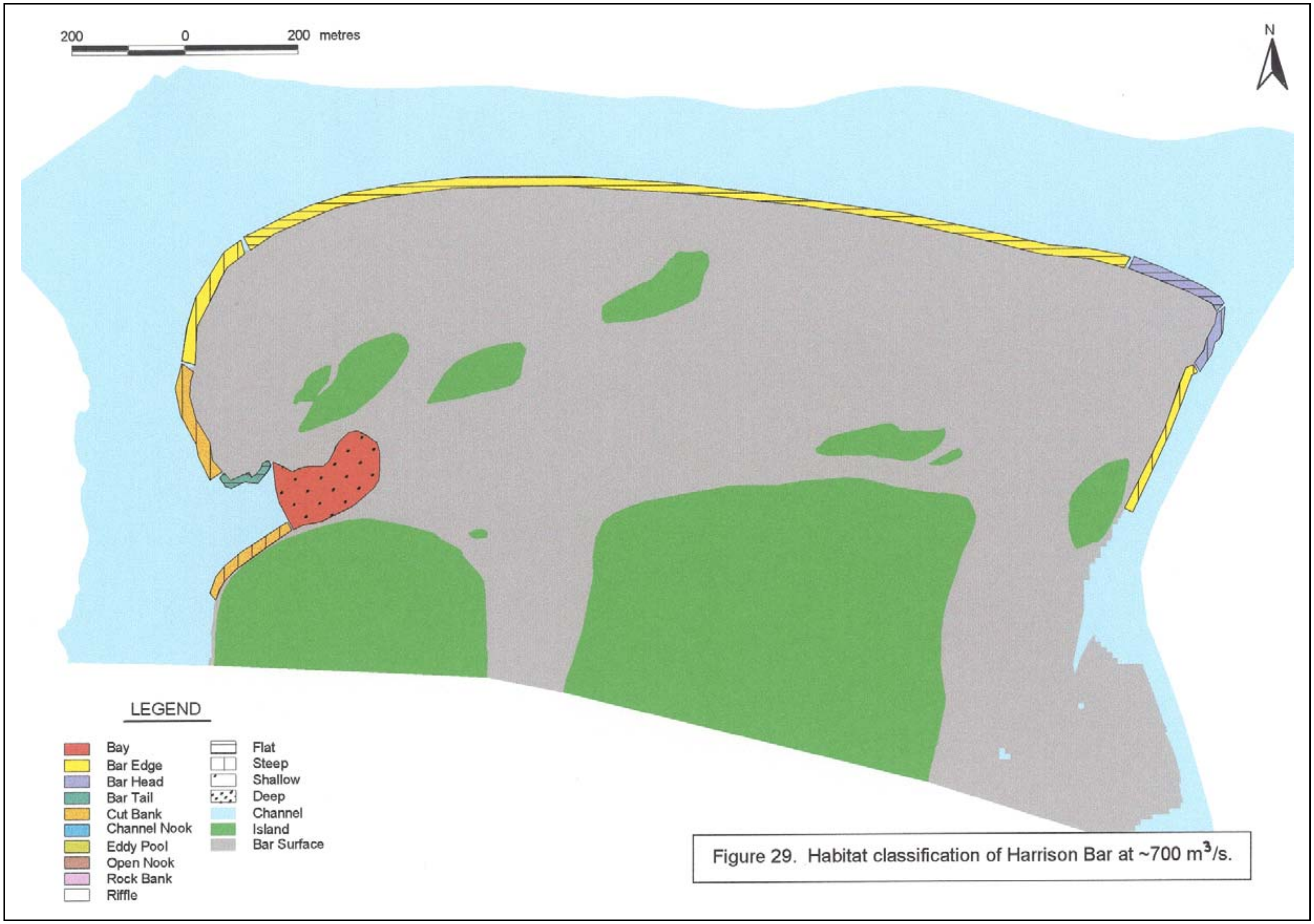


Figure 29. Habitat classification of Harrison Bar at ~700 m^3/s.

8.5 Harrison Bar Habitat Classification

Problems tying the survey data from September 2000 into datum bench marks prevented water level simulations for Harrison Bar. Habitat units are therefore delineated only for low flow conditions equivalent to the water level when air photography was flown in March 2000 (Figure 29). Much of the bar edge habitat has a flat slope and is associated with the extensive sedimentary platform of Harrison Bar. The main channel bar edge surface has little morphological diversity, however, features such as open nooks were apparent along the lower edge during freshet following bar scalping.

A bay at the downstream end of Harrison Bar remains wet throughout the year and offers over-wintering habitat for resident fish and a holding area for winter-run steelhead. It is shallow except at the mouth where a significant back eddy, spilling off flow from the main channel, persists year-round.Harrison Bar lacks a low-elevation side channel, unlike most bars along the gravel reach. Only during freshet do higher elevation side and summer channels convey flow. Very little bankline is vegetated, likely limiting the input of terrestrial insects.

Based on sampling experience on Harrison Bar, habitat unit diversity increases at intermediate water levels as it does for Queens and Calamity bars. Eddy pools, open nooks, and channel nooks are common and the total length of wetted bank and bar edge is relatively high. The lower bay increases significantly in area and becomes connected to the main channel at its top end for 1-2 months during freshet. Summer channels intersect diagonally across the lower bar and feature a range of habitat such as shallow riffles, eddy pools and vegetated cut banks. A narrow and relatively deep channel appeared after the 2000 freshet, intersecting the lower end of the bar opposite Harrison River confluence. It currently remains uncertain whether the channel will remain wet through the winter months or if Harrison Bar will return to a state similar to that depicted in Figure 29.

9.0 Summary

Between Hope and Sumas Mountain, Fraser River flows over a confined alluvial fan consisting of its own alluvial deposits. These deposits, mainly of gravels and sand, force the channel to flow around them, leading to bank erosion and lateral shifting of the channel. The deposited gravels form large bars in the channel or, where the bars build to sufficient height, vegetated islands. The result is a wandering channel pattern with an irregularly sinuous, single-thread channel that is frequently split around large island and bar complexes.

This morphology represents aquatic habitat of exceptional value for a variety of resident and anadromous fishes. The episodically reworked, but seasonally stable gravels provide spawning substrate for chum and pink salmon and for benthic invertebrate production. The secondary channels and slackwater bays provide rearing habitat for at least 24 species of fish, and the multiple channels provide extensive lengths of bankline where hiding zones and drop-in terrestrial food sources occur. Bar edge slopes of varying angle guarantee a range of flow depths, velocity conditions, and substrate types are available for fish and for the insects upon which they feed. In contrast, points of direct erosional attack develop deep scour holes that are used by species such as white sturgeon.

We have linked these morphological and sedimentary characteristics of the gravel reach with ecological attributes to present a hierarchical classification of habitats. The classification consists of three levels, each level having a particular applicability to planning and management. Emphasis has been placed on delineating habitat types with respect to juvenile fish species, both resident and anadromous, known to use the gravel reach for rearing.

At the highest level, we divide the river into five reaches, each of which presents a distinct array of aquatic environments. Reaches are distinguished on the basis of channel gradient, surface grain size, gravel transport rate, and pattern of aggradation, and these differences lend each reach a distinctive distribution of habitats. Listed in downstream order, the reaches are (1) Hope; (2) Cheam; (3) Rosedale; (4) Chilliwack; and (5) Sumas. Each reach is approximately 15 km in length. Both the upper and lower reaches are morphologically simple, whilst having large differences in sediment calibre. The middle reaches, in contrast, show a considerable degree of bar and island development and many secondary channels. Taking note of distinctions between these reaches is believed to be important in strategic planning for fish and fisheries management.

At the intermediate level, we identify pool-bar-riffle units. The number of units recognised along the study reach is 31 and the scale of units averages 2.6 km, or 3.7 channel widths. These units, or sub-reaches, correspond with the characteristic step-length for gravel displacement in the river, and are also characteristic of the organisation of all gravel-transporting channels. A unit consists of a riffle, superimposed bar, and adjacent/downstream pool. A variety of fluvial sedimentary features and habitats is found within a unit and these habitats are replicated from unit to unit, only changing their relative frequency as one moves from reach to reach along the river. The size of these 31 sub-reaches, and the fact that they are the largest identifiable units within which the full range of local habitats may be found, makes them suitable for operational management along the river, and appropriate as planning units for scientific studies of river sedimentation and ecology.

At the finest level of classification, we identify habitat types around individual bars. Field surveys are required to identify these units with reasonable accuracy. Three *channel* types and twelve distinct *habitat* types are recognised on the basis of morphological and hydraulic differences, and differences in the spatial distribution of fish species. Classifying habitat types was an iterative process, using a combination of both air photograph interpretation and field surveys, because it was originally unknown how differently, if at all, habitats should be defined for large rivers in contrast to small streams. Together, physical characteristics and empirically-derived ecological patterns formed the basis for the classification system.

Channel types are classified as seasonally active (summer channel) or perennial (main and side channels), allowing generalisations to be made about the calibre of bed material, the frequency of bed load transport, and flow conveyance capacity. The twelve *habitat types* identify features that are both physically and ecologically distinct and have a likelihood of occurring in each type of channel and within each pool-bar-riffle unit. The habitats differ with respect to morphological, sedimentary, and hydraulic characteristics and, consequently, different collection techniques were used for fish sampling.

A typical pool-bar-riffle consists of 30-50 habitat units. Units associated with large morphological features may occupy areas exceeding 5,000 m^2 whereas smaller units occupy 100-500 m^2. Some habitat types are familiar from former stream classifications (e.g., riffle, eddy pool, cut bank, rock bank) while others are, to our knowledge, previously unrecognised (e.g., channel nook, open nook, bay). Intensive fish sampling over 2 summers and the intervening winter and spring, at 13 sites in the gravel-bed reach, provides the basis for our classification. From our data, distinct patterns of habitat use are emerging. Low-velocity habitats, particularly open nooks, have an exceptionally high rearing value for small, juvenile fish in the summer. Low-velocity habitats also tend to have high species diversity and host fish of a wide range of sizes. High-velocity habitats favour a narrower range of species, including several salmonids and mountain sucker, a blue-listed species in British Columbia. Eddy pools, which develop in the lee of riffles have the highest species diversity of all habitat types, and a wide range of sizes of fish is common.

Because water levels change dramatically through the year, the locations of habitat units change as well. In some cases, units become larger or simply shift laterally on a bar, whereas other units may seasonally disappear. For this reason, we classified two bars at 4 water levels representing winter low flow, summer freshet, and two intermediate stages. These map sequences for Queens and Calamity bars demonstrate seasonal habitat changes that we know to occur on other bars as well.

Detailed surveys of two sites were conducted to identify micro-topography that characterises habitat types. Intensive sampling of the surface sediments, which form the substrate of the habitat, was carried out at these sites as well. We have integrated these data and identified major morpho-sedimentary units on the bars that reflect differences in genesis and sedimentary character. A few examples of units include large, accretionary wedges commonly attached to existing, main channel bar edges and chute-lobe couplets of erosion and deposition that are found in side and summer channels. Bar tail sand-blanket complexes typically develop off the downstream end of bars. Based on field observations, these units are common to bar and island complexes in the gravel-bed reach. We propose a provisional typology of morpho-sedimentary units for lower Fraser River that could be further developed for subsequent work on other bars in the gravel-bed reach.

The results of the topographical, sedimentary, and ecological sampling provide the basis to identify habitat units and predict the degree of fish use around bar and island complexes in the gravel-bed reach of Fraser River. We expect that seasonal patterns demonstrated for Queens and Calamity bars are common to other bars in the reach. We have still to learn how changes to the configuration of the channel affect patterns of fish use around bars, but we expect that the distribution of fish will consistently follow the modification of river morphology along the channel.

10.0 References

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Appendix A. Fish species collected in the gravel reach of Fraser River, July 1999 to September 2000.

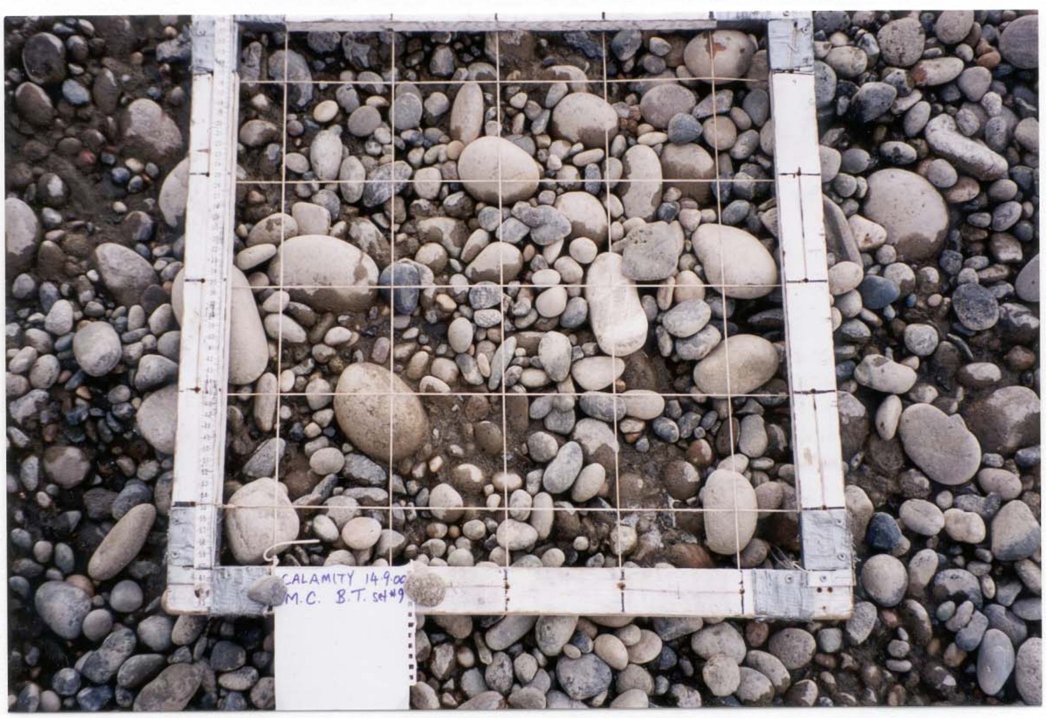
Family	**Species**	**Common Name**
Petromyzonidae	*Lampetra species*	Lamprey (species unknown)
Acipenseridae	*Acipenser transmontanus*	White sturgeon[R]
Salmonidae	*Prosopium williamsoni*	Mountain whitefish
	Salvelinus confluentus	Bull trout[B]
	S. malma	Dolly Varden[B]
	Oncorhynchus clarki	Cutthroat trout[B]
	O. gairdneri	Rainbow trout
	O. gorbuscha	Pink salmon
	O. keta	Chum salmon
	O. kisutch	Coho salmon
	O. nerka	Sockeye salmon
	O. tshawytscha	Chinook salmon
Cyprinidae	*Hybognathus hankinsoni*	Brassy minnow
	Mylocheilus caurinus	Peamouth
	Ptychocheilus oregonensis	Northern pikeminnow
	Rhinichthys cataractae	Longnose dace
	R. falcatus	Leopard dace
	Richardsonius balteatus	Redside shiner
Catostomidae	*Catostomus macrocheilus*	Largescale sucker
	C. platyrhynchus	Mountain sucker[B]
Gasterosteidae	*Gasterosteus aculeatus*	Threespine stickleback
	G. aculeatus trachurus	Marine stickleback
Cottidae	*Cottus aleuticus*	Coastrange sculpin
	C. asper	Prickly sculpin

B: blue-listed

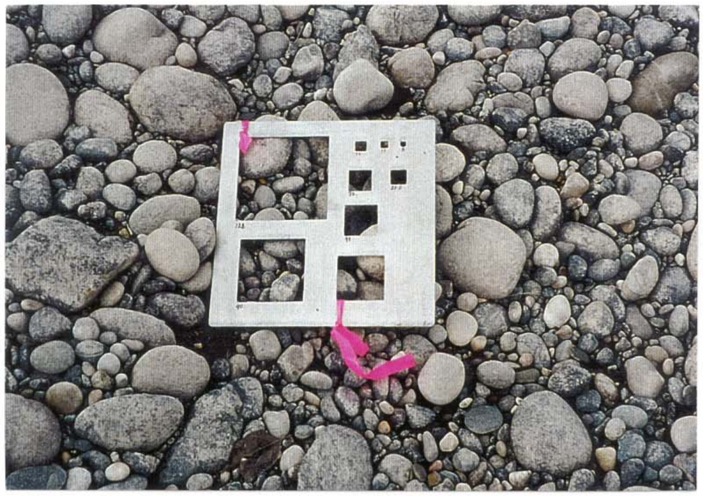
R: red-listed

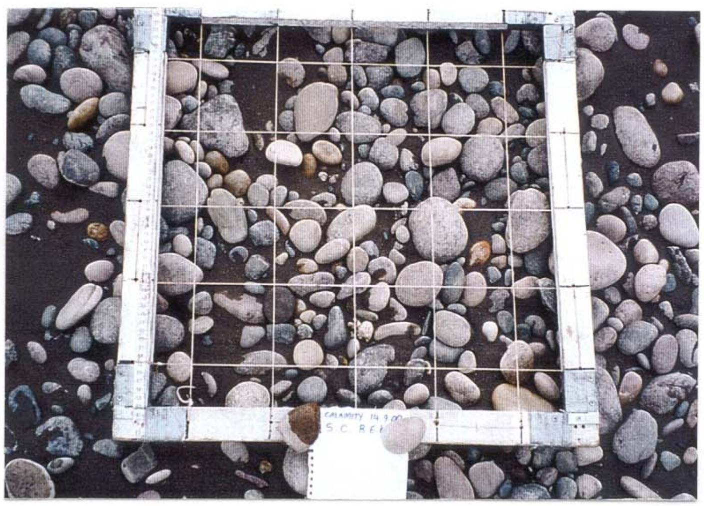
Appendix B. Site photographs representing various habitat types and common substrate "groups" in the river.

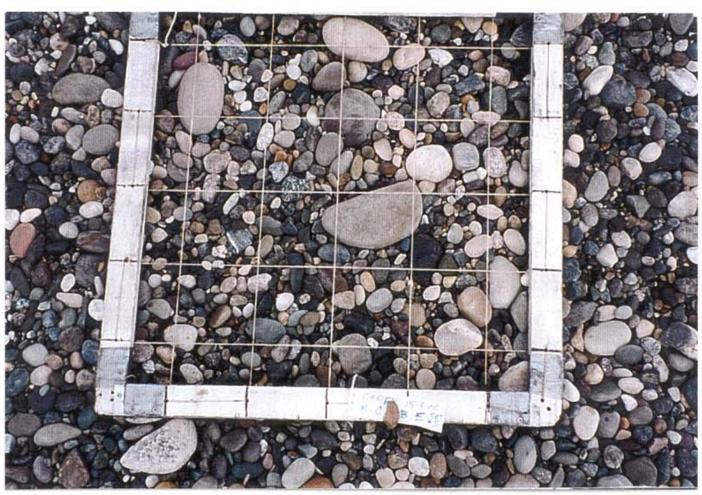
Typical **BAR HEAD** habitat, located on the upstream end of a gravel bar. Flow velocity is generally high, and can result in a back eddy depending on the orientation of the current. The **top photo** was taken on a side channel of Foster Bar in August 2000. The **bottom photo** illustrates the coarse substrate which is characteristic of a bar head (the quadrant has an edge length of 50 cm).



Typical **BAR TAIL** habitat, located at the downstream end of a gravel bar. Flow velocity is generally moderate to low. The **top photo** was taken on Calamity Bar in September 1999. The **bottom photo** shows the small cobble and gravel material that is characteristic of a bar tail.

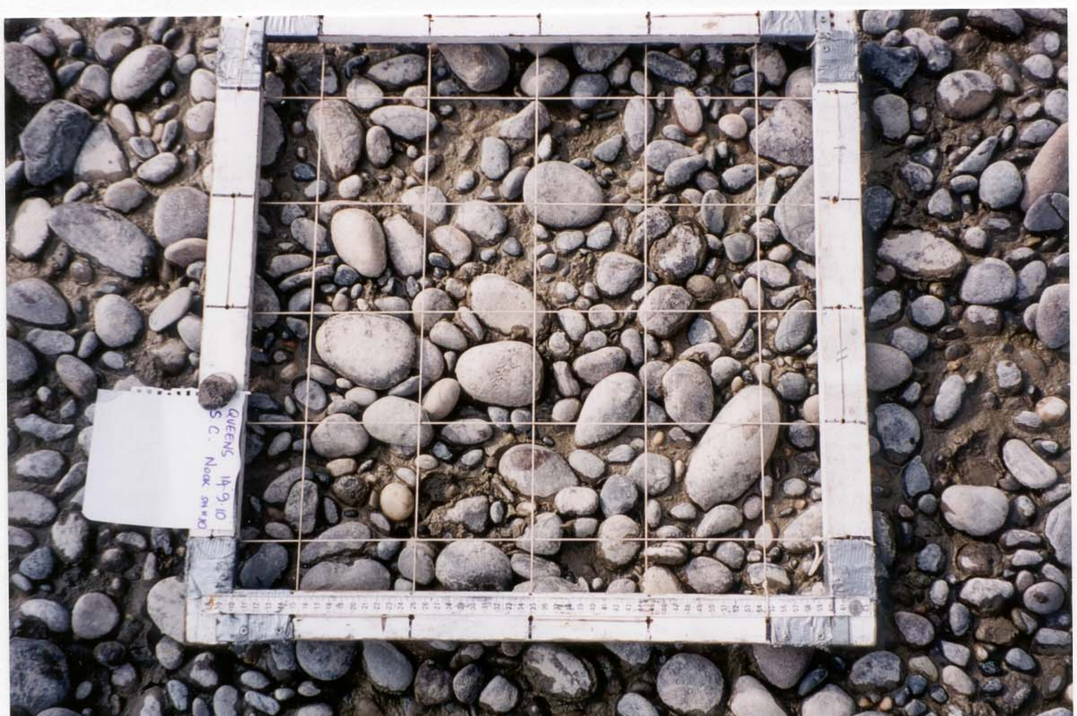






The **above photos** illustrate the range of substrate types, from large cobble to gravel material, associated with the **BAR EDGE** habitat. The template shown in the **top photo** has an edge length of 0.20 m.

Typical **BAR EDGE** habitat that is oriented parallel to the flow and subject to constant flow forces. The **top photo** shows a steep bar edge on Hamilton Bar in September 2000. The **bottom photo** shows a flat bar edge on Harrison Bar in February 2000.

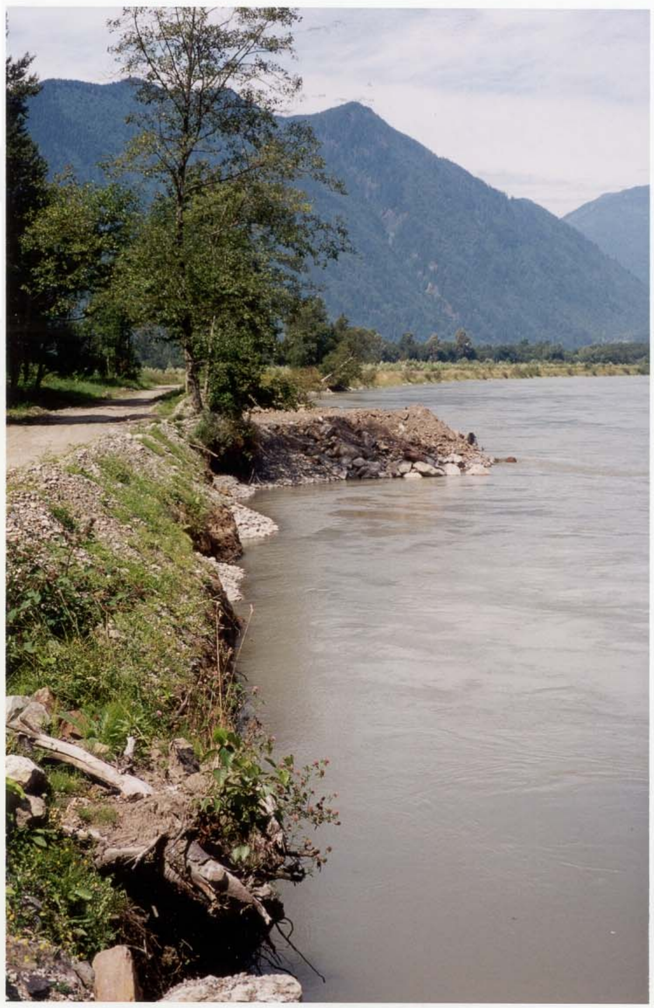


The **above photos** show the variable surface substrate associated with **OPEN NOOKS**.

Typical **OPEN NOOK** habitat, which refers to a shallow indentation located along the bar edge (with no sedimentary barrier from the main channel). Flow is typically reduced and open nooks can be ephemeral due to the shallow water depth. The **top photo** was taken on Powerline Island (August 2000). The **middle photo** shows an open nook within the area of gravel removal on Harrison Bar (May 2000). The **bottom photo** depicts an open nook on a side channel of Queens Bar (August 2000).

Typical **EDDY POOL** and **RIFFLE** habitat. Eddy pools are bound by fast, turbulent riffles, which create a back eddy in the lee of the flow. Riffles are high-gradient areas of shallow fast-moving flow. The **top photo**, taken on Wellington Bar in September 2000, shows a riffle section (left) with an eddy pool in the foreground. The **middle photo** shows a riffle section (middle) with a small eddy pool (left foreground) on Hamilton Bar in August 1999. The **bottom photo** shows a prominent riffle section on Wellington Bar in September 2000.

Typical **CHANNEL NOOKS**, which are dead-end channels of standing water and concave geometry. The channel nook conveys flow at higher discharges and substrate usually consists of sand and embedded gravel material. The **top photo** was taken from the lower gravel removal area on Harrison Bar in April 2000. The **bottom photo** shows a channel nook with woody debris on Lower Herrling Bar in September 1999



Typical **ARTIFICIAL BANKS**, which consist of unnatural bank material (often rip rap). Artificial banks are generally steep and the water is deep immediately offshore. Currents are either fast-moving or form a back eddy. The **top photo** shows an artificial bank along a side channel of Hamilton Bar. Similarly, the **bottom photo** shows an artificial bank along Seabird Island.

Appendix C. Sediment sample summary statistics (w= Wolman, x= photo). Percentiles and sorting coefficients are for distributions truncated at 4mm (see text).

Queens (April 2000)

Site ID	% sand cover	D5, mm (gravel)	D50, mm (gravel)	D95, mm (gravel)	Sorting (gravel)
w1	0.8	9.7	26.9	75.4	0.48
w3	0.0	12.4	26.2	61.0	0.35
w4	39.1	20.1	41.1	83.8	0.32
w5	1.4	10.3	31.9	75.1	0.44
w6	0.0	12.8	27.4	59.0	0.33
w7	0.0	16.8	37.6	81.8	0.37
w8	0.6	9.3	21.8	51.4	0.36
w9	0.0	13.5	27.0	55.3	0.31
w10	0.0	12.9	27.5	61.4	0.35
w11	20.5	14.6	39.0	79.8	0.35
w12	69.5	17.2	34.7	79.4	0.33
w13	50.4	14.7	39.4	72.2	0.33
w14	0.3	9.1	18.1	40.8	0.31
w15	0.0	10.6	22.0	44.6	0.32
w16	31.1	15.8	35.0	79.5	0.37
w17	2.8	8.6	24.1	65.8	0.47
w18	0.8	11.8	28.0	71.5	0.43
w19	16.1	15.4	31.9	70.9	0.34
w20	3.5	8.8	31.4	76.4	0.50
w21	2.5	9.9	22.4	47.7	0.36
w22	2.7	9.0	30.0	85.3	0.55
w23	0.5	10.0	35.0	88.0	0.54
w24	0.5	12.6	43.8	99.0	0.46
w25	1.9	12.1	26.7	69.0	0.38
w26	7.7	9.7	33.5	83.5	0.47
w27	1.9	10.3	36.6	85.8	0.46
w28	4.3	9.3	38.4	86.2	0.51
w29	0.0	12.3	28.7	69.1	0.42
w30	1.1	11.3	28.0	66.3	0.42
w31	0.8	12.2	40.9	96.6	0.45
w32	1.1	9.5	31.2	86.2	0.51
w33	0.0	12.6	23.8	46.8	0.29
w34	0.8	8.5	17.7	61.4	0.41
w35	2.5	9.5	26.5	54.6	0.36
w36	3.7	12.0	25.3	57.2	0.34
w37	5.2	9.6	21.4	43.4	0.34
w38	19.3	12.0	25.2	48.9	0.29
w39	48.3	21.1	42.8	76.6	0.28
w40	1.7	8.3	26.9	61.0	0.45
w41	0.8	9.5	24.8	43.9	0.34
w42	0.0	10.7	27.9	69.5	0.44

Queens (April 2000)

Site ID	% sand cover	D5, mm (gravel)	D50, mm (gravel)	D95, mm (gravel)
x1	0.0	9.6	21.3	50.9
x2	5.0	12.9	36.3	87.6
x3	0.0	11.6	29.9	71.8
x4	0.0	11.7	30.6	73.6
x5	0.0	9.8	22.3	53.4
x6	0.0	11.9	31.3	75.4
x7	3.0	12.2	32.9	79.3
x8	0.0	10.7	25.9	62.0
x9	47.0	11.5	25.0	50.4
x10	39.0	13.1	28.5	57.1
x11	30.0	10.9	23.6	47.7
x12	1.0	13.1	37.1	89.6
x13	16.0	12.8	27.9	55.9
x14	79.0	16.0	34.7	68.8
x15	0.0	11.2	28.1	67.4
x16	0.0	9.5	21.1	50.2
x17	1.0	12.3	33.5	80.8
x18	0.0	11.6	30.0	72.0
x19	0.0	11.9	31.4	75.6
x20	0.0	11.7	30.6	73.6
x21	0.0	12.6	34.9	84.1
x22	0.0	8.8	18.5	44.0
x23	0.0	11.8	30.8	74.0
x24	0.0	10.6	25.8	61.8
x25	0.0	11.1	27.7	66.6
x26	0.0	11.2	28.3	67.9
x27	0.0	12.4	33.8	81.4
x28	0.0	12.4	33.8	81.4
x29	0.0	10.0	23.3	55.6
x30	4.0	12.2	32.8	79.1
x31	0.0	12.4	33.6	81.0
x32	50.0	11.6	25.2	50.8
x33	0.0	11.4	29.0	69.6
x34	0.0	10.2	24.0	57.5
x35	0.0	9.8	22.2	53.0
x36	0.0	9.8	22.4	53.5
x37	0.0	11.4	29.0	69.7
x38	75.0	12.0	26.1	52.5
x39	5.0	10.5	25.2	60.4
x40	2.0	10.2	23.7	56.7
x41	0.0	10.0	23.1	55.2
x42	0.0	9.7	21.8	52.0
x43	5.0	9.3	20.2	48.1
x44	0.0	10.1	23.4	55.9
x45	12.0	15.3	33.3	66.3
x46	0.0	9.7	22.0	52.6

Calamity (April 2000)

Site ID	% sand cover	D5, mm (gravel)	D50, mm (gravel)	D95, mm (gravel)	Sorting (gravel)
w1	1.4	10.5	29.2	63.4	0.44
w2	0.8	12.6	33.9	80.1	0.42
w3	0.0	13.4	31.6	63.2	0.36
w4	0.0	13.1	34.7	73.7	0.38
w5	0.0	13.2	33.5	66.2	0.37
w6	0.0	12.5	30.0	71.4	0.39
w7	0.0	12.8	28.2	62.3	0.34
w8	0.0	16.0	33.1	66.9	0.31
w9	5.0	12.4	29.5	60.6	0.34
w10	0.3	14.7	33.4	67.2	0.35
w11	3.9	13.9	28.6	57.9	0.31
w12	27.7	11.8	24.5	54.5	0.31

Calamity (April 2000)

Site ID	% sand cover	D5, mm (gravel)	D50, mm (gravel)	D95, mm (gravel)
x1	80.0	7.7	16.6	34.1
x2	5.0	10.5	25.3	60.7
x3	20.0	10.8	23.5	47.5
x4	4.0	9.7	21.9	52.2
x5	70.0	8.5	18.6	37.9
x6	0.0	11.6	30.3	72.8
x7	2.0	12.1	32.4	77.9
x8	0.0	12.4	33.6	81
x9	1.0	13.1	37.2	89.7
x10	0.0	11.1	28.0	67.2
x11	1.0	12.0	31.9	76.7
x12	0.0	12.3	33.4	80.4
x13	0.0	11.3	28.5	68.4

Harrison (February 2000, pre-removal)

Site ID	% sand cover	D5, mm (gravel)	D50, mm (gravel)	D95, mm (gravel)	Sorting (gravel)
w1	2.8	9.4	31.9	102.4	0.57
w2	20.7	10.7	23.1	44.5	0.35
w3	16.9	10.3	20.5	37.7	0.29
w4	18.1	9.5	20.2	46.7	0.36
w5	1.0	10.8	22.4	47.1	0.36
w6	4.1	8.7	31.8	103.2	0.60
w7	46.2	14.1	45.7	97.9	0.43
w8	4.4	7.0	26.0	80.9	0.59

Harrison (April 2000, post-removal)

Site ID	% sand cover	D5, mm (gravel)	D50, mm (gravel)	D95, mm (gravel)	Sorting (gravel)
w9	43.3	4.7	13.6	41.6	0.49
w10	0.3	4.2	6.4	25.3	0.35
w11	21.1	4.7	12.9	36.3	0.47

Harrison (September 2000, post-freshet)

Site ID	% sand cover	D5, mm (gravel)	D50, mm (gravel)	D95, mm (gravel)	Sorting (gravel)
w12	0.0	12.0	30.6	88.0	0.45
w13	0.0	11.9	21.0	41.6	0.28
w14	3.2	12.3	25.4	51.6	0.31
w15	1.8	13.5	46.5	90.0	0.43
w16	1.9	9.7	21.1	55.8	0.38
w17	0.7	10.1	22.4	49.0	0.36
w18	0.2	9.9	30.8	76.9	0.49
w19	0.0	8.4	16.3	36.2	0.31
w20	0.0	9.0	19.2	41.0	0.33
w21	0.0	8.9	21.8	51.7	0.38