Normative Flow Studies Project Conceptual Framework

Provisional Final Draft

February 2003

This draft is intended for broad circulation through posting to the project website or other means. Further revisions to this document are not certain but are possible pending feedback from the project Science Review Team, advances in the understanding of the Project Team, or input from other reviewers. Further revision will occur at the discretion of the Project Manager and King County Department of Natural Resources and Parks management.

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King County
Department of Natural Resources and Parks
Water and Land Resources Division

The Normative Flow Project Framework

Objective of the Normative Flow Project

Anthropogenic alterations in the flow regimes of many King County rivers and streams by various pathways is a major factor in the decline of native, diverse, self-sustaining salmonid populations in these same rivers and streams (NOAA 1998). As a result of alteration, current flow regimes do not adequately reflect the adaptive history of salmonids nor support the ecosystem attributes that are necessary for the recovery and long-term survival of these species. No reliable method exists for assessing and evaluating the effects of flow alteration on the ecosystems that support these species. In response, the desired outcome of the Normative Flow Project (NFP) is the development of a reliable method for estimating, assessing and evaluating the effects of anthropogenic alterations to flow regimes on salmonid persistence and recovery in King County rivers and streams. In our view, this will be accomplished most reliably through the development of a framework that defines ecological attributes of the riverine ecosystem that are relevant to salmonid conservation and that respond in a (mostly) consistent and predictable manner to alterations in flow regime. To that end, three tasks are necessary:

1. Relationships between flow regimes and ecological attributes relevant to salmonid conservation must be clarified;

2. Reliable ecological indicators (biological and physical) of the attributes must be found; and

3. Ecologically useful (to the indicators and attributes) descriptors of flow must be developed.

The method must be capable of meeting three objectives:

- it must reliably measure the state of the indicators relative to flow characteristics;
- it must assess the difference between the indicator and a reference or goal condition; and
- it must be capable of evaluating the significance of the difference relative to salmon conservation goals.

The method will then be used to examine the effects from alterations to flow regimes as a result of current and proposed King County activities. The evaluation outcomes will then be used to inform those County activities that influence–or are influenced by–river and stream flow. Through adaptive management, the activities will be adjusted to produce outcomes more favorable to salmon conservation.

Among the activities that have or are likely to alter flow patterns directly or indirectly are: the location and magnitude of development activities and land uses, wastewater treatment, stormwater management, flood control (through the change in structure of the river), water re-use, and transportation network development. Among those activities that are influenced by flow are the restoration and rehabilitation of habitats critical to salmon conservation.

Background

The NFP is a systematic attempt to apply the ecological principles articulated in the *Return of the Kings* (King County 1999) to the problem of salmonid conservation in King County. In that document, the County outlines an ecosystem-based approach to salmonid conservation based upon four assertions:

1. The overriding focus on biomass and numerical goals in fishery management (to the exclusion of critical ecological functions) has promoted the impoverishment of the Pacific salmon resource (paraphrased from Frissell, Liss et al. Pacific Salmon and their Ecosystems. 1996. p.411);
2. The sustainability of a fish population requires protection of the specific physical (including flow) …habitats used by individuals of the population;
3. The sustainability of a fish population requires maintenance of the supporting native community (2 and 3 from Olver 1995);
4. Aquatic habitats critical to salmonids are the product of various processes acting throughout watersheds and within riverine ecosystems. Conservation can only be achieved by maintaining and restoring these processes to their natural rates (from Spence et al., 1996)

Fundamentally, the approach recognizes that the characteristics of riverine ecosystems—disturbance history, distribution and abundance of habitats, and species composition, distribution and abundance—vary over time and space, the result of interactions among physical and biological processes, physical and biological structure of the ecosystem, and various functions of the ecosystem. Salmonids have become adapted to these physical and biological patterns over many thousands of years, and the apparent attributes of salmonid populations – abundance, productivity, diversity and spatial structure (see Viable Salmonid Populations for Conservation, McElhany et al. 2000) – reflect this ecological history. Thus, the maintenance and restoration of salmon (as self-sustaining, extinction-resistant populations) depends upon the integrity of the ecosystem attributes that underlie this adaptation and survival.

Ecological Principles of Salmonid Conservation and the Normative Flow Project

The following principles were set forth in the *Return of the Kings* and are intended to guide King County in its conservation activities; they are also the basis for the NFP.

- Maintain and restore natural watershed processes that create habitat characteristics favorable to salmonids;
- Maintain and restore habitats required by salmonids during all life stages;
- Maintain and restore functional corridors linking these habitats;
- Maintain a well-dispersed network of high quality refugia;
- Maintain connectivity among refugia;
- Protect the core areas first; and
- Employ adaptive management principles in all activities.

These principles, adapted from Spence et al (1996) and the National Research Council (1992) instruct us to attend to basic process and structure as the first principles of ecosystem management. As a result of this approach, and an immediate need to address flow-related issues in King County rivers and streams, the County began the development of the NFP to address the effects of altered flow regimes on conservation efforts. *It was assumed that the goals of salmon conservation could not be reached without a flow regime hospitable to maintaining or recovering the ecosystem attributes upon which salmon depend.*

The NFP

The foundation for the Normative Flow Project reflects the paradigm of natural flow as expressed most recently in a paper published in 1997 by Poff et al. In this paper, entitled The Natural Flow Regime, the authors outlined a framework for the conservation and restoration of riverine ecosystems that stressed the importance of flow and flow patterns to the ecological integrity[1] of these systems. In the paper, five critical components of the flow regime are identified as regulators of ecological processes in river ecosystems: magnitude, frequency, duration, timing, and rate of change of hydrologic conditions (see Figure 3). Similar concepts can be found in other papers as well: Allan and Flecker (1993); Barinaga (1996); Hughes and Noss (1992); Junk, Bayley, and Sparks (1989); Karr (1991); Poff and Ward (1990); and Spence et al (1996).

This natural flow framework is the basis for the assumption of ecosystem integrity that underlies the goals and application of the NFP; the basic assumption of system integrity can be applied to PNW salmonid conservation as well (ecosystem integrity is a necessary precursor to salmonid conservation). Based on the previously cited works, we crafted a set of assumptions that underlie the NFP (see Appendix A) and confine the concept within ecological and evolutionary bounds. Nevertheless, significant questions emerge from the implications of a natural flow paradigm applied to flow-altered rivers: how far from the historical flow pattern can a system depart and still not exceed the limits of ecosystem integrity? That is, are there some departures from natural flow patterns that would allow salmon conservation to be successful? What are the limits of performance of a salmonid ecosystem with regard to flow? How might these departures and their effects on the riverine ecosystem be assessed and evaluated? In a river where structure has been significantly altered, can a normative flow regime be established that meets conservation goals?

Of considerable importance in any restoration activity, especially those involving flow modifications, is the notion of *reversibility*. Some physical and biological changes in ecosystems are exceedingly difficult or even impossible to reverse, the trajectory of system alteration or evolutionary direction having been set. Changes in one or more physical or biological attributes--such as the presence of an invasive species--could render a return to the historic patterns of flow inadvisable. In such cases, extreme care should be exercised when making modifications to

[1] Ecological integrity is an often ambiguous phrase. In this context, ecological integrity generally follows the meaning of Karr (1991) and means "the quality of being sound or complete, self-regulating, and resilient without human interference". More practically, it implies successful self-sustaining salmonid conservation.

system' processes and structure. In other cases, reversibility depends on the resilience of the system to respond to management actions. Highly altered systems require the rebuilding of resilience before management actions are likely to create a response.

Although current assessments of flow are becoming increasingly specific and useful, applications still do not produce clear and robust linkages to the ecosystem attributes that underlay salmon conservation (see Olden and Poff. 2003 for an exception) and most are somewhat cumbersome and data-intensive. Thus, a major task in the development of an ecological assessment must be to determine a set of flow regime attributes and flow-mediated ecological indicators that can inform us of the integrity of the ecosystem as it relates to salmonids. This presumes that we have some idea of the pathways of effect from flow to ecosystem attributes and thence to salmonids; some of this is known qualitatively but lacks the validation or robustness required to be useful in flow evaluation. Moreover, the descriptors used to assess flow cannot be assumed to be ecologically-meaningful; all seem to describe certain attributes of the flow regime with more or less detail but even the most recently developed descriptors possess no explicit pathway to ecosystem performance. Although riverine ecosystems are exceedingly complex, certain pathways and compartments within the riverine system are likely to be more important than others in influencing salmonid survival; illuminating some set of indicators of these pathways is one project objective.

The conceptual framework for the NFP assumes that flow (over many spatial and temporal scales) is a major forcer of many important processes occurring in riverine ecosystems—sediment transport and deposition, nutrient transformation, riparian vegetation growth and diversity, channel migration, woody debris recruitment, among many—and thus a major determinant of observed ecological structure. This is akin to the "master variable" of Power et al. (1995) and Resh et al. (1988). At the same time, the flow (regime) interacts with ecosystem structure (both biological and physical) and with other ecosystem processes to create and maintain the mosaic of habitats and biological processes characteristic of healthy aquatic ecosystems. Flowing water interacts with the underlying geology, valley form and geomorphology of the riverine ecosystem, with riparian vegetation and woody debris, and with the biological structure of the ecosystem as well. These factors must be accounted for in any assessment and evaluation of observed or predicted flow effects. Keeping in mind flow attributes as one among several potential forcers of ecosystem condition, we can treat the other forcers (variables) as boundary conditions or modifiers within which flow operates on the river system. We should be as explicit as possible here; the boundary conditions must be described in a manner that allows us to isolate the effects of flow characteristics on ecosystem indicators. Moreover, by keeping in mind the interaction of flow with other system attributes, we may discover that adjustments in river structure—i.e., the other attributes—will be effective in developing a more normative ecosystem in the absence of our ability to control flow directly.

To avoid examining all the numbingly complex characteristics that result from these interactions, the key will be to derive some small set of ecosystem indicators at various spatial and temporal scales that reliably signal the performance and integrity of the ecosystem as it is affected by flowing water. These indicators should combine physical and biological attributes that reflect flow attributes (Figure 1). We may use the literature of known flow effects (see Appendix B) to investigate appropriate system linkages and derive useful indicators.

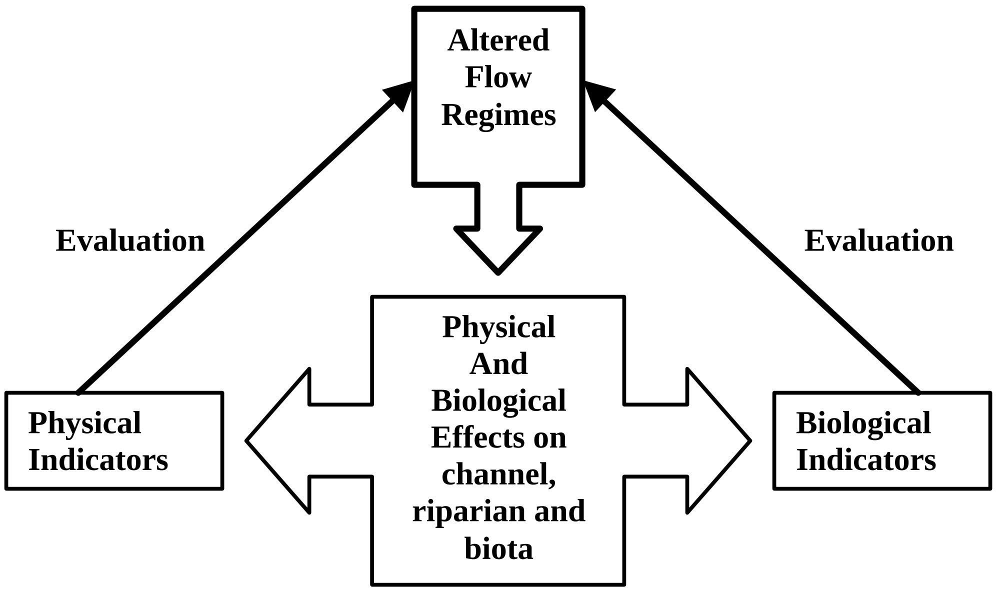

Figure 1.

In Figure 2, we see an example of a most basic framework for developing a model of flow and system attribute relationships. Despite the many "black boxes," such a conceptualization is a first step in developing a more detailed view of the river ecosystem and the effects of flow alterations (Martin et al, 1999). This framework can assist us in tracing the pathways and influences of other effects that will likely confound the interpretation of any indicators we might choose. Figure 3 suggests some of the general attributes of flow that should be examined as a first step in examining the ecological outcomes of flow modifications. The first order of work is to simply describe the dominant pathways between these flow attributes and their ecological counterparts. Once again, it should not be necessary to describe all probable pathways.

There will be some difficulty in sorting out anthropogenic effects from the normal variability within riverine ecosystems. It will be necessary to establish reference systems to "filter" the effects of climate and management actions on the indicators. Never the less, the management of flow has produced many effects unlike those that arise in unmanaged systems (Poff et al. 1997; Waters 2000; Petts et al. 1995)); such effects often possess very different spatial and temporal scales and often show considerably less variation. Few systems in the PNW, however, remain unaffected enough to serve as reference systems. Reference systems, therefore, are most likely to be developed from composites, from the historical information, from the scientific literature, and from simulations.

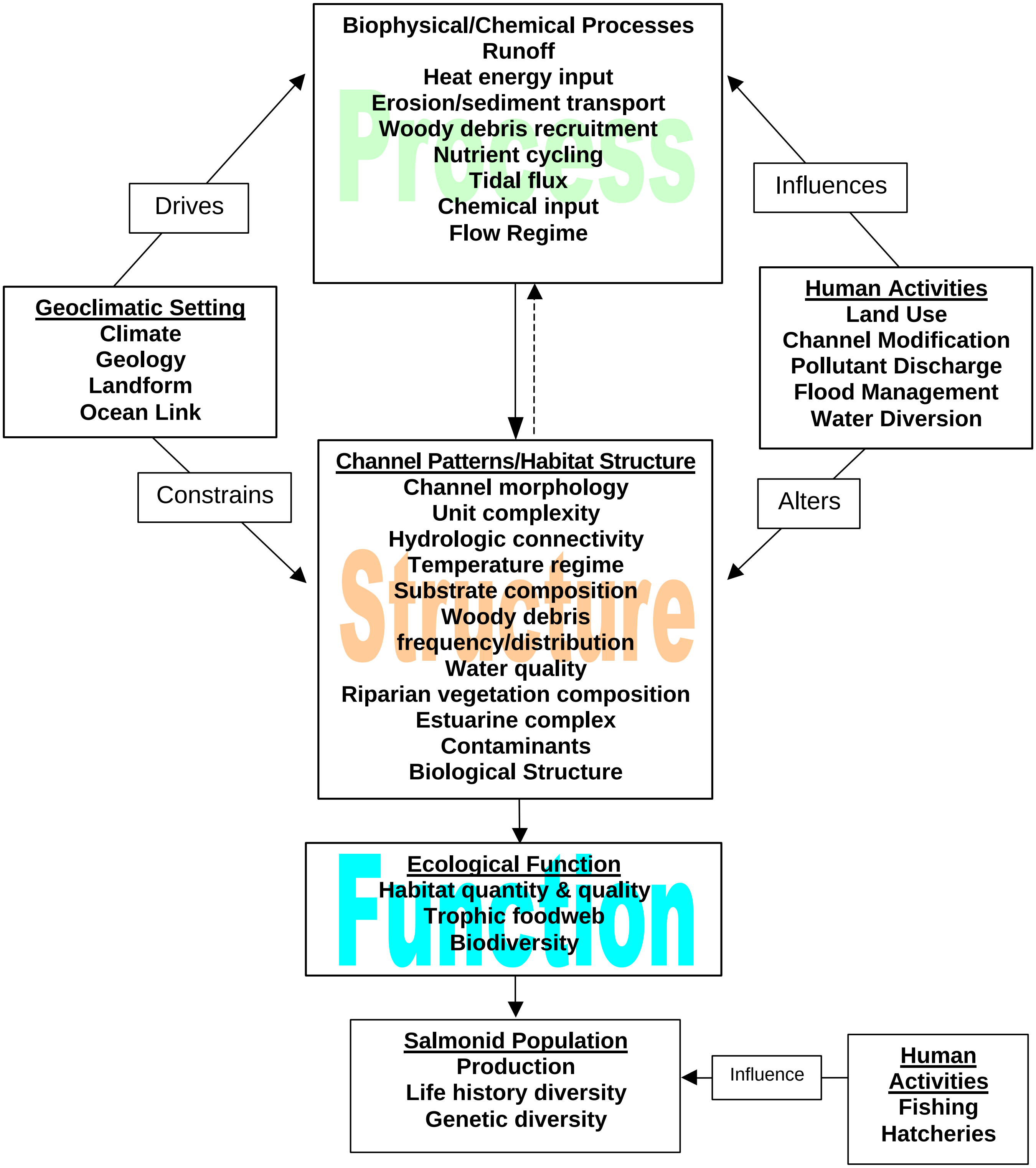

Figure 2 Interaction of human activities with riverine/estuarine ecosystem. Human activities influence salmon populations indirectly through influences on biophysical processes and alterations of habitat patterns, and directly through influences on population production and diversity.

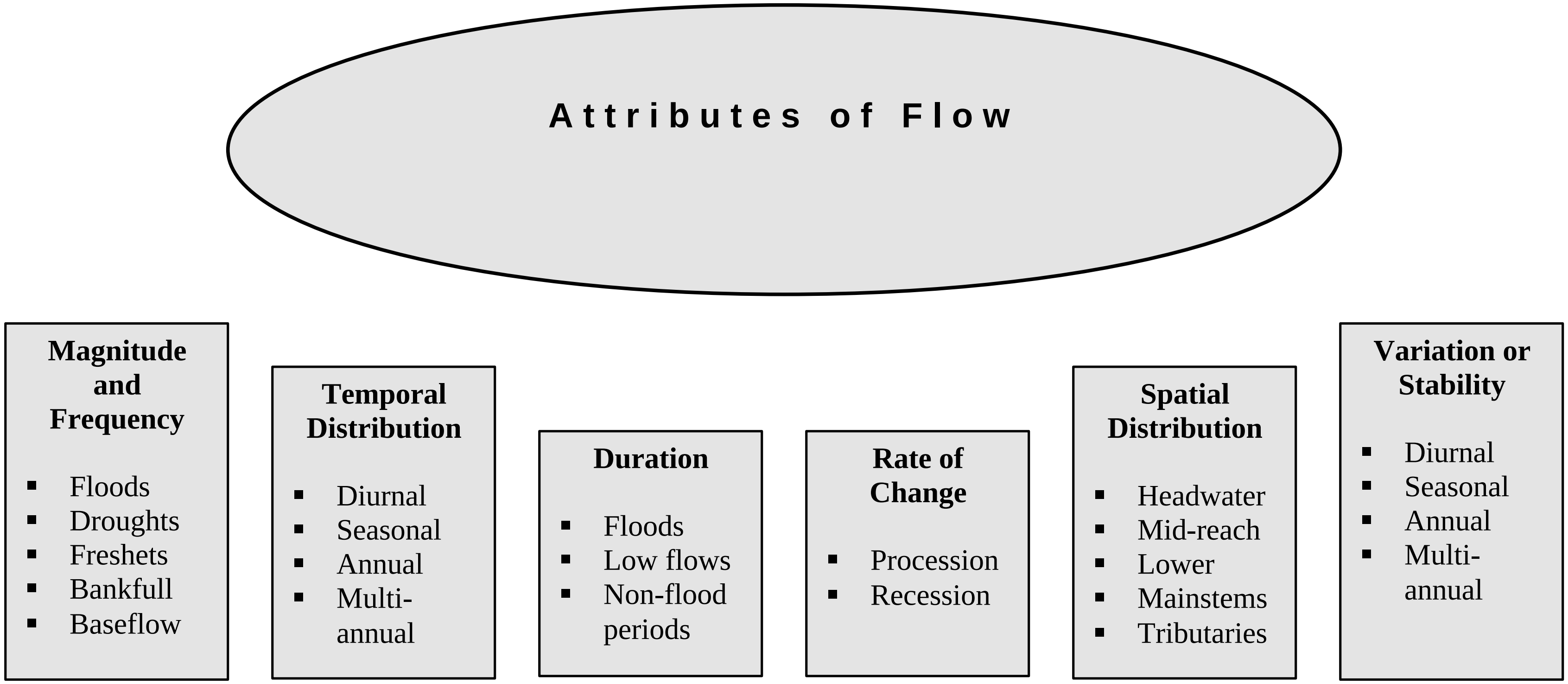
Attributes of Flow
Magnitude and Frequency
Floods
Droughts
Freshets
Bankfull
Baseflow
Temporal Distribution
Diurnal
Seasonal
Annual
Multi-annual
Duration
Floods
Low flows
Non-flood periods
Rate of Change
Procession
Recession
Spatial Distribution
Headwater
Mid-reach
Lower
Mainstems
Tributaries
Variation or Stability
Diurnal
Seasonal
Annual
Multi-annual

Figure 3.

Biological Indicators	**Physical Indicators**	**Chemical Indicators**
Indexes of Biotic Integrity	Habitat complexity	Nutrient Transformation Rates
Diversity Indices	Patch turnover rates	Nutrient Concentrations
Productivity	Spatial configuration	Pollutant concentrations
Particular species, guilds, and communities		Conductivity

Figure 4.

Ecological indicators

The most difficult task of the NFP may be finding ecological indicators that can be confidently linked to (changes in) flow attributes. Some possible general indicator types for biological, physical, and chemical attributes are listed in Figure 4. Many of these attributes have uncertain cause and effect linkages to flow but are strongly correlated with changes in one or many flow attributes. A search of the scientific literature turns up a surprising range of ecological effects attributed to flow modification (see Poff et al. 1997). Certain of these effects may lead the way to appropriate indicators such as species diversity, indices of biological integrity (B-IBI), spatial structure, and productivity. On the physical side, flow alterations—particularly flood control projects—produce effects on ecosystem and patch dynamics that appear to be quite similar in rivers world-wide. Chemical indicators of flow alteration are likely expressed as patterns of differential concentration of elements dissolved in water, or as changes in conductivity, or as pollutant concentrations.

Many of the biological effects of flow alteration require many years to decades to be realized. When the effects are finally discovered, it may be quite difficult or impossible to undo them or their root causes (reversibility). Biological resources may have been irretrievably compromised. Useful indicators must, therefore, if they are to have informative value for management actions, show both near-term and long-term utility. The near-term indicators must track system trajectory and support consideration of corrections in management practice before undue harm is done. Long-term indicators should account for environmental cycles such as the Pacific Decadal Oscillation and the time required for systems to respond to large scale disturbances such as droughts and floods, and to restoration activities. Some combination of quick response indicators and slow response indicators is necessary.

As a system changes due to management activities or natural events, the choice of indicators to reveal system integrity may necessarily also change. For example, system changes may encourage a shift from measuring macroinvertebrates to measuring LWD frequency, or vice versa. The early response of the biota to management actions may be less detectable as the system resets or stabilizes between disturbances or management manipulations. A useful indicator during the first stages of system recovery--when physical processes dominate ecosystem patterns--may give way to indicators of long-term system response as biological processes begin to assert dominance.

Application

If an indicator-based method can be developed for flow-mediated ecological responses, and if it can be made sensitive to variation in spatial and temporal scales, then the many activities that King County undertakes that affect flow could be usefully evaluated. The location and size of development proposals could be analyzed for their stormwater effects or their effects on low flow in stream ecosystems; water re-use could be evaluated to assist in the selection of appropriate locations and volumes for re-use projects; wastewater programs could assess the effects of diversions, inflow and infiltration, and discharges to various water bodies; the County's flood control program could potentially evaluate the effects of levees and revetments on the spatial distribution of flow attributes and thus on ecosystem properties; and the appropriateness and potential success of restoration programs and projects undertaken in flow-altered systems could be more confidently evaluated. Moreover, as the metropolitan area continues to grow and expand, the demand for water will continue to increase. A tool that links flow to ecological attributes may help clarify the choices and tradeoffs that we will have to make in the future as the demand for water grows throughout the region.

Method Development

Development of a method to meet the objectives discussed above is clearly no simple task. Numerous questions must be answered (or at least hypotheses formed), assumptions must be clarified, and attributes of scale and boundary conditions must be determined prior to the development and application of any method. It is not all together clear, for example, whether such a method must be wholly quantitative or could be constructed as an expert (narrative) system that maintains rigorous scientific logic but is largely non-mathematical. Several key steps are apparent for successful method development:

1) Ecosystem attributes of relevance to salmonid conservation must be described and linked to useful flow characteristics;
2) Indicators must be derived from the attributes;
3) Reference systems to describe normal patterns of change in the indicators must be described;
4) Known flow-mediated changes in ecosystem attributes must be gleaned from the literature;
5) A model[2] that links indicators must be constructed to serve as a platform for hypotheses and method development;
6) The indicator-based method must be constructed;
7) The method must be tested for indicator and architecture[3] robustness.

[2] "Model" is used here in the most general sense as a description or representation of a system and does not necessarily imply a mathematical description or a computer simulation.
[3] Architecture refers to the actual arrangement of the elements of the method. Some element may be more important than another so elements may be ordered hierarchically. This is a "first things first" approach.

At this time it is uncertain what form the method will take or even what the form of the "answer" required for various management decisions will need to be. It is possible (and likely) that no single “method” will be appropriate for all decisions that affect flow regimes. For example, a method meant to inform actions that primarily affect hydrology may not be appropriate for informing actions whose effects are primarily hydraulic in nature. A single conceptual model could serve as the basis for analytical guidelines, for a more rigorous expert system for analysis (much like a diagnostic key), or for some form of quantitative method. The NFP will address each of these issues in turn as the method is developed.

Appendix A.

Assumptions and Principles to Guide the Normative Flow Project

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Basic Assumptions

A1. The riverine ecosystem comprises a continuum of mosaics that are, themselves, composed of patches. The patches and mosaics within the river continuum respond to flow differently.

A2. The structure and function of riverine ecosystems depends on the integrity of the driving processes.

A3. Flow is a major forcer (master variable) of structure and function in ecosystems, as evidenced in:
- Physical attributes
- Biotic communities
- Energy transfers

A4. Alterations in flow patterns yield alterations in ecosystem attributes.

A5. The relationship between flow pattern and biotic attributes is indirect but can be described through appropriate indicators.

A6. The degree to which flow can be altered without exceeding ecosystem limits is unknown.

A7. The persistence of a species depends on the maintenance of the specific physical and chemical habitat attributes utilized by individuals of the species.

A8. The persistence of a species depends on the persistence of its supporting community.

A9. If native communities are to persist, appropriate flow patterns will resemble the conditions under which the communities have evolved and to which they are adapted (flow is a selective pressure).

A10. Restoration and maintenance of a normative flow regime is necessary for achieving desirable ecosystem characteristics and will be sufficient to sustain these characteristics in the absence of other critical limiting factors such as pollution, demographic effects, and physical degradation of habitats.

Basic Principles

These principles are derived from the scientific framework expressed in *Return of the Kings* (King County, 1999). This framework is the basis for the County's approach to salmon conservation.

P1. An evolutionary perspective, i.e., flow as a selective pressure, should guide the analysis of flow regimes as they affect biotic communities.

P2. The appropriate model for analysis, evaluation, and application is the ecosystem; effects are mediated through ecological pathways such as trophic dynamics and changes in spatial structure of the system.

Appendix B.

Ecological Responses to Alterations in Components of the Flow Regime[4]

Flow Component	Alteration	Ecological Response	Reference
Magnitude and Frequency	Increased Variation	Washout and stranding Loss of sensitive species	Cushman 1985; Petts 1984; Travnichek et al 1995
		Algal scour/POM loss	Petts 1984
		Life cycle disruption	Scheidegger et al 1995
	Flow stabilization	Altered energy flow	Valentin et al 1995
		Invasion and establishment Of exotic species	Meffe 1984; Moyle 1986 Stanford et al. 1996
		Reduced water and nutrients to floodplain:	
		Seedling dessication	Duncan 1993
		Failed dispersal	Nilsson 1982
		Encroachment of Vegetation into channels	Johnson 1994
Timing	Loss of seasonal peaks	Disruption of environmental Cues: Spawning	Faush et al 1997 Nesler et al 1988
		Hatching	Naesje et al 1995
		Migration	Williams 1996
		Disruption of food web	Power 1992
		Reduced riparian plant recruitment	Fenner et al 1985
		Invasion of exotic riparian plant spp.	Horton 1977
Duration	Prolonged low flows	Diminished plan diversity	Taylor 1982
		Domination by xeric plants	Busch and Smith 1995
	Change in inundation frequency	Altered plant cover types	Auble et al 1994
	Prolonged inundation	Change in vegetation functional types	Bren 1992; Conner et al 1981
		Loss of riffle habitat suitable for aquatic insects	Bogan 1993
Rate of Change	Rapid stage changes	Washout/stranding of aquatic insects	Cushman 1985; Petts 1984
	Accel. flood recession	Failed seedling establishment	Rood et al 1995

[4] References can be found in Poff, N.L. et al. 1997.

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