Puget Sound Technical Recovery Team Technical Comments: Combined Template and Probabilistic Network Analysis

Duwamish-Green Chinook Population

This technical feedback has three components:

- Brief summary of results of our review concerning certainty, and discussion and recommendations of factors we believe are critical to address in order to improve certainty of your plan;

- Consolidation of technical reviewers' composite and detailed comments on your June 30th draft; and

- A description of the methods by which we performed the certainty analysis (i.e., the probabilistic network analysis).

The "near-term steps" suggested in Section 1 of the feedback should occur by April 30th, because they will help you finalize your draft chapter. The "long-term steps" should generally occur as you implement your adaptive management program.

I. SUMMARY OF CERTAINTY ANALYSIS

The content of this section summarizes the results of our probabilistic network analysis (for description of the approach, see *Section III* of this document.) We view using this certainty analysis in an iterative fashion, to help you in guiding plan revisions. This analysis also will help us strategically track the elements of your plans and how information at each step affects the overall certainty that the proposed actions in your plan will contribute to population and ESU recovery. This section is divided into separate discussions of the certainty in habitat, hatchery and harvest management elements of your plan. You will notice that several questions within each "H" encourage us to check how well the habitat, hatchery and harvest strategies are integrated in the plan. We fully expect that the certainty in your plan's outcomes can be increased by providing more information and documentation—we have highlighted areas we think would be particularly fruitful to focus on in near-term revisions in each section below.

Habitat

1. *Did the analysis use one or multiple independent models to understand potential fish responses to habitat actions? What is the nature of the analytical support for the model linking population status to changes in habitat-forming processes and in-stream habitat conditions?*

Overall, the analytical support associated with the landscape → habitat → fish response model is moderate.

A single *qualitative* model is the basis for describing the links between land use, habitat-forming processes, habitat structure and population response. This model is adapted from Spence et al. and is mainly a multi-scale, process-based model of salmon recovery. There has been a narrative attempt to link this model with the VSP attributes described in McElhany et al., but a clear and precise logic framework has not been developed that would allow even a qualitative prediction to be made for population attributes. The Muckleshoot Indian Tribe has developed a quantitative model (SHIRAZ) for this watershed but it has not been made available to this planning group and is not discussed in this plan.

The general conceptual model is well documented in Spence et al. However, documentation of the assumptions that support the model in its local application is not. Certainty of this element could be much higher if the assumptions used to apply the model to the local riverscape were described and possible alternative assumptions discussed. This would necessarily combine the historical analysis with the current inventories to arrive at a set of assumptions and hypotheses that link changes in land use and management over time to habitat and population characteristics that exist today.

There has been no sensitivity analysis of the general model although such an analysis could be accomplished using a probability network or Bayesian logic model to evaluate the effect of model relationships and changes in assumptions on model predictions, even on this qualitative model. Such a sensitivity analysis would clarify the effects of varying the input assumptions of the model on the expected outcomes. In a watershed so severely impaired, such an analysis could provide a useful look at potential limits to recovery.

Empirical support for the general model has not been discussed in the plan although much of the data probably exists to do so. Spence et al. has marshaled considerable information to support the process-based model and local information that could be brought to bear to assist in validating the major relationships and calibrating the model to watershed conditions. This could be accomplished, for instance, by bounding the abundance extremes derived from an application of the model with historical and current capacity estimates. To some degree this has been done for spatial structure by using the geomorphic model of Benda and Martin (the Core Areas work) to examine and predict the distribution of spawning Chinook in the Green River.

Near-term steps to improve certainty:

- Highlight where multiple lines of evidence were used to support the analytical model for linking land use to habitat-forming processes to habitat conditions to fish response;
- Develop a stronger logical framework between the qualitative process model and the VSP parameters;
- Improve the documentation of the Spence et al model by clarifying how the model applies to the Duwamish-Green population;
- Provide more empirical evidence that the model is applicable to the current conditions of the system and to the VSP responses of the population.

Long-term steps to improve certainty:

- Develop and apply a sensitivity analysis to the qualitative model to determine the relative importance of the assumptions and inputs of the model to habitat and fish response;
- Employ a quantitative model (consistent with the assumptions of the qualitative one) to begin the task of providing numerical estimates and predictions of population response to recovery actions.

2. *How well supported are the hypotheses for (1) the VSP parameters most limiting recovery and (2) the habitat-forming processes or conditions that are limiting the population response? What is the nature of the watershed-specific data used to support (either of) these hypotheses?*

The hypotheses for (1) and (2) above are moderately well-supported. The VSP hypothesis is that productivity is the attribute most limiting recovery in this population. The data to support this hypothesis derives mainly from work on abundance and productivity done by the TRT and contained in the Abundance and Productivity tables. This work is model-based, however and direct empirical evidence is difficult to obtain since the population is a combination of hatchery and wild fish. There is some evidence from juvenile trapping that productivity is limiting in the lower river but this is a very short-term data set. Data from smolt traps may be corroborative but documentation is poor.

The habitat hypothesis is that the changes in structure of the river system and the estuary, mainly due to physical modification of the river channel, floodplain and estuary, and the construction of, and subsequent flow management at Howard Hanson Dam, are responsible for the observed reduction in productivity of the extant life history trajectories. This may have affected diversity and spatial structure as well. A sub-hypothesis suggests that competition with hatchery fry may be depressing growth rates for natural lower river-reared fry in the transition zone of the river. The empirical link among the obvious habitat changes and the VSP parameters is not well-defined, however, since historical (pre-dam) observations of the population attributes are largely unknown. The Collins et al. historical work and the historical analysis carried out by the WRIA 8 technical team provides excellent evidence for the habitat alterations that are hypothesized to lead to changes in VSP attributes. Estimates of historical abundance have been done using multiple methods in an attempt to triangulate the estimate but these have not been compared with capacity-based estimates.

Near-term steps to improve certainty:

- More precisely describe the link between land use and habitat-forming processes. Land cover and use maps could be produced that would become the basis for assessing hydrologic change, erosion and sediment processes, and woody debris inputs, for example;
- The limiting factor work could be brought to bear more directly through the qualitative model to support the hypotheses;
- Develop capacity estimates for historic and current habitat conditions using the method of Sanderson et al.

Long-term steps to improve certainty:

- Develop a monitoring strategy to collect juvenile survival data by habitat type for the river, the estuary and the nearshore;
- Employ existing models to investigate the mechanistic links between land use and the processes that affect habitat conditions.

3. I*s the recovery strategy consistent with the recovery hypotheses for population status and key habitat factors limiting recovery?*

The recovery strategy is not consistent with the hypotheses for these reasons:
The strategy rests on local improvements in habitat conditions in the mainstem river, estuary and nearshore, and on the creation of large scale refugia in each of those environments. However, this strategy is not linked to population recovery goals—the improvements in VSP parameters needed for recovery. There are no specific population goals in the plan at this time. Nor is the major factor of flow reflected in the strategy.

Furthermore, there is no examination of the assumptions or goals for either hatchery or harvest management and the implications for the habitat strategy and actions. The strategy therefore, cannot be an integrated one and is not consistent with an integrated hypothesis.

Near-term steps to improve certainty:

- Specify recovery goals—even interim or provisional ones—for the VSP parameters, but especially for abundance and productivity;
- Specify habitat goals to meet the VSP targets;
- Obtain the harvest and hatchery management programs for this population and evaluate their assumptions and implications for the habitat strategy. Adjust the habitat strategy if necessary and provide the rationale;
- Enlarge the strategy to include all elements of the recovery hypotheses.

4. *Does the habitat recovery strategy preserve options for recovery of all four VSP parameters across all Hs?*

The strategy does not preserve options for recovery of the population. Two elements are missing that are required to preserve options for recovery. The first is an integrated strategy that links the management of the individual Hs for this population; the second is an adaptive management plan to respond to environmental conditions and fish response that informs the development and choice of management objectives and alternatives.

Near-term steps to improve certainty:

- As in 3 above, evaluate the hatchery and harvest strategies for this population to understand the implications for the habitat strategy.

Long-term steps to improve certainty:

- Develop an explicit adaptive management program for this plan. This should include decision models, a monitoring element with metrics and data requirements, criteria for assessing change, and decision criteria and critical points along the recovery timeline.

5. *Are the habitat recovery actions consistent with the recovery strategy?*

The actions are not considered to be consistent with the strategy.
In the plan the PSTRT reviewed, there were few specific actions to evaluate. There were a set of necessary future conditions but no actions had been developed to attain them. The neat term action agenda (NTAA) lacked the necessary documented links to the newly developed strategy and to VSP outcomes. Furthermore, the actions have no logical spatial or temporal relationship to the recovery hypotheses or to the strategy. This element could easily become a "yes" when the actions now under development are reviewed.

Near-term steps to improve certainty:

- The set of actions in the next version of the plan must be clearly related to the strategy set forth for recovery. There must be a logical argument from the hypotheses through the strategy to the nature, choice, location and sequence of the actions.

6. *How well have the habitat actions been shown to work?*

Since there were few actions to review, it is difficult to answer this question with confidence. A tentative "No" must be given at this time but it could easily become "yes" after the next review. There is, however, an important concern about the general nature of the actions proposed and implied in the recovery strategy and the necessary future conditions. The Green River is strongly flow managed and bears little resemblance to the historic river where Chinook are thought to have been abundant. The recovery actions lean strongly toward LWD placement and gravel supplementation. In a regulated river, how well are these projects assumed to work? The model for such actions is mainly in forested, non-regulated rivers and their effectiveness at producing the necessary conditions in the Green River may be questionable.

Near-term steps to improve certainty:

- Provide empirical evidence that such projects are effective in regulated rivers. Effectiveness should be measured in both short and long time frames and by the persistence of the conditions described in the necessary future conditions work.

Note: Since the plan contains no hatchery or harvest management strategies or actions, no Probabilistic Network analysis was done. When these elements are received by the TRT, an analysis using the probabilistic network will be carried out.

II. Consolidated Comments on Technical Review Template

REVIEW TEMPLATE FOR TECHNICAL REVIEW OF DRAFT WATERSHED PLANS

Reviewer's Name: **PSTRT and Adjunct Reviewers**

Watershed Plan: **Duwamish-Green River**

Populations or ESUs considered: **Duwamish-Green**

Summary

Overview of Shared Strategy questions and how well the watershed plans address the technical aspects of those questions. In particular, what is the watershed's technical basis to the answer to the questions from the Shared Strategy: (1) What are the major physical and biological changes necessary to meet the population planning targets? And (2) What are the expected changes in H's and fish population responses over the next 5-10 years?

Review of Plan--Overview

Overall summary of approach, scope of plan (geography, species, populations, ESUs, included), stated goals, participants in plan development, etc.

This is not so much a recovery plan as it is an assessment or series of assessments that culminates in a set of "necessary conditions"—both biological and physical—that are considered necessary for the populations(s) in the Green River to attain viability. The "necessary future conditions" (NFC) section is suggested to be the jumping off point for the development of the actions that will lead to recovery. The NFCs, although they are not written in the form hypotheses are, in fact, coarse hypotheses about viability. The basis for the NFCs is the combination of the VSP parameters with guidance from various sources about ecosystem attributes required to provide and maintain the habitats for Chinook salmon. It is not known, nor is it predicted, whether or not the necessary future conditions advocated in the plan will be sufficient to achieve population viability.

The document covers the present extent of the Duwamish-Green River system and its single population of Chinook. Although it began as explicitly multi-species, it appears to assume that the ecosystem-based approach advocated in the plan will result in sufficient habitat heterogeneity that all native species will benefit. (Given the dramatic changes in the watershed in the past 100+ years, that may not be a valid assumption).

Plan development included 26 local governments, 2 federal agencies, 2 state agencies, and several stakeholder groups operating mainly through the watershed Forum and Steering Committee. There was, however, no tribal involvement with this draft.

Brief narrative of how well the plan addresses the following; including strengths and weaknesses:

1. **What biological and physical changes does the plan state are required for the population(s) in the watershed to achieve their targets?**

   For watersheds without targets, what biological and physical changes are needed for the habitat to be considered functioning for anadromous fish?

The watershed has no TRT/Shared Strategy targets for either abundance or productivity. The plan, therefore, attempts to combine VSP with Properly Functioning Conditions as a starting point. However, through the change analysis, the plan also attempts to bound the VSP parameters using the historic condition as a template. So, the plan suggests that several biological and physical changes are required to meet the necessary conditions for a viable salmonid population. In general, the equilibrium spawner abundance must increase to between 17, 000 and 37, 000 (the plan suggests a value near about 26,700 may be an appropriate target (but this value is never established as a target); NOR spawners must make up at least 90% of the population when that value is reached. Productivity of NORs must increase quickly to avoid swamping by hatchery fish; diversity of life history trajectories should increase with a (tentative) goal of re-establishing a population in the upper watershed; spatial structure should be re-built to mirror the historic condition.
As far as physical changes, passage at the Howard Hanson Dam should be made easier for adults and juveniles; the transition zone for physiological adaptation in the lower watershed must be expanded; restoration of lost habitats in the Middle Green must be undertaken; reductions in sediment loading in the upper watershed are important; and the flow regime should be normalized as much as possible.

2. **What biological goals does the plan aim to achieve (in 5-10 years and over longer term)**

   What are fish-based and habitat, hatchery or harvest management-based goals?

The biological goals established in the plan are limited to general discussions of the VSP parameters related to the "necessary future conditions". A specific goal, however, is found in productivity: in the near-term, productivity of NOR breeders should be increased from its current low of less than 300/year to >1000/year; productivity of the NOR portion of the population should be increased to ≥ 1.02; long term habitat goals are indicated in the NFC for each sub-unit of the watershed. An example is the goal of recovering 40% of the lost habitats in the lower watershed below the old White River confluence. This value of 40% is derived from the following assumption: the lower watershed is effectively 60% smaller, in a hydrologic sense, than it was when both the White and the Cedar/Lake Washington watersheds were still tributary to the Duwamish. Without these watersheds, however, the Duwamish has only a bit more than a third of its historic flow. This equates to a concomitant reduction in the energy required to form habitats and considerably less water to occupy them.

3. **What is the biological RATIONALE for identified actions in all of the H's (i.e., is the "hypothesis-strategy-action" logic presented in the watershed guidance document used?)**

(a) What is the population's current status for all 4 VSP (this should come out under the hypotheses)?

There is little quantitative detail concerning the VSP parameters. According to the plan, all VSP parameters have been compromised to some degree, but the magnitude of this change is unknown. Of these, productivity and abundance appear to have been changed the most in the population now extant in the Green. Diversity in the watershed suffered greatly when the early returning spawner type was extirpated from the watershed. At least for the fall population, spatial structure has suffered the least and may even have expanded somewhat to Soos and Newaukum Creeks under the influence of hatchery management. The plan suggests that, overall, natural productivity has suffered the greatest decline.

(b) What is the population's predicted status for all 4 VSP over the short- and long-term?

There is no quantification of the predicted status of the VSP attributes in the future. The nearest the plan comes to a prediction is this: if the necessary future conditions are achieved, the population is predicted to be at viability with all VSP parameters within historic ranges. But this prediction is not supported with any quantitative analysis that relates the NFCs to viability.

(c) What are critical threats affecting the populations? Have all been identified and considered in the stated hypotheses? Are there potential threats that are missing from the plan? Be explicit about each threat or potential factor limiting recovery.

The population faces the same threats that face most other Puget Sound populations: habitat loss, water quality problems brought on by land use practices—this population also faces a threat from Elliott Bay contamination, habitat fragmentation and modification from flood control practices. It also faces a threat from flow modification, catastrophic events (the most recent lahar from Mt. Rainier flowed through this valley), and from demographic stochasticity.

(d) Is the strategy for H management changes consistent with the identified hypotheses for current population status, desired future population status, and primary threats? What elements of the strategy are missing? Be explicit about each threat or potential factor limiting recovery.

No strategy is apparent in this document; that work is forthcoming. Moreover, there is virtually no discussion of harvest and hatchery programs and no evaluation that would inform the habitat strategy development.

(e) How are actions in the H's linked to fish population status? Both existing and future/planned H actions should be addressed. Are these links based on empirical or modeled estimates or both? Be explicit about each threat or potential factor limiting recovery.

Habitat actions are linked through the development of logical narratives based in the VSP principles that are then interpreted and applied thorough principles from ecosystem management and conservation biology. There is no quantitative model for this watershed. Harvest and hatchery actions have not been considered nor have other H strategies been reviewed and evaluated for integration with habitat.

(f) What are the plan's stated assumptions about existing habitat conditions or actions outside of the WRIA jurisdictional boundaries covered in the plan (freshwater and estuarine/nearshore)?

Two assumptions are key: 1) The splitting of the historic watershed into three parts will have a long-term effect on viability, especially on viability of an early-spawning population; and 2) the nearshore of areas outside of the population's watershed such as Vashon Island will be key to its recovery. No other assumptions are explicitly made.

(g) Are future options preserved in the proposed strategy-action links? How so? Be explicit about each threat or potential factor limiting recovery.

The answer must be "No". Without explicit strategy-action links called out in the plan, the degree of uncertainty surrounding the actions derived from the "necessary future conditions" is likely to be quite high. In addition, without explicit strategies for harvest and hatchery programs, an isolated habitat strategy cannot insure options for recovery. Aspects of this uncertainty could be addressed by the development and implementation of an adaptive management strategy. Such a program, when taken as the only mechanism to address uncertainty, cannot replace a thoughtful evaluation of uncertainties associated with strategic choices and with actions. The adaptive management program cannot become a "see what works" approach to actions.

4. What is the empirical or modeled SUPPORT for the answers to question #3? How wel do the assessment data for the population status and the H's support the hypotheses proposed?

There is no modeled support for the answers to question 3. The plan did undertake a "change analysis" –comparing current conditions to historic conditions--to provide an empirical basis for hypotheses about VSP and the Hs. The change analysis included an historic reconstruction of the lower river and its floodplain; an evaluation of geomorphic conditions in the middle and upper river; the use of geomorphic template to assess spatial structure; and an analysis of population condition (productivity and abundance) based mainly on the TRT analysis.

Threats to the population are taken from the LFA from the Washington Conservation Commission and from some analyses of juvenile and nearshore productivity carried out by the technical team. The threats that are listed as missing were suggested by the change analysis and by evaluating the TRT analysis for abundance and productivity (these are, in fact, model outputs).

The strategies have not yet been developed but should be derived from the strategic assessment guided by the VSP principles and the principled found in the documents listed at the start of the NFC work: NOAA West Coast Salmon Guidance, the ManTech Report, and the NRC work Restoration of aquatic ecosystems.

At this point the links between populations and actions are missing. It could be assumed that they will be based mainly on the logical connections made in the Strategic Assessment since no modeling effort has yet been identified. If the SHIRAZ model output becomes available, it could be used as a line of evidence for hypothesis setting.

(a) What is the population's current status for all 4 VSP (this should come out under the hypotheses)?

Empirical evidence for current status comes mainly from examination of spawner:recruit data, model results from PSTRT efforts, an analysis of historic to current habitat conditions, other historical evidence (for loss of early spawn timing, for example), and from limited research on juvenile productivity in the lower river. However, no quantification of the current VSP attributes of diversity and spatial structure has been attempted.

(b) What is the population's predicted status for all 4 VSP over the short- and long-term?

No quantification has been attempted to predict VSP status based on the conditions proposed in the NFC.

(c) What are critical threats affecting the populations? Have all been identified and considered in the stated hypotheses? Are there potential threats that are missing from the plan? Be explicit about each threat or potential factor limiting recovery.

Information used in the threat analysis includes the Limiting Factors Analysis, historic to current "change" analyses (including Collins et al.), habitat inventories for most segments of the river (the nearshore had not been inventoried as of this review), and a variety of other analyses related to land use, water quality, and flow.

(d) Is the strategy for H management changes consistent with the identified hypotheses for current population status, desired future population status, and primary threats? What elements of the strategy are missing? Be explicit about each threat or potential factor limiting recovery.

No overall H strategy has been developed.

(e) How are actions in the H's linked to fish population status? Are these links based on empirical or modeled estimates or both? Be explicit about each threat or potential factor limiting recovery.

Neither a quantitative model nor direct empirical evidence supports the actions to population status at this time. The relationships are, at this point, mainly qualitative.

(f) What are the plan's stated assumptions about existing habitat conditions or actions outside of the WRIA jurisdictional boundaries covered in the plan (freshwater and estuarine/nearshore)?

(g) Are future options preserved in the proposed strategy-action links? How so? Be explicit about each threat or potential factor limiting recovery.

5. **How are the individual and interacting effects of the H's on the 4 VSP parameters considered for each population? How likely is it that the proposed suites of H actions will achieve the short- and longer-term stated goals? How certain are we in their translation into effects on salmon population VSP?**

   It would be helpful to make note of the assumptions the plan makes about the effects of hatchery and harvest management, existing habitat actions, and survival in the nearshore/ocean, for example.

The interacting effects of the Hs on the VSP parameters are not considered at this time. Except for the short section on the effects of hatchery fish on the spawning grounds and their alleged interactions with NORs, no discussion of the interactions of the Hs on VSP has been developed. The plan lacks a discussion of the hatchery and harvest assumptions that are necessary for such an evaluation. Given that the actions, even under habitat, are poorly developed at this time, the likelihood of achieving viability—even with the NFC—cannot be determined. Furthermore, we cannot be highly certain that NFC will result in appropriate and sufficient improvements to the VSP parameters.

6. **How does the plan acknowledge uncertainties and how are they factored into decisions, future actions?**

There is a general, qualitative discussion about uncertainty at the end of the NFC document but it addresses these issues only in a most cursory fashion at this time. The discussion does not try to estimate the uncertainty, even in a qualitative manner. The discussion acknowledges uncertainty in data, future conditions and effectiveness of actions but lacks an analysis of these uncertainties that could inform strategies and actions. Further development of a framework to evaluate uncertainty awaits the adaptive management element of the plan. At the time of this review, no adaptive management program has been developed.

(a) Uncertainties in data and information?

(b) Uncertainties in environmental conditions in the future?

(c) Uncertainties in effectiveness of actions?

7. **Reviewer: What is the estimated overall level of risk for the population(s) included in this plan, relative to low-risk (i.e., viable) population criteria? What is your rationale for this risk estimate? How certain are you in the estimation for each VSP parameter?**

   The probabilistic network analysis should help inform the answer to this question.

8. Make any suggestions for approaches or methods for addressing concerns mentioned above or reducing gaps in the plan.

1. At some point in the quite near future, perhaps as soon as the strategy-action hypotheses have been developed, some sort of quantification will have to occur that links actions to outcomes. This could be empirical, drawing from several relevant studies or it could be modeled using SHIRAZ, EDT or some other, as yet undiscovered, model.
2. Attempt to at least evaluate the uncertainties (qualitatively) in the information used thus far to set the NFCs.
3. Using the same guidance documents referenced in the NFC, develop the strategy and hypotheses for attaining VSP more explicitly. From these, it should be rather straightforward to develop appropriate actions for achieving the NFC through the strategy;
4. A land use analysis keyed toward effects on habitats and VSP should be undertaken immediately. This should employ a "current path" analysis and a future scenario or scenarios that attempts to link the large watershed (or sub-basin) scale effects of land use and management (sediment, hydrology, nutrients and other water quality attributes, woody debris recruitment, and salmonid use to variation in landscape attributes and management).
5. Develop an adaptive management program for this plan. See the PNA for a brief discussion of the elements to be included.

III. Analyzing Certainty of Biologically Effective Recovery Plans

All watersheds in the Puget Sound are unique. Not surprisingly, different watershed planning groups identify different long-term and short-term goals and propose different suits of actions to achieve those goals. The certainty that the actions in every watershed will be biologically effective in moving the populations towards recovery is a key factor in the recovery of the whole evolutionarily significant unit (ESU). Consequently, the Puget Sound Technical Recovery Team (TRT) has focused its analysis of watershed recovery plans on identifying ways to increase the certainty of the plans. The TRT hopes that these analyses will encourage watershed groups to improve the certainty of plans before the TRT does it analysis of the final plans next year.

To provide these analyses, the TRT used a probabilistic network (PN). A probabilistic network is a graphical model that shows how different states of the world of interest—in this case the scientific factors that provide certainty of biologically effective actions—are related (Figure 1). The basic approach is to assess certainty by applying conditional probabilities, which can be expressed as "Given event *b*, the likelihood of event *a* is *x*." In Figure 1, for example, the states of the variables in boxes that point to another variable (e.g. "Use of Independent Models" and "Analytical Support") are the events that condition the likelihood of the states for the latter variable (e.g. "High", "Moderate", and "Low" in the Certainty of the General Fish Response Model). Users provide evidence for the initial conditioning events (or diagnostic nodes); software for PNs use a set of sophisticated algorithms for recalculating the joint probability distributions for all the potentials based on tables of conditional probabilities provided by the analyst (Jensen 2001). Using a PN gave the TRT a rigorous, transparent, repeatable method of analyzing certainty across watershed plans and habitat, harvest, and hatchery management sectors.

Methods

The Puget Sound Technical Recovery Team (TRT) used the PN in Figure 1 to assess separately the certainty of biologically effective actions for each plan in four management sectors, 1) freshwater habitat, 2) nearshore habitat, 3) hatchery production, and 4) harvest. Each assessment also considered how well integrated actions were across categories and how the actions affected characteristics of viable salmonid populations (McElhany et al. 2003). The network graphically shows the logic of how different scientific variables affect the biological certainty of effective recovery plans. The model is based on the TRT's *Integrated Recovery Planning for Listed Salmonids: Technical Guidance for Watershed Groups in the Puget Sound* (http://www.sharedsalmonstrategy.org/files). The network shows that the overall biological certainty of an effective recovery plan depends on the certainty of the recovery strategy (Recovery Strategy), the robustness of the strategy (Preserves Options), and the expected effectiveness of actions chosen to implement the strategy. The certainty of the recovery strategy in turn is conditioned by the certainty of how well we understand the biological, physical, and chemical processes that affect the population (i.e. Recovery Hypothesis), which depends on well recognized sources of scientific uncertainty (Lemons 1996), such as model uncertainty (Use of Independent Models), framing uncertainty and stochasticity (Analytical Support), and empirical support for the hypothesis (Watershed Data Quality). After identifying the model structure, the TRT identified and defined different states of the variables (Tables 1-6).

Conditional probabilities may be derived from frequencies from empirical data, simulation results, or subjective probabilities. When data are too few to parameterize simulation models, use of subjective probabilities is important (Bedford and Cooke 2001) and analysts have developed methods for estimating these (e.g. Ayyub 2001). Using experts to estimate subjective probabilities has inherent biases that can be difficult to control (Kahneman et al. 1982, Otway and von Winterfeldt 1992). Using estimates of conditional probabilities within a logical, transparent model such as a PN

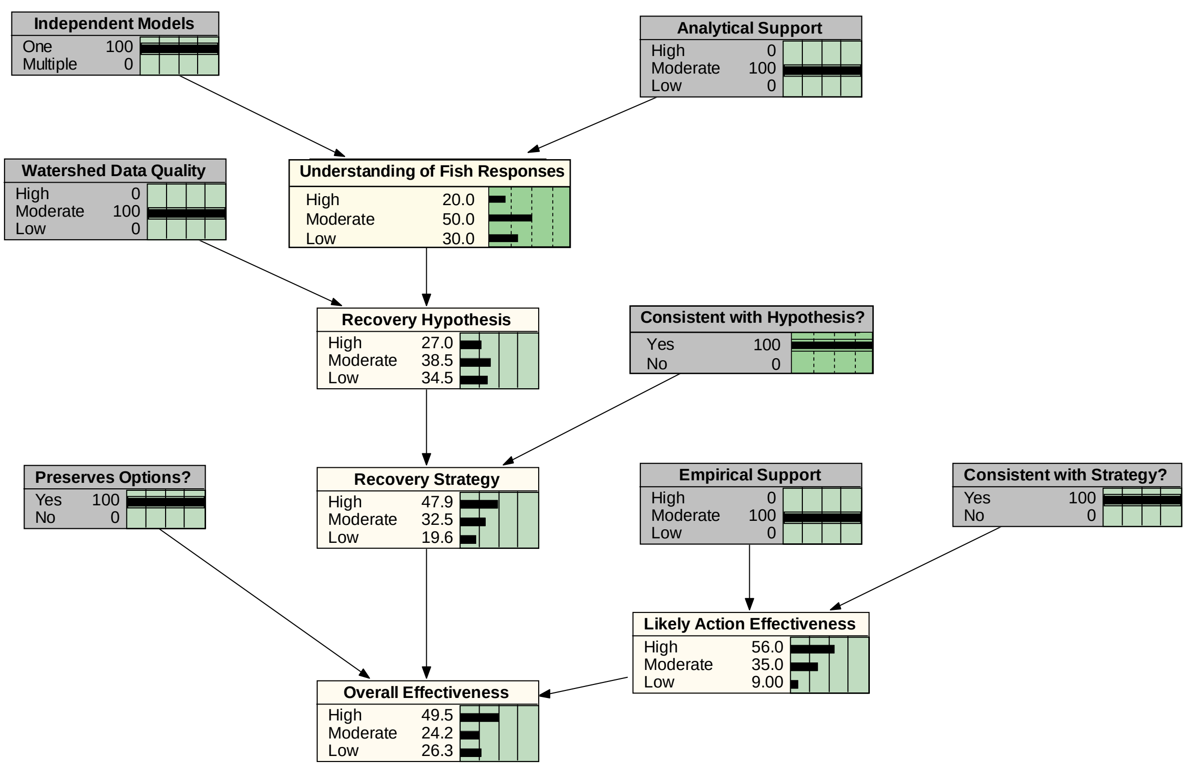

Figure 1. Probabilistic network for evaluating the biological certainty of effective recovery plans illustrating the results of a hypothetical review. Diagnostic nodes are shaded. Numbers at each node are the probabilities for each and the bars show the distribution of the results.

may reduce these problems compared to asking experts to provide absolute certainty estimates directly without a model. The TRT estimated conditional probabilities using a Delphi process (Helmer 1968, Ayyub 2001) in which TRT members iteratively estimated conditional probabilities individually; the distributions of the results were compiled and shared; and new estimates were generated. Sensitivity of the model was evaluated using the mutual information index (Pearl 1988) which measures the reduction in entropy of variable *A* due to a finding at *B*.

The TRT qualitatively assessed the states of seven diagnostic variables (box titles in parentheses) that address these questions:

1. Did the analysis use one or multiple independent models to understand potential fish responses to actions? (Independent Models)
2. How well supported is the model? (Analytical Support)
3. How well supported is the recovery hypotheses with watershed specific data? (Watershed Data Quality)
4. Is the recovery strategy robust by preserving options for recovery? (Preserves Options)
5. Is the recovery strategy consistent with the recovery hypothesis? (Consistent with Hypothesis)
6. Are the recovery actions consistent with the recovery strategy? (Consistent with Strategy)
7. How well have the recovery actions been shown to work? (Empirical Support)

The possible answers to these questions are in Tables 1-6. Reviewers usually choose one state, but if this is not possible because of uncertainty, reviewers could assign probabilities to different states (e.g., “Low” = 10%; “Moderate” = 90%). Analyses were performed using Netica (Norsys Software Corporation, Vancouver, BC; http://www.norsys.com).

Interpreting the Results

Even the best recovery plan is inherently uncertain because the future is so difficult to predict. Consequently, the quantitative estimates of certainty generated by the TRT are less important than the relative improvement that watershed planners need to make. For similar reasons, the quantitative estimates of certainty generated by the TRT are not relevant to analyses of certainty performed by regulatory agencies, which depend on a different interpretation and standard of certainty. Based on the TRT analyses, watershed planners may be able to increase the certainty of biological effectives several fold by focusing on several key factors. These are described in individual watershed analyses.

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Table 1. Attributes for different states of analytical support for models.

Analysis	Total Score	Attributes (Maximum Possible Score)
Habitat Models High Moderate Low	 0.60 -1.00 0.21 - 0.60 0 - 0.20	• Qualitative and/or quantitative description of the relationship landscape processes, landuse, and habitat condition – (0.1 for each analysis) • Qualitative and/or quantitative description of the relationship between habitat condition and population viability (VSP) characteristics – (0.1 for each analysis; 025 for each VSP characteristic) • Model structures and parameters for each VSP characteristic documented; assumptions discussed and defended – (0.2) • Sensitivity of model to changes in parameters known – (0.2) • Model tested empirically and calibrated to watershed – (0.2)
Harvest Models High Moderate Low	 0.60 -1.00 0.21 - 0.60 0 - 0.20	• Qualitative and/or quantitative description of link between demographic processes, harvest effects, and population viability (VSP) characteristics– (0.2 for each analysis; 0.05 for each VSP characteristic) • Model structures and parameters for each VSP characteristic documented; assumptions discussed and defended – (0.2) • Sensitivity of model to changes in parameters known – (0.2) • Model tested empirically and calibrated to watershed – (0.2)
Harvest Models High Moderate Low	 0.60 -1.00 0.21 - 0.60 0 - 0.20	• Qualitative and/or quantitative description of link genetic and ecological processes, hatchery effects, and population viability (VSP) characteristics – (0.2 for each analysis; 0.05 for each VSP characteristic) • Model structures and parameters for each VSP characteristic documented; assumptions discussed and defended – (0.2) • Sensitivity of model to changes in parameters known – (0.2) • Model tested empirically and calibrated to watershed – (0.2)

Table 2. Attributes for different states of the quality of watershed data (support for hypotheses)

States	Attributes
High	• Used empirical population, habitat, and management data from the local watershed at multiple spatial scales to support hypotheses; sources clearly documented; assumptions explained
Moderate	• Used empirical population, habitat, and management data for watersheds or populations within the species' range OR used local watershed data but data highly uncertain or assumptions not well explained
Low	• Used theoretical support for hypothesis or expert opinion based on biological principles and local knowledge of the watershed

Table 3. Attributes for different states of consistency of recovery strategy with recovery hypothesis.

States	Attributes
Yes	Clear and logical relationship between the recovery hypothesis based on processes and conditions for habitat, harvest, and hatcheries and the recovery strategy as evidenced by • Main elements of strategy organized around dominant recovery hypotheses • Elements of strategy reflect spatial attributes of recovery hypotheses • Elements of strategy reflect temporal attributes and action sequencing of recovery hypotheses
No	No clear and logical relationship between recovery hypotheses and strategy; one or more of attributes listed above missing

Table 4. Attributes for different states of preservation of options in the recovery strategy

States	Attributes
Yes	• Strategy protects existing population viability (VSP) structure and opportunities for future improvement in habitat, harvest, and hatchery conditions; adaptive management & monitoring program maintains options for implementing strategy
No	• Strategy does not protect existing VSP structure or opportunities for future improvement in habitat, harvest, and hatchery conditions; adaptive management & monitoring program does not maintain options for implementing strategy

Table 5. Attributes for states of consistency of actions with recovery strategy.

States	Attributes
Yes	• Clear and logical relationship between the short-term and long-term actions and recovery strategy recovery hypothesis • Elements of strategy reflect spatial attributes of recovery hypotheses • Elements of strategy reflect temporal attributes and action sequencing of recovery hypotheses • No strong relationship between fish response models and recovery hypothesis
No	• Actions generally consistent with recovery strategy but major actions are missing or staging of major is inconsistent with recovery hypothesis • Little relationship between actions and strategy; major short-term and long-term actions do not follow from the recovery hypothesis and strategy

Table 6. Attributes of empirical support of recovery actions.

States	Attributes
High	• Evidence for effects of suites of actions (in habitat, harvest, or hatcheries) is clear and unambiguous; broad applications have been tested with similar results; uncertainty incorporated in assessments
Moderate	• Some empirical evidence of effectiveness in similar settings; few tested applications; some conflicting results; predictions of effect do not incorporate uncertainty
Low	• Little or no empirical evidence of the action being effective or appropriate