King County

King County Department of Natural Resources and Parks
Water and Land Resources Division
Normative Flow Project
Technical Memorandum
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RE: Indicators Supporting a Method to Relate Human Actions, Instream Flow and Biological Conditions in Puget Sound Lowland Rivers and Streams

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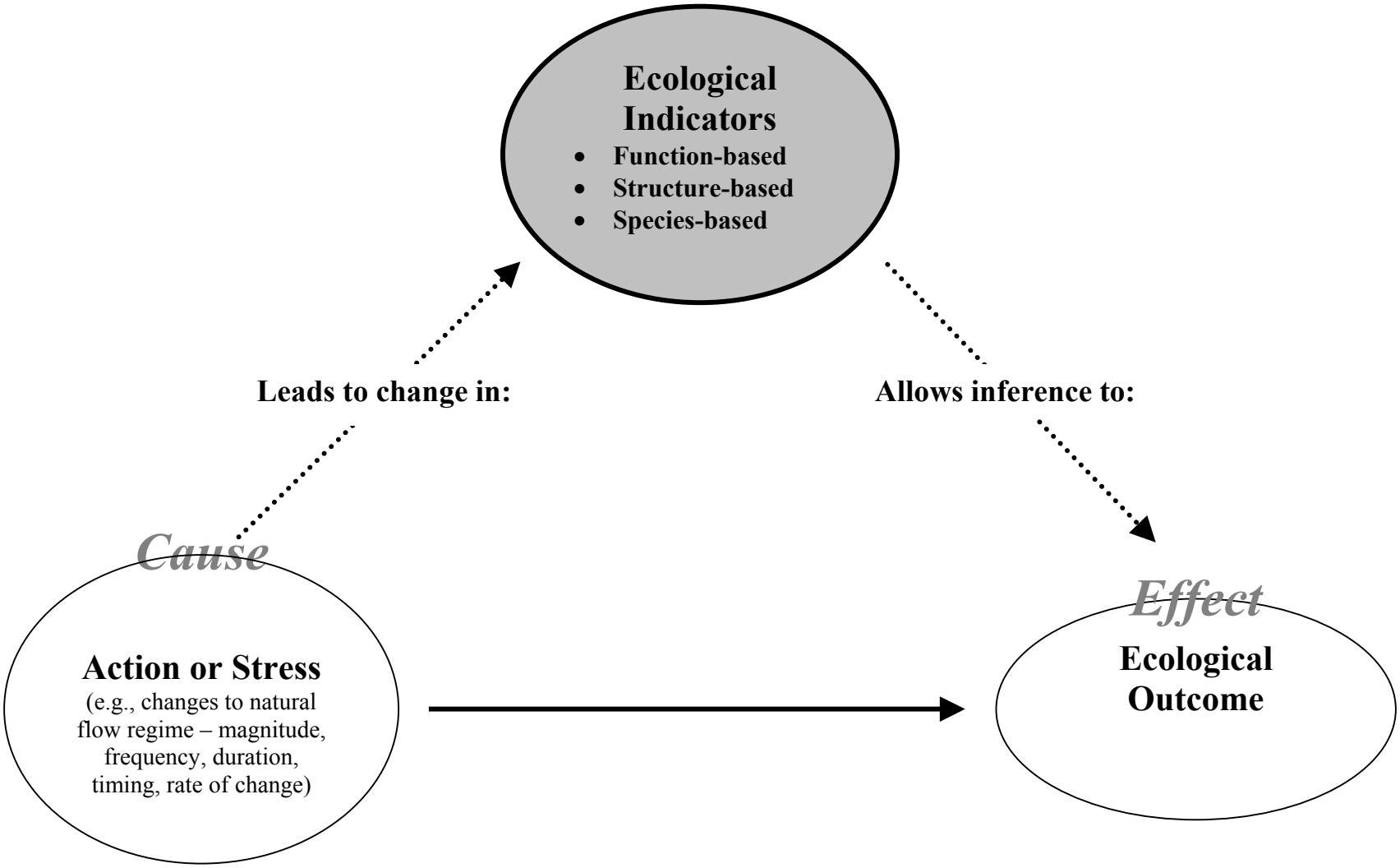
The Normative Flow Project (NFP) asserts that the flow regime of rivers and streams has a major role in determining the structure and function[1] of the riverine and riparian ecosystems that support multiple biological objectives including salmon conservation (see the NFP Conceptual Framework). It is difficult, however, to measure ecosystem function directly--temporal and spatial scales required for confident conclusions are often long and large. Nevertheless, a signature of anthropogenic alteration in the flow regime should be detectable in at least some of the physical, chemical, and biological attributes of the ecosystem and, therefore, could be useful in evaluating and predicting effects of human actions on salmon conservation and other biological objectives. We believe the indicators presented here hold promise for distinguishing anthropogenic flow-mediated effects from chemical effects, biological effects (such as invasives or predation), and the direct effects of salmon management activities.

Using scientific literature that documents effects of different characteristics of flow on river and stream ecosystems, and discussions with the project's Science Review Team (SRT), the NFP

[1] Including species presences, abundances, and relationships.

Figure 1: Indicator-based Approach to Understanding the Ecological Consequences of Stresses



technical team arrived at these four groups of indicators that might prove useful for characterizing some of the relationships between flow and ecosystem structure and function (see Figure 1). The groups are arranged below from the more specific descriptors of relationships to the more coarse. The first two indicator groups are intended to describe season-specific measures of instream flow, habitat structure and biology that should have process-based relationships. The third group is intended to describe characteristics of the flow regime that are altered by human activities and that are ecologically important (i.e., they affect biota and habitat structure and quality across seasons, years, and decades). The final group is intended to describe landscape scale factors that may correlate to flow alterations and, potentially, biological conditions. Information about relationships within these indicator groups should be useful for informing management decisions across a range of programs implemented by DNRP and others, including reclaimed water, wastewater system management, land use management, stormwater management, and instream flow management, in the pursuit of salmon conservation and other biological objectives.

Analyses we are undertaking now have been selected to assess the effectiveness of these indicators at providing a signal of flow-driven effects on ecological function at the stream or river scale. Acting on the project objectives, and addressing a significant gap in the technical literature, our primary focus in these analyses will be on exploring the relational indicators in the first two groups. The indicators shown, through this testing, to be effective at describing relationships of interest will become the foundation of the Method anticipated as a major product of the Normative Flow Project.

It is important to note that data limitations have bearing on our ability to test several indicators that reflect relationships of interest. Within the lists of indicators presented here, in particular the first and second groups, we note the indicators for which we have data as well as indicators that, while showing promise, cannot be tested currently because we do not have appropriate or sufficient data. We recommend that attention be given to clarifying the data needs for these indicators and that collection efforts to fill these gaps be scoped and implemented as soon as possible. It is also important to note that our confidence in river-scale indicators of flow-biology relationships is lower relative to that for stream-scale indicators and that our near term analyses will reflect this circumstance. The SRT has suggested pursuing river-scale instream flow "experiments" through which data collection and analyses can improve our confidence in river-scale indicators. We recommend taking specific action to develop and implement such "experiments". We believe that filling key gaps and exploring further the applicability of certain indicators to river scale settings will enable valuable testing and ultimately will increase the confidence in our hypothesized *human activity – flow – biology* relationships at the stream and river scale.

Finally, at this time we strongly recommend against the use of any of these indicators individually as an adequate descriptor of the relationship between biological phenomena and a human action that causes a change in hydrology. This is certainly the case prior to the evaluation of their effectiveness and is likely to be the case even after this evaluation. Although our hypothesis is that such relationships can be described using indicators, given potentially confounding factors it is likely that sufficient confidence will be provided only through the use of multiple indicators rather than a single indicator.

1. Indicators of Flow-Biology Relationships

These are indicators of biological responses to flow, specifically indicators of biological response to flow alteration. The paired hydrologic and biological variables in this category have been selected to represent hypotheses about specific mechanistic relationships between flow and biology. Because the nature and strength of the links between hydrology and biology have a temporal component, the time period within which each hydrologic measure will be computed corresponds to the portion of the water year that is relevant to the biological indicator it will affect. Moreover, biological patterns in river ecosystems can be the result of other, non-flow disturbance as well. Thus, a set of possible co-variates is listed along with the presumed response of the indicator.

We believe that the only readily available biological data set that is currently sufficient to test biology-flow relationships is a compilation of benthic invertebrate data that have been collected by various groups in the Puget Sound lowlands to compute the Benthic Index of Biotic Integrity (B-IBI). Metrics to assess effects of flow on benthic invertebrates are currently our most developed relational metrics. We are also in the process of developing hypotheses about links between flow and measures of juvenile salmon condition, frequency, and density (with help from the SRT). Other measures of salmon-flow links may be developed at a later date.

The Flow-Biology Relationship indicators are listed in Appendix 1.

2. Indicators of Flow-Floodplain Structure Relationships

These are indicators that assist assessment of relationships between flow and riparian vegetation and between flow and river/floodplain geomorphology. Riparian vegetation is included under flow-floodplain structure because the maintenance of native riparian vegetation is closely tied to flow regimes and the resulting geomorphic dynamics of floodplains. The links between flow and riparian vegetation and flow and floodplain geomorphology, especially the latter, will describe the distribution, community composition, and age structure of riparian vegetation, and the structure (patch composition and distribution) and patch turnover rates that are created by flow and provide necessary (though not sufficient) support for invertebrate and fish species. Use of these indicators may help eliminate certain flow changes as causes of biological conditions and encourage exploration of other causes, e.g., water chemistry or temperature changes. As is the case for the Flow-Biology Relationship indicators, co-variates and hypothesized responses of the indicators are provided for these indicators.

The Flow-Floodplain Structure Relationship indicators are listed in Appendix 2.

3. Indicators of General Hydrologic Integrity

The General Hydrologic Integrity (GHI) indicators include a set of hydrologic summary statistics that characterize natural flow regimes and the types and degree of hydrologic change associated

with an altered watershed condition (most often a result of human actions such as urbanization, withdrawals, bypasses, impoundments, hydraulic efficiencies, etc). At this time we are not investigating direct ties with a specific biological response for these indicators, but they will be useful in a different way. The GHI indicators will be used to describe hydrologic condition, provide the basis for describing change from predevelopment hydrologic conditions, and will be related to general indicators of biological function. As such, exploring relationships between general hydrologic indicators and biological condition may lead to more specific hypotheses about specific relationships between flow and biology. In contrast to the indicators in the remaining two groups, which focus on flow attributes during specific biological seasons of interest, GHI metrics typically describe the entire water year.

The primary focus of the Normative Flows Project is to investigate relationships between hydrologic and biologic change. Although flow-biology relationships are the primary focus, characterizing and understanding hydrologic change in Puget Sound lowland streams and rivers is an important component of the project. Therefore, GHI indicators will be useful in characterizing and understanding the ecological important consequences of altered hydrology.

The GHI indicators are:

- High Flows (frequency, magnitude, duration)
- Low Flows (frequency, magnitude, duration)
- Stream Power above threshold of significance:
    1. Bed-sediment movement
    2. Redd disturbance – seasonal
- Event Frequency Analysis
    - ♦ Frequency (w/ magnitude and duration) of 1.7, 5, 15, 25, 65 and 100 year high-flow events
- IHA/RTV composite annual statistics:
    1. Monthly magnitudes
    2. Magnitude/duration of extreme high/low
    3. timing of annual extremes
    4. frequency/duration of high/low pulses
    5. rate/frequency of flow rate change
- T-Qmean - Annual
- Q2(Forested)/Q10(Current)

4. Indicators of Human Activity

This group of indicators should be considered a coarse-level screen of watershed alterations that likely affect the hydrologic regime of streams and rivers. These are relatively common indicators of development activities that alter land cover, change flow pathways, or affect instream flow management directly. They therefore can also be helpful in explaining the source of hydrologic changes that are discovered through analysis involving the GHI indicators.

The Human Activity Indicators are:

- % Forest cover
- % Impervious surface
- Road crossings
- Road density
- Point alterations of water quantity: dams, withdrawals, and by-passes

Researchers have identified gradients or thresholds for some of these indicators that correlate with measurable alterations in some component of the flow regime--quantity, duration, flood frequency, etc.; for others, direct alteration or manipulation of flow can be easily measured. This set of indicators can be used to evaluate a watershed or basin for likely changes to flow patterns which, if found, would lead to further analysis using the GHI indicators.

Appendix 1: Indicators of Flow-Biology (FB) Relationships

Note: In the text describing the Metrics, "[increase]" and "[decrease]" are the expected direction of the response in the indicator's metric to the flow alteration. Indicators for which we haven't concluded the direction of the response are noted by "[TBD]". Applicability reflects whether the indicator applies to small streams, larger rivers, or both types of systems.

Indicator FB_1: Invertebrate Community Composition or Attributes
Metric(s): B-IBI [TBD]

Applicability: Small Streams

When to Measure (Streams): early autumn

Where to Measure (Streams): Riffle patches within pool/riffle segments

Relevant Hydrologic Attributes: Timing, magnitude, duration, frequency, rate of change in annual hydrograph (All)

Hydrology Metric(s): General hydrologic integrity indicators

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Annual

Rationale for indicator: Overall B-IBI score is a general indicator of the biological effects of multiple human activities that change aspects of aquatic ecosystems (in the five groups described by Karr and Chu (1999): water quality, habitat structure, food sources – energy, flow, and biotic interactions); because this indicator integrates flow effects with other effects, this is used as a general descriptor of biological condition. However, it may be more strongly related to some aspects of flow or flow alteration than others; higher B-IBI scores are correlated with presence of salmon in streams, but the relationship is poorly understood.

Other covariates to measure: Use co-variates appropriate for general hydrologic integrity indictors (e.g., precipitation, geology, channel type, land cover, road density, water quality)

Other notes:

Indicator FB_2: Invertebrate Community Composition or Attributes
Metric(s): % dominance of three most common taxa [increase]

Applicability: Small Streams

When to Measure (Streams): early autumn

Where to Measure (Streams): Riffle patches within pool/riffle segments

Relevant Hydrologic Attributes: Timing, magnitude, frequency of spring freshets

Hydrology Metric(s): *Timing*: 2 highest peak flows during season; # days to the mean flow for the season; *Magnitude*: mean 7-day average flow; *Frequency*: # peaks 2X season mean flow; *Variability*: CV of the mean 7-day average; # reversals; measures of skewness (e.g., compare 1, 3, 7 day max flows; ratio daily max/weekly mean; ratio (weekly and season) median/mean); *Duration*: duration of peaks > 2X mean flow; *Over time*: proportion of years or % of time that there is a significant difference in # peaks, duration peaks, or # reversals (like IHA/RTV group 4; RTV analysis of # peaks above SMF

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): March 21 - June 21

Rationale for indicator: Under greatly increased or decreased disturbance regime (I.e., frequency and magnitude of disturbances) species diversity is expected to decrease; communities will be dominated by a few taxa able to tolerate changed conditions; % dominance under reference conditions assumed to reflect natural disturbance regime. Spring period assumed to be when change in timing, frequency and magnitude is most important because it coincides with emergence/reproductive period - i.e., increased or decreased disturbance during this time, or changes in the timing of flow events may prevent reproduction of some species. % dominance should respond more rapidly than # long-lived taxa.

Other covariates to measure: Degree-days; timing of emergence and/or egg deposition for major taxa; grain size (will affect availability of flow refugia and affect how flow translates into disturbance; bed mobility

Other notes: looking for the 'center of gravity' of discharge during season - i.e., does it shift in time

Indicator FB_3: Invertebrate Community Composition or Attributes
Metric(s): # long-lived taxa [decrease]

Applicability: Small Streams

When to Measure (Streams): early autumn

Where to Measure (Streams): Riffle patches within pool/riffle segments

Relevant Hydrologic Attributes: Timing, magnitude, frequency of winter peaks and spring freshets

Hydrology Metric(s): Same as for (2) above

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): December 15 - March 21; and March 21 - June 21

Rationale for indicator: Increase in frequency of disturbance or flashiness during times of normally stable or stable and falling flows increases the likelihood that longer-lived taxa will be exposed to disturbance during vulnerable life stages, e.g., during growth/feeding periods or during overwintering periods; longer-lived taxa will not persist. This metric should respond more slowly than others (e.g., % dominant 3 taxa) to changes in timing, magnitude, and frequency of spring freshets, i.e., change in disturbance regime will tend to disrupt life-cycle of longer-lived species but they may persist for some time due to egg banks/overlapping generations. Longer-lived taxa may respond more strongly to the # years, the proportion of years, or the # successive years with significant differences in frequency, timing, magnitude of spring floods rather than the degree of change in these metrics.

Other covariates to measure: Degree-days (water degree days will be affected by flow); timing of emergence and/or egg deposition for major taxa; grain size' bed mobility

Other notes:

Indicator FB_4: Invertebrate Community Composition or Attributes
Metric(s): # intolerant taxa [increase]

Applicability: Small Streams

When to Measure (Streams): early autumn

Where to Measure (Streams): Riffle patches within pool/riffle segments

Relevant Hydrologic Attributes: Timing, magnitude, frequency of spring freshets; Magnitude, frequency, duration of low flows during summer low flow season

Hydrology Metric(s): Same as for FB_2 above (% dominant 3); and # times flow < historical median seasonal low flow for 3, 6, 12, and > 12 days; *Duration*: proportion of season that flows < historic median seasonal low flow for more than 3 days or more

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): March 21 - June 21; and June 21 - Oct 15

Rationale for indicator: Same as for FB_2 and FB_3 above; also may be more susceptible than other invertebrate taxa to increases in frequency, magnitude and/or duration of low flows

Other covariates to measure: Degree-days (water degree days will be affected by flow); timing of emergence and/or egg deposition for major taxa; grain size; WQ,

Other notes:

Indicator FB_5: Invertebrate Community Composition or Attributes
Metric(s): # clinger taxa [decrease]

Applicability: Small Streams

When to Measure (Streams): early autumn

Where to Measure (Streams): Riffle patches within pool/riffle segments

Relevant Hydrologic Attributes: Magnitude, frequency, duration, rate of change of spring freshets

Hydrology Metric(s): *Duration*: peaks > 2X season mean; *Magnitude*: peaks > 2X season mean; *Variability*: # reversals; compare 1, 3, 7 day max; daily max/weekly mean, median/mean (weekly and season); 75%ile and 95%ile rise rate; *Frequency*: # peaks > 2X season mean, *Timing*: NA

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): March 21 - June 21

Rationale for indicator: Clinger taxa are expected to be more vulnerable than other taxa to changes in velocity, rates of change in flow magnitudes, increased flashiness; aseasonal spikes

Other covariates to measure: bed mobility; grain size; stream size (stream order may be a convenient substitute for actual stream size or use total watershed area of the stream or segment.); water quality.

Other notes:

Indicator FB_6: Invertebrate Community Composition or Attributes
Metric(s): EPT Index (Ephemeroptera-Plecoptera-Trichoptera) [decrease]

Applicability: Rivers

When to Measure (Rivers): early autumn

Where to Measure (Rivers): Riffle patches within pool/riffle segments

Relevant Hydrologic Attributes: All

Hydrology Metric(s): General hydrologic integrity indicators

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Annual

Rationale for indicator: Overall EPT index is a general indicator of habitat quality or ecosystem integrity; explicit relationships not known so use as a general descriptor; relationship of EPT index to salmon also not known

Other covariates to measure: Sediment size, bed mobility, water quality.

Other notes:

Indicator FB_7: Invertebrate Community Composition or Attributes
Metric(s): Total # taxa [decrease]; % predator taxa [decrease]; % tolerant taxa [increase]

Applicability: Small Streams/Rivers

When to Measure (Streams): early autumn

When to Measure (Rivers): early autumn

Where to Measure (Streams): Riffle patches within pool/riffle segments

Where to Measure (Rivers): Riffle patches within pool/riffle segments

Relevant Hydrologic Attributes: All

Hydrology Metric(s): General hydrologic integrity indicators

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Annual

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Annual

Rationale for indicator: Related to increases in stream power, velocity, magnitude and frequency of peak flows. As the frequency of flow disturbance or flow variability changes (either increase or decrease), taxa composition will respond. These alterations

tend to favor generalists taxa over specialist taxa. Tolerant species should increase as magnitude/frequency of peak flows, flashiness, stream power increases.

Other covariates to measure: For % tolerant; grain size; land cover

Other notes:

The following Indicators need resolution of data availability and/or rationale issues and therefore are unlikely to be included in the first round (2Q-3Q2003) of testing.

Indicator FB_8: Coho salmon condition
Metric(s): Condition (weight X 100/length) of 1+ coho [decrease] and Ratio: Condition 1+ coho March / Condition 1+ coho July [decrease]

Applicability: Small Streams/Rivers

When to Measure (Streams): March - April, June - July

When to Measure (Rivers): March - April, June - July

Where to Measure (Streams): pools > 1m3

Where to Measure (Rivers): main stem and side channels

Relevant Hydrologic Attributes: Magnitude, frequency of aseasonal spring and winter peaks

Hydrology Metric(s): *Magnitude*: peaks > historical seasonal mean flow or bankfull flow or 2X winter low flow; (some measure of historical flow that would be meaningful for fish to have adapted to and that would still be meaningful today; get feedback from SRT); *Frequency*: peaks > historical seasonal mean flow or bankfull flow or 2X winter low flow, (some measure of historical flow that would be meaningful for fish to have adapted to and that would still be meaningful today; get feedback from SRT); *Variability*: Magnitude and Coefficient of Variation of rise (not rise rate), number of reversals; compare 7, 21, 30 day mean flow (measure of magnitude of sustained flows with no resting times for fish); Measures of skewness/flashiness (e.g., Daily peak/weekly mean, median/mean, TQmean, CV daily flows, CV weekly mean); *Duration*: NA; *Timing*: NA

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Both: March 21 - June 21 (spring feeding/growth period); Dec 15 to March 21 (winter rearing period)

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Both: March 21 - June 21 (spring feeding/growth period); Dec 15 to March 21 (winter rearing period)

Rationale for indicator: Increased flashiness (as indirect measure of disturbance) and increased frequency, duration, or magnitude of peaks (times of high flow) increase stress on juveniles during winter and spring rearing periods (i.e., reduce the amount of time that can be spent feeding, increase energy expended holding position or finding food, or decrease food availability); increased duration of peaks may also increase interspecific interactions in flow refuges; duration of peaks (rate of change) is related to probability of stranding;

Other covariates to measure: presence of off-channel habitat will affect options for fish response

Other notes: Condition factor at the end of the winter will give an idea of how winter conditions affected growth and condition factor measured in the late spring will reflect how effective the spring growth period was at ameliorating the effects of winter. The ratio of these two condition factors (spring/winter) for 1+ coho could provide an index of the relative amount of growth that was achieved each year and would be more informative than condition at one time only. The expectation of effect would depend on the timing of the flow alterations (winter vs. spring) but in general, one would expect the ratio to decrease (less growth from winter to spring). Condition factors in unregulated river systems would serve as a basis for comparison with regulated systems.

Indicator FB_9: Riparian vegetation
Metric(s): % flood intolerant plant species [increase]; % obligate wetland/hydric plant species [decrease]; % of area (e.g., channel migration zone) covered by each vegetation type

Applicability: Small Streams/Rivers

When to Measure (Streams): summer, at full leaf out

When to Measure (Rivers): summer, at full leaf out

Where to Measure (Streams): unconfined alluvial segments; within channel migration zone

Where to Measure (Rivers): unconfined alluvial segments; within channel migration zone

Relevant Hydrologic Attributes: Frequency and duration of bankfull flows (annual hydrograph)

Hydrology Metric(s): *Frequency*: of > bankfull flows (assume historic 1.7 yr. event is bankfull); *Duration*: of > bankfull (assume historic 1.7 yr. event is bankfull); *Magnitude*: NA; *Timing*: NA; *Variability*: NA

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Annual hydrograph

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Annual hydrograph

Rationale for indicator: Frequent overbank floods preclude the establishment of flood intolerant/upland species, or species that cannot tolerate prolonged saturation of soils in the rooting zone; a reduction in flood frequency changes soil moisture conditions and disturbance regime to allow establishment and persistence of flood intolerant or upland plant species.

Other covariates to measure: Local land use/land cover

Other notes: % area is a riverscape indicator - add this under riverscape indicators: % area dominated by flood intolerant vegetation…

Indicator FB_{10}: Riparian vegetation
Metric(s): % non-native plant species [increase]; see notes

Applicability: Small Streams/Rivers

When to Measure (Streams): summer, at full leaf out

When to Measure (Rivers): summer, at full leaf out

Where to Measure (Streams): unconfined alluvial segments

Where to Measure (Rivers): unconfined alluvial segments

Relevant Hydrologic Attributes: Frequency, magnitude, duration, timing (see rationale and notes)

Hydrology Metric(s): *Frequency*: of > bankfull (assume historic 1.7 yr. event is bankfull); *Duration*: of > bankfull (assume historic 1.7 yr. event is bankfull); *Magnitude*: of 1.7 year events; *Timing*: NA; *Variability*: NA; Over time: % of time (on annual basis) that flows are above bankfull

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Annual hydrograph

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Annual hydrograph

Rationale for indicator: A change in the natural disturbance regime frequently is associated with increase in relative abundance and/or dominance by non-native riparian plants. Need to develop specific hypotheses for individual species and predicted response to change in frequency, duration, magnitude and timing of floodplain inundation. For example, decrease in flood frequency, stream power may increase likelihood of establishment of reed canarygrass.

Other covariates to measure: Undetermined

Other notes: choose specific indicator species that are likely to invade channel migration zone under different hydrologic alterations, e.g., Japanese knotweed or butterfly bush

Indicator FB_{11}: Riparian vegetation
Metric(s): Coefficient of Variation of age composition of tree/shrub species [decrease]

Applicability: Small Streams/Rivers

When to Measure (Streams): summer, at full leaf out

When to Measure (Rivers): summer, at full leaf out

Where to Measure (Streams): unconfined alluvial segments

Where to Measure (Rivers): unconfined alluvial segments

Relevant Hydrologic Attributes: Frequency, magnitude, duration, and timing

Hydrology Metric(s): *Frequency*: historic 1.7, 5, 15, 25, 65, 100 yr. events (i.e., calculate from historic flow regime and then assess change); *Duration*: historic 1.7, 5, 15, 25, 65, 100 yr. events (i.e., calculate from historic flow regime and then assess change); *Magnitude*: 1.7, 5, 15, 25, 65, 100 yr. events; *Timing*: NA; *Variability*: NA

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Annual hydrograph

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Annual hydrograph

Rationale for indicator: A change in the natural disturbance regime frequently is associated with reduction in number of age classes of trees present; a decrease in disturbance may result in selective loss of younger age-class/smaller size-classes; an increase in disturbance may result in a bimodal distribution with very young/small classes and larger/older classes, an initial increase in young age-classes and an eventual change in structural type (i.e., trees to shrub and/or emergent vegetation)

Other covariates to measure: riparian land uses; vegetation alteration independent of hydrology

Other notes: expect selective loss of younger age-classes?; increased skewness in age-distributions; CV best indicator?

Indicator FB_{12}: Riparian vegetation
Metric(s): Timing of seed dispersal &/or germination of dominant riparian tree species [expected responses are species specific - see rationale]

Applicability: Small Streams/Rivers

When to Measure (Streams): spring; evaluate seed dispersal from literature and/or field observations from March – June

When to Measure (Rivers): spring; evaluate seed dispersal from literature and/or field observations from March – June

Where to Measure (Streams): unconfined alluvial segments; within channel migration zone

Where to Measure (Rivers): unconfined alluvial segments; within channel migration zone

Relevant Hydrologic Attributes: Timing

Hydrology Metric(s): *Timing*: mean Julian day of 1.7, 5, 15, 25, 65, 100 yr. events

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Annual hydrograph

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Annual hydrograph

Rationale for indicator: Timing of native riparian tree/shrub (I.e., cottonwoods, willows) seed dispersal and germination is frequently closely tied to timing of flood events that create conditions suitable for establishment (e.g., 1.7 to 50+ yr. events); there should be a correlation between the timing of flood events and seed dispersal of native willows and cottonwoods. Under altered timing of flow events, species with different timing of reproductive events should be favored. Specific relationships need to be developed and related to season-specific hydrologic metrics. For example, black cottonwood disperses seeds in May-June and seeds are viable for two weeks. Red alder disperses seeds mostly in fall, but does disperse seeds throughout year and they remain viable for several months. Black cottonwood likely will not persist if timing of flood events is altered during the April-July period.

Other covariates to measure: riparian land uses; degree of alteration of vegetation independent of hydrology;

Other notes: may need to distinguish vegetative reproduction; develop species specific predictions about what types of change in timing will affect dominant native species

Indicator FB_{13}: Migration and Emergence Indicators
Metric(s): Shift in mean or median date (or CV) of Ephemeroptera and Plecoptera emergence. Delay or damping of spring freshets is likely to cause delays in emergence times of aquatic invertebrates.

Applicability: Small Streams/Rivers

When to Measure (Streams): March – May

When to Measure (Rivers): March – May

Where to Measure (Streams): Riffle patches within pool/riffle segments

Where to Measure (Rivers): Riffle patches within pool/riffle segments

Relevant Hydrologic Attributes: Timing, frequency, magnitude of spring freshets, rate of decline and total volume of flow.

Hydrology Metric(s): *Duration*: peaks > 2X season mean; *Magnitude*: peaks > 2X season mean; *Variability*: # reversals; compare 1, 3, 7 day max; daily max/weekly mean, median/mean (weekly and season); 75%ile and 95%ile rise rate; *Frequency*: # peaks > 2X season mean, *Timing*: NA

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): March 21 - June 21

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): March 21 - June 21

Rationale for indicator: spring high flows are seasonal cues for emergence along with temperature

Other covariates to measure: Water temperatures

Other notes:

Indicator FB_{14}: Migration and Emergence Indicators

Metric(s): Shift in mean or median date (or CV) of outmigration for coho fry (compare to historic and reference systems). Delay or damping of spring freshets is likely to cause delays in emergence times of aquatic invertebrates.

Applicability: Small Streams/Rivers

When to Measure (Streams): April - June

When to Measure (Rivers): April - June

Where to Measure (Streams): side channels/backwater sloughs

Where to Measure (Rivers): side channels/backwater sloughs

Relevant Hydrologic Attributes: Timing, frequency, magnitude of spring freshets, rate of decline and total volume of flow.

Hydrology Metric(s): *Duration*: peaks > 2X season mean; *Magnitude*: peaks > 2X season mean; *Variability*: # reversals; compare 1, 3, 7 day max; daily max/weekly mean, median/mean (weekly and season); 75%ile and 95%ile rise rate; *Frequency*: # peaks > 2X season mean, *Timing*: NA

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): March 21 - June 21

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): March 21 - June 21

Rationale for indicator: timing of spring high flows is cue for out-migration

Other covariates to measure: Availability of off-channel and channel edge habitats

Other notes:

Indicator FB_{15}: Fish Community Composition
Metric(s): Native fish species richness [decrease]

Applicability: Small Streams/Rivers

When to Measure (Streams): early autumn (Sept - Oct)

When to Measure (Rivers): early autumn (Sept - Oct)

Where to Measure (Streams): multiple river/stream segments, especially alluvial segments with high habitat variability

Where to Measure (Rivers): multiple river/stream segments

Relevant Hydrologic Attributes: All

Hydrology Metric(s): General integrity indicators

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Annual

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Annual

Rationale for indicator: Might be part of an index but not meaningful of itself (see notes) without investigation of disturbance regimes; general descriptor of alteration.

Other covariates to measure: Undetermined

Other notes: Fish Community Composition indicators could be valuable for linking flow changes to biology if shifts in specific composition can be interpreted in light of specific flow alterations. More needs to be known about life history and ecology of non-salmonids to interpret changes in species composition, but these could lead to better predictions about consequences of flow alteration and additional useful indicators.

Indicator FB_{16}: Fish Community Composition
Metric(s): Sculpin richness, frequency, abundance [decrease]

Applicability: Rivers

When to Measure (Rivers): early autumn (Sept - Oct)

Where to Measure (Rivers): multiple river/stream segments

Relevant Hydrologic Attributes: All

Hydrology Metric(s): General integrity indicators

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Annual

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Annual

Rationale for indicator: Might be part of an index but not meaningful of itself (but see notes) without investigation of disturbance regimes; utility would be increased if linked

with information gained from FB 13 and FB 14. sculpins (as benthic dwellers) may respond more sensitively to flow alterations than species found up in the water column..

Other covariates to measure: Temperature, water quality, habitat structure.

Other notes: Fish Community Composition indicators could be valuable for linking flow changes to biology if shifts in specific composition can be interpreted in light of specific flow alterations. More needs to be known about life history and ecology of non-salmonids to interpret changes in species composition, but these could lead to better predictions about consequences of flow alteration and additional useful indicators. Fishery management activities must be factored into this indicator

Indicator FB_{17}: Coho salmon abundance
Metric(s): Density of 1+ coho [decrease?]

Applicability: Small Streams/Rivers

When to Measure (Streams): March – May

When to Measure (Rivers): March – May

Where to Measure (Streams): pools w/ volume > 1m3

Where to Measure (Rivers): main stem wood-anchored pools, side channels,

Relevant Hydrologic Attributes: Frequency and magnitude of peak spring flows

Hydrology Metric(s): Frequency and magnitude of flows > 2X seasonal mean flows…

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): March 21 - June 21

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): March 21 - June 21

Rationale for indicator: Density in certain habitats and frequency of occurrence in (use of) different habitats (or habitat patches) together give information about factors that affect distribution of fish. At landscape level, use to answer questions like "where are the biological hotspots", "has the number of productive areas decreased". Important factors will include predation, prey availability, nutrients (and effect on prey availability) and, specifically, effect of flow on these factors.

Other covariates to measure: Undetermined

Other notes: Use monitoring to develop contingency table probabilities of finding fish in different habitats then use to predict where would expect to find fish. Could perhaps use data from southeast Alaska or Oregon Coast range to develop initial probabilities. Could be useful in adaptive management. See work done in Missouri. These kinds of metrics need to be called out as a separate category important for maintaining the long-term viability of the population.

Indicator FB_{18}: Coho salmon distribution
Metric(s): Frequency of 1+ coho [decrease]

Applicability: Small Streams/Rivers

When to Measure (Streams): March – May

When to Measure (Rivers): March - May

Where to Measure (Streams): pools > 1m3

Where to Measure (Rivers): main stem pools, side channels,

Relevant Hydrologic Attributes: Duration of seasonal peaks during spring

Hydrology Metric(s): Duration of peak flows > 2X seasonal mean flow

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): March 21 - June 21

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): March 21 - June 21

Rationale for indicator: Undetermined

Other covariates to measure: Undetermined

Other notes:

Indicator FB_{19}: Chinook salmon abundance
Metric(s): Density of 0+ chinook [TBD]

Applicability: Small Streams/Rivers

When to Measure (Streams): April- June

When to Measure (Rivers): April - June

Where to Measure (Streams): Main channel pools

Where to Measure (Rivers): River edge habitats

Relevant Hydrologic Attributes: Magnitude, frequency, duration of low flow during transition period from summer low flows to winter baseflows

Hydrology Metric(s): Number, magnitude, duration of peaks < .5x seasonal mean flow, daily min/weekly mean, 1 day min, 3 day min, 7 day min, season min,

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Sept 1 - Dec 15 of previous year

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Sept 1 - Dec 15 of previous year

Rationale for indicator: Affects access/entry to spawning and incubation success

Other covariates to measure: Undetermined

Other notes:

Indicator FB_{20}: Chinook salmon distribution
Metric(s): Frequency of 0+ chinook [decrease]

When to Measure (Streams): Late April to Early June

When to Measure (Rivers): June

Where to Measure (Streams): Main channel pools

Where to Measure (Rivers): River edge habitats

Relevant Hydrologic Attributes: Timing, magnitude, and duration of winter and spring season high flows

Hydrology Metric(s): Julian day of first flow during season that is >2X seasonal mean flow; Julian day of the daily and weekly peak flows for season;
Daily peak/weekly mean; median/mean; TQmean; CV daily flows; CV weekly mean flows;
Duration of peaks >2X mean seasonal flow

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Both: December 15 - March 21; March 21 - June 21

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Both: December 15 - March 21; March 21 - June 21

Rationale for indicator: Distribution of fry is related to the distribution of available habitat patches for fish over winter and spring following emergence (timing of high flows). Magnitude of seasonal peaks will affect energy expended by fish to find food and refuge; magnitude will also affect concentration of food items and therefore location of suitable foraging areas.

Other covariates to measure: Undetermined

Other notes: Must be aware of fishery management activities in the systems, especially fry outplantings and hatchery releases.

Indicator FB_{21}: Chinook salmon distribution
Metric(s): Frequency of 0+ chinook [decrease]

Applicability: Small Streams/Rivers

When to Measure (Streams): Late April to early June

When to Measure (Rivers): June

Where to Measure (Streams): Main channel pools

Where to Measure (Rivers): River edge habitats

Relevant Hydrologic Attributes: Timing of last peak flow during season

Hydrology Metric(s): Julian day of the latest flow > 2X seasonal mean flow (?)

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): March 21 - June 21

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): March 21 - June 21

Rationale for indicator: affects last opportunity for outmigration

Other covariates to measure: Undetermined

Other notes:

Appendix 2: Indicators of Flow-Floodplain (FF) Structure Relationships

Indicator FF_1: (Salmon Access) Riverscape features
Metric(s): Duration and frequency of lateral connectivity to side channel features [Increase or Decrease]

Applicability: Small Streams/Rivers

When to Measure (Streams): Winter/Spring

When to Measure (Rivers): Winter/Spring

Where to Measure (Streams): unconfined alluvial segments

Where to Measure (Rivers): unconfined alluvial segments

Relevant Hydrologic Attributes: Frequency, magnitude, and duration

Hydrology Metric(s): *Frequency*: > bankfull (1.7 yr.) flows; *Magnitude*: bankfull (1.7 yr.) flows; *Duration*: # days > bankfull (1.7 yr.) flows; % of season that flows exceed historic 1.7 yr. flow; *Timing*: NA; *Variability*: NA

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): December 15 - March 21

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): December 15 - March 21

Rationale for indicator: Affects access of juvenile salmon (0+ chinook and coho) to off channel areas during spring growth period when refuge from predators, velocity refuges and/or food are critical determinants of growth and/or survival. Duration of these events may affect stranding – salmon may strand or fail to enter if events are too short in duration or the rate of rise and fall is rapid.

Other covariates to measure: geomorphic setting/channel type; channel confinement (e.g., natural or levees); channel alteration (entry/exit conditions and edge conditions)

Other notes: need local habitat attributes as covariates: channel type, geomorphic setting, channel confinement, channel alteration, …

Indicator FF_2: Riverscape features
Metric(s): Frequency of channel rejuvenating flows [Increase or Decrease]

Applicability: Small Streams/Rivers

When to Measure (Streams): NA

When to Measure (Rivers): NA

Where to Measure (Streams): unconfined alluvial segments

Where to Measure (Rivers): unconfined alluvial segments

Relevant Hydrologic Attributes: Frequency, magnitude, and duration

Hydrology Metric(s): *Frequency*: frequency of flood events that were historic 15 & 25 yr. flows; *Magnitude*: 15 & 25 yr. flows; *Duration*: 15 & 25 yr. flows; flows > historic 15, 25 yr. flows; % of year that flows exceed historic 15, 25 yr. flows; *Timing*: NA; *Variability*: NA

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Annual

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Annual

Rationale for indicator: Capacity of river to maintain side-channel habitats and habitat complexity…linked to habitat complexity, productivity

Other covariates to measure: geomorphic setting/channel type; channel confinement (e.g., natural or levees); channel alteration

Other notes: need to citation for return intervals for rejuvenating, channel forming flows; need to define rejuvenating and channel forming events

Indicator FF_3: Riverscape features
Metric(s): Frequency of channel forming flows [Increase or Decrease]

Applicability: Small Streams/Rivers

When to Measure (Streams): NA

When to Measure (Rivers): NA

Where to Measure (Streams): unconfined alluvial segments

Where to Measure (Rivers): unconfined alluvial segments

Relevant Hydrologic Attributes: Frequency, magnitude, and duration

Hydrology Metric(s): *Frequency*: frequency of events that were historic 50 & 65 yr. flows; *Magnitude*: 50, 65 yr. flows; *Duration*: 50, 65 yr. flows; flows > historic 50, 65 yr. flows; % of time (% of year) that flows exceed historic 50, 65 yr. flows; *Timing*: NA; *Variability*: NA

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): Annual

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): Annual

Rationale for indicator: Capacity of river to form off-channel habitat complexity and occupy channel migration zone… - linked to habitat complexity, productivity

Other covariates to measure: geomorphic setting/channel type; channel confinement (e.g., natural or levees); channel alteration

Other notes: need to add spatial indicators of these processes and their alteration in basin - I.e., for basin, what % of basin has had channel-forming flows altered? Also, need to link to what's happening on floodplains - I.e., what portion of CMZ or floodplain is inundated with different events? What portion of CMZ or floodplain is inundated annually? What is duration of annual inundation?

The following Indicators have unresolved data availability or rationale clarity issues and therefore are unlikely to be included in the first round (2Q-3Q2003) of testing.

Indicator FF_4: (Salmon Access) Riverscape features
Metric(s): Duration and frequency of seasonal low flows that disconnect 1/2/3 order tributaries [TBD]

Applicability: Small Streams/Rivers

When to Measure (Streams): Late Summer/early Fall (Aug. 15 – Oct. 15)

When to Measure (Rivers): Late Summer/early Fall (Aug. 15 – Oct. 15)

Where to Measure (Streams): At tributary junctions; basin or sub-basin units

Where to Measure (Rivers): At tributary junctions; basin or sub-basin units

Relevant Hydrologic Attributes: Magnitude, frequency, duration of low flows during summer low flow season

Hydrology Metric(s): # times flow < historical median seasonal low flow for 3, 6, 12, and > 12 days; *Duration*: proportion of season that flows < historic median seasonal low flow for more than 3 days or more

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): June 21 - Oct 15

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): June 21 - Oct 15

Rationale for indicator: During this period, coho and steelhead juveniles are dispersing from spring rearing areas into feeding areas throughout the channel network; tributaries disconnected by low flows represent habitat that is inaccessible, so habitat area is limited, potentially increasing competition for food and exposure to predators. Low flows that disconnect tributaries would also exacerbate effects of high temperatures/low DO during this period. 3 days was assumed to be critical time that salmon could wait or hold before stress and/or mortality increased.

Other covariates to measure: channel type; local riparian vegetation cover; stream temperatures

Other notes: separate metrics for 1st, 2nd, 3rd order tributaries? Or just total number tributaries in a basin or sub-basin; may need to revise definition of disconnection; Dunne and Leopold - <1 cfs for 1/2 order tributaries in our systems? Use 1, 3, 5 cfs? Expectation for duration of disconnecting low flows is that 50% of the time flows would be below median low flow, so >50% of time below those flows would be a significant change?

Indicator FF_5: (Salmon Access) Riverscape features
Metric(s): # of tributaries disconnected at seasonal low flows; % of tributaries disconnected [TBD]

Applicability: Small Streams/Rivers

When to Measure (Streams): Late Summer/early Fall (Aug. 15 – Oct. 15)

When to Measure (Rivers): Late Summer/early Fall (Aug. 15 – Oct. 15)

Where to Measure (Streams): At tributary junctions; basin or sub-basin units

Where to Measure (Rivers): At tributary junctions; basin or sub-basin units

Relevant Hydrologic Attributes: Frequency

Hydrology Metric(s): Spatial frequency: # and % of tributaries with flow < historic median seasonal low flow for > 3 day;

Season for measuring/ evaluating hydrology metric in Small streams (< 5th order): June 21 - Oct 15

Season for measuring/ evaluating hydrology metric in Rivers (5th order and greater): June 21 - Oct 15

Rationale for indicator: Same rationale as above; proportion of drainage network that is affected by low flows is another measure of habitat availability and accessibility and therefore of salmonid distribution within the channel network

Other covariates to measure: Temperature conditions that cause an effective disconnection.

Other notes: