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Selection and Modeling of Sustainability Indicators for the Fraser River Basin

Final Report

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Selection and Modeling of Sustainability Indicators for the Fraser River Basin

Final Report

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EXECUTIVE SUMMARY

The Fraser River Basin is one of the fastest growing regions in Canada and it accounts for the majority of British Columbia's population and economic production. Policy-makers and residents alike are concerned that future quality of life in the Basin may decline if its resources are not managed sustainably. A large number of groups have expended considerable effort to define sustainability goals and, to a lesser extent, select sustainability indicators. Many hope that collection and monitoring of such indicators will provide important policy guidance to decision-makers and will also provide a means for tracking sustainability.

This project was designed as a practical experiment to investigate the selection and modeling of sustainability indicators on an ecosystem basis. The goals are: (i) to select indicators that could be linked to an operational definition for sustainability within the Fraser River Basin; (ii) to assess the accessibility, quality and relevance of the best available data for developing such indicators; (iii) to apply conventional and state-of-the-art modeling techniques for discerning the linkages among indicators in the Fraser River Basin; and, (iv) to provide recommendations for further indicator selection and modeling research.

The major methodological conclusions of this research program focus on the following themes:

1. It is important to link sustainability goals to movements of a *small slate of individual indicators*; single indicators can rarely be linked to any specific sustainability goal.

2. The *poor quality, inaccessibility and irrelevance* of existing data are more pervasive constraints to reliable indicator modeling than is commonly thought.

3. Modeling is most appropriate at *aggregated spatial scales* such as provinces or large watersheds; modeling at smaller ecosystem-based spatial levels is feasible but unreliable.

4. *Linking the use of deterministic and qualitative modeling approaches* is a useful means for projecting indicators and discerning important policy linkages. By contrast, conventional statistical modeling approaches are frequently inappropriate because of unreliable or non-commensurable data.

The implications that this has for future work in the realm of indicator selection and modeling is, in our view, quite profound. In general, it implies a significant reduction in indicator specification efforts, indicator modeling and model interpretation:

1. In contrast to much of the current indicator work, which relies on selecting a large number of detailed specific indicators, it would be more fruitful to focus attention on a small number of indicators within selected 'indicator classes' (such as economic, social, environmental or human health indicators). The precise specification of the indicator within each of these classes is of less consequence.

2. Indicator modeling work should focus on larger scale systems, as opposed to smaller ecosystem units.

3. Indicator modeling work is most suited to identifying qualitative policy trade-offs and implications on large systems, rather than to forecasting specific indicators. Modeling efforts should focus on such general policy-related tasks.

4. Data gathering efforts should not be increased, but, for the most part, can be scaled down substantially. This can be achieved by insuring that data gathering be informed - but not unduly constrained - by available model frameworks.

5. Greater focus is required on modeling frameworks that can use incomplete data sets or qualitative information, including 'fuzzy logic' models, advanced neural network models, and other such 'non-statistical' techniques. Linking existing model structures (such as input-output models) to external qualitative models is also important.

I. INTRODUCTION

The ecological, economic and social health of the Fraser River Basin, in British Columbia (B.C.), is under intense pressure from a growing population, accelerated resource extraction and rapid economic development. The Basin, which covers some 232,000 sq km and is home to about 60% of British Columbia's population, consists of four major sub-basins: Nechako, Upper Fraser, Thompson, and Fraser (Table 1 and Figure 1). Some of the more significant impacts on the environment include: (i) land-use degradation from inappropriate agricultural practices, large-scale mining development, and non-sustainable forestry; (ii) water pollution from agricultural intensification, industrial development and human settlements; (iii) water depletion from over-abstraction; (iv) air pollution from industry and transport; and, (v) biodiversity loss from habitat destruction and environmental degradation. Addressing such degradation, with its concomitant economic and social pressures, is a strong impetus for developing appropriate policies of sustainable development for the Fraser River Basin.

To identify sustainability, much work has been done in the selection of 'indicators' that will assist policy-makers in identifying appropriate policies and in monitoring the effectiveness of policy interventions. Such indicator exercises have often been criticized for degenerating into a collection of long 'laundry lists' of variables or into compendiums of historical statistical data. Interpretation of these measurements and data becomes cause for disagreement among analysts, and many indicator exercises have retreated into philosophical discussions relating to the meaning and implications of sustainable development. While all of these exercises have, no doubt, provided a more critical basis for selecting indicators, most policy-makers continue to be frustrated by the lack of tangible progress in identifying one or two useable indicators that are easy to understand and not too expensive to measure.

The more common criticisms of indicator work can be narrowed down to three methodological barriers that are seldom adequately addressed. First, indicator exercises often lack an ecosystem-based perspective. Many focus on political boundaries or on the reference frames of small interest groups without paying attention to how indicators fit within a given ecosystem (for the purposes of this study, we are referring to a specific spatial framework, as opposed to conceptually defining the ecosystem). Second, indicator exercises typically lack a projective perspective; they are often snapshots of current conditions or, more typically, elaborate descriptions of past conditions. Third, they ignore linkages among various policy goals associated with sustainability; indicators dealing with social conditions, economic conditions, and environmental quality are addressed in isolation of each other.

This study is an attempt to break through some of these barriers. It uses the Fraser River Basin to select and to model sustainability indicators, but places additional emphasis on: (i) selecting an appropriate ecosystem unit; (ii) conducting a dynamic projective analysis; and, (iii) addressing explicitly the linkages between indicators and policy levers.

Table 1. Selected Demographic Indicators for the Fraser River Basin

	Area sq km	Population 1991	Population Growth 1971-1991
Nechako Sub-basin	46 939	73 802	1.12%/yr
Upper Fraser Sub-basin	65 949	55 575	2.21%/yr
Thompson Sub-basin	55 991	146 984	1.95%/yr
Fraser Sub-basin	63 094	1 662 105	2.25%/yr
Total Fraser River Basin	231 973	1 938 466	2.17%/yr

There are many aspects of this work that are experimental. In essence, this study sought to answer one relatively simple and practical question: "Is it feasible and meaningful to identify indicators within a specific ecosystem unit, and to model them as a dynamic system that provides insights into policy trade-offs and indicator linkages?" In answering this question, the study sheds light on a number of issues such as:

1. Linkage of given indicators to *operational definitions* of sustainability. The study process synthesized over 150 published 'sustainability goals' from 12 different sources of relevance to the Fraser River Basin, to arrive at an indicator framework that would accommodate most of the issues and goals stated in these publications.

2. Quality and relevance of existing *data sources* for conducting such modeling. An extensive data gathering and screening task obtained published and unpublished data related to the Fraser River Basin, to the 4 discrete sub-basins within the Basin, and to 19 different 'sub-sub-basins' within these sub-basins. Historical data over the period 1971 to 1991 were assessed for over 100 data series relating to economic, environmental, human health, demographic, and institutional indicators.

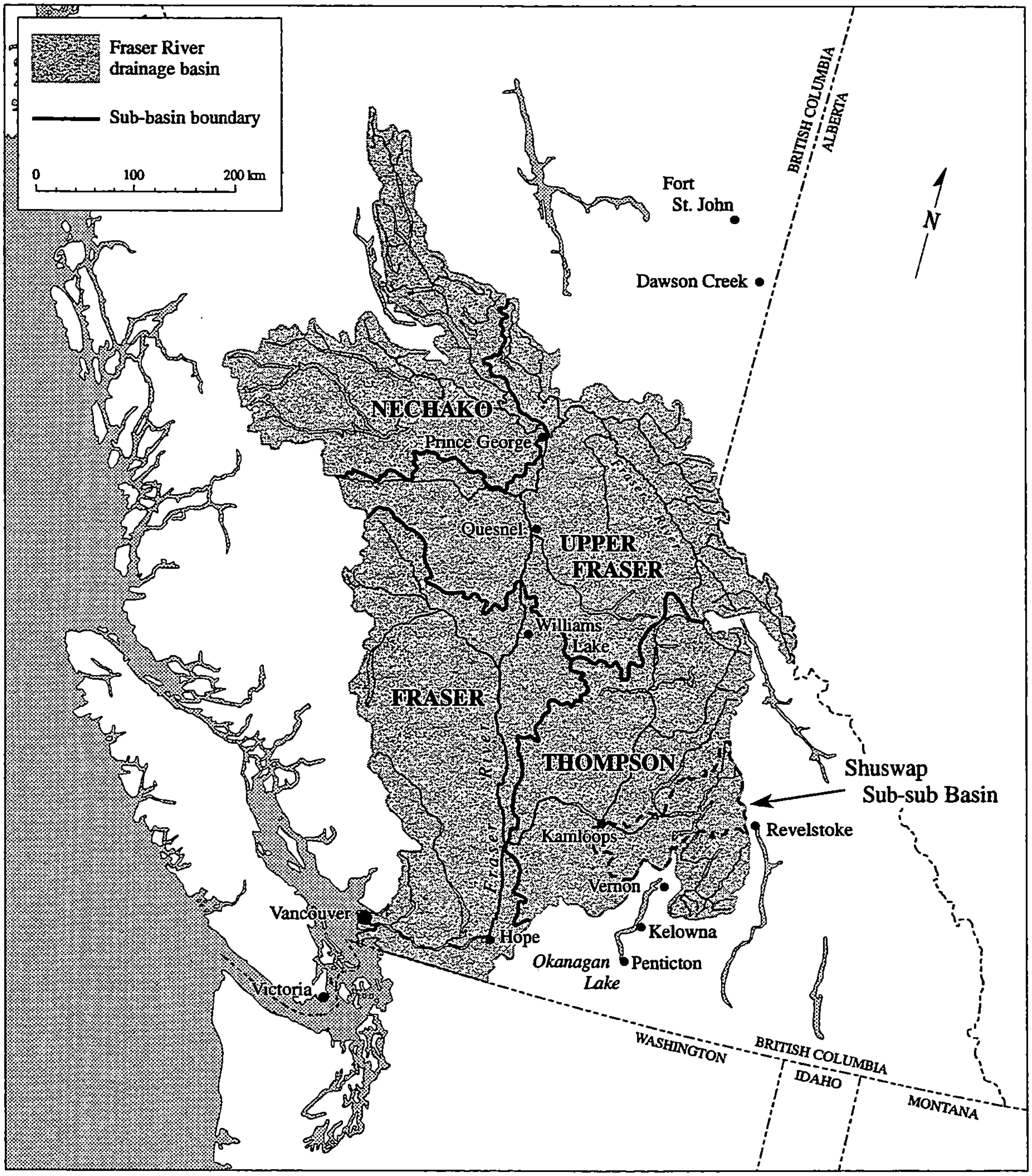
3. Types of *models* and ecosystem units that are most appropriate for conducting such analyses. Three sets of model frameworks – including simple correlation models, a deterministic input-output model, and a dynamic complex system model – were applied and linked at an aggregated level of the Basin; in addition, an experimental 'hotspot' model was specified in the Shuswap area (Figure 1).

These exercises provide further insights into how future indicator selection and modeling efforts should be designed.

A number of major themes arise from this work relating to sustainability goals, data quality, and the scale and nature of modeling exercises. Each of these is highlighted within a separate section of this report. Section II focuses on "A Sustainability Framework for the Fraser River Basin", highlighting an operational framework that was selected for this exercise; the major theme of this section relates to the use of a slate of indicators. Section III summarizes the "State of Data in the Fraser River Basin"; the major theme of this section relates to the pervasive constraints in using existing information for the types of analyses typically required in policy-oriented modeling. Section IV, entitled "State of Modeling in the Fraser River Basin", summarizes results of the modeling efforts and highlights themes relating to the most practical scale for analysis and the most practical modeling framework for projective analyses. Section V summarizes the major policy and research implications of the work. Selected summaries of previous background documents, and of the detailed modeling results, are provided in a separate technical document.[1]

[1] Summaries of relevant portions of earlier working papers are presented in Annexes A, B and C in the technical supplement to this report.

Figure 1. The Fraser River Basin showing the Nechako, Upper Fraser, Thompson, and Fraser sub-basins. The Shuswap sub-sub-basin is also shown (boundaries as defined by the former Inland Waters Directorate of Environment Canada).



II. A SUSTAINABILITY FRAMEWORK FOR THE FRASER RIVER BASIN

Theme 1. "It is important to link sustainability goals to movements of a *small slate of individual indicators*; single indicators can rarely be linked to any specific sustainability goal."

Substantial effort has been expended in B.C. and elsewhere in defining the meaning of 'sustainable development.' The only major point of consensus from these efforts is that sustainable development means different things to different people. In this study, for example, sustainability 'goals' were extracted from recent working groups involved with planning or policy debate in the Fraser River Basin. These included the Commission on Resources and Environment (CORE), the B.C. Round Table on Economy and Environment, Environment Canada, B.C. Ministry of Environment, Lands and Parks, B.C. Ministry of Health, the Sustainability Reporting Task Force of the Fraser River Management Program, and the Westwater Research Centre's Fraser River Basin Project. A polling of these bodies yielded no fewer than *157 sustainability goals* for the Fraser River Basin.

Reducing the many different specific goals to a small set of general goals resulted in a synthesis into five broad categories (Box 1 and Annex A in Technical Supplement). These five, as a set, were capable of addressing the plurality of issues raised by various stakeholders. It is evident, however, that individual stakeholders will want different levels of emphasis on any given goal, or will want to focus on specific aspects within each general goal. The main impetus behind specifying a small number of general goals, however, was to permit an eventual evaluation of tradeoffs among these goals within a modeling framework.

Box 1. Sustainability Goals for the Basin

- Maintain ecosystem integrity and diversity.
- Meet basic human needs for social and economic development.
- Maintain intergenerational distribution and options.
- Improve intragenerational distribution and entitlements.
- Improve local empowerment and decision-making.

There are two conceptual elements (or assumptions) of the approach used in this project that are different from many other indicator studies. These elements reflect: (i) flexibility in the set of values; and (ii) decision-making using a process of 'procedural rationality'.

Flexibility in the value set raises a general issue of how values, objectives, targets, and indicators are related. In the case of the Fraser River Basin, with the wide diversity of values and goals of various interest groups and decision-makers, the general tact taken within this project, was to select the indicator set and the modeling environment in a manner that could flexibly accommodate a plurality of values or goals. *Procedural rationality* refers to the existence of a decision-making process that occurs within an environment of (i) a plurality of goals and values; and (ii) inherent uncertainty. It assumes the existence of long-term decision-making structure that may change the specific values, goals or targets through time as previously uncertain outcomes become revealed. Decisions made at any point in time within such a structure, stated simply, attempt to 'satisfice' a set of prevailing goals at that time. It contrasts to the 'conventional rationality' assumptions of neo-classical economics to the extent that it permits perfectly rational decisions that might, over time, appear to be inconsistent or erratic. The role of 'indicators' in such a 'procedurally rational' process is that the indicator set must be capable of addressing different goal sets at different times.

It is evident from the stated goals of the agencies involved in the Fraser Basin, that there is a plurality of issue areas that needs to be considered. These issues can be categorized according to the broad system that they address: (i) ecological (air, water, land, and biota); (ii) economic (production and consumption); (iii) social (cultural and human security); and, (iv) institutional. Further, each issue area has three primary dimensions: (i) present state of the system; (ii) intergenerational distribution ('options'); and, (iii) intragenerational distribution ('entitlement').[2] All of these issues and dimensions should be tracked through time (i.e., each indicator of a state, intergenerational distribution, or intragenerational distribution dimension is specific to one moment in time). Box 2 shows the resultant matrix framework for the selection of a small set of indicators. Key attributes of this framework include:

(a) an indicator of 'entitlement' - whether it is economic entitlement or ecological entitlement (such as access to safe drinking water) - will often have important underlying social dimensions. The social aspects of sustainability will therefore be inherent throughout much of the indicator set.

(b) 'culture and human security' - within this framework - is interpreted in the broad sense and potentially includes, for example, religious freedoms, health, literacy, democratic freedoms, security of social structures (e.g., family units), and incidence of crime.

(c) 'institutional' issues give heed to the increasing concern within the literature for 'sustainable institutions.' Institutional issues within British Columbia, for example, potentially include private property rights, industrial concentration, taxation, and government function and accountability.

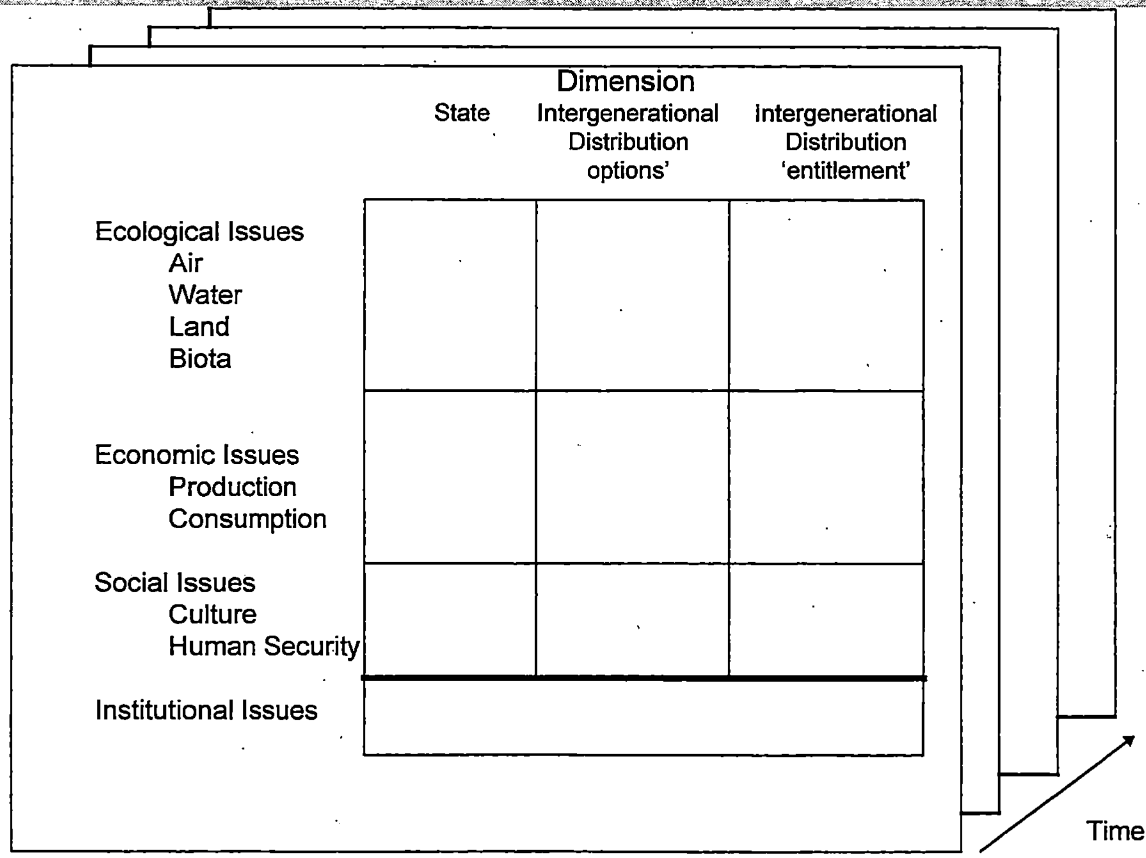
The project focuses on indicators that, while being critical to a particular identified issue, do not necessitate the adoption of a particular value judgement (e.g. this indicator must go up for the Fraser River Basin to be sustainable). In addition, it focuses on selecting indicators that are 'multiple-telling' through covering more than one of the issue areas. Also, in recognition of the 'stress-response' function duality, some of the selected indicators for data collection focus on 'stress' and others on 'response'; that is, indicators will represent human activity stressors, physical or chemical stressors to the environment, or will represent biological responses (both by humans and natural biota) to those stressors.

The selection of indicators of sustainability for the Fraser River Basin followed four main idealized criteria: (i) ability to aggregate meaningfully to the basin and sub-basin levels; (ii) availability of a comprehensive annual time series; (iii) rationale of the indicator linkage with an appropriate dimension of an issue area; and (iv), cost and accessibility of the data. It was often necessary to compromise the first two criteria in order to obtain a representative indicator data set. (Refer to

2 A fourth dimension - spatial distribution within the Fraser River Basin - is also identified. This dimension, however, is addressed in the modeling of the indicators.

Technical Supplement, Annex A for further detail). Box 3 shows the selected indicators for this Fraser River Basin study. An outline of the rationale (issue linkage) behind the selection of each indicator is in Appendix 1 of this report.

Box 2. An Indicator Framework



The final indicator short-list exhibited a number of other important properties, which we believe are critical to indicator selection for linkage modeling:

1. Efficiency of Indicator. Indicators were selected that could, potentially, reflect more than one issue area or dimension simultaneously. For example, an indicator of human health (e.g., respiratory illness) may provide insights into both the human condition as well as the condition of air quality. The use of an efficient indicator set implies that modeling of the indicators will, in turn, be easier and, equally important, it reduces the overall information acquisition or gathering costs.

2. Functionality of Indicator. Most projective system modeling casts information within some form of 'cause-effect' framework, even if the cause-effect relationships are

relatively specious. Indicators that may provide a 'link' in such a chain are therefore preferred for indicator modeling. In this study, a conventional 'stress-response' functionality was adopted in selecting indicators; the final indicator slate represented an acceptable balance between stress functions and response functions.

3. Flexibility within Changing Goal Structure. A key assumption of all of the projective modeling activity is that goals will, inevitably, change. It would be naive to assume that, given the plurality of sustainability goals that currently exists, the relative weights or even the fundamental emphases will be fixed in perpetuity. As more information becomes available, as preferences change, or as other factors become important, it is inevitable that the basic operational definition of sustainability will in itself change; what is acceptable today may be completely unacceptable 20 years from now.

The flexibility of the indicator set, as noted in the last item above, has rather broad (and admittedly potentially contentious) implications for the selection of indicators. The practical implications this has for the indicator set is that: (i) it is non-tautological; and, (ii) movements in individual indicators or in the set of indicators are non-normative.

A non-tautological indicator set simply prevents the goals themselves from becoming indicators. For example, if a goal were stated as "increase number of jobs held by women" and an indicator were defined as "the number of jobs held by women", then the linkage is clear but trivial; it permits no exploration of the linkage of broader goals to general movements in the indicator set.

A non-normative indicator set permits different interpretations of the same set of indicators. In practice, this implies that an indicator is again detached from a specific goal. For example, while everyone may agree that gross domestic product (GDP) is an important economic indicator, we might disagree as to whether GDP should be increasing, stable, fluctuating or decreasing. A modeling environment that reflects such non-normative indicators will have greater policy applications.[3]

In summary, these considerations imply that *any single indicator can not itself be linked to any specific sustainability goal on a one-to-one basis.* Moreover, *interpretation of a given indicator set may itself depend on the relative weights of sustainability goals.* In particular, the indicator set that is chosen for the Fraser River Basin is intended to reflect a relatively small number of tractable indicators that can be used to address a plurality of sustainability goals.

[3] We acknowledge, however, that selection of an indicator set may, itself, be a normative procedure. By saying that we are focusing on human development goals, ecological diversity, or on the options of future generations, we are clearly making normative judgments that these factors are, in one way or another, important. This 'higher level' of normative selection can be separated from the individual movements of indicators that are eventually selected. Again, the example of GDP is instructive: by selecting it within an indicator set we are saying (normatively) that economic production should have some bearing in decision-making. Interpretation of its desired movements can, however, be a separate issue.

Box 3. Selected Indicators for the Fraser River Basin Indicator Study			
	State	**Intergenerational Distribution (options)**	**Intragenerational Distribution (entitlement)**
Air	-SO_2, CO, and ground level ozone* -respiratory disease incidence rate -[sectoral emissions]	-skin cancer incidence rate	-respiratory disease incidence rate by gender -skin cancer incidence rate by gender
Water	-[BOD generation]	-municipal wastewater treatment by type	-proportion of population served by municipal water
Land	-area of farmland -ratio of timber volume billed to area harvested	-intensity of agricultural fertilizer application -proportion of forest harvested by clear-cutting	-urban population partition
Biota	-recreational boat angler days*	-salmon escapement* -ratio of forest land area planted to harvested	-forest recreation site and trail use
Production	-labour force -unemployment rate	-bankruptcy rate -municipal solid waste disposal rate	-proportional employment in resource industry
Consumption	-water use -income	-water intensity -investment income	-income distribution
Culture	-ethnic diversity -religious diversity	-ethnic diversity -religious diversity	-educational attainment
Security	-crime rate -economic dependency -in migration rate -rate of death by external cause	-educational attainment -cancer incidence rate -live birth rate	-cancer incidence rate by gender -ratio of average house price to rental rate* -economic dependency by gender
Institutional	-proportional employment in public utilities and administration	-proportional employment in finance	-rate of home ownership -average rural farm size

notes: -indicators denoted with * are site specific.
-some indicators are "multiple-telling", yet their multiple placement is not necessarily noted.
-[ ] denotes indicators to be estimated during modeling process.

III. STATE OF DATA IN THE FRASER RIVER BASIN

Theme 2. "The *poor quality, inaccessibility and irrelevance* of existing data are more pervasive constraints to reliable indicator modeling than is commonly thought."

When indicator 'wish lists' are developed, analysts of sustainable development typically disregard the efforts that might be required to monitor conditions, to gather information, or to prepare secondary analyses of the raw data. Consequently, at an implementation level, indicator monitoring exercises often fail (or are down-scaled) to reflect the realities of high data acquisition costs. Alternately, the required volumes of data seem to be generated by sacrificing data quality and reliability. In either case, the 'demand' for indicators far exceeds the realistically available 'supply', and an ad hoc process of filling in the information gaps often ensues.

As noted previously, a key goal of this study was to assess the ability of *existing* information sources to provide indicators at an *ecosystem* (in this case, river basin) level that are relevant to *projective* modeling. A rigorous data gathering exercise was initiated to compile all potentially relevant indicators that might meet these conditions (Annex B and Annex C in Technical Supplement). In addition to the Fraser River Basin and the 4 sub-basins within it, the basic geographic unit that was used for recording information was the sub-sub-basin. Both provincial and federal sources of information were used, along with some "experimental" information sources obtained from taxation and census statistics which were provided geographically coded on an ecosystem basis. Where the volume of information was excessive, secondary analyses were conducted to generate new indicators (such as a religious diversity index based on individual religions) or to aggregate existing indicators (such as aggregation from small census districts to watershed sub-sub-basins; refer to Annex C in Technical Supplement for an outline of the calculation of these indicators).

The general verdict of the data quality review is that data reliability is worse than what is normally represented to be the case. This has exceedingly significant implications for many existing exercises which rely on data that are represented, among other things, to be measured independently on an ecosystem basis.

The reasons for 'excluding' indicators are most readily seen with reference to a specific example (Box 4), in which indicators were selected for eventual inclusion within the complex system models. Of a total of 130 candidate indicators,[4] 83% of these were excluded because they could not be used meaningfully in a statistically valid exercise. The majority of the exclusions, 68 indicators in total, arose because the indicators were found not to be independently estimated (as was commonly represented). In these cases, the sub-sub-basin statistics correlated perfectly

[4] For the purposes of data gathering, a total of 130 data series were defined, based on the original basket of 39 indicators. For example, the 'labour force' indicator was disaggregated to include data series for each of the 16 specific sectors specified in the deterministic model. For the complex systems modeling, the 130 data series were reduced eventually to a final set of 11 data series (Box 4).

Box 4. The Indicator Selection/Exclusion Sieve (for the complex systems modeling)

A number of data quality control procedures were applied in selecting the indicators that would be used in the final modeling. The steps outlined below show the 'exclusion exercise' that selected the indicators used in the complex system model.

It should be noted that the original set of 39 indicators could, in fact, be represented as approximately 130 different indicators once various levels of spatial aggregation were applied or different types of indices were used. For example, the 'income distribution' indicator was tested using 2 different quintile cutoffs, as well as a GINI index, before final selection was made.

Potential Exogenous Indicator Set	130 indicators
Exclusions in First Level Screening	- 88 indicators
Final Screened Data Set in Correlation Models	42 indicators
Exclusions in Second Level Screening	- 31 indicators
Final Exogenous Indicator Set in Complex System Model	11 indicators

Control Procedure	Reason for Exclusion	Examples	Exclusions
Non-Independent Measurement	Indicators linearly extrapolated from others.	Labour Force, Employment	68
Non-Commensurability compared to others.	Indicators cannot be statistically Salmon Escapement	Ambient SO2,	20
Insufficent Observations	Cross-section or time series too limited.	Replanting	20
Redundancy	Highly correlated to other indicators.	Cancer Rate	9
Independent Behaviour	No linkages detected.	GINI, Ethnic Diversity	2

with those at a provincial level, implying that a simple estimating procedure (usually a linear estimation based on relative populations) had been used at the generation stage to estimate the indicator for the sub-sub-basin. While this estimating procedure may be a valid means for providing an approximation for that indicator in that sub-sub-basin, it completely undermines the credibility of analyses that unwittingly rely on such data to draw important policy conclusions. For this reason, all such data were excluded from the statistical analyses included in the models.

Another statistical reason for excluding information series was the non-commensurability of the data (20 series were excluded for this reason) or the limited sample size (which also caused rejection of 20 indicators). These information series – which included indicators such as recreational angler days, salmon escapement, concentration levels of pollutants at specific sites, and others – provide important measures but, as with much of the 'ecological' data for the ecosystems, the measurement conventions did not permit comparisons to be made *in a statistical framework* to the other indicators.[5]

The general trend, for all indicators, was that data reliability tended to degrade as the system size became smaller. This reflects the fact that most information is, still, aggregated to a high (provincial) level before being disaggregated again to smaller ecosystem-based units.

There are, however, two exceptions to this generally discouraging verdict regarding data quality. First, administrative data based on income tax returns or census data were used reliably to aggregate from a small measurement unit (postal code zone or census division) to a larger unit (the sub-sub-basin). The drawback to using such administrative data, however, is that data acquisition is expensive, the time series that are available are limited to demographic and economic information, and some of the currently available information will become suppressed in future censuses to reflect cost-cutting measures by government. Second, provincial healthcare statistics that were locally recorded showed strong evidence of being independently and accurately monitored; aggregating these to a sub-sub-basin level was a feasible exercise. Such human health statistics would therefore warrant closer consideration in future exercises.

Scenario Development and the Futuring Exercise

The first paragraph of this report identified a number of significant impacts associated with population growth and economic development in the Fraser River Basin. These included: (i) land-use degradation from inappropriate agricultural practices, large-scale mining development, and non-sustainable forestry; (ii) water pollution from agricultural intensification, industrial development and human settlements; (iii) water depletion from over-abstraction; (iv) air pollution from industry and transport; and, (v) biodiversity loss from habitat destruction and environmental degradation. These impacts, along with a qualitative assessment of the future direction of various activities (social, economic and environmental) in the Basin were identified in a one-day meeting and follow-up futuring exercise with 16 key stakeholders involved in sustainability research in the Fraser River Basin. This exercise was used to generate the types of changes in final demand -- and hence, economic and pollutant output-- that might be expected. This process was used to *guide* the development of scenarios (the attempt was not to identify specific scenarios in this process).

Two approaches were used. First, some of the key problems/impacts in the Fraser River Basin were identified in general discussion and through small group meetings. Second, using these key problems, a futuring exercise was designed to assess what types of impacts might occur in the future given these problems. The futuring exercise was based on the development of a "futures wheel," in which a specific problem or variable is identified and then a set of first, second and third round impacts are speculated. For example, if one assumes continued economic growth (at a given rate), a first round impact might be continued atmospheric pollution. This, in turn, might lead to more restrictive environmental policies, and so on.

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[5] Such information would, however, be a useful input to non-statistical modeling procedures; these are taken up in Section V.

Given the experimental nature of this study, the scenario development and futuring exercise were used simply as *guides* to allow the modelers to make projections or hypothesize scenarios within the framework of the futuring discussion. If the sustainability framework presented here was applied to a specific region for planning purposes, then the futuring exercise could be carried out in a more rigorous manner to obtain specific scenarios for analysis.

IV. State of Modeling in the Fraser River Basin

Theme 3. "Modeling is most appropriate at *aggregated spatial scales* such as provinces or large watersheds; modeling at smaller ecosystem-based spatial levels is feasible but unreliable."

Theme 4. "*Linking the use of deterministic and qualitative modeling approaches* is a useful means for projecting indicators and discerning important policy linkages. By contrast, conventional statistical modeling approaches are frequently inappropriate because of unreliable or non-commensurable data."

Many would regard it as pure folly to attempt to model something as complex as the Fraser River Basin; it is, after all, one of the most productive watersheds in the country and includes one of the most dynamic cities in the world-Vancouver. But the general goal in any modeling exercise is to provide a simplified representation of the real-life system. Attempts to model real-life systems in too fine a detail invariably get bogged down in complexities, which in turn hinder understanding the linkages and dynamics within the system. Modeling the Fraser River Basin is no different; reliable and stable models are often characterized by a relatively small number of variables. Some of these variables exactly mirror conditions in the real-life system, while others are meant as proxies. The challenges for developing a simplified model for the Basin are: (i) to be able to replicate known conditions reasonably well within the model; (ii) to do so using available information; and, (iii) to be able to optimize or simulate future conditions under various control 'scenarios'.

Three different modeling approaches were adopted in the Fraser River Basin: (i) correlation modeling using pair-wise and multivariate analyses (Annex D in Technical Supplement); (ii) deterministic modeling using input-output structures with satellite accounts for environmental impacts (Annex E in Technical Supplement); and, (iii) complex system models using qualitative policy variables linked to dynamic and non-linear quantified indicators (Annex F in Technical Supplement). The models are tied together by using the relationships derived from the correlation and deterministic models to help define and tune the complex system models. Detailed descriptions of the model equations, the linkages among indicators, and indicator sources, can be found in the Annexes. Spatial modeling in the correlation studies is done at three different scales: (i) the Fraser River Basin as a whole; (ii) the four individual sub-basins; and, (iii) 19 selected sub-sub-basins in the Basin.[6] The deterministic modeling is conducted exclusively at the largest scale (Fraser River Basin as a whole), while the complex system modeling is conducted at the Basin level and at an experimental 'hotspot' level corresponding to the Shuswap sub-sub-basin. This section summarizes the models, highlights selected results, and identifies key themes and modeling implications.

[6] Three of the 19 sub-sub-basins are actually just outside of the Fraser River Basin – they represent the Okanagan Lake area – but were included within the correlation studies to provide a greater cross-section of 'pooled' data that would be relevant to the immediately adjacent Shuswap area.

Correlation Models

Correlation models are commonly used to describe linkages among indicators. These range from complicated multivariate econometric models to very simple models that track the correlation between two variables. In principle, they can be used to determine whether correlations are: (i) positive, negative or neutral; (ii) strong or weak; and, (iii) immediate or time-delayed. Many such correlation models have underlying structural models that may attribute some cause-effect relationship. But the nature of the statistical techniques usually constrains such modeling exercises to describing coincidental correlations from which the analyst must infer underlying structures given other knowledge or information.

Correlation studies for the Fraser River Basin were conducted on a 'screened' set of 42 indicators (Box 4). For each of these 42 indicators, there was a theoretical maximum of 115 observations on which to conduct the correlations; this maximum corresponds to observations for 5 years (1971, 1976, 1981, 1986 and 1991) over 23 different ecological units (19 sub-sub-basins and 4 sub-basins). However, for 20 of the 42 indicators (e.g., 'replanting') there was a statistically insufficient number of observations. After excluding these 20 indicators, a reliable set of 22 indicators were tested in various pair-wise and multiple regressions. Box 5 shows the 22 indicators selected.

Box 5. Selected Sustainability Indicators for Modeling

employed labour force
total labour force
labour in resource industries
unemployment rate
urban partition
crime rate
net in-migration rate
per capita value added from manufacturing
bankruptcy rate
GINI coefficient
respiratory disease rate
cancer rate
live birth rate
ASMR
university education
per capita water consumption
ethnic diversity index
proportion connected to water
ratio of forest land to harvested
ratio of timber area billed to harvested
religious diversity index
population

Two stages of correlation modeling were conducted: a data screening stage and a data analysis stage. Data screening was undertaken to check general data quality and coverage. This pointed to a number of limitations in the data such as exact unity in correlation coefficient, suggesting that some data for each sub-sub basin were simply allocated according to provincial proportions. Thus, subsequent analyses focused on a smaller subset of what were regarded as potentially more reliable data. The data analysis stage provided a basis for identifying pair-wise quantitative linkages and values in other models. The pair-wise analyses were used to isolate potential linkages, which were then more formally explored through multivariate analyses. Table 2 provides a diagnostic summary of the results of these analyses, indicating the extent and nature of linkages within designated indicator 'sets'.

The following selected conclusions from this exercise are notable:

1. Some variables (e.g., GINI coefficients, ethnic diversity) showed independent behavior that was not significantly linked to any other potential explanatory variable.
2. Some variables with potentially multiple determinants could be adequately explained by a single variable. For example, crime rates were strongly correlated to urbanization and the following variables did not provide any additional explanatory power to variations in crime: migration levels, bankruptcies, poverty levels, and unemployment levels.
3. Some variables could be explained by multiple linkages. For example, the set of variables [unemployment; resource sector activity; general health] could be estimated as a linked system of equations.
4. Some variables demonstrated apparently perverse (counter-intuitive) yet statistically significant behavior. For example, water use per capita was inversely correlated to income per capita; as incomes go up, water use intensity goes down. This likely reflects the fact that industrial water use at the margin is less water intensive than is municipal water use.
5. Some variables were shown to be adequate proxies for other similar variables (for example, many of the health indicators were highly correlated, suggesting that not all need to be included in a model of general social conditions).

The major utility of the correlation models is that they permit: (i) screening out poor data; (ii) identification of an efficient indicator set through removing redundant indicators; and, (iii) estimation of specific relationships.

Table 2. Selected Summary of Multivariate Correlation Studies	
Indicators Set	**Linkages Detected and Modeling Implications**
Employed Labour Force; Total Labour Force	Perfectly correlated (R^2=0.9992): Not independently estimated. May use one or the other interchangeably in Complex System Model.
Proportion of Labour employed in resource industries; unemployment rate; urban partition	Correlated at 95% significance level (t=2.04 and t=4.15); use estimated elasticities in Complex System Model.
Unemployment rate; urban partition	Correlated at 95% significance level (t=2.39); use Resource Employment Share (RESEMPLSH) as Complex System Proxy.
Crime rate; urban partition (URBPART); net in-migration rate (MIGIN); per capita value added from manufacturing enterprises (VALADDPC); bankruptcy rate; GINI coefficient; unemployment rate (UNEMPL)	Significant correlation between CRIME and URBPART (t=2.22), independent of other explanatory variables: MIGIN (t=0.40); BANKRUPTCY (t=1.44); VALADDPC (t=1.02); GINI (t=0.20); UNEMPL (t=0.74); Focus on urban partition as explanatory proxy indicator for CRIME and others within Complex System Model.
Health indicators: Respiratory disease incidence rate; cancer rate; live birth rate; age standard mortality rate of death by external cause (ASMR); time [7]	High levels of correlation among all variables. Focus on any one health indicator in Complex System Model as proxy and exclude others. Lower levels of autocorrelation detected in ASMR.
Unemployment rate; age standard mortality rate of death by external cause	Moderate potential linkage between health and unemployment (R^2=0.34). Use a variable linkage in Complex System Model permitting sensitivity tests.
Proportion of +15 population with some university education; unemployment rate; net in-migration rate; per capita value-added from manufacturing enterprises	Education positively correlated to income (t=2.1) and independent of others; use explicit link between education and income within Complex System Model.
Per capita water consumption; per capita value-added from manufacturing enterprises	Significant negative correlation (t=2.00). Use computed income elasticity at means with Complex System Model.
GINI coefficient; [Other] [8]	Uncorrelated; GINI exhibits statistically independent behaviour.
Ethnic diversity index; [Other]	Uncorrelated; Ethnic Diversity exhibits statistically independent behaviour.
Per capita water consumption; proportion of population connected to municipal water supplies; urban partition	Uncorrelated.
Ratio of forest land area planted to harvested; ratio of timber area billed to area harvested; time	Uncorrelated; insufficient degrees of freedom to obtain statistic significant results.

[7] "Time" signifies tests for auotcorrelation on annual data that were gathered for some variables.
[8] "Other" signifies a representative cross-section of other key indicators.

Deterministic Model

The deterministic modeling component is based on the set of 1990 input-output economic accounts for British Columbia. These accounts describe the structure of production in an economy and are widely used around the world to track flows of goods and services between industries in a given region, between industries and their customers, and between different regions. The basic structure of an input-output table is simply an accounting framework of inter-industry dollar flows. Additional columns are added to represent final demand sectors; these represent the goods that are purchased by consumers or the government, or that are privately invested or exported. Additional rows are added to represent payments to government and labour. The Canadian tables, which are regionalized by province, are of a commodity-by-industry type and are available in three different levels of aggregation. This study used tables corresponding to the small (or S) level of aggregation, which includes 43 commodities and 16 industries; these were further reduced to a 'square' 16 by 16 industry matrix and subsequently augmented to include final demand sectors and environmental satellite accounts. Basically, these tables provide an economic 'snapshot' of a regional economy for a given year. These data tables form the basis for the calculation of 'technical co-efficients' which indicate the level of technological development of a given economy.

To assess the linkages between indicators, the deterministic modeling focused on environmental and economic indicators and, in particular, on the generation of waste products associated with economic activity. Economic activity here is represented by dollar transactions between industries in the regional economy. Because of the availability of data (which must be assigned to one of the 16 economic sectors), the model structure focused on air contaminants, economic output, and employment. Eight airborne pollutants were selected for this study: total particulate matter (TPM), carbon monoxide (CO), nitrous oxide (NOx), sulfur dioxide (SO2), volatile organic compounds (VOCs), carbon dioxide (CO2), methane (CH4), and chlorofluorocarbons (CFCs).[9]

Given that the final demand sector contains the demand by households, government or exports, the model can then be used to assess the impacts of changes in any of these sectors on any given indicator. The futuring exercise, mentioned earlier, helped to generate the types of changes that might be expected and provided input to the set of scenarios that were subsequently developed. For the Fraser River Basin as a whole, four scenarios are simulated over a fifteen-year time horizon that started in the base year of 1990 (the year of the input-output table and the pollution accounts). Summary results of these scenarios are shown in Box 6. How reliable are these projections? They provide an estimate of the general increase or decrease in pollution which can be expected given specific changes in final demand. The analysis is a static one; that is, it is assumed the level of technology remains constant over time and that prices do not change (and no product substitution is allowed).

[9] Any indicator which has a link to the economic activity of the input-output sectors could be used in the satellite accounts. To demonstrate the utility of the deterministic modeling, the generation of waste products was the focus of this study, since the most reliable links to economic output - in terms of the data available for the Basin, are with these indicators.

Box 6. Deterministic Model Results

The scenario development and futuring exercise noted above provided general guidelines for the types of scenarios which could be used in the deterministic modeling. From these guidelines, the project team selected four specific scenarios which could be used to demonstrate the utility of the deterministic model. These scenarios - described briefly below - were based on three general trends identified in the futuring exercise: (I) continued population growth in the Basin (at the same rate as in the 1980s); (ii) a decline in government services due to a downsizing of the public sector; and (iii) continued export demand for forest products. The four scenarios are:

#D1 **Retail Trade increases at 3.6% per year** (some of which is due to tourism). The assumption was that the increase in retail trade over the past decade would continue at the same rate it did in the 1980s, in response to continued population growth in the Fraser River Basin.

#D2 **A decline in the final demand for Community, Business and Personal Services by 15% by year 2005.** In this scenario, there is a decline in the government demand for certain services based on expected cutbacks in social services. While it is possible that this demand will be made up from other final demand categories (i.e., households), the objective was to isolate the impacts of government cutbacks to one sector.

#D3 **Increase in the demand for Forest Products by 1.5% per year**. This is an 'export driven' scenario, resulting from the implications of NAFTA and increased demand from abroad. The amount is consistent with annual increases in the demand for that sector's output from 1984 to 1994.

#D4 **Construction increases by 2.6% per year**. Again, this is a population growth-driven scenario, and reflects the historical growth in the demand for construction and the expected population growth for the Fraser River Basin over the next decade.

Change in pollution emissions (by 2005) from base year of 1990 because of changes in final demand:

Scenario	TPM	CO	NOx	SOx	VOC	CO2	CH4	CFCs
#D1	2.34%	2.36%	2.51%	2.42%	2.48%	2.44%	1.93%	11.80%
#D2	-1.01%	-1.17%	-2.03%	-1.17%	-3.83%	-0.73%-	0.72%	-2.97%
#D3	1.11%	0.99%	0.63%	0.15%	0.39%	0.31%	0.18%	0.08%
#D4	13.14%	13.27%	11.60%	14.36%	9.99%	12.29%	11.72%	7.39%

The examples illustrate that deterministic modeling, despite the constraints of linear functions and fixed technology, is a useful exercise in linking indicators of sustainability, particularly economic and ecological ones (and, more specifically, economic indicators and waste production). Social indicators, such as religious diversity or crime, are more difficult to link to economic activity and, therefore, are less amenable to the type of modeling posed here. Nevertheless, deterministic modeling has three appealing features. First, such models explicitly recognize the links between and among indicators. Second, they give a general sense of the magnitude of the changes which can be expected given various policy and other scenarios. Finally, they can provide useful input into other qualitative modeling exercises, such as the complex system models used in this study.

Complex System Models

The science of 'complexity' focuses on the analysis of adaptive systems that exhibit complex behaviour. A complex adaptive system's four distinct attributes are: (i) there are agents in the system that act in parallel; (ii) these agents are organized along many layers and are capable of re-organizing and self-organizing; (iii) they operate by sets of 'rules' which, in effect, are equivalent to the anticipation of future events and conditions; (iv) the complex system allows niches of certain types of activity to establish themselves. Many systems have been found which fit into such a description, including: economic structures, living organisms, neurological networks, and ecosystems. Common features of such systems are that they generate 'surprises' and that certain types of phenomena 'emerge' as a result of system complexity. The only effective means found to date to investigate these phenomena is the use of simulation. Describing such systems has led to the development of complex system simulator models that augment simple deterministic cause-effect models.

One risk in using complex system models is that they have a tendency to become overly complex. There is often a temptation to try to 'model the entire system' which can add complexity without necessarily adding to understanding. The models in the Fraser River Basin complex model set were developed through progressively increasing the complexity of the indicator linkages until the models became 'unstable', and then simplifying the models such that they were stable yet were still able to replicate existing conditions moderately well.

There are a number of major advantages to using complex system models in the Basin. First, they reflect the existence of adaptive feedback loops that occur in the system; population migration in and out of the region is one of the most obvious feedbacks to changing economic, social and environmental conditions. Second, complex models provide a framework for specifying qualitative relationships that still allows meaningful modeling of the system. Third, unlike deterministic models which are fundamentally linear in nature, complex system models allow non-linear relationships to be specified for the entire system or for selected 'hotspots' within the system. Finally, policy variables or institutional arrangements can themselves become part of the dynamic 'rule set' of the complex system. The Fraser River Basin models, for example, include a built-in health care response policy variable that is endogenously sensitive to the level of pollution generated within the model.

The major data requirements for complex system models involve the use of time series of high level indicators coupled with knowledge (or hypotheses) of linkages among indicators. These linkages can also be specified as policy variables, which in effect allow explicit modeling of the 'rules' by which the system behaves.

For this research, a prototype example of a complex system model was developed for the Fraser River Basin as a whole. The prototype model draws from the complete set of all indicators on which the data were collected to demonstrate model structure and hypothetical linkages in four sectors: economic activities; social conditions; environment; and, policies and institutions. The prototype model was subsequently simplified to remove 'unnecessary' or inefficient indicators. Complexity was also reduced to improve system stability. The resultant model structure was then further fine-tuned for the Fraser River Basin to develop a set of four base models as described below.

The Basin complex model set consists of four 'base' models (i) a Backcast Model used to develop approximations for many of the control parameters within the model. The model is based on conditions from 19971-1991. It was tuned with a view to hitting 1991 targets that were consistent with the 1991 Forecast Model (Box 7); (ii) a Forecast Model used to project conditions for the entire Fraser River Basin from 1991 onwards. Its design is based on a combination of qualitative policy variable controls, estimated coefficients from the correlation studies, and tuned approximations based on 1971-1991 simulations developed through the Backcast Model (iii) a Linked Forecast Model used to provide a forecast linked to those of the Deterministic Model. This is linked to a single sensitivity scenario in the deterministic model, primarily through the pollutant coefficients, although the production forecasts and population forecasts in this simulation are also tuned to coincide to those in the deterministic model; and, (iv) a Hotspot Model for the Shuswap sub-sub-basin whose structure is identical to the Forecast Model, although its estimated coefficients and initial values are based on sub-sub basin data. Each of these uses a simplified set of linkages between various indicators, along with sets of 'policy dependent' indicators that could be controlled by policy makers. Elasticities based on the correlation models, pollution

Box 7. Complex System Model for the Fraser River Basin – Projection Accuracy

The base case Fraser River Basin model was 'backcast' to 1971 to ensure that the values generated over a 20 year forecast were stable (a full statistically meaningful fit was not calculated as the number of observations were not adequate; specific readings were available, at best, for only 5 years). The backcasting was not done for the hotspot as the viable data set for the hotspot was smaller than was that for the Basin as a whole.

The method of backcasting is as follows: (i) model structure and linkages are established based on a rule set of dependencies among variables; (ii) start values for 1971 are entered into the model; and, (iii) the model is run without additional interventions until the year 1991. Projected results for 1991 are compared to actual results of a selection of 'auditable indicators' which are generated internally within the model and which can be verified against actual indicators; a target of plus or minus 10% accuracy was established for the 20 year time horizon. A higher accuracy target is achievable but it results in greater model complexity which, when applied to the Forecast model beyond 1991, generated unrealistic instabilities (such as projected attainment of 100% urbanization) under certain scenarios.

The following shows the projection accuracy of the final model:

Indicator	Description	Deviation*
GDP	Gross Domestic Product for Fraser River Basin	+ 7.8%
POPTOT	Total Fraser River Basin Population	- 8.6%
CRPLND	Total Fraser River Basin Area in Cropland	- 0.3%
POLLUTION	Weighted Pollution Index Linked to Damage Function	+ 9.7%
ASMR[10]	Proxy Human Health Index	+ 2.8%

* (Projected - Actual) after 20 years

coefficients based on the deterministic model, and starting values based on 1991 observations, were used in the forecasting exercises. The STELLA modeling environment was used to provide forecasts of up to 30 years (Technical Supplement Annex F).

[10] Age standard mortality rate of death by external cause

As with the deterministic model, the complex models are run using different 'scenarios'. The scenarios in the complex model are, however, conceptually different from those in the deterministic model. The deterministic model stipulates, for example, demand growth exogenously and then projects any changes in environmental impacts based on model coefficients. In the complex model, however, many indicators are determined within the model as the model steps through each year of the scenario; the only exogenous inputs relate to policy levers or to external influences such as world demand. The eleven indicators that are maintained in the final complex system model are shown in Box 8.

Box 8. Eleven Indicators Maintained

labour force
labour in resource industries
unemployment rate
urban partition
crime rate
net in-migration rate
per capita value added from manufacturing
bankruptcy
ASMR
university education
per capita water consumption

For example, while population growth is exogenous in a deterministic model, the complex models treat population growth as an endogenous variable determined by birth rates, death rates, and net migration to the region (which in turn depends on economic and other conditions). As such, no direct mapping of the deterministic model scenarios and the complex model scenarios is normally possible.

The complex system model scenarios therefore focused on the sensitivity of projections to changes in the rule base or to changes in external policy variables (Box 9). In all situations, the base 'reference case' corresponds to: (i) exogenous growth (ie, external demand for all products) of 1.5% per year; (ii) a land policy that selectively reduces the amount of cropland by 1% annually; (iii) a health policy that increases healthcare efforts in direct response to increased pollution damages. Simulation results are also presented for a case where the complex model is linked to the deterministic model in a fashion that constrains final economic growth in both models to be the same.

The complex system model can be used to interpret specific policy tradeoffs and indicator linkages. Any given interpretation will rely on a comparison of two or more scenarios. For example, in scenario #C2 the health/unemployment linkage[11] is removed and compared to the base case (#C1). There are, clearly, an infinite number of comparisons that might be made. Some specific interpretations - based on the results shown in Box 9 and Technical Supplement Annex F - are that:

1. Removal of the health/unemployment linkage (#C2) demonstrates that higher growth and population would have been projected had this linkage been ignored.

2. When health policies fail to adjust to higher pollution loads (#C3), there is a further decrease in economic production.

3. Doubling the amount of cropland removed from production in an active conservation scenario (#C4) leads to economic output levels that are about 20% less than the reference

[11] See Table 2 for health indicator linkages.

case. It is noted, however, that per capita GDP is only about 4% lower; the feedback adjustments of migration in effect permit standards of living to be relatively unaffected.

4. In the 'linked' scenario (#L1), the complex model projects average population growth over the period to be 2.83% per year, compared to the linear deterministic model which assumes 2.24% per year. The higher population growth in the complex model projections is attributed to a 'feedback' response from increasing migration levels.

Box 9. Complex System and Linked Model Results

Selected scenarios are presented to demonstrate the results of the complex system models at the Basin and Hotspot (Shuswap) levels. Unless otherwise noted, results are presented for a 30 year simulation.

#C1 Reference Case. This corresponds to the simulation with all rule sets and policy variables at default values.

#C2 Remove Health/Unemployment Linkage. This demonstrates the model's adjusted feedback response to a change in the rule base. In the reference case, unemployment rates are linked to human health whereas in this scenario the link is nullified.

#C3 Decreased Pollution Response. This simulates the impact of changing a policy variable related to pollution response. In the reference case, the rule base assumes a 'fully mitigative policy' which automatically increases healthcare expenditures as pollution damages increase. In this scenario, the policy response is set to 'zero' to show the impact of no mitigative response; additional scenarios could be shown for any level between these two extremes, of course.

#C4 Enhanced Conservation Policy. This simulates the impact of doubling the amount of land set aside for explicit conservation by removing it from productive agricultural land. In the reference case, agricultural land availability is lost from two major sources: urban encroachment and explicit conservation. This scenario increases the proportion attributable to conservation.

#L1 Linked Reference Case. This corresponds to a 15 year projection (for the Fraser River Basin alone) in which the economic growth and pollution forecasts are constrained to those in a simulation of the Deterministic Model; population is determined endogenously within the complex model. The corresponding deterministic model results show average economic growth of 3.5% per year and population growth of 2.24% per year.

Forecast Model for Fraser River Basin

		1991	2021				2006
Indicator	Description	Base	#C1	#C2	#C3	#C4	#L1
GDP	GDP Index	100	162.02	163.06	161.57	128.61	167.88
POPTOT	Population Index	100	167.76	168.63	167.37	139.49	151.99
WATER	Water Use	1 377	2 326	2 338	2 321	1 952	2 047
POLLUTION	Pollution Index	60	93	93	93	84	93
ASMR	Human Health Index	0.54	0.73	0.73	1.35	0.73	0.63

Forecast Model for Shuswap Area

		1991	2021			
Indicator	Description	Base	#C1	#C2	#C3	#C4
GDP	GDP Index	100	136.42	137.39	136.22	110.36
POPTOT	Population Index	100	118.50	119.16	118.36	102.24
WATER	Water Use	38	44	44	44	38
POLLUTION	Pollution Index	10	14	14	14	11
ASMR	Human Health Index	0.32	0.51	0.51	0.68	0.51

Modeling Implications

It is clear from the examples in this section that modeling effectiveness depends a great deal on the scale of the analytical unit. While different watershed scales were addressed by the various model structures, the most successful and reliable modeling is associated with the aggregated spatial scales:

1. In the correlation modeling, data quality became less reliable at smaller scales.
2. The deterministic modeling is, because of the nature of the input-output frameworks, particularly useful at an aggregate spatial scale; that is, the provincial level or large watershed level. Deterministic modeling can also be used to provide estimates of the structure of regional economies in watersheds which cross provincial (or international) borders, assuming the input-output tables are compatible. However, its utility is limited at the sub-basin or sub-sub-basin level, due to inadequate or suppressed data.
3. Complex system models can be designed at virtually any scale because some of their features are qualitative in nature. The reliability of such models is, however, suspect at smaller scales because of poorer data quality at these scales and lack of an historical audit framework; the historical data were adequate at the Fraser River Basin level to test model reliability over a 20 year backcast, but this was not possible for the Shuswap sub-sub-basin model.

These models are particularly useful in discerning linkages between indicators and policy variables in a projective setting. In the case of the deterministic modeling, for example, the development of satellite accounts can be a major contribution to better understanding how changes in one indicator – or sets of indicators – affect other indicators. This applies to economic-ecological linkages, although some social indicators could potentially be included as well. In the case of the complex system models, the inclusion of qualitative policy variables permits analysts to assess tradeoffs even where data are relatively sparse.

Most important, the conclusions and results derived from the various modeling efforts are all relatively consistent and can be used in complementary analyses; it is clear that time is better spent focusing on a small number of indicators which can be linked at fairly aggregate spatial levels. Once modeling moves to the more local level the benefits are far outweighed by the costs of data acquisition and the problems of data availability and reliability. A corollary to this is that statistical modeling techniques that focus and rely on extensive disaggregated data series will be expensive to support and, in the end, will have questionable reliability.

V. SUMMARY AND POLICY IMPLICATIONS

This project focused on the Fraser River Basin with a view to identifying and modeling indicators at various ecosystem scales in a forward-looking framework. The central themes and conclusions that arise from the Basin research are that: (i) sustainability goals should be seen in the context of a relatively small slate of indicators; (ii) data quality and reliability are generally poor; (iii) modeling at large aggregate scales is an effective approach; and, (iv) linking deterministic and qualitative models is a useful means for projecting indicators and discerning linkages.

But what are the specific directions that indicator research – in the Fraser River Basin and elsewhere – should take in view of these conclusions? The directions require, in our view, a considerable refocusing of efforts on many fronts. In general, it implies a significant reduction in indicator specification efforts and information monitoring and collection, and a significant reorientation of indicator modeling and model interpretation efforts. Specifically, the following actions are warranted:

1. In contrast to much of the current indicator work, which relies on selecting a large number of detailed specific indicators, it would be more fruitful to focus attention on a small number of indicators within selected 'indicator classes' (such as economic, social, environmental or human health indicators). The precise specification of the indicator within each of these classes is of less consequence.[12] Work in the Fraser River Basin, for example, found that many indicators were closely correlated (and hence substitutable) and that a proliferation of indicators did not necessarily improve the reliability of models to provide informed policy guidance.

2. Indicator modeling work, and any ancillary data gathering that might be required, should focus on larger scale systems, as opposed to smaller ecosystem units. This represents a major re-orientation from more recent efforts. Work for the Fraser River Basin showed that data at the smaller ecosystem level were not reliable, even when they were represented as being independently estimated; most frequently, small ecosystem level data were in turn estimated based on higher levels of aggregated data. Furthermore, models of large scale systems are more readily linked together because they can rely on commensurable data; many of the data that were available at the small ecosystem level were non-commensurable and could not be used reliably in statistical analyses.

3. Indicator modeling work is most suited to identifying qualitative policy trade-offs and implications on large systems, rather than to forecasting specific indicators; modeling efforts should focus on such general policy-related tasks. Much indicator work has ignored the policy angle, focusing instead on estimating – at times to an allegedly high level of precision – the movements of specific indicators. In reality, most policy choices

[12] A corollary to this is that there is no reason, from a modeling perspective, to require all jurisdictions to collect exactly the same type of information. Such a 'harmonization' approach is currently being advocated for international monitoring projects but, if experience from this study can be extended elsewhere, it is clear that past efforts at harmonization have not necessarily provided more reliable information.

and judgments are relatively imprecise; it is incongruous to attempt precise indicator forecasting when the underlying driving policy choices are themselves fairly vague.

4. Data gathering efforts should not be increased, but, for the most part, can be scaled down substantially. The most reliable and promising 'alternative' data that we accessed in this study were those associated with human health; these were easily cast at smaller ecosystem system scales and could be readily aggregated to higher levels. Again, however, it would not be necessary to monitor and model a wide range of health indicators.

5. Greater focus is required on modeling frameworks that can use incomplete data sets or qualitative information. The techniques used in this study, for example, each ran into substantial constraints when they started to rely on conventional 'statistical' approaches to modeling: (i) the correlation models could provide only partial information because of the non-commensurability or incompleteness of data sets; (ii) the deterministic model could not be applied to smaller scale systems because of lack of a statistical database; and, (iii) the complex models could not be adequately tuned for small-scale systems because of incomplete historical data. Only when these three techniques were combined, and further enhanced by the inclusion of qualitative policy variables, could the data be used efficiently in a variety of policy applications. In addition, it is likely that other more advanced quantitative modeling techniques (which were not used here) could make more efficient use of the data that are available. The most promising of these techniques are likely to be 'fuzzy logic' models, advanced neural network models, or other 'non-statistical' rule-based techniques that rely on expert judgment.

If there is one key lesson to be learned from this exercise it is perhaps this:

> **"The selection and modeling of sustainability indicators is far from an exact science; it will likely remain a judgmental art for some time to come."**

Appendix 1. Outline of the Linkage Between Indicators and Issue Areas	
Indicator	**Issue Linkage**
SO_2, CO, and ground level ozone	-contributing agents to acute environmental degradation.
respiratory disease incidence rate	-response to air-born contaminants.
sectoral emissions	-degree of taxation on the natural environmental assimilation abilities.
skin cancer incidence rate	-response to excessive radiation exposure partly due to long-term deterioration of ozone.
BOD generation	-degree of taxation on the natural environmental assimilation abilities and potential for hyperbiological activity.
municipal wastewater treatment by type	-degree of taxation on the natural environmental assimilation capacity.
proportion of population served by municipal water	-personal health.
area of farmland	-potential land area for agricultural production.
ratio of timber volume billed to area harvested	-efficiency of timber production.
intensity of agricultural fertilizer application	-potential depletion of natural soil nutrient base, or conversely, enhancement of productive capabilities.
proportion of forest harvested by clear cutting	-potential for soil erosion and loss of biotic base, or conversely, efficient use of a land resource.
urban population partition	-distribution and type of land use.
recreational boat angler days	-pressure on aquatic resource base.
salmon escapement	-potential for maintenance of fishery stocks.
ratio of forest land area planted to harvested	-potential for maintenance of forest stocks and/or transformation of the forest to monoculture.
forest recreational site and trail use	-direct access and exposure to the natural environment.

continued ...

Indicator	Issue Linkage
labour force	-production potential.
unemployment rate	-utilization of labour force.
bankruptcy rate	-stressor on future investment potential.
municipal solid waste disposal rate	-efficiency of resource use.
proportional employment in resource industry	-direct dependency on resource base.
water use	-taxation and use of the water resource base.
income	-potential for consumption.
water intensity	-income relation of water use for consumption.
investment income	-propensity to save and invest.
income distribution (e.g.,GINI coefficient)	-equitable distribution of the potential for consumption.
ethnic diversity	-cultural diversity and base for future generations.
religious diversity	-cultural diversity and base for future generations.
educational attainment	-exposure to diversity of culture and ideas, and security of future provisions.
crime rate	-personal safety.
economic dependency	-economic consumption security.
in migration rate	-neighbourhood stability.
rate of death by external cause	-personal safety.
cancer incidence rate	-uncertainty of long-term health risks.
live birth rate	-provision of future generations.
ratio of average house price to rental rate	-accessibility of secured home tenure.
proportional employment in public utilities and administration	-institutional ability for public sector provisions.
proportional employment in finance	-institutional ability to provide for savings and investment.
rate of home ownership	-personal home entitlement.
average farm size	-distribution of land entitlements.