Babine Watershed

Monitoring Framework

prepared for

Babine Monitoring Trust Governance Design Group

by

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Table of Contents

1. Introduction

Land and Resource Management Plans (LRMPs) set broad goals and objectives[1] for resources and values on a tract of land. More detailed land use plans (e.g. Sustainable Resource Management Plans, Landscape Unit Plans, Management Direction Statements) refine objectives and provide strategies (or indicators and targets)[2] that aim to achieve each objective or goal. The intention is that the strategies will achieve each objective and that, together, the objectives will achieve the broad goal. For example, seral stage strategies aim to achieve the objective of a natural seral stage distribution, which in turn, contributes to achieving the goal of maintaining biodiversity. Additionally, the Forest and Range Practices Act (FRPA) lists objectives for forest resources and describes default strategies for achieving objectives. Six government-approved land-use plans include objectives and management strategies for the Babine Watershed: Bulkley LRMP, Kispiox LRMP, Babine Landscape Unit Plan (LUP), Nilkitkwa LUP, West Babine Sustainable Resource Management Plan (SRMP), Babine River Corridor Park Management Direction Statement (MDS).

Designing strategies is insufficient to ensure that goals will be met: the application of strategies—and their success—must be monitored. *Implementation monitoring* asks whether strategies are being followed and whether targets are being met. In recent years, various government agencies and forest companies have been gaining experience at implementation monitoring[3]. In the Bulkley portion of the Babine Watershed, the results of LRMP implementation monitoring are compiled into a State-of-the-Forest Report. Because of uncertainty about the effects of management on complex natural and social systems, implementation monitoring, while necessary, is insufficient to determine if strategies are successful. *Effectiveness monitoring* asks whether strategies (or target values for particular indicators) achieve objectives and goals; that is, it monitors the consequences of management.

Effectiveness monitoring is often more difficult than implementation monitoring. Strategies, particularly when expressed as indicators and targets, can usually be measured easily because they alter some amount or pattern of a land-based attribute (e.g., seral stage, road density). Conversely many objectives and goals cannot be assessed by measuring land-based attributes and require field sampling (e.g., grizzly bear populations, recreational user surveys), often over many years. Some goals and objectives are inherently difficult to measure directly (e.g., biodiversity) and need surrogates. Time and funding limitations prevent effectiveness monitoring of all objectives and strategies.

In the past, most effectiveness monitoring has simply measured change to a goal or objective of interest (e.g. water quality, grizzly bear population). This approach has often failed, for two reasons. First, due to high levels of natural variability, it is often difficult to detect changes until consequences are severe. For example, a natural three-fold variation in annual flood levels makes it difficult to detect a two-fold change in mean flood levels even though the consequences of such a doubling may be severe. Similarly, most studies of population trends do not have sufficient statistical power to detect even large, biologically significant, changes. Second, even if changes are detected, the cause may remain mysterious. For example, a decline in water quality

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[1] In this document, "goals" are very broad, while "objectives" are more specific and more easily measurable.
[2] Strategies are only measurable if they can be expressed as indicators and targets.
[3] See companion document: Price and Daust. 2004. Gaps in Past Monitoring and Current Monitoring Responsibilities in the Babine Watershed.

at the mouth of a watershed could have resulted from excessive harvesting, poor road location, road use at sensitive times, unusually heavy rainfall, or some other factor. Monitoring projects that focus solely on detecting consequences cannot be used to revise management strategies, and thus cannot be used to confirm or amend land-use plans. Well-designed studies to detect negative consequences, however, can be important triggers for action.

An alternative approach to effectiveness monitoring assesses the *linkage* between strategies and the focal values of objectives and goals. This approach uses monitoring to improve understanding about cause-and-effect relationships, specifically, about how particular strategies affect associated objectives. In this way, it tries to avoid the "black box" problem associated with simply measuring outcomes, and increases the chances of learning while continuing to manage. The approach starts by sketching curves that describe the "best-guess" relationship between strategies and the risk to objectives. It considers the level and types of uncertainty associated with the relationship. In this way, expert opinion and relevant literature provide the basis for future learning. Monitoring projects then improve knowledge about the relationship by investigating the consequences of a range of management strategies.

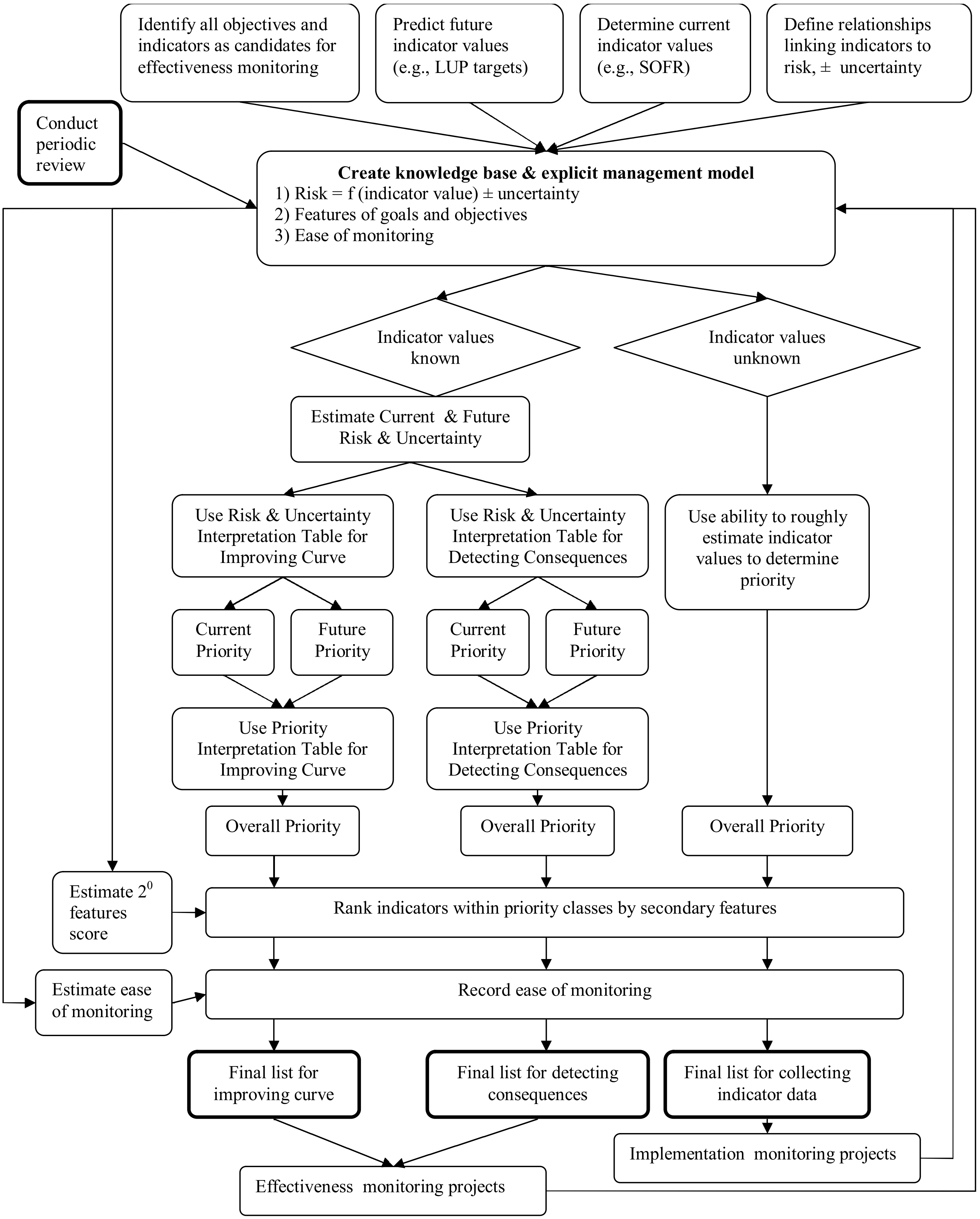
Considering the level of risk and uncertainty associated with following a given strategy is particularly useful in designing efficient, effective monitoring programmes. Objectives at high risk with relatively low uncertainty should be the focus of monitoring designed to detect negative consequences. Channelling funds into a selected number of well-designed, sufficiently long-term projects will improve the chances of obtaining meaningful results. Conversely, objectives with relatively high levels of uncertainty should be targeted for monitoring designed to improve knowledge about the relationship between the strategy and risk to the objective, thus reducing uncertainty. The Monitoring Framework described in this document uses risk and uncertainty to identify the most effective targets for monitoring by highlighting objectives where risks and/or uncertainty are high (Box 1). By including cause-effect relationships, it also broadens the scope of monitoring to include a wider range of topics and of study types. In general, it allows more information to be used to develop strategies that reflect objectives.

This Monitoring Framework provides a scientific basis and transparent decision-making process for setting monitoring priorities in the Babine Watershed. Following the procedures described in this document results in three separate lists of monitoring priorities:

- a ranked list of objectives for collecting indicator data (for objectives with insufficient data to perform the analyses);
- a ranked list of objectives for monitoring to improve knowledge and reduce uncertainty;
- a ranked list of objectives for monitoring to detect negative consequences.

Within each list, objectives are ranked initially by priority as determined from risk and uncertainty estimate, and then—within each risk rank—by supplementary features relating to benefits. Each objective is also accompanied by a relative cost estimate. Using the Monitoring Framework will help the Babine Monitoring Trust to allocate funds to those monitoring projects that provide the most useful feedback on the effectiveness of the management strategies included in the land-use plans.

Box 1. Framework for determining monitoring priorities (different types of projects are shown in bold)



Contents of Monitoring Framework

The Monitoring Framework consists of two relatively unchanging sections that describe the approach, and four appendices that may change over time to reflect current knowledge. The body of the text includes a discussion of the **Theoretical Background** to the risk-based approach and a set of **Procedures** that determine monitoring priorities for each objective and strategy included in the land-use plans. Appendix 1, the **Land-use Plan Summary**, summarises the current commitments (goals, objectives and strategies) in the land-use plans and FRPA that require monitoring. Appendix 2, the **Knowledge Base**, provides current scientific information about the relationships between planned management strategies and the objectives and goals listed in the land-use plans. The Knowledge Base forms the core of the Monitoring Framework, including all of the relevant available information needed to assess the priority for monitoring for each objective and management strategy. It is designed to be updated as knowledge improves. Appendix 3 contains the current **Tables of Monitoring Priority** that result from following the procedures in the Monitoring Framework. Appendix 4 contains a template for an **Annual Monitoring Plan**.

A companion document[4] summarises past monitoring projects in the Babine Watershed and discusses current roles and responsibilities of government agencies and industry sectors for monitoring.

[4] Price and Daust. 2004. Gaps in Past Monitoring and Current Monitoring Responsibilities in the Babine Watershed.

2. Theoretical Background

Risk Curves

In this Monitoring Framework, risk curves are explicit hypotheses about how strategies influence objectives. Essentially, they plot the risk to an objective on the Y-axis—defined as the likelihood that an objective will not be achieved—against indicator values—representing a strategy—on the X-axis.

A crucial first step is to design a good indicator. Indicators are measurements that index the state of often complex, difficult to assess, objectives. Good indicators respond to the full spectrum of possible strategies, are related clearly to the objective of interest, can be measured or described simply, are relatively insensitive to factors beyond the strategies considered, and are appropriate for the purpose and scale considered (Beasley and Wright 2001). Much work has been completed during land-use planning to select indicators. This framework uses those indicators listed in the land-use plans as a starting point and describes their limitations as uncertainty around the indicators.

To allow comparison of risk levels among values or resources (necessary to decide upon monitoring priorities), Y-axes must be similar. All curves in this framework plot "Risk to an objective" on the Y-axis. In this way, with the assumption that all LRMP goals are equally worthy of monitoring, it is possible to compare, for example, graphs for grizzly bear habitat with those for water flow and the aesthetic value of wilderness. Because some objectives are difficult to monitor directly, some Y-axes use surrogates. For example, risk to "Minimise human/bear interaction" is hard to monitor, whereas risk to "Bear mortality due to human/bear interaction" is relatively easy.

In its simplest form, risk increases linearly with increases in the indicator (Figure 1).

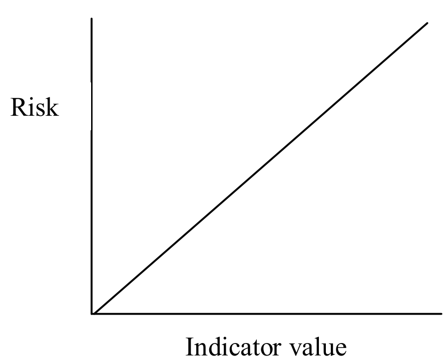


Figure 1. Hypothetical linear risk curve

Sigmoidal risk curves are common in natural systems (Figure 2). In this case, the system is relatively insensitive to perturbation up to a point (i.e. the risk of severe consequences is low), but after reaching a threshold, the probability of severe consequences increases rapidly up to a second threshold where the probability of severe consequences is high.

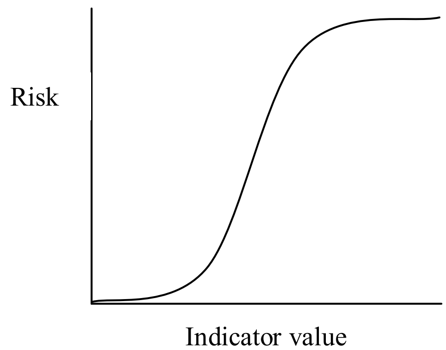


Figure 2. Hypothetical sigmoidal risk curve

A flat risk curve (Figure 3) shows that an indicator is unrelated to risk to the objective—and is hence not a useful indicator.

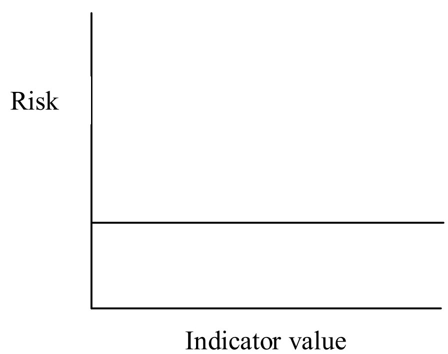


Figure 3. Hypothetical flat risk curve

As well as the Y-axis label, the points on the Y-axis, representing levels of risk, must be equivalent across objectives. The following definitions apply to all curves in the framework: at low risk, even well-designed studies are unlikely to detect any severe consequences to the objectives; at high risk, most studies will detect severe consequences to the objective (i.e., the objective will not be achieved); at medium risk, some studies will detect consequences, and others will not. As an example supported by theoretical and empirical research, studies of the consequences of different amounts of habitat can be plotted on a sigmoidal curve: very few studies with more than 70% intact habitat detected changes in species presence or abundance; most studies with less than 30% intact habitat detected changes; and studies with between 30 and 70% vary[5]. Hence, in this case, greater than 70% habitat would represent low risk, 30 – 70% would represent medium risk, and less than 30% would represent high risk. It is important to note that the general curves are drawn based on a range of habitat types, and that, within the

[5] Dykstra, P.R. 2004. Thresholds in habitat supply: a review of the literature. BC Ministry of Sustainable Resource Management Conservation Branch and BC Ministry of Water, Land and Air Protection Biodiversity Branch. Wildlife Report R-27.

framework, these general curves are assumed to apply to the specific habitats of the Babine Watershed.

Ideally, risk curves should be based on published studies conducted within a particular area (here, the Babine Watershed). More realistically, they are based on published studies from other regions, modified by local expert opinion. When published information is particularly sparse, expert opinion alone can be used to draw preliminary curves. The specification of quantitative risk curves for application to monitoring decisions is still novel. Very few data are presented in a manner appropriate for developing curves; hence the reliance on expert opinion. Generally, initial data are insufficient to draw different curves for different landscapes, sub-watersheds, ecosystems or organisms.

Risk curves will be continually refined through monitoring. Over time, it should be possible to differentiate among risk curves in landscapes, watersheds or habitats of different character, or among different organisms. In some cases, local knowledge may already be sufficient to redraw general risk curves to be more specific.

Risk curves carry several benefits. Explicitly-drawn risk curves are useful to summarise current knowledge and to force consideration of uncertainty. Without help from explicit risk curves, strategies are usually developed based on hidden, implicit risk curves, often confounding values with knowledge. In some cases, risk curves will suggest that strategies are unlikely to achieve objectives. This is because land-use plans reflect implicit assumptions about how strategies achieve goals and because implicit assumptions may miss important factors that become obvious with explicit expression of assumptions.

Explicitly-drawn curves can also help separate knowledge from values in multi-stakeholder discussions. Different stakeholders have different implicit risk curves, complicating debate. A set of common risk curves illustrating current knowledge can facilitate discussion.

The alternative to drawing risk curves assumes that current knowledge is insufficient to draw even hypothetical curves and begins with a hypothesis of no information about the relationship in question (such an assumption could still be drawn explicitly, with uncertainty bands covering all possibilities). This approach seems to avoid making use of the considerable research and management experience to date and can result in ad-hoc monitoring programmes.

Approaches that define risk categories (e.g. Low, Medium and High) without presenting explicit curves, simply rely on implicit curves (step functions). Such approaches bring simplicity, but are less amenable to expressing and testing hypotheses about the relationship between strategies and risk to objectives because they suggest unrealistically abrupt changes in state. This framework records knowledge using explicit risk curves, but uses three risk categories to support decision making. The range of indicator values in each risk class varies with the shape of the risk curve.

Uncertainty

Mathematically, the relationship between the risk to an objective and a particular indicator can be expressed as

$$Y = f(X)$$

where Y = risk to objective, X = indicator and f = the risk function.

Uncertainty about the level of risk can be partitioned into uncertainty about the indicator (X) and uncertainty about the function (f) relating the indicator to risk. A top priority is thus to ensure that the indicator is appropriate before calculating the uncertainty around the risk function. A third source of uncertainty arises from uncertainty about the actual value of X at any time (e.g., the future seral stage distribution will vary because of natural disturbance). This uncertainty is not included in uncertainty around the risk function but can be easily estimated by determining risk for the range of possible indicator values. For many indicators, this uncertainty should be relatively low.

Uncertainty about the risk function can also be partitioned into resolvable and irresolvable uncertainty. Resolvable uncertainty arises from lack of study. Irresolvable uncertainty may result from inherent stochasticity (e.g. it is not possible to predict the location of a beetle outbreak). While the former uncertainty is amenable to reduction by monitoring, the latter is not.

The uncertainty around the risk curve, including indicator uncertainty and function uncertainty, is represented by a probability distribution around the estimated risk curve. On a 2-dimensional graph, uncertainty can be envisioned as a band around the best-guess line (Figure 4). More accurately, the band is actually a hill coming out from the page, with the edges of the uncertainty band defining the base of the hill and the risk function defining the peak. Points on the hill show the probability that a given actual risk will occur for any particular indicator value.

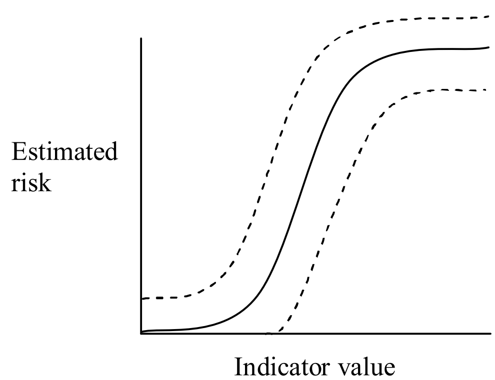


Figure 4. Hypothetical sigmoidal risk curve with uncertainty bands.

Risk curves with uncertainty bands can be used to create uncertainty estimates for risk categories: select risk class midpoint, determine the corresponding indicator value, determine the risk levels at the edge of the uncertainty bands (Figure 5) and create classes describing uncertainty as a distribution of risk levels (Figure 6).

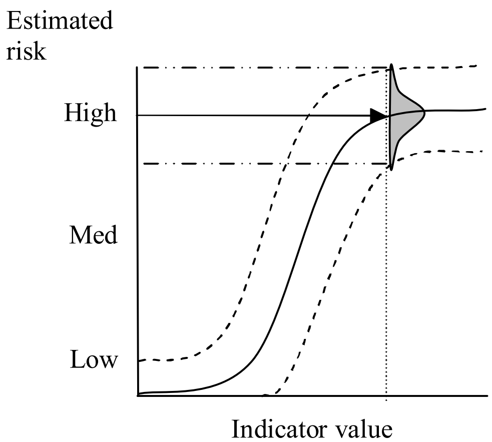


Figure 5. Determining uncertainty for the high risk class (an example).

Because uncertainty is seldom well-defined, the framework usually does not show uncertainty on the risk curves, but discusses three relative levels of uncertainty in text. “High” uncertainty means that actual risk can shift two classes from the level estimated from the risk curve (i.e., risk varies from low to high), although the level suggested by the risk curve is still more probable (Figure 6). As uncertainty decreases, the probability that the estimated risk level is correct increases. “Medium” uncertainty means that potential risk can shift one class either side; “low” uncertainty means that actual risk is very likely within the class estimated from the risk curve. For example, when a risk curve suggests that risk is “low” with “low” uncertainty (the lower right box in Figure 6), the chance that risk is actually medium or high is miniscule. Probability distributions of actual risk for each possible combination of estimated risk level and uncertainty level show how these two factors interact (Figure 6).

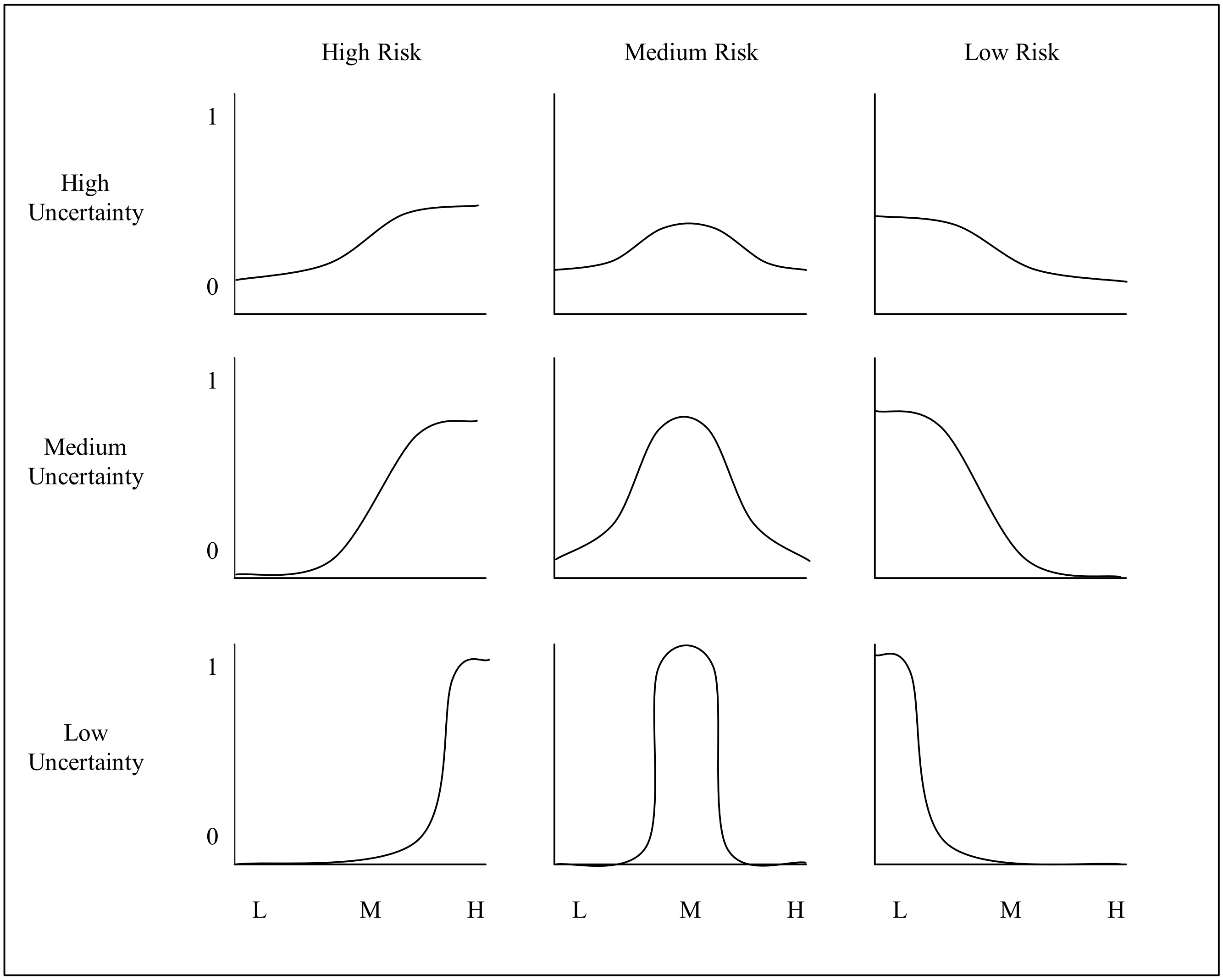


Figure 6. Probability distributions of risk for each category of estimated risk and uncertainty. The X-axis shows low, medium and high estimated risk classes. The Y-axis shows the probability, from zero to one, that actual risk is within an estimated risk class. These curves are the "hills" forming the third dimension of the band shown in Figure 4.

Interpretative Tables

The level of estimated risk and the level of associated uncertainty together determine priority for monitoring. Effectiveness monitoring aims either to reduce resolvable uncertainty in order to define better the relationship between an indicator and risk to an objective, or to detect negative consequences of management early.

The Monitoring Framework uses interpretative tables based on the probability distributions in Figure 6 to convert estimates of current and future risk and uncertainty into monitoring priority scores. For monitoring to improve a risk curve and reduce uncertainty, all objectives with high uncertainty rank first. Objectives with medium risk and medium uncertainty also rank first because risk may fall in any of the three risk categories. All objectives with low uncertainty rank third; the remaining objectives (that could fall into two categories) rank second (Table 1 and Figure 6).

Table 1. Priority for improving risk curve based on estimated risk and uncertainty. Cells in table match the probability distributions in Figure 6.

		Risk		
		High	**Medium**	**Low**
Uncertainty	**High**	1	1	1
	Medium	2	1	2
	Low	3	3	3

For monitoring to detect negative consequences, objectives with high risk and low or medium uncertainty rank first, those with low risk and low or medium uncertainty rank third, and the remainder rank second. These remaining five situations all have a mean risk probability of medium, or very close to medium (Table 2 and Figure 6).

Table 2. Priority for detecting negative consequences based on estimated risk and uncertainty. Cells in table match the probability distributions in Figure 6.

		Risk		
		High	**Medium**	**Low**
Uncertainty	**High**	2	2	2
	Medium	1	2	3
	Low	1	2	3

Risk and uncertainty estimates can provide useful information about management strategies without any monitoring. For example, if uncertainty is low, the level of risk associated with a particular strategy or target will be well-known. If risk to the objective is low, with low uncertainty, planning direction is confirmed and implementation monitoring is sufficient to ensure that the listed strategy or target is being followed. If risk to the objective is high, with low uncertainty, planning direction should be reviewed and perhaps amended: either the objective could be modified (as it will likely not be achieved) or the associated strategies or targets could be altered.

Because the level of risk may change over time as management strategies are implemented, the Monitoring Framework estimates risk and uncertainty for both current and future indicator values. Current indicator value is based on inventory data; future indicator value is based on the targets listed in the land-use plans. When current or future indicator values are missing and not estimable, these objectives receive a high priority for collecting indicator data. If indicator values are missing but estimable, objectives receive a medium priority for collecting indicator data. When current and future indicator values are available or estimable, the priorities determined from the risk and uncertainty tables (Tables 1 and 2) are combined into a single rating using a second set of interpretative tables.

For monitoring to improve risk curves and reduce uncertainty, combined priority is based more on future priority than on current priority, because refining future targets allows for a potential change in strategy (Table 3). For monitoring to detect consequences, conversely, the combined priority is based more on current than future priority because negative consequences may be imminent (Table 4).

Table 3. Combined priority for improving risk curves and reducing uncertainty based on current and future priorities.

		Current Priority 1	2	3
Future Priority	1	1	1	2
	2	2	2	3
	3	3	3	4

Table 4. Combined for detecting negative consequences based on current and future priorities.

		Current Priority 1	2	3
Future Priority	1	1	2	3
	2	1	2	3
	3	2	3	4

Cost/benefit Analysis

Relative Benefits

The benefits of monitoring for any particular objective are defined primarily by the level of risk and uncertainty estimated during the risk and uncertainty analyses. Benefits include the need to detect negative consequences (important when risks are relatively high and imminent) and the need to decrease uncertainty about the level of risk associated with a particular action (important when uncertainty is high). These benefits are converted into four classes of monitoring priority using the interpretative tables described above. Within each priority class, objectives are ranked by supplementary measures of benefits, and are accompanied by cost estimates based on the ease of monitoring.

Three supplementary features of objectives and goals affect the relative benefits of monitoring: 1) the influence of a goal on other goals, 2) the influence of an objective on a goal, and 3) the recovery period for an objective. Each feature is scored from 1 to 3 (0.5 divisions are permissible); scores are simply added to form a secondary monitoring score ranging from 3 to 9. A fourth feature, the uncertainty about achieving a goal given that all objectives are achieved, is important in considering the scale of monitoring projects, but is not included in the secondary monitoring score.

Uncertainty about achieving a goal increases if important factors are not addressed by listed objectives or if objectives are vague. High, medium and low uncertainty levels are assigned subjectively (score 1 – 3, respectively). If achieving all of the objectives listed under a goal is unlikely to achieve the goal (i.e., high uncertainty), these objectives are relatively less worthy of monitoring at the scale of the Babine Watershed. For example, changing ocean conditions, as well as management activities within the Babine Watershed, impact fish populations. Achieving objectives within the Babine will not necessarily achieve the broader goal of conserving fish. Hence monitoring fish within the Babine without coordination with other projects would be less useful than monitoring a goal that is less influenced by outside factors. A high uncertainty signals the need for a broader-scale monitoring project and coordination outside the Babine Watershed.

Although all goals are assumed to be equally important on their own, some goals depend on others (e.g. maintaining tourism opportunities depends on maintaining fish, which, in turn, depends on maintaining water quality). All else being equal, a goal that influences other goals is more important to monitor. Goals that have one or no dependent goals score 3, goals with two or three dependent goals score 2 and those with more than three score 1.

Similarly, some objectives have a higher influence on a goal than others (e.g. amount of each ecosystem has a higher influence on biodiversity than does pattern of ecosystems). Within a goal, objectives with highest influence score 1, those with lowest score 3; the others score 2. It is important to maintain consistency across goals. Hence, objectives within a goal should score an average of 2: goals with a single objective, or with objectives of equivalent influence, score 2; numbers can be similarly altered to achieve consistency in other cases.

Finally, objectives that recover very slowly or not at all are considered more important to monitor because failure to achieve such an objective has lasting consequences. Recovery potential considers both the unaided recovery period (assuming that land-use strategies are altered) and recovery potential given a significant mitigation effort. Minor mitigative efforts are not distinguished from unaided recovery. If recovery period is longer than 100 years, objectives score 1, if it is between 10 and 100 years, it scores 2, and if it is less than 10 years, it scores 3.

Relative Costs

The Monitoring Framework discusses relative costs in terms of the ease of monitoring for each objective. Some monitoring projects will be relatively easy while others will involve experimental designs and field work that will be costly in both time and money. The assessment of ease is subjective, because it is only possible to estimate actual costs after particular studies are designed. The assessment considers such factors as the need for new data (gathered from field work or remote sensing), the appropriate spatial and temporal scale to achieve meaningful results, the complexity of the design (experimental or retrospective), the need for special skills or equipment, and the complexity of new analysis required.

When sufficient information is available, and monitoring is possible, a simple point system can estimate relative costs (Table 5). For each category, points can be assigned relating to the relative cost of a study. For example, a study of grizzly bear populations would require new field data that is costly to obtain: cost = 3 for that category; whereas a study of epiphytic lichen communities would require relatively cheap field data: cost = 1 for that category. Some categories can have a cost of 0 (i.e. if no new data is required); others cannot (e.g. there will always be some analysis required). The final cost estimate is converted to a four-point scale, where monitoring is easy (cost: 3 – 67, medium (cost: 8 – 10), difficult (cost: 11 – 13) or very difficult (cost: 14 – 16). This approach is crude, but can provide the initial estimates needed to identify the potential costs of a study. Expert opinion will be useful in estimating the costs for particular types of studies.

Table 5. Relative cost estimates based on ease of monitoring.

Category	Cost range
New data: remote sensing (none, easy to obtain, difficult to obtain)	0 – 2
New data: field study (none, easy, medium or difficult to obtain)	0 – 3
New data: study design (none, retrospective or experimental)	0 – 2
Appropriate scale: time (< 2 years, 2 – 10 years, >10 years)	1 – 3
Appropriate scale: space (within watershed, several watersheds, outside Babine)	1 – 3
Special skills/equipment (none, some, much)	0 – 2
Analysis of new or existing data (simple, medium or complex)	1 – 3
Total	3 – 16

The Monitoring Framework does not provide a formula to analyse costs and benefits, but merely lists costs alongside the monitoring priority for each objective. Decisions about which projects to fund will depend upon the priority and upon available funding. For example, a particular high-priority monitoring project that requires 20 years to collect sufficient data might only be started after a lower-priority, but more affordable project, while funding commitments are being put in place. Beginning a 20-year project and stopping after 5 years wastes money, and likely provides little in the way of improved knowledge.

3. Procedures

Creating and Updating Knowledge Base

The Knowledge Base stores the information—on risk and uncertainty, on secondary features and on monitoring costs—necessary to determine monitoring priority. It includes goals, objectives and strategies identified in land-use plans and summarised in Appendix 1. The table below lists the steps taken to fill in the information in the knowledge base.

Table 6. Steps to create knowledge base.

1. Construct a risk curve that explicitly relates an indicator (on the X-axis) to risk to an objective, goal or value (on the Y-axis), using
   a. published literature,
   b. existing curves from other areas or data for similar ecosystems,
   c. expert opinion (preferably based on a workshop with several experts).
2. Estimate uncertainty around the risk curve based on similar sources. Partition uncertainty into different sources, and estimate whether the uncertainty can be resolved. Record uncertainty for each risk class.
3. Use state-of-the-forest report, Bulkley Aquatic Resources Committee reports, other available information and local knowledge to determine current indicator value.
4. Use targets listed in land-use plans to determine probable future indicator value.
5. Determine current and future risks by locating indicator values on X-axis of risk curve and reading estimated risk level off Y-axis.
6. Determine uncertainty around estimated risks based on 2 above.
7. Document supplementary factors that modify benefits, including
   a. uncertainty about achieving goal if all objectives are achieved,
   b. influence of goal on other goals,
   c. influence of objective on goal,
   d. recovery period for objective.
8. Document ease of monitoring using relative cost table for
   a. collecting indicator data (if necessary),
   b. monitoring to improve knowledge and reduce uncertainty (for each type of uncertainty),
   c. monitoring to detect negative consequences.

The Monitoring Framework is designed to be a living document. Its usefulness depends upon regular updates to ensure that the knowledge base contains the most recent information, and that monitoring priorities are based on the most recent information. Each year, the Babine Monitoring Trust should assess the need to revise or update the Knowledge Base prior to determining funding priorities (Table 7).

Table 7. Assessing the need to update the Knowledge Base.

1. Have the results of recent local research and monitoring studies been included in Knowledge Base (see list of updates in Knowledge Base and annual monitoring reports)
   a. if yes, proceed with the framework
   b. if no, note that updating Knowledge Base has a high priority for funding and proceed
2. Has the information in Knowledge Base been reviewed within the last five years by topic experts to incorporate relevant published results from other regions (see review dates in Knowledge Base)?
   a. if yes, proceed with the framework
   b. if no, note that conducting a review is high priority and proceed
3. Is the Table of Monitoring Priorities (Appendix 3) based on the latest version of Knowledge Base.
   a. if yes, proceed with the framework
   b. if no, note that revising the table is a high priority and proceed

Determining Monitoring Priorities

These procedures provide an objective method of determining priorities for monitoring. They pose a series of questions to be answered sequentially and refer to information in the Knowledge Base (Appendix 2) and to tables interpreting this information.

Answers to the questions are used to

- assess features of the goal and objective that influence the benefits of monitoring,
- estimate the current and future risk and uncertainty associated with a particular strategy,
- determine the priority for collecting indicator data (when necessary),
- determine the priority for monitoring to improve knowledge and reduce uncertainty,
- determine the priority for monitoring to detect negative consequences,
- estimate the ease of collecting indicator data and of monitoring to improve knowledge or to detect negative consequences, and
- determine priorities for other actions.

The procedures are designed to be followed in order. The supporting information needed to answer the questions are usually contained in the Knowledge Base (Appendix 2)—advice from topic experts may also be helpful, particularly if the Knowledge Base has not been updated recently.

The Monitoring Framework includes Tables of Monitoring Priority (Appendix 3) obtained from following the procedures with currently available data.

Assess secondary features of goal that influence monitoring priority

For each goal in the Land-use Plan Summary, answer the following questions:

1. What is the uncertainty (low, medium, high) about achieving the goal, given the objectives (see Knowledge Base)?

2. Does this goal have a low, medium or high influence on other goals (see Knowledge Base)?

Assess secondary features of objective that influence monitoring priority

For each objective under a given goal, answer the following questions:

3. Does this objective have a low, medium or high influence on the goal (see Knowledge Base)?

4. What is the recovery period (short, medium, long) of this objective (see Knowledge Base)?

Determine secondary monitoring score (used to refine monitoring priority)

For each objective under a given goal, answer the following questions

5. What is the secondary monitoring score, based on features of the goal and the objective (sum the scores from questions 2 – 4 as shown in Table 8)?

Table 8. Features of goals and objectives that determine secondary monitoring score (lower scores have higher priority)

Category	Range*
Influence of focal goal on other goals (High = 1, Medium = 2, Low = 3)	1 – 3
Influence of focal objective on goal (High = 1, Medium = 2, Low = 3)	1 – 3
Recovery period of objective (Long = 1, Medium = 2, Short = 3)	1 – 3
Total = Secondary Monitoring Score	3 – 9

* 0.5 divisions are permissible

Estimate current and future risk and uncertainty

For each indicator under a given objective, answer the following questions:

6. Are there sufficient data about current and future indicator levels to estimate risk (see Knowledge Base)?
   - If yes, go to next question.
   - If no, is a rough estimate of the indicator value still possible?
     - If yes, record that an estimate was made; priority for collecting indicator data is 2 (medium); consider increasing uncertainty related to risk estimates; go to next question.
     - If no, priority for collecting indicator data is 1 (high); stop.

7. Based on current indicator values, what is the current risk to the objective (low, medium, high), and related uncertainty (low, medium, high; see Knowledge Base)?

8. Based on indicator targets and strategies, what is the future risk to the objective (low, medium, high), and related uncertainty (low, medium, high; see Knowledge Base)?

Determine priority for monitoring to improve risk curves

For each indicator under a given objective, answer the following questions:

9. What is the current priority for improving risk curves (use Table 9 and current and future risk and uncertainty estimates)?

10. What is the future priority for improving risk curves (use Table 9 and current and future risk and uncertainty estimates)?

Table 9. Priority for improving risk curve based on estimated risk and uncertainty.

		Risk		
		High	**Medium**	**Low**
Uncertainty	**High**	1	1	1
	Medium	2	1	2
	Low	3	3	3

11. What is the overall priority for improving risk curves (use Table 10 and priority estimates from questions 9 and 10)?

Table 10. Overall priority for improving risk curve based on current and future priorities.

		Current Priority		
		1	**2**	**3**
Future	**1**	1	1	2
Priority	**2**	2	2	3
	3	3	3	4

Determine priority for monitoring to detect negative consequences

For each indicator under a given objective, answer the following questions:

12. What is the current priority for detecting negative consequences (use Table 11 and current and future risk and uncertainty estimates)?

13. What is the future priority for detecting negative consequences (use Table 11 and current and future risk and uncertainty estimates)?

Table 11. Priority for detecting negative consequences based on estimated risk and uncertainty.

		Risk		
		High	**Medium**	**Low**
Uncertainty	**High**	2	2	2
	Medium	1	2	3
	Low	1	2	3

14. What is the overall priority for detecting negative consequences (use Table 12 and priority estimates from questions 11 and 12)?

Table 12. Overall priority for detecting negative consequences based on current and future priorities.

		Current Priority		
		1	**2**	**3**
Future	**1**	1	2	3
Priority	**2**	1	2	3
	3	2	3	4

Estimate ease of monitoring

For each indicator under a given objective, answer the following questions:

15. Is the priority for collecting indicator data either a one or a two?
    - If yes, how easily can indicator data be collected (easy, moderate, difficult, very difficult)?
    - If no, do not estimate ease of collecting indicator data.

16. Is the priority for improving the risk curve either a one or a two?
    - If yes, how easily can uncertainty around the risk curve be resolved (easy, moderate, difficult, very difficult; use Knowledge Base and Table 13)?
    - If no, do not estimate ease of resolving uncertainty.

Table 13. Relative cost estimates based on ease of monitoring: Easy: total = 3 – 6, moderate: total = 7 – 11; difficult: total = 12 – 16).

Category	Cost range
New data: remote sensing (none, easy to obtain, difficult to obtain)	0 – 2
New data: field study (none, easy, medium or difficult to obtain)	0 – 3
New data: study design (none, retrospective or experimental)	0 – 2
Appropriate scale: time (< 2 years, 2 – 10 years, >10 years)	1 – 3
Appropriate scale: space (within watershed, several watersheds, outside Babine)	1 – 3
Special skills/equipment (none, some, much)	0 – 2
Analysis of new or existing data (simple, medium or complex)	1 – 3
Total	3 – 16

17. Is the priority for detecting negative consequences either a one or a two?
    - If yes, how easily can negative consequences be detected (easy, moderate, difficult, very difficult; use Knowledge Base and Table 13)?
    - If no, do not estimate ease of detecting negative consequences.

Determine priority for other actions

For each indicator under a given objective, answer the following questions:

18. Is uncertainty about achieving a goal high (given that the objectives are achieved; Question 1)?
    - if yes, consider broadening scale of project and cooperating with other agencies.

19. Is future risk high and future uncertainty low (use future risk and uncertainty estimates)?
    - if yes, note need to review land-use direction and consider amending objective, strategy or target (risk and uncertainty estimates indicate that objectives will not be met by strategies).

20. Is future risk low and future uncertainty low (use future risk and uncertainty estimates)?
    - if yes, confirm land use direction

21. Are current and future risks and uncertainties low (use current and future risk and uncertainty estimates)?

- if yes, consider using objective as a control in a larger study

22. Is risk decreasing over time from a high current value to a moderate or low future risk with moderate or low uncertainty (use current and future risk and uncertainty estimates)?
    - if yes, this objective is a high priority for implementation monitoring

23. Is current or future uncertainty high and a large part of the uncertainty irresolvable (use current and future uncertainty estimates and see Knowledge Base)?
    - If yes, consider decision analysis to decide whether to change the strategy to allow for uncertainty.

Create a list of monitoring priorities for collecting indicator data

For all goals, objectives and indicators with missing indicator data (current or future values; estimated or not), complete the following steps:

1. Record whether current or future indicator values are missing for each indicator.
2. Record the priority for collecting indicator data (question 6).
3. Record the secondary monitoring score (question 5).
4. Record the ease of collecting indicator data (question 15).
5. Sort the indicators in order of priority for collecting indicator data.
6. Within each priority group (all indicators that have same priority), sort the indicators by the secondary monitoring score.

Create a list of monitoring priorities for improving the risk curve

For all goals, objectives and indicators with existing or estimated indicator values, complete the following steps:

1. Record whether current or future indicator values are estimated.
2. Record the priority for improving the risk curve (question 11).
3. Record the secondary monitoring score (question 5).
4. Record the ease of resolving uncertainty around the curve (question 16).
5. Sort the indicators in order of priority for improving the risk curve.
6. Within each priority group (all indicators that have same priority), sort the indicators by the secondary monitoring score.

Create a list of monitoring priorities for collecting indicator data

For all goals, objectives and indicators with existing or estimated indicator values, complete the following steps:

1. Record whether current or future indicator values are estimated.
2. Record the priority for detecting negative consequences (question 14).
3. Record the secondary monitoring score (question 5).
4. Record the ease of detecting negative consequences (question 17).
5. Sort the indicators in order of priority for detecting negative consequences.
6. Within each priority group (all indicators that have same priority), sort the indicators by the secondary features score.

Select monitoring topics to fund

There are now three lists of monitoring topics. The relative benefit of monitoring a particular indicator within a list is shown by the order of the list; the relative cost, expressed as the ease of monitoring, is shown next to each indicator. As a default assumption, each list has an equal priority. Note, however, that lack of indicator data limits the scope of the other monitoring priority lists. The final benefit-cost analysis and selection from each list is left to the discretion of the decision-makers. Reviewing the relevant information in the Knowledge Base may help distinguish amongst candidate monitoring topics.

4. Definitions

Goal: broad aim listed in land-use plan

Objective: specific, measurable aim listed in land-use plan beneath broader *goals*

Strategy: management strategy listed in land-use plan designed to achieve an *objective* or *goal*; measurable strategies can be expressed as *indicators* plus *targets*

Indicator: measurable index of a *strategy*; used as the X-axis in risk curves

Target: level of *indicator* listed in land-use plan; used to determine the X-value on *risk curves* to estimate future *risk* and *uncertainty*

Risk: probability of not achieving an *objective* (i.e. of a severe consequence); used as the Y-axis in *risk curves* to determine relative benefits of *effectiveness monitoring*; at "low" risk, even well-designed studies are unlikely to detect any severe consequences to the objectives; at "high" risk, most studies will detect severe consequences to the objective; at "medium" risk, some studies will detect consequences, and others will not; the severity of consequences are not included within the risk curves but are considered as *secondary features*

Risk curve: explicit diagram of the best-guess relationship between an *indicator* and estimated *risk* to an *objective*

Uncertainty: the width of the band around a *risk curve* showing the possible actual risks associated with a particular indicator value; used to determine relative benefits of *effectiveness monitoring*; "high" uncertainty means that actual risk can shift two classes from the level estimated from the risk curve (i.e., risk varies from low to high), although the level suggested by the risk curve is still more probable; "medium" uncertainty means that potential risk can shift one class either side; "low" uncertainty means that actual risk is very likely within the class estimated from the risk curve

Implementation monitoring: studies that ask whether strategies are being followed and whether targets are being met.

Effectiveness monitoring: studies that ask whether *strategies* (or *targets*) achieve *objectives* and *goals*; i.e. studies of the consequences of following designed management strategies

Ease of monitoring: estimate of relative cost of *monitoring* study based on type of study, need for special skills or equipment, and appropriate spatial and temporal scale for meaningful results

Secondary features: features of *goals* and *objectives* that influence the benefits of *effectiveness monitoring*

5. List of Appendices

Appendix 1: Land-use Plan Summary

Appendix 2: Knowledge Base

Appendix 3: Monitoring Priority Tables

Appendix 4: Annual Monitoring Plan Template