APPENDIX H

Technical Methods and Analytical Tools

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As the City of Portland follows the steps of the watershed management process presented in Chapter 3 of the *Framework,* it will use a variety of technical methods and analytical tools to assess current conditions in Portland's watersheds, rivers and streams; analyze and prioritize potential protection and restoration actions; and estimate the effects of those actions. The analogy of a toolbox is appropriate for describing the City's approach to using various technical methods and analytical tools. Given that each method or tool has a specific purpose or utility, and specific limitations, the entire "toolbox" will be needed to construct an understanding of watershed conditions, needs and actions.

The technical methods and analytical tools fall into three broad categories: empirical data collection, models, and management and decision-making tools. Each of these categories of tools is described in this appendix.

Analytical tools are not used directly to make decisions about watershed management, but they are useful in understanding and answering questions about watershed processes. No single analytical tool or method can be expected to answer all questions; analytical tools simplify and explain narrow portions of the broad and complex environmental system in the lower Willamette River. For this reason, the City's analytical "toolbox" contains a variety of analytical tools designed to address specific needs. These tools will be used in combination to inform watershed management decisions. In general, the City's approach emphasizes empirical data collection, as there is no substitute for actual data when assessing conditions and actions in Portland's watersheds, rivers and streams. Models are simplified representations; they have limitations and require assumptions that yield uncertainty, and often they cannot be tested. However, models are indispensable in evaluating current conditions that would be too costly or complex to measure adequately with empirical data. Models also are helpful in evaluating potential scenarios or conditions (such as future alternatives) for which data collection and testing are not possible.

Data collection, modeling, and decision-making tools will not in and of themselves yield decisions about the management of Portland's watersheds; rather, they will be used in combination with other information to understand watershed conditions and needed actions.

It is important to emphasize that the empirical data collection, modeling, and management and decision-making tools described in this appendix will not in and of themselves produce decisions with respect to resource conditions, needs and actions in Portland's watersheds, rivers and streams. They will, however, be used in combination with other information to inform such decisions.

Empirical Data Collection

The City of Portland regularly monitors a number of environmental indicators developed for use in characterizing the riverine-riparian ecosystem and determining the City's progress in achieving its watershed health goals. The City's monitoring program consists of several elements:

- A data gathering strategy, including scales and protocols
- Monitoring locations
- Monitoring parameters and methods
- Data quality assurance and quality control
- Data collection
- Data analysis and evaluation

The monitoring to be conducted for the watershed management process builds on existing monitoring programs that the City of Portland already is conducting as part of the management of its water, sewer, and other resources and facilities. In some cases, needed monitoring data will be obtained by revising or augmenting existing monitoring activities. In some instances, new, independent monitoring projects may be needed.

Types of monitoring that the City of Portland currently conducts are listed in Table H-1.

TABLE H-1
Examples of Types of Monitoring (by Purpose) Being Conducted by the City of Portland

Type of Monitoring	Type of Monitoring
Treatment processes (influent or effluent monitoring)	Discharge monitoring
Compliance monitoring (TMDL, NPDES, ESA, others)	Maintenance-generated sediment quality analysis (from stormwater facilities and sumps)
Spill identification and tracking	Groundwater level and quality analysis
Waterways sediment risk evaluation	Public health and safety—bacteria at contact use sites
Water quality and quantity facility monitoring	Physical systems characterization (stream geomorphology, flow characteristics)
Assessments of operation and maintenance practices for water quality effectiveness	Precipitation and other metadata
Mixing zone analysis	Pollutant source identification (chronic)
Ambient water quality evaluation	Flow monitoring (in-system and surface water)
Stormwater quality associated with facilities	

While a considerable amount of monitoring data have been and continues to be collected, significant gaps and variations remain in coverage across the City's watersheds. Because time and budget constraints generally prohibit the collection of the data needed to fill these gaps in the near term, proposed analyses have been designed to capitalize on the strengths and balance the weaknesses of existing data and programs. The availability and adequacy of existing data and information will determine the extent to which the critical questions can be addressed during watershed characterization (see Steps 3 and 4 in Chapter 3). In some cases, the unevenness in the depth and breadth of the available data will limit what watershed health questions can be answered. In general, though, the data are sufficient to provide at least general direction to watershed planning. In many cases the data are adequate to support very specific recommendations.

Fisheries Studies

The *Framework* currently places an emphasis on hydrology, water quality and aquatic/riparian habitats, notably because of the importance of these watershed processes and features to fish species listed under the Endangered Species Act (ESA). Thus fisheries studies conducted by the City are particularly important as technical tools for use in helping to analyze the conditions and needs of the City's watersheds and waterways.

In 1998, the City Council resolved to assist in the recovery of ESA-listed species in Portland. Beak Consultants was retained to assess the potential for various City activities to affect the Lower Columbia River evolutionarily significant unit (ESU) of steelhead that recently had been listed as threatened under the ESA. Beak Consultants compiled information to define City activities that have the potential to affect steelhead, determined pathways by which effects might occur and identified options and next steps for planning and implementing ESA conservation planning and compliance.

Beginning in 1998, the City contracted with the Oregon Department of Fish and Wildlife (ODFW) to conduct a four-year fish evaluation study along the banks of the Willamette River. The intent of this study was to evaluate the relationship between fish in the lower Willamette River and bank treatments and near-shore conditions. The study was conducted year-round, such that seasonal distributions and patterns of use could be evaluated. In addition, migration travel time and salmonid consumption by predators was evaluated as part of the study.

In addition to the mainstem Willamette fish study, a complementary tributary study was conducted from July 2001 through June 2003. This study was designed to evaluate fish presence and absence, seasonal distribution and biotic integrity of fish populations in key tributaries to the lower Willamette River. Watersheds evaluated included Johnson Creek (including Crystal Springs), Tryon Creek, Stephens Creek, Miller Creek, Saltzman Creek, Doanne Creek and Balch Creek.

The City continues to conduct seasonal fish presence and absence surveys in key tributary reaches. Studies are conducted quarterly to evaluate seasonal presence and are designed to document fish presence in reaches where proposed stream restoration and fish improvement projects have been identified. This will allow the City to monitor the success of these projects.

In addition to these fish surveys, the City conducts a modified rapid bioassessment survey that is consistent with the U.S. Environmental Protection Agency's (EPA) environmental monitoring. To date, these surveys have been conducted in the Tryon and Johnson Creek watersheds. Types of data collected to evaluate watershed conditions include percent fines overlaying stream bottom substrate, evidence of bank erosion, dominant habitat type, presence of large wood and large substrate, maximum pool depth, composition and size of riparian vegetation, and percent tree canopy closure. These surveys are conducted once annually per monitoring site.

The City evaluates U.S. Geological Survey (USGS) flow data and stream temperature data seasonally. These data are measured continuously at the USGS flow gauges in several of Portland's watersheds. The City evaluates these data to determine seasonal patterns in flow and temperature, to evaluate compliance with temperature standards and to assess the degree of hydrologic alteration through evaluation of the indicators of hydrologic alteration described in Appendix G and other aspects of watershed characterization.

The City relies on other empirical studies conducted by state and local governments, municipalities and institutions and other interest groups to augment instream data collected by the City. For example, from 1999 through 2001, ODFW conducted fish surveys in Fanno Creek (including areas in the larger Tualatin River basin). Data from these surveys have been invaluable in evaluating fish presence and distribution in Fanno Creek basin. Key entities that conduct empirical studies include the following:

- Johnson Creek Watershed Council
- Friends of Tryon Creek
- Ducks Unlimited
- ODFW
- Metro
- Multnomah County

In addition to collecting biological community and instream habitat survey data, the City has conducted numerous studies and developed comprehensive reports that characterize hydrology, water quality, riparian ecology and wildlife in lower Willamette basin tributaries, mainstem reaches and the Columbia Slough. These comprehensive characterizations evaluate the indicators described in Appendix G and other factors relevant to watershed planning.

Modeling

The City has a number of modeling tools available to assist in technical analyses of the conditions and needs of the City's watersheds and waterways. These models vary in scope and complexity, and their application will vary depending on the analytical needs or problems in particular watersheds. In evaluating potential models to use, the following questions are considered:

- Is the model needed for the analysis (perhaps in lieu of or in addition to empirical data)? If so, is the model appropriate for the purpose of the analysis?
- To what extent will the model be able to extend the City's knowledge and ability to address critical questions using existing data?
- How understandable is the model and its results?
- What are the model's strengths and limitations relative to the problems for which it will be applied?
- How can the model's uncertainty be reduced?
- Can the model be used in combination with other models or data collection to more completely address questions and reduce uncertainty?
- Can the model be implemented within current time and budget constraints?
- Will the time, expense, and data necessary to operate the model result in commensurately better planning decisions?

The appropriate use of models will be further defined in consultation with stakeholders and technical experts during the alternatives development process. The models used, the level of confidence associated with their use and the basis for decisions about priority actions will be documented. Similarly, policy makers will be well informed about the limitations of the models selected.

Three key modeling tools are described in this section:

- **Ecosystem Diagnosis and Treatment, or EDT.** The EDT model has been selected by the Northwest Power and Conservation Council for subbasin planning work across the region and has been used extensively in Puget Sound, including in the urban systems in the Seattle-Tacoma area. The model forecasts the response of fish and wildlife populations[1] to specific habitat conditions and is made up of a detailed database of stream habitat characteristics and species-specific algorithms that have been peer-reviewed by leading Pacific Northwest scientists. EDT is used to identify key environmental problems, determine protection and restoration priorities and evaluate the effectiveness of watershed restoration alternatives in meeting objectives for habitat conditions and fish and wildlife populations.

- **Integrated Hydrologic and Water Quality System Modeling.** Hydrologic and water quality models provide tools for the analysis, planning and management of a wide range of water resources and environmental problems related to surface water and groundwater, in particular when the effect of human interference is to be assessed. These models simulate flow and the transport of dissolved contaminants and sediments in both surface water and groundwater. Areas of application include water use, water resources management, wetland protection, surface and groundwater interaction and contaminant transport. The results of analyses from these models can be used as inputs to EDT to determine whether actions aimed at hydrology or water quality improvements meet City objectives.

- **Habitat Equivalency Analysis (HEA) and Net Environmental Benefit Analysis (NEBA).** The HEA model was developed by the U.S. Department of the Interior and has been used extensively by the National Oceanic and Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service (USFWS) and numerous state resource agencies. The HEA model uses output from EDT and other information to calculate the amount of ecological benefit that is expected to result from a particular restoration action over time. HEA takes into consideration how well a restoration action will perform over the long term—whether its benefits will be maintained at a steady level, increase or decrease (and if so, at what rate). In addition, HEA expresses the ecological benefits of various restoration actions using a common unit of measure, making the model useful in comparing the long-term benefits of different potential actions.

  NEBA combines output from HEA concerning future ecological benefits with the costs of various restoration actions. By calculating a cost-per-unit-of-benefit value for each restoration action being considered, NEBA identifies those watershed activities that offer the greatest potential benefit for the amount of money spent.

Each model reflects current scientific understanding, has been applied in a number of other venues and complements the capabilities of the other models. Together they provide a suite of models for identifying the most effective approaches to restoring urban watersheds and evaluating how well those approaches will meet stated objectives for watershed health.

[1] EDT is currently focused on evaluation of salmon and steelhead populations but is being developed further to evaluate a broad range of fish and wildlife species.

Combined with the use of empirical data, these modeling tools will assist the City in characterizing existing conditions and constraints in a watershed; this characterization then can be used to develop solutions to address specific habitat limitations and problems. The modeling, combined with empirical data, allows the development of a scientifically grounded understanding of the causes of environmental changes and declines in water quality and species such as salmon.

EDT

EDT is an analytical tool that relates habitat features and biological performance to fish survival and productivity. The model captures a wide range of environmental information, making it accessible to planners, decision makers and scientists in a form that explains the underlying mechanisms of the ecosystem. EDT acts as an analytical framework that brings together information from empirical observation, local experts and other models and analysis.

What is EDT?

EDT, or Ecosystem Diagnosis and Treatment, is an analytical tool for rating the quality and quantity of habitat with respect to one or more focal species.

EDT uses salmon as a “probe,” or indicator, to identify the most significant problems in a watershed and the priority stream or river reaches for protection and restoration.

EDT can best be described as a scientific model. It differs from many models used in fish and wildlife conservation in that it is habitat based and attempts to explain and model the mechanisms behind phenomena. This contrasts with more conventional statistical models, which typically focus on fish population dynamics and provide correlation-based predictions of events without necessarily explaining the underlying mechanisms.

EDT constructs a model of a subbasin as a basis for planning and for use in comparing alternative future scenarios. The EDT model is based on the premise that habitat shapes biological performance of a salmon population and that individual habitat attributes can be related to fish performance, based on existing scientific knowledge. EDT provides measurable metrics to gauge progress. The model relates habitat characteristics to salmon population performance in terms that can be related to recovery standards for fish populations listed under the Endangered Species Act. EDT also is useful in planning effective recovery strategies because it contributes to the understanding of the complexity of ecological systems and how habitat change affects fish populations.

Although EDT is a salmon habitat model, it has implications beyond salmon. The City uses salmon as a biological “probe” of the aquatic environment in the belief that an environment that supports productive populations of native fish species has desirable characteristics that are consistent with the needs of other native fish and wildlife species. By using salmon as a key biological indicator, the City can draw on the rich scientific literature related to salmon and evaluate actions relative to species that have important social value and legal implications.

Unlike statistical models, which seek to reduce complexity to a small number of predictive or correlated variables, EDT helps describe the complexity of ecological systems.

The underlying premise of EDT is consistent with the *Framework*’s salmonid ecology principles, which explain that the persistence, abundance, diversity and productivity of species such as salmon are a reflection of the habitat conditions those species experience over the course of their life histories. For a species to recover, it must have the appropriate quantity, quality, location and connectivity of habitat at each stage in its life history. For aquatic species, habitat conditions are a function of conditions throughout the watershed, which in urban settings is influenced heavily by human actions. In Portland, stream conditions and associated species are likely to be affected by the area's continual development, and restoration and management of aquatic habitat in urban areas will likely require redirection and modification of actions that constrain habitat conditions. Because Portland is an urban setting, successful watershed restoration will require not only an understanding of the biological basis for restoration, but also the incorporation of engineering, social and economic aspects.

How EDT Works

EDT has two major components:

- **A detailed description of the habitat.** EDT describes habitat using 45 biologically significant attributes that relate to specific aspects of habitat for each month of the year for each stream reach.[2] These attributes reflect the environmental indicators described in Appendix G.
- **A set of rules that describe how a species responds to that habitat.** The rules describe the focal species' response to environmental conditions in terms of life stage productivity and capacity. By integrating a species' response to environmental conditions over the species' life history, EDT provides information on population abundance, productivity and diversity.

Taken together, the environmental attributes and rules in EDT provide, respectively, monitoring attributes and research hypotheses that can serve as the foundation for accountability, monitoring and research. These environmental attributes and rules can be developed and tested using a variety of statistical methods and research. In this way, EDT provides a scientific basis for natural resources planning and action.

During the characterization stage of the watershed management process (Steps 3 and 4), EDT is used to diagnose problems and constraints in the watershed relative to the needs of species such as coho salmon. In other words, terms such as "good," "bad," "healthy" or "unhealthy" are defined with respect to the biological needs of the species.

It is important to emphasize that the environmental attributes EDT uses to describe and evaluate habitat have a strong relationship to the watershed health indicators described in Appendix G. The connections between EDT attributes and *Framework* indicators are shown in Table H-2.

The diagnosis begins with a characterization of the current habitat conditions. EDT brings together information regarding the current condition and actual quantity of habitat and provides a forum for documenting existing knowledge, including the quality and reliability of that knowledge. A second characterization is also developed, to provide a standard against which to compare current conditions. This second characterization is of "reference" habitat conditions that could reflect various reference states, such as historical conditions or the

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[2] A stream reach is a distinct portion of a stream defined by valley form, land use or other criteria, such as tributary confluences.

habitat's ecological potential, meaning the conditions that would exist if all habitat attributes were functioning properly.

EDT then compares current conditions to the reference conditions for each stream reach in order to assess the quality and quantity of habitat for the focal species at different life history stages as a function of habitat in that reach. Constraints, habitat changes and restoration opportunities are identified. Planners then have a blueprint that identifies problems that need to be addressed in a watershed and the features or ecological functions that need to be preserved, enhanced or restored.

TABLE H-2
Connections Between EDT Attributes and the *Framework* Indicators

EDT Attributes		Corresponding *Framework* Indicators
Change in interannual variability in high flows, changes in interannual variability in low flows, intra-annual flow pattern and intradaily flow variation	**Watershed Hydrology**	Hydrograph alteration
Channel confinement		Floodplain quality and connectivity
Riparian function	**Physical Habitat**	Riparian condition: width, composition and fragmentation
Fine sediment, embeddedness, small cobble/riffle habitat type		Channel substrate (fine/coarse)
Primary pools, backwater pools and pool tailouts (for tributaries); area of shallow water (< 20 ft) (for large rivers)		Refugia
Off-channel habitat		Off-channel habitat
Wood		Large wood
Temperature/daily maximum; temperature/spatial variation	**Water Quality**	Water temperature
Dissolved oxygen		Dissolved oxygen
Nutrient enrichment		Nutrients and chlorophyll *a*
Turbidity		Total suspended solids
Metals in water column, metals/pollutants in sediment/soils, miscellaneous pollutants in water column		Toxic contamination of water sediments and biota, 303(d)-listed parameters, other parameters (as determined by the weight of evidence)
Benthos diversity and production, fish community richness	**Biological Communities**	Biotic integrity, benthic macroinvertebrates, salmonid population structure
Fish species introductions, hatchery fish outplants, predation risk		Species interactions (predation, competition, etc.), exotic species
Water withdrawals	**Human Activities**	Water withdrawals
Hydromodifications, channel length, obstructions to fish migration		Channel alterations
Harassment (boat traffic, lights, noise, etc.)		Harassment

Integrated Hydrologic and Water Quality System Modeling

MIKESHE and other hydrologic and water quality models complement the capabilities of EDT. Using the output from EDT, the hydrologic and water quality models aid the development of effective restoration approaches in the following ways:

- By identifying and quantifying sources of degradation (see Restoration Guideline 3.3)
- By predicting the effectiveness of protection and restoration actions in addressing these sources
- By evaluating the degree to which a set of restoration actions will achieve protection and restoration objectives

> **Integrated Hydrologic and Water Quality System Modeling**
>
> The City of Portland uses a variety of modeling tools to simulate and predict the hydraulic and transport behavior of the City's combined, sanitary, stormwater and natural drainage systems:
>
> - EPA's SWMM, PDX SWMM, XP SWMM
> - HEC-1, HEC-RAS
> - DHI's MIKESHE
>
> These hydrologic and water quality models complement EDT by identifying and quantifying sources of degradation and evaluating the effectiveness of potential restoration actions.

Historically the City of Portland has used a variety of modeling tools, including EPA's SWMM, PDX SWMM, XP SWMM, HEC-1 and HEC-RAS and the Danish Hydraulic Institute's (DHI) Mouse, to simulate and predict the hydraulic and transport behavior of the City's combined, sanitary, stormwater and natural drainage systems. More recently, the City of Portland has implemented DHI's state-of-the-art MIKESHE system, an integrated set of hydraulic, hydrologic and water quality modeling tools. MIKESHE is used to simulate flow and the transport of solutes and sediments in both surface water and groundwater. Areas of application include water use, water resources management, wetland protection, surface and groundwater interaction and contaminant transport.

MIKESHE is a physically based model, meaning that it uses computer simulation to portray the actual physical conditions and processes affecting flow and the transport of solutes and sediments in the watershed. Because the MIKESHE modeling software has a modular structure, individual components can be used independently and customized to specific needs, depending on the availability of data and the aims of the given study. The flow processes represented in MIKESHE include rainfall interception and evapotranspiration, overland flow and channel flow, and snowmelt and groundwater flow. Each of these processes operates in the model at its own spatial and time scale.

For example, daily rainfall might be distributed into a few zones across a watershed, because of topographic relief. Infiltration and evapotranspiration will vary with vegetation, surface cover, slope and soil properties and are automatically calculated and distributed in the model, based on the values for such parameters. Stream and river flows typically show the quickest response to rainfall events, whereas groundwater typically shows the slowest. In areas with shallow groundwater that is in full contact with local surface water, the model provides a dynamic description of the interaction between surface water and groundwater at daily or even hourly intervals. This is of particular importance to the City of Portland in understanding stormwater runoff behavior and response during storm events.

The MIKESHE model or other hydrologic models can also be used to help test specific proposed solutions. For example, if characterization reveals that high stream flows have scoured gravels and reduced the spawning success of Chinook salmon, the MIKESHE model can be used to help assess how watershed features and activities, such as impervious areas or stormwater system modifications, affect flow runoff quantities delivered to and routed through the stream. Planners and analysts can work back and forth to explore the feasibility and contribution of different actions. The result is a management alternative that contains a prioritized set of actions that address identified environmental problems and that are based on explicit scientific knowledge.

Similarly, a proposal to develop a subdivision near a creek can be evaluated as to the expected increase in effective impervious surfaces and the impact of this increase on surface flow, groundwater and pollutant inputs. These changes in the physical environment can then be entered into EDT to examine their potential impact on the habitat and performance of the species of interest.

Habitat Equivalency Analysis (HEA)

The HEA model was originally developed by the U.S. Department of the Interior and has been used extensively by NOAA, USFWS and numerous state resource agencies. The model has been useful in natural resource damage assessment cases (both in Comprehensive Environmental Response, Compensation and Liability Act [CERCLA] and Oil Pollution Act regulatory cases) to determine restoration actions required to address levels of damage (referred to as "injury") to natural resources from contaminants and pollution spills.

The HEA model focuses on the amount of ecological services performed by a natural resource, such as a particular habitat, over time. "Ecological services" refers to the functions that a natural resource provides to benefit the environment and human uses. A sample resource would be a wetland, which typically provides ecological services such as sediment stabilization, water quality improvements (as a result of natural filtration), storm protection, nesting areas and materials for birds and—for both fish and birds—forage and refuge from predators. Other services a wetland might provide include opportunities for commercial or recreational fishing, bird watching and hunting.

What is HEA?

Habitat Equivalency Analysis (HEA) can use output from EDT and other sources to calculate the amount of ecological benefit that is expected to result from a particular restoration action over time. HEA takes into consideration how well a restoration action will perform over the long term—whether its benefits will be maintained at a steady level, increase or decrease (and if so, at what rate). In addition, HEA expresses the ecological benefits of various restoration actions using a common unit of measure, making the model useful in comparing the long-term benefits of different potential actions.

What is NEBA?

Net Environmental Benefit Analysis (NEBA) combines output from HEA concerning future ecological benefits with the costs of various restoration actions. By calculating a cost-per-unit-of-benefit value for each restoration action being considered, NEBA identifies those watershed activities that offer the greatest potential benefit for the amount of money spent.

HEA can use out put from EDT and other information to calculate how much the ecological services performed by a particular habitat will change over the long term as the result of a particular restoration or protection project. The model considers such factors as the size of the project area, the time it will take for the restoration project to "mature" to the point that it provides its full level of ecological service, how much of an increase that full level of ecological service represents, how long the full level of service will last and, if there is an increase or decrease in the level of service over time, whether that increase or decrease will be gradual or precipitous.

Because HEA calculates the long-term ecological benefits that will accrue from each potential action and expresses those benefits using a common unit of measure (typically discounted service-acre-years, or dSAYs), the model is useful when comparing the respective merits of various restoration actions being considered for implementation.

Net Environmental Benefit Analysis (NEBA)

To ensure accurate comparisons of restoration actions that have widely different time frames, a HEA/NEBA analysis back-calculates future costs and ecological benefits into today's dollars. This accounts for the changing value of money over time.

The output of the HEA model is a statement of the respective ecological benefits that will result from various potential restoration actions. A net environmental benefits analysis takes this information and pairs it with the costs of developing and implementing each restoration action, to identify those actions that offer the greatest ecological benefit for the amount of money spent. Put simply, because the future ecological benefit and cost of each potential project are known, NEBA can calculate the cost per unit of benefit for each restoration action being considered. This information has obvious applications when selecting among different restoration options.

Used together, the HEA model and a NEBA entail the following steps:

- Quantifying the ecological services, or benefits, that will be provided by potential restoration projects, using the HEA model with input from EDT, MIKESHE and other tools
- Identifying the costs of developing and implementing the potential projects
- For each project, calculating the cost per unit of ecological benefit or, conversely, the level of benefit that will be provided for each dollar of cost

The net environmental benefit analysis is simply a comparison of (1) the ecological gains or losses associated with each management alternative, and (2) the costs associated with each action.

The end product is a balance sheet that provides a comparison of which options or activities offer the greatest net environmental benefit per project cost when compared to the other options.

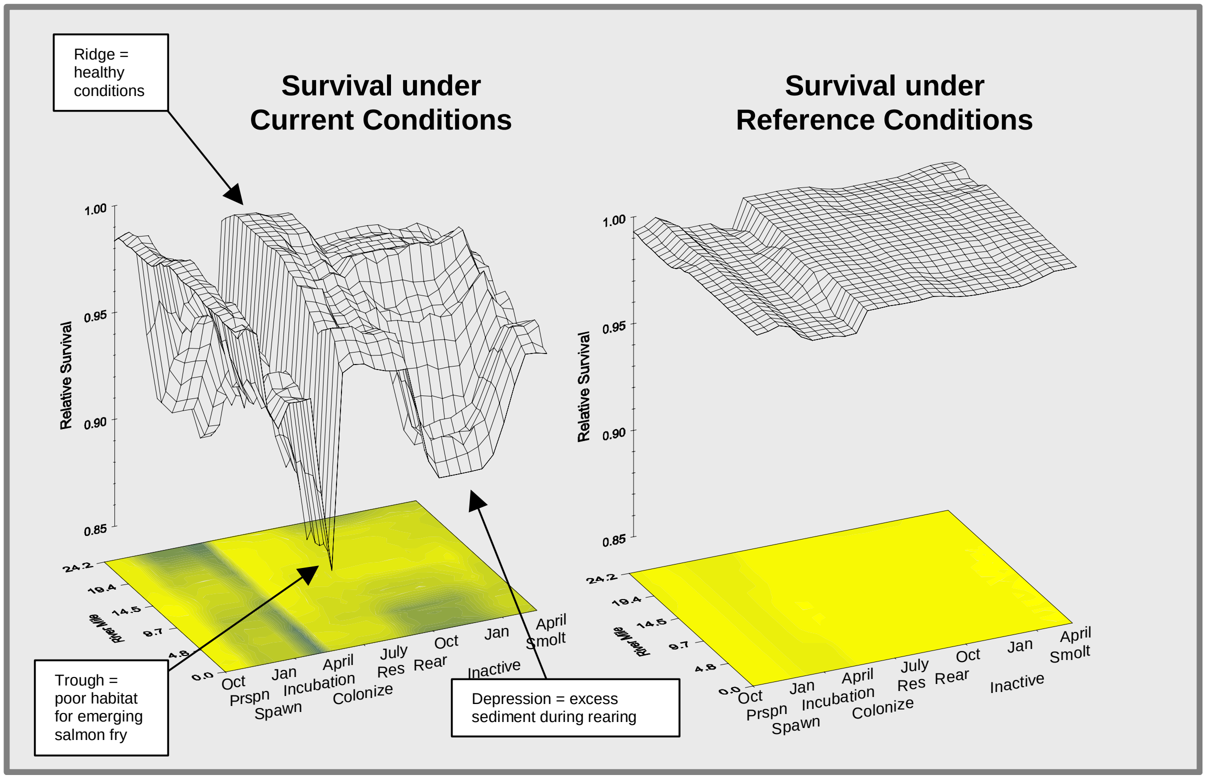
If desired, a NEBA can also include a quantification of the human use value, such as commercial fishing or bird watching, associated with a particular management action.

Examples of Output from the City's Modeling Tools

The models provide a variety of types of outputs that can be useful in developing and evaluating potential watershed management actions. Some of these are discussed below.

Output Useful in Pinpointing Habitat Problems and Opportunities. The City uses output from EDT to compare the current habitat conditions in a watershed to reference conditions, which usually reflect historical conditions or conditions that would exist if all environmental attributes in a stream reach were functioning properly. Figure H-1 is a sample comparison of two "survival landscapes" for a particular stream. It shows survival rates of a salmon population by location and through time under current conditions and reference conditions. Pits and valleys in the landscapes are times and places within the watershed where salmon survival declines as a result of habitat conditions. High points or peaks indicate higher survival rates.

FIGURE H-1
Sample Comparison of Salmon Survival Under Existing Conditions in a Stream and Under Reference Conditions



The figure shows that, under current conditions, there is a deep "trough" in the landscape during the spring months along the entire 24-mile length of the river being modeled. This trough indicates a time-sensitive environmental problem—in this case, a lack of adequate habitat complexity when salmonid fry are emerging from gravel in the spring. The figure also indicates an additional problem, represented by the depression during the winter months in the first few river miles. This depression corresponds to excess accumulation of fine sediment in the streambed during the spawning period. Another key feature of this particular survival landscape is the somewhat high "ridge" running next to the deep trough, during late spring and early summer, particularly in the upper river miles. This indicates a watershed asset, meaning properly functioning watershed conditions that, if maintained, are likely to help sustain important species and habitats.

Output Useful in Prioritizing Actions. By comparing survival under current and reference conditions, as in Figure H-1, areas where change is greatest and thus restoration is most needed become clear. Likewise, areas where change is the least might indicate opportunities for protection.

It is also useful to compare the difference between current conditions and potential future degraded conditions. This is the "preservation" value of the habitat, meaning the value of the current habitat if it is prevented from being further degraded from the existing state. Likewise, the difference between current conditions and potential future restored conditions is the "restoration" value of the habitat, meaning the value of the habitat if it is restored from the existing state to the habitat's assumed full potential. Figure H-2 represents these differences schematically.

FIGURE H-2
Schematic Representation of Preservation and Restoration Values

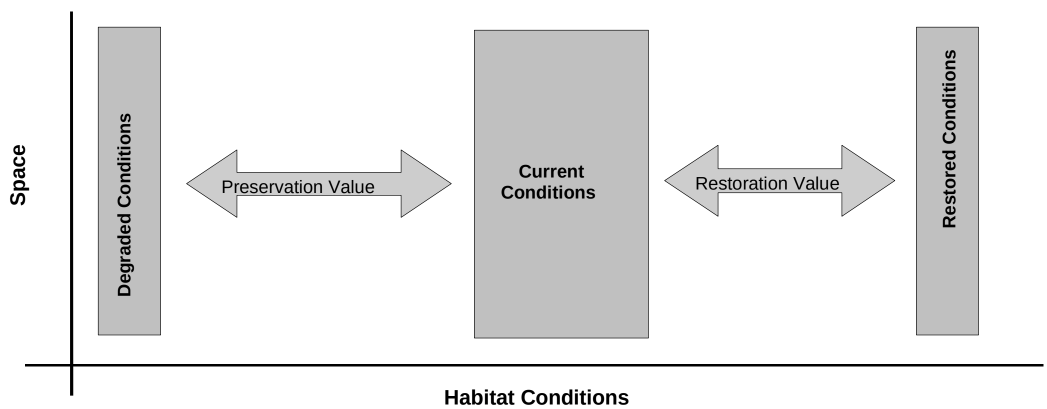
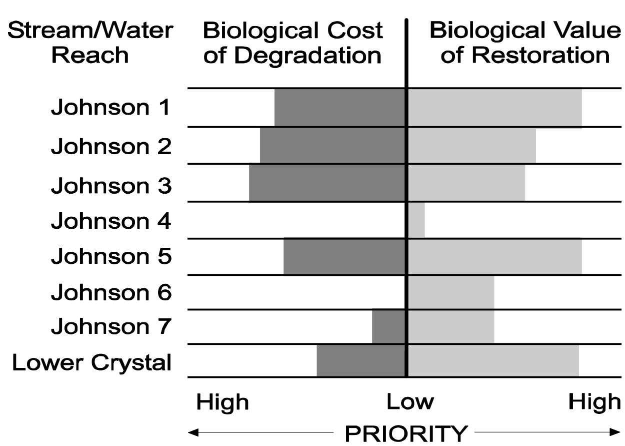


Figure H-3 shows how preservation and restoration values can be tied to specific stream locations. In Figure H-3, the biological costs of degradation and the value of restoration suggest how restoration or preservation activities in various stream reaches might be prioritized.

FIGURE H-3
Preservation and Restoration Values for Johnson Creek Stream Reaches (for Fall Chinook)



Output Useful in Identifying Factors That Affect Survival and Capacity of Focal Species. The City uses output from EDT to assess the quality and quantity of habitat in a watershed relative to the biological requirements of a fish species, such as Chinook salmon. In each of their life stages, Chinook have unique habitat needs that must be met if the species is to persist and thrive. In the characterization stage of the watershed management process, habitat conditions are identified and compared to the needs of each life stage. This information can be summarized in a chart like the one in Figure H-4, which shows how various habitat characteristics, such as flow, channel stability and water quality, affect the survival and capacity of Chinook salmon life stages in each reach of a creek. The sizes of the circles represent the amount of change that has occurred relative to reference conditions. By looking at each reach of the stream in this manner, areas and types of change are highlighted and priorities for restoration actions can be identified.

Output Useful in Performing Economic Analyses (HEA/NEBA). Economic analyses will play a role in the watershed management process, as a way to compare the costs and benefits of potential restoration actions and possibly to aid in a natural resources damage assessment under CERCLA. The primary tools the City will use for these are HEA and NEBA.

As described earlier in this appendix, the HEA model expresses the ecological benefits of different courses of action in a common unit—typically the service-acre year, or SAY[3]—so that the long-term benefits of different potential actions can be compared. Figure H-5 diagrams a sample of such a comparison of two alternate restoration scenarios theoretically being considered for a particular location. Scenario A involves tree planting and reductions in the amount of impervious surfaces. Scenario B involves erosion controls and development rules. For both scenarios, the wedge above the baseline services line represents the ecological services that would result if the actions were implemented.

FIGURE H-4
Factors Affecting the Survival and Capacity of Coho in a Sample Reach of Johnson Creek

Life stage	Relevant months	% of life history trajectories affected	Productivity change (%)	Life Stage Rank	Change in attribute impact on survival															
					Channel stability	Chemicals	Competition (w/ hatch)	Competition (other sp)	Flow	Food	Habitat diversity	Harassment/poaching	Obstructions	Oxygen	Pathogens	Predation	Sediment load	Temperature	Withdrawals	Key habitat quantity
Spawning	Oct-Jan	0.6%	-29.2%	6					High		Extreme	High					High			Moderate
Egg incubation	Oct-May	0.6%	-77.9%	1	High				High			Moderate					Extreme	Moderate		Moderate
Fry colonization	Mar-May	0.6%	-30.2%	5	High			Moderate	High	High	Extreme						High			Extreme
0-age active rearing	Mar-Oct	0.4%	-68.2%	2	High		High	Moderate	High	High	Extreme	Moderate		Moderate	Moderate	Moderate	Small	Moderate		High
0-age migrant	Oct-Nov	0.4%	-12.8%	8							High						Moderate			Moderate
0,1-age inactive	Oct-Mar	0.3%	-88.4%	3	High				Extreme	High	Extreme						High	Small		High
1-age migrant	Mar-Jun	0.3%	-0.2%	9							Moderate									Moderate
1-age resident rearing	Mar-May	0.3%	-37.5%	7	Moderate		Moderate	Moderate	High	High	High	Moderate					Small			High
1-age transient rearing																				
2+-age transient rearing																				
Prespawning migrant	Sep-Nov	0.6%	-0.1%	10							Small	Small								Moderate
Prespawning holding	Oct-Dec	0.6%	-32.4%	4					High		Extreme	High					High			Moderate
All Stages Combined		1%																		

1/ Ranking based on effect over entire geographic area. 2/ Value shown is for overall population performance.

Notes: Changes in key habitat can be caused by either a change in percent key habitat or in stream width.
Potential % changes in performance measures for reaches upstream of dams were computed with full passage allowed at dams (though reservoir effects still in place).

KEY

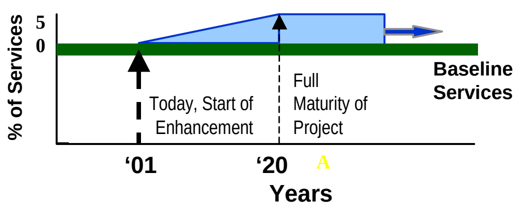
NA = Not applicable

	Loss	Gain
None		
Small	●	○
Moderate	●	○
High	●	○
Extreme	●	○

[3] A service-acre year is the area (in acres) of usable and suitable habitat that is available over a year's time.

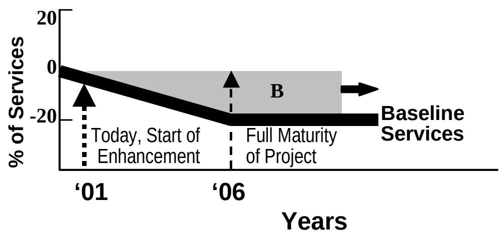
FIGURE H-5
Sample HEA Comparison of Two Hypothetical Scenarios

Scenario A: Tree Planting/Impervious Surface Reductions



Water quality and salmonid benefits = 60.2 SAYs
Recreation/fishing benefits = $120,326

Scenario B: Erosion Control/Development Rules



Water quality and salmonid benefits = 2,499 SAYS
Recreation/fishing benefits = $1,249,489

Note: SAY = service-acre years

Under Scenario A, the full benefit of the tree planting and impervious surface reductions would first be realized in the year 2020. Over the 50-year life span of the project, water quality and salmonid benefits would amount to 60.2 SAYs and recreation and fishing benefits would provide $120,326 in public fishing and recreational value.

This compares to water quality and salmonid benefits of 2,499 SAYs under Scenario B, which involves erosion control and development rules that would prevent further degradation. Under this scenario, full benefits would first be realized in 2006, offering $1.2 million in public fishing and recreational value over the 50-year lifespan of the project.

Table H-3 shows the net environmental benefits analysis for the two scenarios, using the project cost and HEA-calculated ecological value in SAYs to compute a dollar cost per unit of value generated under each scenario. The NEBA indicates that Scenario B would result in greater ecological benefit overall at a lower per-unit rate ($0.32 per unit compared to $2.08 per unit).

An important aspect of the HEA/NEBA analysis is the ability to assess the accrual of ecological value generated by actions over time. Thus the analysis takes into account the ecological value of an action not only today but as it will accrue into the future. The analysis also can demonstrate both the ecological and monetary value of implementing certain actions sooner rather than later.

TABLE H-3
Net Environmental Benefits Analysis Comparing Benefits and Costs under Two Hypothetical Scenarios

Alternative	HEA Ecological Value Generated	Cost	$/eco	Public Use Value Generated	$/pv
Scenario A: Riparian Buffer/ Impervious Surface	60.2 SAYs	$250,000	$4,152	$120,326	$2.08
Scenario B: Erosion Control/ Development Rules	2,499 SAYs	$400,000	$160	$1,249,489	$0.32

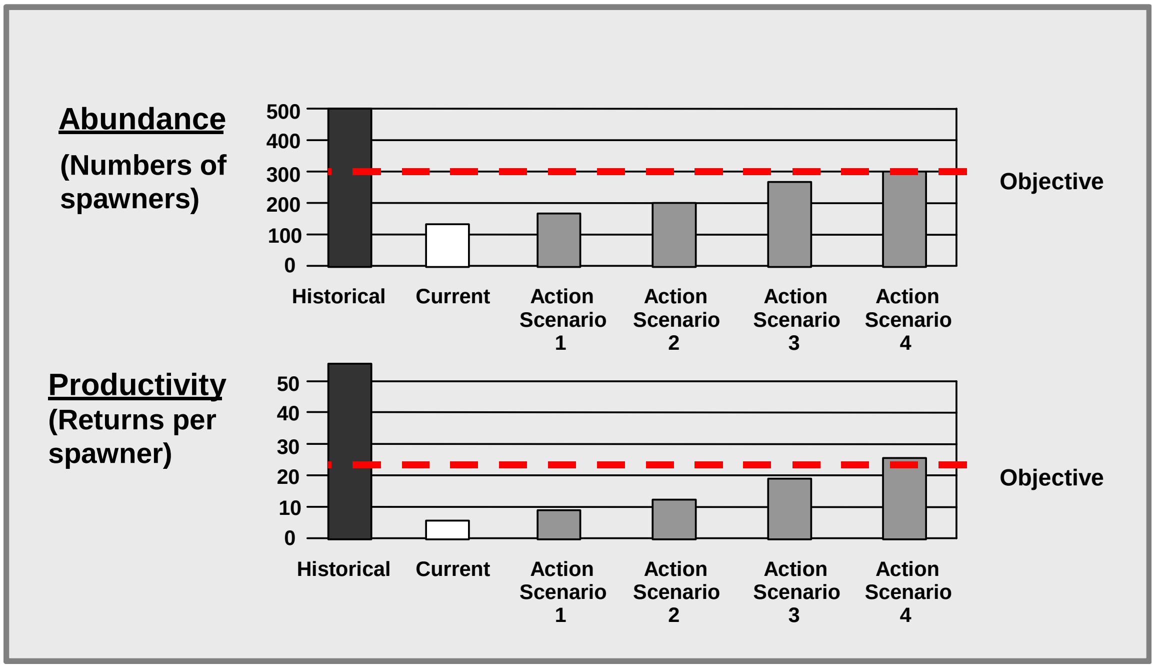
HEA = habitat equivalency analysis
SAY = service acre-year
$/eco = cost per ecological credit
$/pv = cost per $ of value generated

Integrating Components of the Models

The various models can be integrated as needed to characterize current watershed conditions and assess the effects of different management actions on watershed processes and habitat attributes. For example, as a preliminary step, geographic information system (GIS) spatial analysis could be used to manage data and produce maps that depict current conditions and conditions that would occur under various action scenarios. Mathematical models such as MIKESHE could then be used to estimate hydrology and water quality conditions at various locations and reaches within the watershed. (These models are useful in helping policy makers understand the relative magnitude of potential changes in conditions that are likely to result from different action scenarios. Similarly, the use of models helps ensure thorough documentation of the assumptions used in evaluating different management options and in facilitating discussions among stakeholders and technical experts.) EDT would then be run for several scenarios, to compare graphically the predicted effects on fish abundance, productivity and diversity (see Figure H-6). This analysis provides information valuable in the prioritization and selection of a preferred set of actions.

In addition to comparing different alternative sets of actions, this same approach can be used to track the progressive effectiveness of a preferred set of actions over time. This allows for evaluation of when a benchmark or objective will be achieved.

FIGURE H-6
Graphical Comparison of Potential Action Scenarios



An Additional Analytical Tool: Spatial Analysis Using GIS

An additional analytical tool the City is likely to use is GIS for spatial analysis of data related to watershed data. Currently the City maintains a wide range of data on natural features, infrastructure, zoning, development and other components that support the planning, development, maintenance and management of City functions. This includes natural resource data (information on soils, vegetation cover, water features, topography, watersheds, floodplains, wetlands, etc.) and regularly updated information on the built environment (streets, tax lots, transit, population, land use, stormwater drainage, water mains and sewer lines, building footprints and public places such as schools and parks). These data are stored and organized using GIS software and can be analyzed spatially in support of the watershed management process presented in Chapter 3.

The multiple bureaus within the City of Portland regularly share GIS data. This allows the bureau most closely tied to each type of information to maintain the data and provide the most current information to the other bureaus. For example, information on street features is tracked by the Portland Department of Transportation, while information on building permits and land use reviews is maintained by the Bureau of Development Services. Water main data are the province of the Bureau of Water Works, and the Bureau of Environmental Services (BES) is responsible for sewer line and stormwater drainage data. Most of the bureaus use various types of Environmental Systems Research Institute (ESRI) brand GIS software, such as ArcView 3.x and 8.1, ArcInfo 8.1 and MapObjects. BES currently uses MapInfo but can regularly share data with other GIS platforms with little difficulty. The City also shares data with Metro, the area's regional government. Metro provides broader regional coverage of GIS data, while the City maintains more detailed data on conditions within Portland. The coordination and data sharing between the two entities provide for stronger data sets and greater cost effectiveness.

The City uses GIS to display data on maps (or "coverages") of various resources and land features. The high quality and extensive body of spatial data available for watershed management will support sophisticated analyses of environmental conditions and link conditions to human actions throughout the watershed. The resolution and quality of data will be important in mapping the locations of environmental problems, identifying the potential pathways contributing to the problems, quantifying sources and developing solutions.

Management and Decision-Making Tools

The City also has the option of using multi-attribute analysis software and environmental management systems to evaluate potential restoration and protection actions and manage the planning activities, staff responsibilities, practices and resources needed to implement selected actions on an ongoing basis. These tools are described below.

Multi-Attribute Analysis Software

When selecting a preferred alternative, it may be helpful to use methodologies or software packages specifically designed to conduct a multi-attribute analysis of different alternatives. Such an analysis provides a systematic means of applying and tracking the rating of alternatives based on various evaluation factors and criteria. The analysis also generates a total score for each alternative, with the score reflecting the degree to which that alternative is likely to achieve the City of Portland's identified values, taken as a whole. The total score is simply the sum of scores derived for each evaluation factor, in which the score for each factor is determined by multiplying the value given each factor (based on quantitative or qualitative criteria) times the factor's established weighting.

Two types of outputs are likely to be particularly useful when reviewing the results of a multi-attribute analysis:

- **Benefit contributions by component values.** This provides information about which value, or evaluation factor, most influences an alternative's relative ranking, either high or low. Essentially, this output explains why a particular alternative is ranked as it is. As a simplified example, consider a hypothetical situation in which two alternatives are being proposed in a watershed area to reduce erosion and sediment loading to protect existing areas of high-quality habitat. Alternative A includes actions to change zoning to prevent streamside construction that contributes to erosion and sediment loading. Alternative B includes actions to revegetate streamside riparian areas to prevent channel bank erosion that contributes to erosion and sediment loading. The multi-attribute analysis reveals that the total score for both alternatives is the same. However, an examination of the contribution to the score by evaluation factor indicates that Alternative A is rated higher than Alternative B for technical effectiveness in actually reducing soil material that contributes to erosion and sediment loading, but is rated lower than Alternative B in overall costs of implementation and maintenance.
- **Weighting sensitivity analysis.** This shows how much the weighting of a particular value could vary without affecting the relative rankings. By determining a particular value's

threshold—beyond which the rankings of alternatives would change—the analysis identifies the degree to which the weighting of a particular value influences an alternative's ranking. This analysis is particularly useful when there may be some uncertainty in the weightings to be assumed in the analysis. Using the same simplified example as above, a weighting sensitivity analysis might show that, if the weightings were changed (over the range of uncertainty) such that the costs of implementation and maintenance were weighted more lightly, and technical effectiveness was weighted more heavily, Alternative A might achieve a higher total score and surpass Alternative B in rank. On the other hand, a weighting sensitivity analysis might show that, if the weightings were changed such that the costs of implementation and maintenance were weighted more lightly, and technical effectiveness was weighted more heavily, the total scores for both alternatives might remain very close, indicating that the ranking is insensitive to the weightings over the range of uncertainty.

Environmental Management System (EMS)

The City of Portland may develop an internal environmental management system, or EMS, for use in preparing and implementing the watershed management plans created through the watershed management process described in Chapter 3. The EMS would guide the detailed, day-to-day management activities needed to implement the *Framework* and would provide a structured, consistent approach to long-term watershed management.

The most commonly used EMS is an internationally accepted and proven management tool that was developed by the International Organization for Standardization (ISO). This EMS conforms to ISO 14001, which defines an EMS as part of an overall management system that includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining environmental policies and strategic plans. In the City of Portland's case, the EMS would be structured to help the City achieve a desired level of environmental performance—that is, the achievement of the watershed goals, objectives, targets and benchmarks established for each of the watersheds, following the process described in Chapter 3.

The City's EMS, referred to as the Watershed Management System, or WMS, could be patterned after the ISO 14001 model. Ultimately, WMS would integrate the scientific principles, restoration guidelines and watershed health goals and objectives into the City's everyday operations. In this way, the watershed approach described in the *Framework* would become part of the daily responsibility for all employees of the City—not just those on watershed teams. Senior management would play a direct and active role in WMS by monitoring and measuring the City's progress toward its watershed health goals and continually looking for ways to improve its efforts.

Addressing Uncertainty

The City's watershed planning process embraces, rather than fights, the inevitable uncertainties associated with the analysis of complex interactions between biological and human systems. All models and analytical approaches are abstractions of reality subject to varying degrees of uncertainty. The key to effective analysis in an uncertain world is to frame an approach that recognizes that uncertainties will always remain in specific data, analyses and assumptions. In the City's watershed planning process, uncertainties will be addressed as follows:

- By clearly communicating the methods, strengths and limitations of each analysis.
- By explicitly identifying uncertainties and assumptions.
- By incorporating corroborative analyses to validate key conclusions independently. Results provided by each analytical approach will be corroborated with independent analysis using alternative methods. For instance, EDT projections of rearing densities from habitat conditions can be independently validated using empirical field observations. This way, the limitations of any single approach or model cannot drive conclusions, and all available information and tools can be incorporated. Some opportunities to corroborate tools will be elective and used on a case-by-case basis depending on time, resources and the perceived risk of not verifying uncertainty.
- By using analyses to identify the importance of uncertainties. Model sensitivity analyses will be used to evaluate the size of the response of the model to the variability of a particular model attribute. If a model is very responsive to a particular attribute and the attribute has been measured with a fair amount of uncertainty, then it is of value to invest in additional study to reduce that uncertainty. If the model is not responsive to the attribute, there is probably little value in reducing that uncertainty. In such a manner it can be determined which uncertainties are most important to reduce with focused data collection.
- By drawing conclusions based on the weight of all evidence rather than any specific analytical result, and by building in appropriate safety factors to buffer risks. A weight-of-evidence approach considers the net balance of all the evidence, rather than the specific certainty of individual observations. Safety factors are extra margins of protection for uncertain outcomes—for instance, engineers include safety factors in their calculations to overbuild structures to make sure they will hold up.