River reach characterization: a survey strategy for river regime and environmental monitoring and analysis

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ABSTRACT Studies of river regime have evolved from ad hoc description of fundamental hydraulic geometry (width, depth, velocity, slope and bed material relations) to include a broad range of morphologic, hydrologic, hydraulic, and environmental considerations. This paper outlines a hierarchical approach to river surveys that systematically describes river regime for "traditional" water resource engineering purposes, and for biological and chemical description and analysis. Hydraulic and morphologic (H&M) surveys range from a simple description of hydraulic geometry at a cross section to detailed reach descriptions of channel form and processes. Integrated river surveys (IRS) seek to explain river behaviour and the associated biological and chemical regimes, in the context of the river basin and its formative processes and how these evolve with time and space, and how river systems respond to impacts such as land use change. The benefits and information requirements of each level of survey are discussed.

INTRODUCTION

River surveys have developed for several different reasons: river engineers required information for design of hydraulic structures such as bridges; geomorphologists studied rivers to gain a scientific understanding of the formative processes and behaviour of rivers; water quality focused on water chemistry; and aquatic ecologists described rivers to explain biotic - abiotic relations. Environment Canada's river programs have traditionally been split along these disciplinary lines. However, the need to take a more integrated approach is emerging:

* the mutual benefits of merging the scientific and engineering approaches to river regime analysis have become increasingly recognized (e.g. Kellerhals & Church, 1989);

* the role of sediment and biotic interactions in contaminant storage and transfer determine that the fluvial environment is not a passive or inert conduit through which contaminants are routed (e.g. Allan, 1986); and

* the fluvial system provides the physical (or abiotic) framework within which biotic responses occur (e.g. Stalnaker, Milhous & Bovee, 1989).

Given that the physical river framework largely determines, or is highly correlated with, the distribution and characteristics of biological and chemical regimes in time and space, it is clear that the physical attributes of the river system must be considered in determining how, where and when biological and chemical investigations should be undertaken in the riverine environment. Further, there is no doubt that environmental impact and state of the environment analyses will require integrated studies that couple the physical framework with the chemical and biological character of river systems. The need for these types of linked studies is accelerating as evident with initiatives such as sustainable development and the legal requirements for environmental assessments of developments.

The objective of this paper is to present an approach that will be the basis of a proactive strategy that forcasts the demands for river surveys so that expertise can be developed, and surveys undertaken in anticipation of and in response to impending physical, biological and chemical aquatic ecosystem issues in the Western and Northern Region (WNR) of Canada.

RIVER SURVEY CONCEPTS

The premise of the river survey strategy is that it is not possible to adequately describe water resource engineering impacts, or biological or chemical impacts on river systems, without first developing an understanding of the physical attributes of the system to be impacted.

Systematic description of river form and processes provides information to address a suite of traditional water resource engineering and environmental issues. For example, bed material information can be used to describe channel stability for pipeline crossing design, for aggregrate inventory, and for aquatic habitat description.

A hierarchical survey approach is proposed. The information from the surveys may be selectively applied for a particular problem, with the recognition that for broader applicability and transfer of information, a number of river attributes must be systematically described.

Surveys are undertaken for various purposes and in various locations. "Representative reach surveys" provide an overview of river character for a significant length or reach of river. For river regime analysis the representative reach is defined by the river channel form and processes and hydrologic regime. For other applications, such as water quality or fisheries habitat, representative sections are based on river regime, but also include attributes such as land use and the attributes of the study question (e.g. territorialism of species, and sources and in-river behaviour of specific contaminants).

Representative reach surveys obviously provide information about that particular section of river. As well, by virtue of being representative, the documented section can be used as a reasonable analogue of a far greater length of river providing inferences on channel width, depth, velocity and bed material and bank conditions. Once a signifant number of representative sections have been described, areal transfer of the information can be made in a manner analagous to hydrologic regionalization. Then the representative reach information can be used for inventory and management choices.

"Critical survey reaches" represent hydraulic or morphologic conditions that are critical for a particular aquatic use. For example, a bedrock reach may represent an impediment to river transportation and to fish passage upstream. Thus, the reach is "critical" for these particular uses.

"Special reach surveys" are generally project specific. For example, the river reach downstream of a dam may be the focus of a detailed hydraulic and morphologic analysis to determine the reach characteristics following dam construction. Subsequent surveys would allow the evaluation of changes attributable to construction of the dam. The special study reach may in fact be "representative" of conditions upstream and downstream or be "critical" for particular aquatic uses.

In addition, special studies may be warranted in order to develop an understanding of particular river reach phenomenon such as permafrost channel evolution, and local and general scour. These studies may be directly applicable to a particular problem, or may be purely to develop expertise and experience for future applications.

SURVEY STRATEGY

The Sediment Survey Section of Environment Canada initiated a national river hydraulic and morphologic (H&M) survey program that focused on river regime analysis for water resource engineering applications, with incidental environmental applications. The objectives of the program were to maximize hydrometric and hydrologic data at streamflow gauging sites to better understand river processes; for direct applications to water resource engineering problems; and to develop expertise.

The three level H&M survey program described by NHC (1986) is in the initial phase of implementation. However, it is apparent that a far greater environmental focus is required at the same time as maintaining water resource engineering applicability. As a result, this paper proposes to adjust and expand the H&M approach to address a suite of water resource engineering and environmental needs in a hierarchical fashion. In addition, increasing demands and decreasing resources will necessitate, at least in the short term, a shift in strategy from a large number of surveys to document representative river types and physiographic areas, to a specific needs driven approach.

Level 1 Hydraulic and Morphologic Surveys

Level 1 surveys are based on existing hydrometric data collected and analyzed at stream gauging stations. The main type of data available are water level records (current and historic), velocity distributions and stream widths and depths across gauging sections at or near hydrometric stations.

The cross sectional information at gauging sections are a by-product of the derivation of streamflows at hydrometric stations. The hydraulic geometry relationships are fundamental to good hydrometric practice in terms of evaluating rating curves and extending rating curves, and can be used for preliminary engineering analysis (e.g. open water and under-ice hydraulic conditions for pipeline design) and to provide some idea of hydraulic conditions for applications such as streamflow conditions for dispersion of toxic spills (e.g. for a given water level, what is the average velocity of the streamflow?), and flow dynamics for aquatic habitat conditions (e.g. flow velocities for fish passage, and suitability for vegetation growth). In addition, hydrologic information can be derived from the hydrometric information to provide estimates of flow conditions over time (Table 1).

Level 1 information usually refers to a single cross-section, and this cross section is placed at a wadeable section, bridge site or cableway with an emphasis on hydraulic control rather than morphologic significance or representativeness. As a result, the information at a single cross-section is difficult to evaluate for representativeness unless additional cross-sections are surveyed or observations are undertaken.

Level 2 Hydraulic and Morphologic Surveys

The second H&M survey level enhances the information derived from the basic hydrometric program and provides additional information and analysis capabilities with a minor increase in field survey and interpretation. Level 2 surveys provide a qualitative description of channel form and stability and describe the range of morphologic conditions in a reach (e.g. cross sections of a pool, transition and cross over in a meandering stream) (Table 1). In addition, the hydraulic control of the hydrometric station is described with a cross valley bottom form survey and with longitudinal water surface profiles.

Level 2 surveys provide:

* hydrologic, hydraulic and morphologic information for hydrometric station management (e.g. stratification by size and basin type; gauging records can be compared with frequency of events);

* hydraulic information for slope area calculations of extreme discharge events;

* description of channel form in the gauge reach for:
  - evaluation of possible hydraulic controls elsewhere in the reach
  - determination of the variance around the gauge site
  - determination of how represenatative the gauged reach is of conditions upstream and downstream; and

* provision of summaries of streamflow and channel characteristics for descriptive and comparative purposes.

TABLE 1 Summary of river survey attributes.

LEVEL 1: <u>HYDRAULIC AND MORPHOLOGIC SURVEY</u>

Undertaken at the streamflow gauging cross section

<u>Basic Hydrometric Information:</u>

* water level records (current and historic)
* metering information
  - flow velocity distribution across channel
  - depth measurements across channel
  - water surface widths
* station information including
  - station history
  - benchmark tie-ins
  - metering locations
  - extreme water levels
  - field photographs
* ice information
* water temperature

<u>Derived Hydrometric Information:</u>

* hydraulic geometry relations
  - stage-discharge/velocity/area
  - velocity distribution
* water level in the cross section
* ice conditions
  - ice thicknesses
  - freeze-up and break-up dates
* specific gauge variations
* long profiles (at a few slope area sites)
* cross-sections
* local terrain analysis
* hydraulic roughness

<u>LEVEL 2: HYDRAULIC AND MORPHOLOGIC SURVEY</u>

Undertaken to document the range of morphologic conditions at streamflow gauging stations

* bed and bank materials
* channel morphology, and stability
* cross sections to describe the range of conditions in the gauge reach
* gauging section valley bottom form
* previous high water and ice levels.

LEVEL 3: <u>HYDRAULIC AND MORPHOLOGIC SURVEYS</u>

Surveys undertaken over two morphologic cycles or 10 to 15 river channel widths at streamflow gauging stations

* general reach information
  - reach maps and aerial photographs
  - geomorphic description
  - location of cross-sections, photographs, bed material samples, geomorphic features

* hydrologic regime
  - hydrometric station description
  - rating curve for survey date
  - mean discharges
  - flow duration
  - flood frequency

* channel/water slopes
  - field survey and photo distances
  - water surface profiles on survey date
  - longitudinal water surface profile
  - channel slopes

* hydraulic geometry of the river reach
  - typical cross-sections
  - elevations of
    - benches
    - valley flat
  - rating curve extension
  - stage-discharge relations
  - hydraulic geometry at
    - cross sections
    - for the reach

Description of the major geomorphic and physiographic characteristics of the river reach, valley and basin:

* upstream valley terrain
* valley wall
* terraces
* relation of channel to valley
* valley flat
* channel form
* channel stability
* bed and banks
* bed rock below channel

LEVEL 4: <u>INTEGRATED RIVER SURVEYS</u>

Surveys undertaken over two morphologic cycles or 10 to 15 river channel widths at specific issue sites

A multidisciplinary dynamic sampling and post mortem approach to document and explain:

* the form and processes of river reaches to provide the abiotic framework for comprehensive biological and chemical analysis

* the relationship of the biological and chemical regimes to the abiotic attributes of the river system such as the flow regime, the sediment regime, and channel bed and bank stability

* the behaviour of the river and historic evolution of the river reach and how these attributes may effect the biological and chemical regimes.

<u>LEVEL 5: INTEGRATED RIVER SURVEYS</u>

Level 4 Integrated River Surveys undertaken over several river reaches throughout a river system

Surveys are repeated over time to establish short and long term responses to changing conditions:

* to develop an understanding of the links between the physical, biological and chemical regimes throughout river systems

* to predict the consequences of changes to river systems such as river diversions, damming, land use change and climatic change

* to verify models with repeat surveys over time and space

Level 3 Hydraulic and Morphologic Survey

Level 3 surveys provide detailed descriptions of the hydrologic regime, reach hydraulics, and the composition and processes of a river reach over two or more morphological cycles (e.g. pool, riffle, pool riffle) or 10 to 15 channel widths (Table 1). The surveyed channel reach is related to the local valley conditions that determine channel form and processes and the extent of the reach representativeness is determined. Drainage basin conditions are also described (Table 1).

Level 3 H&M surveys are based on the description of river conditions across Alberta, Canada, undertaken by Kellerhals, Neill & Bray (1972). The 110 Albertan surveys are routinely used for preliminary engineering design of riverine hydraulic structures such as bridges, pipeline crossing and water intakes, and for route planning. The hydrologic and morphologic information has also been used for regionalization of regime relations (e.g. Bray, 1972).

In terms of providing information for aquatic habitat description, a Level 3 survey describes the spatial variability of bed material in the context of the hydraulics at individual cross sections at key points across and along the surveyed reach. The assumption is that the biotic character of rivers is related to the abiotic conditions. The objective is to provide a relatively simplistic description of some of the physical characteristics that are highly correlated with aquatic habitat, but with a focus still very much on description for water resource applications.

It is proposed that the habitat component of a level 3 survey is based on the Incremental Instream Flow (IIF) Method (Bovee & Milhous, 1978), which has two objectives: to document existing conditions; and to develop a predictive ability to forcast the consequences of river regime changes resulting from activities such as flow manipulation and land use change. It is recognised that the approach will evolve to reflect local knowledge and conditions. For example, bank form, composition and processes would be quantified to provide information for both habitat and channel stability analysis.

Survey results are directly applicable to water quality analysis. Sampling locations in the cross section may be ascertained from the Level 1 flow distribution relationships, but with Level 3 surveys, sampling locations may be related to channel morphology. Thus, for example, the misleading sediment associated contaminant loadings caused by sampling downstream of an eroding relatively uncontaminanted bar deposit on the MacKenzie River could have been avoided (Carson, 1991).

The detailed description of the river reach, valley form and processes, and the influence of the drainage basin on the site, provide a snap shot of information that would be central to state of the rivers reporting. The interpretation of site representativeness makes information transferable for inventory application and for preliminary engineering, biological and chemical analysis within similar reaches of the same river system.

Level 4 Integrated River Survey

Level 1 to 3 surveys focus on the physical river framework in isolation. While these levels of survey provide the basic building blocks for comprehensive biological and chemical description of the aquatic environment, there is a need for addition information and a somewhat different perspective to address environmental description and impact assessment. Level 4 surveys provide a multidisciplinary approach with a focus on the relationship of river form, processes and behaviour to the biological and chemical regimes. The approach is explicitly integrated.

In terms of the physical framework description, a Level 4 Integrated River Survey (IRS) approach seeks to provide information on physical conditions regarding:

- the form and processes of river reaches to provide the abiotic framework that is necessary for comprehensive biological and chemical analysis;

- the relationship of the biological and chemical regimes to the abiotic attributes of the river system such as the flow regime, the sediment regime, and channel bed and bank stability; and

- the behaviour of the river (e.g. quantitative rates of sedimentation and bank migration) and historic evolution of the river reach and how thses attributes may effect the biological and chemical regimes.

The first aspect addresses issues such as where and when to undertake biological and chemical sampling. The second aspect describes the physical context for interpretation of sampling. The third aspect describes the variance in channel characteristics over time to provide an historic context and outline of future abiotic conditions. In terms of aquatic ecosystem applications, the premise of a Level 4 IRS is that it is not possible to adequately describe the aquatic ecosystem without consideration of the abiotic conditions at the time of sampling and without due consideration to variations in the abiotic regime over time. As a gross example, a currently pristine mountain stream may have limited biological activity at the time of a summer bioassay because of previous drought conditions. Unless the flow history is considered, the productivity assessment is difficult to interprete.

Much of the level 4 information is described in a level 3 H&M survey, but the emphasis changes from generic description to address a range of possible issues, to the specific description to address particular physical, biological and chemical concerns. In addition, the description is more detailed in the description of form and processes and quantitative in terms of behaviour.

For example, detailed bed material composition description with interpretation of the genesis of these deposits, provides the opportunity for the specification of where to sample bed material for geoaccumulated sediment associated contaminants. Taking the correct sample(s) and properly interpreting the results are key to the successful (and legal) application of sediment quality guidelines (SQG). Knowing how to sample, where to sample and how many samples to collect is critical for SQG applications.

Level 4 surveys will generally have two elements: dynamic sampling and a post mortem approach. In dynamic sampling the spatial and temporal variability of attributes such as river regime and biologic and chemical regimes, are measured. This type of information will be used to develop relationships between physical framework attributes (such as water depths and velocities, sediment quality and depositional history), biologic productivity, and water quality.

A post mortem approach of past physical river conditions and associated biological and chemical regimes may be developed. For example, sequential aerial photographs and topographic maps can be used to describe drainage basin conditions and river channel form. This information can be coupled with historic hydrometerological conditions to describe the reponse of the channel to changing boundary and energy conditions. Historic water quality surveys, biologic surveys, and geoaccumul-ated chemical and biological evidence, may in turn be coupled with the river behaviour information to describe the relations between past physical river and basin conditions and instream biological and chemical attributes.

A Level 4 survey provides the type of information required for environmental impact assessment on the physical, biological and chemical properties of a river system. These surveys seek to explain the attributes of the river system in response to external and intrinsic controls and how these changes have occurred over time; and provides detailed information for water quality and aquatic habitat analysis in a river system context with an integrated multi-disciplinary study team approach. These surveys should be undertaken at selected sites, in response to or in anticipation of, significant basin developments, or for description of the state of the environment.

Level 5 Integrated River Survey

Level 5 Integrated River Surveys are essentially Level 4 IR surveys undertaken over several reaches through river systems with repeat surveys over time. These surveys recognise that impacts are cummulative and that the range of conditions experienced at a point are determined by local conditions and by the state of the system.

Level 5 surveys are repeated with changing flow conditions and boundary conditions to determine seasonally dependent attributes such as over-wintering habitat avaibility, mixing under an ice cover, and bed stability over a range of flow conditions. These surveys are also repeated over a time frame of years to document the abiotic and associated biotic and chemical responses to changing conditions induced by actions such as stream diversions, impoundments, land use change and climatic change.

The objectives of level 5 Integrated River Surveys are ultimately to be able to undertake integrated aquatic ecosystem environmental impact assessments, specifically:

* to develop an understanding of the links between the physical, biological and chemical regimes throughout river systems;

* to predict the consequences of changes to river systems such as river diversions, damming, land use change and climatic change; and

* to verify models with repeat surveys over time and space.

CONCLUSIONS

The river survey strategy provides a strategic framework to address traditional water resource engineering needs and provides the basis for integrated analysis of the physical, biological and chemical attributes of river systems. The first three levels of survey focus on description of river regime with progressively greater detail for water resource engineering applications and with increasing "incidental" environmental applications. The fourth and fifth survey levels are fully integrated aquatic ecosystem surveys.

The ultimate objectives of the Integrated River Surveys (IRS) are to develop an understanding of the links between the physical, biological and chemical regimes throughout river systems; to predict the consequences of changes to river systems such as river diversions, damming, land use change and climatic change; and to verify models with repeat surveys over time and space.

The objective of the strategy is to provide a range of approaches for the development of expertise and an information base to address a wide range of river related problems. These integrated river surveys will become a key element in fulfilling the mandate of Environment Canada in aquatic ecosystem description, analysis and management, but will require considerable committment in order to be achieved.

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