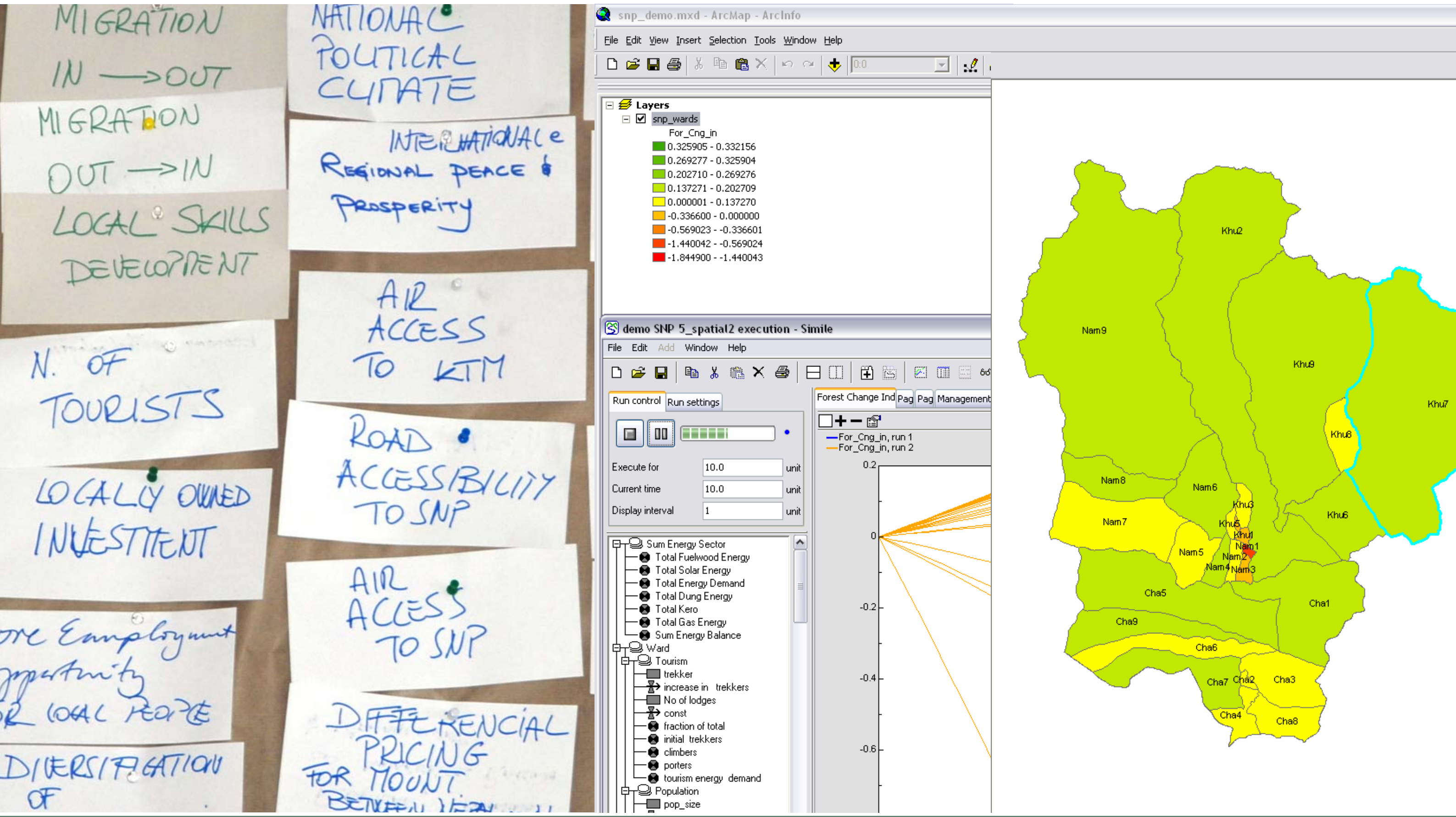
HKKH Partnership
for ecosystem management

Decision Support Toolbox Design

Participatory and computer based components



HKKH Working Papers

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About the HKKH working papers

In the framework of the HKKH Partnership Project several technical papers have been developed by the four Partners and the Technical Team. Before being finalized and published, these documents require further collaborative work and review by a wide range of resource persons and stakeholders. The **HKKH working papers** is a selection of draft documents printed and distributed in a limited number to share the wealth of knowledge developed so far and stimulate feedback and debate.

For additional information and any queries, please contact the PMU at info@hkkhpartnership.org.

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LIST OF ACRONYMS

CESVI	Cooperazione e Sviluppo
CKNP	Central Karakoram National Park in Pakistan
DEM	Digital Elevation Model
DGCS	Directorate General for Development Cooperation, Italian Ministry of Foreign Affairs
DNPWC	Department of National Parks and Wildlife Conservation
EMM	Ecosystem Management Model
Ev-K2-CNR	Ev-K2-CNR Committee
GIS	Geographic Information System
ICIMOD	International Centre for Integrated Mountain Development
ICT	Information and Communication Technologies
IUCN-ARO	IUCN Asia Regional Office
QNP	Quomolongma Nature Preserve
RDBMS	Relational Data Base Management System
RONAST	Royal Nepal Academy of Science and Technology
SAARC	South Asian Association for Regional Cooperation
SNP	Sagarmatha National Park
TAR-China	Tibet Autonomous Region of PR China
TRPAP	Tourism for Rural Poverty Alleviation Project
HKKH	Hindu Kush-Karakoram-Himalaya
DSS	Decision Support System
SES	Social and Ecological System or Socio-Ecosystem
CSD	Causal Look Diagram
SFD	Stock and Flow Diagram

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1 Executive Summary

The HKKH Partnership Project (ref. HKKH General Operation Plan) aims to accomplish institutional consolidation and capacity building for systemic management of mountain socio-ecosystems. The Project methodology will be applied at three test sites in the HKKH mountain ranges, including Sargarmatha National Park (Nepal), Central Karakoram National Park (Pakistan), and Quomolongma Nature Preserve (Tibetan Autonomous Region of China). These protected areas embody specific social and ecological systems (SES) characterized by differing governance institutions. The primary tool of the Project, developed through a participative and adaptive approach, will be the Decision Support Toolbox (DST), with the aim of addressing the needs of different of stakeholders to support key components of the decision-making process in SES management. The DST includes hard and soft system methodologies, such as participatory modules and computer based tools. Designed to be appropriate to the present and projected operating conditions of SES across spatial and temporal scales, the DST is customized to the technological infrastructure of each area, and takes into account the step-by-step processes necessary to make it operational by the end of the Project period. The DST will not only be applicable to the targeted areas, but also as a tool for general socio-ecosystem management across the globe.

2 Methodological Objectives

- To provide useful information to support the management of complex socio-ecosystems at the landscape level.
- To account for the biophysical and human dimensions in linked socio-ecosystems.
- To support the iterative process of adaptive management.
- To improve the use of scientific knowledge in management practices and decision-making processes.
- To account for socio-ecosystem processes occurring at different spatial and temporal scales.
- To use a management-oriented research perspective of socio-ecosystems (as opposed to a descriptive approach).
- To develop a socio-ecosystem analysis according to a systemic or holistic approach, highlighting interconnections among system elements, causal relationships, and overall system behavior.
- To provide assessments of possible impacts of alternative management options through simulation of system states for given scenarios.
- To adopt an interdisciplinary approach/perspective.
- To use spatially and temporally explicit representations of socio-ecosystems.

3 Introduction

The methodologies employed to achieve effective socio-ecosystem management require an integrated holistic approach. Consequently, the methods developed for use in the HKKH Project employ various cutting-edge theoretical concepts and approaches discussed in document A.1.1.1. These perspectives assist in the development of the Decision Support Toolbox (DST), which will be of use to multiple stakeholders in the management of the targeted social and ecological systems (SES), and will benefit many more. The development of the tools in the DST requires hard and soft system thinking, accepting the complex holistic nature of SES, which embody non-linear, uncertain, and heterogeneous characteristics. The strategy utilized in the development of these methods is to view social and ecological systems, both generally and in the case study areas, as integrated wholes that require soft and hard system thinking in order to develop tools for sustainable management. Supported by extensive research, the Project views no division between social and ecological systems, and rather views them holistically in the development of tools to support their integrated function across spatial and temporal scales (Holling, 2001; Saberwal, 2001; Forsyth, 2003; Lister, 1997; Berkes et. al., 1998; Lovell et. al., 2002). Sustainability, in this sense, refers to both economic and environmental sustainability, or sustainable development. Indeed, Pirot et. al. (2000) explain that environmental sustainability is not possible unless management also focuses on the livelihoods of the stakeholders living within the targeted region—a perspective that is central to the IUCN's Ecosystem-Based Management approach.

In the development of methods that will produce effective decision support tools for SES management, the combination of systemic hard and soft system approaches affords the opportunity to bring in multiple voices in a collaborative way to create sustainable solutions. Recall from document A.1.1.1, that a systemic lens is a simple thinking technique for gaining systemic insights into complex situations. The fundamental assumption behind systemic thinking is that everything interacts with, affects, and is affected by, the things around it. Thus, systemic thinking is a combination of analytical thinking (the understanding of a situation's parts) and synthetical thinking (the understanding of how things work together) (Leleur, 2005). Knowledge itself is systemic, as it exists within determinate technical-social-cultural-historical frameworks, and is characterized by quality, rather than by some absolute standard (Ravetz, 2006). Consequently, systemic thinking helps to frame different approaches of addressing the SES, which in this case, will be a combination of hard and soft system techniques.

Hard system thinking entails starting from a carefully defined objective, which is taken as a given. This is the starting point for certain topics of inquiry, such as structural engineering. This approach assumes a relatively well-structured problem situation in which there is virtual agreement on what constitutes the problem (Checkland, 1989). It views a system as a systemic whole with an emphasis on processes of transformation, such as a focus on which inputs are processed into outputs. This thinking takes systemic images to be models, or simplified representations of real world wholes. Representation is central to this modality. The better the outcomes of techniques, such as computer-based modeling, coincide with actual observed events, the better hard system thinkers consider the knowledge to be (Engel, 1995).

The fact remains, however, that many problems do not function this way and are much more non-linear and hard to define, especially those concerning human culture. Indeed, any situation in which people try to act together will be complex simply because individuals are autonomous. Shared perceptions have to be established, negotiated, argued, and tested in complex social processes. As a result, soft system thinking is a learning system, facilitating learning about the problematic human situation and leads to taking purposeful action in the situation aimed at improvement, which seems more sensible to those involved (Checkland, 1989). Soft system thinking focuses on the accommodation between social actors and practices. Rather than viewing the system as systemic, soft system approaches employ systemic images as instruments of inquiry. Therefore, different actors across scales may construct alternate systemic images, even if they follow the same general rules. Soft system thinking allows the heterogeneity within a system to emerge, such as the behavior of various institutions (Engel, 1995).

Hard and soft system methodologies, based on hard and soft systemic thinking, have individual strengths, and when combined, complement one another, creating innovative holistic models for socio-ecosystem management. Further, these techniques afford opportunities to integrate the concept of management-oriented research into the methodology, reinforcing the Project's applicability to multiple stakeholders across scales. This process reinforces the premises of post normal and the new sciences, where multiple perspectives are integral to understanding the dynamics of a SES, in addition to the approach of adaptive management and the principles of the IUCN's Ecosystem-Based Management. (Ravetz, 2006; Lister, 1997; Holling, 2001; Woodhill and Roling, 1993; Salfysky et. al., 2001; Pirot et. al., 2000; IUCN, 2006; Berkes et. al., 1998). An integrated methodology will therefore avoid the pitfalls of orthodox positivist science, which typically overlooks the non-linear, uncertain, and heterogeneous nature of complex socio-ecosystems (Forsyth, 2003; Holland, 1998; Lister, 1997). All hard and soft system methodological approaches utilized in the DST are complementary, and therefore no tool is more essential or useful than another. Consequently, the integrated methodology of the Project requires the use of the entire tool spectrum to accomplish the stated objective of sustainable socio-ecosystem management.

This methodological document will therefore describe the individual methods, but will also link them together, highlighting how each technique is necessary to achieve the overall objectives of the DST. The Project accepts that the intended beneficiaries of a technique may be different than the users, such as managers using the outputs of the Decision Support Toolbox, but not certain local people. However, it must avoid taking a top-down approach and rather be seamlessly integrated with participatory soft system methods to ensure that the Project equitably addresses SES function across scales, and gives agency to local stakeholders to govern their own resources. Indeed, globally and regionally, local governance has proven to be much more sustainable and long lasting after resource management projects leave (Bajimaya, 2005; Ali and Butz, 2005; Poudel, 2005; Namgyal, 2005; Pirot, et. al., 2000; Varughese and Ostrom, 2001).

This methodological document will begin with the soft system methods because they assist in the development of the hard system techniques, and will consequently, be initiated first. The participatory method of scenario planning begins the discussion, which assists in identifying key drivers that certain stakeholders view as critical for system function both in the present and future. It also helps to involve different voices, especially on the local level, in the early stages of the Project, which can influence the direction and content of other methods. This method reinforces the principles of post normal and the new sciences, as well as management-oriented research, as it involves stakeholders from multiple scales at the onset, allowing their perspectives to assist in shaping subsequent methods. This is especially important in the identification of topics or themes modeled in the resilience analysis of decision-making, which naturally follows as a soft system method from scenario planning. Both methods employ the resilience theory and analysis in their development and approach and can also assist in an adaptive management-based learning paradigm (See A.1.1.1 for detailed explanation of both approaches). Scenario planning also aids in identifying the relevant drivers from various stakeholders that will be utilized by the technical team in the hard system method of System Dynamics Analysis, which is based on the methodologies of Sterman (2001), Binder et. al. (2005), and Muetzelfeldt and Massherder (2003). This technique begins with scenario planning and focus groups, followed by qualitative modeling, and ultimately, quantitative modeling techniques.

The resilience analysis of decision-making will utilize the results of the scenario planning and focus groups with key stakeholders to identify key drivers within the system, which can subsequently be modeled in this soft system technique. Taking into account the resiliency perspective, this method allows the key drivers and their related decisions on multiple scales to be modeled in order that specific tools can be identified and employed in the appropriate contexts. It allows the key drivers to be broken down by decisions, which can therefore identify tools that can build resilience back into the system in its current and future configurations. This method differs from traditional decision analysis, as it views the system as non-linear, uncertain and heterogeneous, and therefore the key drivers can change over time (temporal scale) and space (spatial scale). Non-equilibrium ecology and other related principles are therefore crucial to this method, to avoid the pitfalls of traditional resource management, where the system is viewed an unchanging and the resulting management strategy and tools do not address its non-linear nature adaptively (See A.1.1.1 for the discussions on orthodox science, the human/nature dichotomy, and adaptive management). This method is also useful in tandem with hard system methods, such as qualitative and quantitative computer-based modeling. These techniques can be employed as tools to support the identified decisions that are crucial to SES function. Collectively, they are tools that will make the system function better in its current and potential future states, can be utilized by a spectrum of stakeholders across scales, and will benefit an even broader population to achieve effective SES management.

The hard system methods are effective tools to support the soft system techniques and to bring specific outcomes based on the strengths of the methods. One important component of utilizing these methods is that they must accept change and the uncertainties inherent in SES function (Forsyth, 2003; Lister, 1997; Pirot et. al., 2000; Walker et. al., 2002). Additionally, they must be adaptable to different scales across time and space. With this perspective, they are extremely important and effective tools for resource management. Further, these approaches must accept the limitations of orthodox science, the value of incorporating multiple voices, and the applicability of research to management across scales, especially to local stakeholders.

Systems dynamics analysis, based on the methodology of Sterman (2001), Binder et. al. (2005), and Muetzelfeldt and Massherder (2003), will be engaged as a hard system method to identify the functioning of key process in socio-ecosystem function. Consequently, this will be a critical tool employed by various stakeholders in the management of the SES, making the system function better in the present and future. The steps in effectively modeling the dynamics are as follows:

1. Preliminary Qualitative analysis (causal diagram)
2. Identification of stocks and flows in the system
3. Identify sources of information that impact the flows
4. Identify the main feedback loops
5. Draw a causal loop diagram linking stocks, flows, sources information
6. Write the equations that determine the flows
7. Estimate parameters and initial conditions
8. Simulate the model and analyze results
9. Test alternative management options and inspect respective system behavior.

A diverse matrix of stakeholders will be involved in this iterative process, which reflects the principles of adaptive management and components of post normal and the new sciences. The preliminary qualitative analysis and resulting quantitative analysis and simulation will be treated as two distinct, albeit complementary, methods, since both can afford their own conclusions and can work together in the modeling process. As stated, this method will be supported by the participatory soft system techniques, creating an integrated holistic methodology, benefiting multiple scales of stakeholders in the target areas.

Together, the soft and hard system methods create the baseline tools for use in the Decision Support Toolbox Software. The software aims to assist multiple stakeholders, both as users and beneficiaries, to manage the SES in sustainable ways. It is an innovative instrument that can adaptively account for the non-linear, uncertain, and heterogeneous characteristics of complex social and ecological systems across different spatial and temporal scales. Intended uses will not only embody the results of the soft and hard system techniques, but will also be updated and innovated as the system changes and reconfigures. This tool will be place-specific to the targeted regions, and will serve as a pragmatic instrument for socio-ecosystem management in general, expressing innovation that will ensure its practicality beyond the Project period. It incorporates the outputs of the hard and soft system methodologies described above, creating a cutting-edge tool for socio-ecosystem management, based on sound science and the most contemporary methods.

4 Methods

4.1 Soft System Tools

4.1.1 <u>Scenario Planning</u>

4.1.1.1 Introduction: Brief Theory and Evolution of Scenario Planning

Scenario planning was developed in military and business circles in the 1950s as a technique to deal with uncertainty in forward analysis of complex contexts. This technique is meant to identify and stimulate analysis around alternative (hypothetical) futures as a way of short-circuiting biased and entrenched views of the world and prepare for developments which could not be anticipated by simply extrapolating from past trends. In this context, scenarios are not forecasts or estimates. They are rather alternative, plausible future trajectories of change in a system. In the words of the Millennium Ecosystem Assessment, (2005) a "scenario is a plausible, simplified, synthetic description of how the future of a system might develop, based on a coherent and internally consistent set of assumptions about key driving forces and relationships among key variables." Therefore, scenarios are described through narrative presentations, and may include qualitative or quantitative definitions.

Scenario planning techniques were developed by two main schools of thought (Bradfield et. al., 2005):

The intuitive-logic school: this model was first established by Shell. The general approach entails the development of narrative descriptions of alternative futures, based on intuitive logic and involving a range of stakeholders. A large number of experiences and models have since been developed, which cannot be coalesced in a unified methodology. The wide range of methodologies developed by various authors and groups, reflect the range of problem applications and practitioners, which have evolved applied experiences.

The probabilistic modified trends school: This refers to a range of experiences and models based eminently on quantitative and expert driven analysis. In this approach, historical data (time-series) are extrapolated to generate possible future trends (probabilistic forecasts) and combined with expert judgments and narrative descriptions to build quantitatively determined alternatives, often involving computer modeling and proprietary methodologies and tools, to address possible future unpredictable factors. These applications typically aim at improving policy effectiveness in handling reasonably well-defined problems (although it has a narrower focus than the former model).

As Bradfield et. al. (2005) point out, the intuitive logic school is a flexible approach designed to guide a process of continuous learning and adaptation within organizations, which becomes the overall goal for the adoption of scenario planning techniques. Established practices mostly rely on internal expertise within the organization/context; external expertise are brought in to facilitate the process, rather than to offer substantive expert advice. Knowledgeable or 'remarkable people' with extensive sector specific experience can thus be included in the exercise to open new perspectives.

The approach is versatile and suitable to address a wide range of problem scales. It relies on a number of general techniques, such as stakeholder analysis, brainstorming, and simulation modeling. These are used to structure coherently narrative and qualitative descriptions of future alternatives, e.g., through matrices, which help to organize the information that constitutes scenarios along key perspectives/parameters. Scenarios produced (typically 2-4) should be equally plausible and probable, internally coherent and logically structured. The narrative produced are evaluated for internal consistency and eventually used to assess alternative strategic options, to identify unforeseen events and implications and to recognize early warning signals of system change.

Scenarios in this approach are different from exercises of "what-if planning," which produce forecasts of outcomes based on a range of assumptions. In scenario planning, individual scenarios do not have attached probabilities or estimates. Rather, it is assumed that elements of a given scenario may happen, and therefore, the purpose of the approach is not to devise "optimal scenarios," but to assess system change over trends of key drivers, accommodating unexpected yet plausible surprises. Managers can thus explore long-term perspectives, escaping from pressing near-term concerns, embodying the following components:

- Identifying drivers of systemic change in their environment.
- Identifying future trends, opportunities and threats.
- Questioning their assumptions about the environment, which surround their organization's operations bringing into the open ambiguities and uncertainty.
- Testing policies and options in face of surprises and unforeseeable events.

Consequently, SP can support a process of organizational learning and continued review.

SP studies have been used for decades to study global change in business and security applications. It has been proposed most particularly in contexts characterized by high uncertainties and driven by uncontrollable external drivers (Peterson, et. al., 2003), which are common in conservation practice (Figure 1). In the environmental arena, SP has been applied to the study of global environmental change, such as in climate change related studies, and more recently, in the Millennium Ecosystem Assessment (Carpenter et al., 2005). The latter high profile study involved analysis at global scale, as well as at sub-global (regional) scale.

Figure 1: Appropriate Applications of Scenario Planning (Peterson et al., 2003)

Uncertainty	**High**	**Adaptive management**	**Scenario planning**
	Low	**Optimal control**	**Hedging**
		Controllable	**Uncontrollable**
		Controllability	

4.1.1.2 Applications of Scenario Planning to Socio-Ecological Systems at a Regional Scale

There is still limited experience in the application of SP to environmental analysis at regional and local scales. Below are two experiences summarizing the use of SP as a way of providing practical examples regarding its application to regional contexts:

1. Peterson et al. (2003) studied scenarios for the Northern Highlands Lake District, Wisconsin (see also Resilience Alliance, 2006). The geographical scope was a district of ca. 5,000 km2, with a population of ca. 90,000; the landscape is dominated by open water (lakes), which provides important ecological services and contributes to the local economy (tourism, fisheries). The area has been extensively researched by scientists over a long period. The main external drivers of change are climate change and human migration, affected by social and economic dynamics of the wider regional context. Ecological changes driven by anthropogenic factors have shaped the landscape for decades and determine its ecological vulnerability and capacity to provide continued services in the future. Migration and ecological vulnerability were identified as weakly controllable drivers of change, as well as fraught with fundamental uncertainty. A study team developed three alternative scenarios, which were plotted against axis representing the two key external variables. Scenario analysis was used to identify risks, areas of vulnerability, potential surprises and opportunities arising from the interactions of components of the complex socio-ecological regional system.

2. Bohensky et al. (2006) applied SP to the Gariep River Basin, a very large catchment (665,000 km^2) encompassing an extensive area of South Africa (including 40% of the population) and the whole of Lesotho, as well as major agricultural and mining regions, large hydraulic projects, industrial, urban and rural areas. A team of planners and researchers delivered the study. They reviewed the ecological services and history of the area and analyzed scenarios over a 30-year time span. The scenarios were drawn from the four global scenarios of the Millennium Ecosystem Assessment (in turn based on global social, political and economic drivers) and adapted to the study scale and national context. Trends of each driver were identified under each of the four scenarios. The team analyzed the implications of these alternative trends for a range of ecosystem services across the four scenarios: a simulation modeling application proved too complex and the team eventually settled for brief narrative descriptions, later illustrated through spider diagrams. The analysis of scenarios was used in

particular to explore trade-off between ecosystem services and biodiversity resources under the different range of alternatives. This also helped to highlight different dynamics among sub-regions of the study area.

This preliminary review of experiences point out a number of lessons learned, as well as areas requiring further investigation and empirical studies. The application of SP to these contexts has been mainly through academic exercises, which have involved (mainly technical/scientific) experts. However, these experiences show little involvement of stakeholders, outside experts, and planners, nor a close relation with real world planning and decision-making processes. Conversely, SP holds good potential as a basis for communication and stakeholder participation processes for the following reasons: a) intuitive analysis based on narratives does not preclude non-technical participation; and b) decisions and options can be discussed and observed from a range of perspectives and outside the straight-jacket often imposed by legal, institutional and management frameworks.

A clear identification of the management problem(s) at the outset helps to keep group discussions in focus and to pursue consensus on future uncertainty. Insofar as SP is used to explore broad future outlooks outside a problem solving approach because fundamental uncertainty risks can mar the analysis, preventing the group to converge on its review of alternatives. A problem-solving approach can also help catalyze stakeholder interest in the process. Stakeholders, particularly in contexts of semi-subsistence economies and developing countries, need to see tangible benefits deriving from planning studies to ensure meaningful and motivated participation. Approaches to achieve this need to be explored and a larger set of relevant experiences, if available, should be reviewed.

The above argument may well apply to contexts of crisis or where stakeholders face critical immediate decisions. SP could theoretically be well suited to address those circumstances. However, immediate priorities and stakeholder conflicts could hinder participation in a process, which is specifically designed to overcome narrow and near-term perspectives and engage in broader enquiries. Empirical evidence of SP benefits is still limited and anecdotal. The pilot studies reviewed call for more analysis and applications in experimental contexts.

The issue of participation in SP process, as much as in any similar decision support processes, is not peripheral—since one of the main goals would be to change or broaden mindsets to build capacity to address future challenges and uncertainty, failing to engage stakeholders would be a fundamental waste. The literature on SP reports similar issues for exercises in business contexts. For example, Burt and Van Heijden (2003) list the following real world hurdles, which may prevent effective participation by small and medium enterprises in SP exercises:

- Managers are too concentrated in the day-to-day fire-fighting and skeptical of embracing processes inspired by “big theories” and facilitated by external consultants.
- Managers are focused on their immediate business environment and its trends, rather than on the long-term and broader trends which will shape the wider business context in the future.
- Managers may simply not have time for that.
- Organizational structures and culture may promote homogeneity in thinking, rather than a healthy diversity of points of view, which could help coping with future unforeseen developments.
- Managers prefer forecasting (which cannot deal with uncertainty) and incremental change rather than exploring fundamental uncertainty, hence this strengthens “business as usual” mindsets.
- Managers can be defensive and resist SP-type of explorations of the future and their assumptions, for fear that future opportunities or threats might expose their weaknesses.
- Managers see decision-support as a tool or moment to optimize business and win over competition, rather than as an ongoing learning process.

The same study recommends that SP address the following requirements to be accepted and successful:

- The exercise should have a clear purpose relevant to the client.
- SP practitioners need to have a trusting relationship with clients based on dialogue and understanding of their perspectives.

- The relationship should be built on a strategic analysis level, with the shared understanding of its importance for the survival and growth of the client, as well as of its process oriented nature.

Most of the considerations above may apply well to contexts of environmental analysis or conservation at regional scale. Importantly, planning and conservation institutions and their managers are ordinarily faced by similar challenges and constraints. The problem would be even more acute in contexts of participatory management of natural resources, where conflict, mediation, overlapping jurisdictions, grey policy frameworks and complex societal dynamics are part and parcel of the decision-making process.

4.1.1.3 Methodology for Scenario Planning

The HKKP Project therefore proposes to develop scenarios through a process outlined in Walker et. al. (2002), elaborated by Peterson et. al. (2003) and Cumming (2005), schematically outlined in Figure 2 and further described below. The process involves the following six steps:

1. *Problem or goal identification:* entails the identification of a problem area relevant to stakeholders concerns. It enables the activity to focus on the analysis of actionable points, such as how ecosystem goods and services could change and affect tourism in the national park over the next 10 years or what is the vision agreed by stakeholders for national park management.

2. *System description:* includes socio-ecosystem components such as ecosystems, institutions, people, and dynamic relations among the system components.

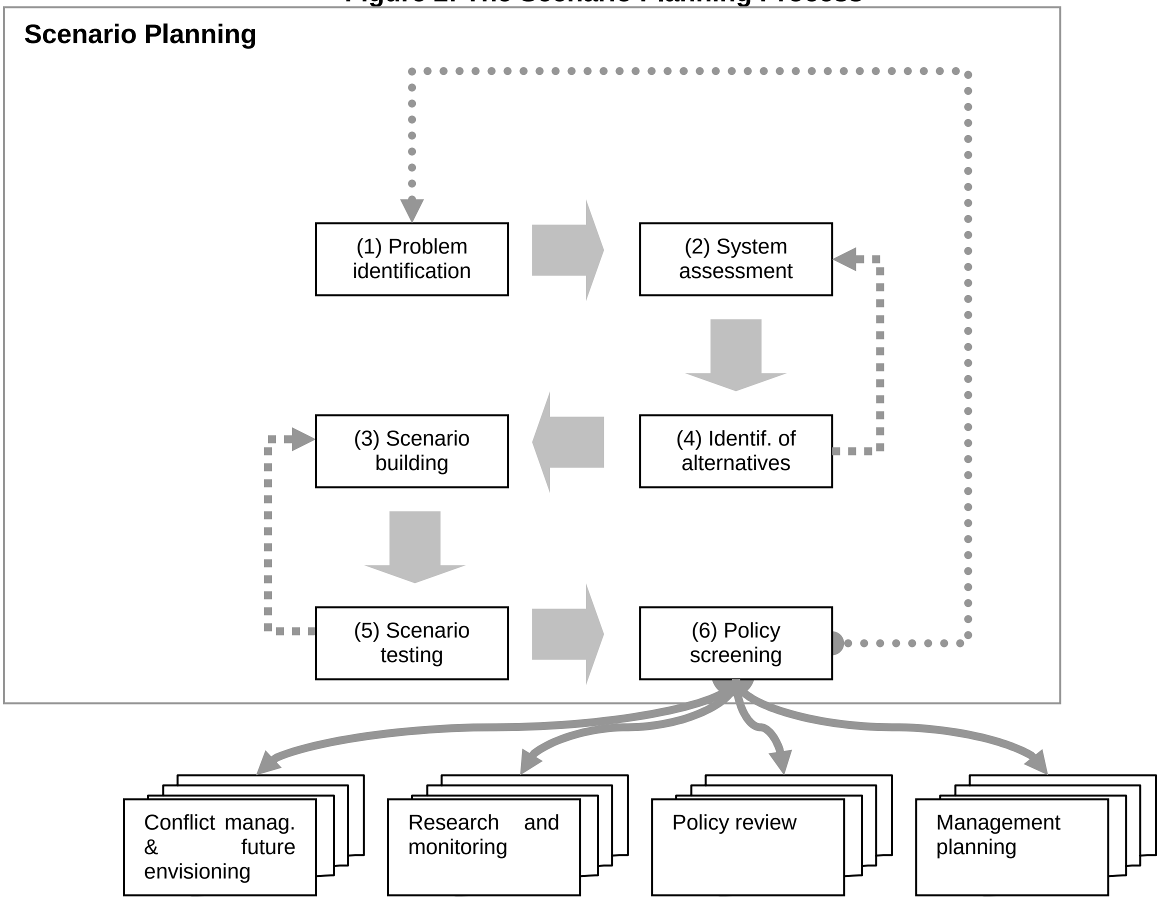
3. *Identification of alternatives:* identifies plausible alternative ways the system could evolve in response to possible future events, based on the existing system structure and dynamics. It includes the listing of predictable and unpredictable variables, capturing explicitly the major areas of uncontrollable uncertainty, such as unpredictable external drivers (e.g., climatic patterns, national economic growth, etc.). Controllable factors of uncertainty should be included as actionable elements within alternative scenarios.

4. *Developing scenarios:* these are built by adding external drivers and internal actions to the system dynamics and alternative paths identified in the previous steps. The outcome is the formulation of a text-based representation for each identified alternative future, which describe the future system configuration, linking the present state and events with future hypothetical states and events. The narrative description should be clearly and convincingly formulated, easily communicable and should keep a clear focus on the problem or goal identified in the first step. Each scenario must be able to trigger lateral thinking and bring attention to future unexpected opportunities and options for action. Importantly, there is no blueprint to develop and write scenarios. A number of techniques can be used to develop analysis and narratives (e.g., writing fictional speeches of key figures) and to explore trends along identified alternatives (e.g., Delphi technique).

5. S*cenarios appraisal and testing:* each scenario is assessed for internal consistency, through a review of the plausibility of assumed actors' behavior (e.g., through stakeholder participation), simulation modeling, and expert opinion.

6. *Policy screening:* uses scenarios to identify, develop, and test alternative policies and management decisions and to formulate research and monitoring agendas. Scenarios are reviewed against one another to trigger new perspectives on future plausible change and possible actions.

Figure 2: The Scenario Planning Process



The exercise needs to be based on an iterative process, whereby, the identification of alternatives (third step) may drive to deepen the assessment of the system (second step), or scenario testing (fifth step) requires an interactive formulation of alternative scenarios, which are gradually refined for internal consistency. The approach may suit a number of different goals, often very relevant to conservation efforts and complementary:

- To bring together stakeholders (e.g., park communities, experts, park managers, policy makers, etc.) to query respective assumptions, expectations and different worldviews and identify actionable issues and desirable future outcomes.
- To test the outcome of existing or plausible policy frameworks vis-à-vis plausible future evolutions of the system.
- To identify areas of uncertainties and lead research efforts towards them, in a manner relevant to stakeholder concerns and agendas.
- To develop and test management frameworks, plans and options against plausible long term evolutions of the system in face of uncertain and controllable external forces.

4.1.1.4 Linkages to Other HKKH Project Components

The SP application serves as a stand-alone module in the set of tools to support socio-system management within SES. It is specifically designed as a participatory tool and soft-system application. In addition, the following linkages to additional HKKH project components are proposed:

- The key drivers identified by the groups, as well as the content of the scenarios can be used to develop the topics and themes for decision-making modeling, described in the next section.
- The process assists in the development of simulation modeling, such as utilizing the outcomes of the SP iteration to refine the modeling assumptions and framework.

- Outcomes of the simulation modeling exercises can feed the iterative development of future scenarios. A possible conceptual framework for this integration is presented in the following section.
- At a later stage, assuming a useful outcome from the process proposed herewith in relation to the SES specific scope/problems highlighted above, SP outputs could be suitably adapted for public awareness raising for local stakeholders (drama, media, etc.) to share and broaden the impact of the exercise.

4.1.1.5 Conclusion

Scenario planning is therefore the selected experimental step towards developing the overall decision support methodology and set of tools pursued by the HKKH in the DST, employing the resilience analysis framework (see A.1.1.1) to provide theoretical guidance to the broader system development. Concurrently, the SP exercise is in its own merit a methodology to assist different stakeholders in addressing practical problems and management objectives. Those problems and concerns are inherently fraught with uncertainty and require decisions based on long-term perspectives, strategic analysis and mediation among multiple stakeholders. The decisions will likely be taken while stakeholders would keep changing their perspectives in response to context change and management interventions.

Chermack (2004) points out that decision failures are very common in dynamic decision-making contexts (e.g, where the system changes while we make decisions). Besides technical errors, most failures are due to the inability to foresee novel factors. There is a set of structural causes of this situation. Scenario planning can thus be a useful tool to help address these limitations of real-life decision-making within complex systems socio-ecosystems (Table 1).

Consequently, SP can be used as a tool to build resilience back into the system both in the present and the future. It helps to identify key drivers and potential future system configurations that can be used as guides to develop adaptive and participatory outputs that can help the system function better, increasing its resilience. The tool can also be used to pair conservation and development in sustainable ways, which reinforces its utility across spatial and temporal scales.

Table 1: Advantages of Scenario Planning in Dynamic Decision-Making Contexts (Chermack, 2004)

Causes for unexpected decision error	Benefits of scenario planning
Bounded rationality: limits to human and organizational problem-solving capabilities. Decisions are typically taken based on partial and certain, but limited, information; they are broken down in sub-decisions; rules of thumbs gradually develop and prevail.	Scenarios can provide a vast amount of information in a detailed narrative format, which can be easily remembered (hence more easily acted upon).
Tendency to overlook endogenous variables: decision makers typically focus on exogenous variables to be acted upon, overlooking feedback loops within the system that keep re-configuring the system in response to external (exogenous) variables.	Scenarios can be integrated with system thinking and internal variables can be explicitly considered and built in models.
Stickiness of information and knowledge: the transfer of information and knowledge (e.g., specialist expertise) has transactional costs.	Scenario development requires frequent and intense interactions through forums, thus providing a means to reduce transfer costs in building shared expertise.
Friction of information and knowledge: Information and knowledge transfer is mediated by social values and interactions. Interactions among multiple individuals serve as check and balances in decision making, preventing errors. Expertise requires the accumulation of experience: therefore, friction is necessary. Removing friction (e.g., through automated processes) can increase decision failure.	Scenarios are typically formulated through interactions among multiple individuals /stakeholders, thus enabling early identification of errors.
Mental models, cognitive maps, policies: Mental models are conceptual frameworks, often unconscious, through which people explain the world. Often they are the key and only drivers of decisions. Policies are formal statements of shared/agreed cognitive maps.	One of the core aim of scenario planning is making managers' mental models explicit (conscious) and modifying them through the development of shared understanding, testing of assumptions and polices.

4.1.2 Resilience Analysis of Decision Making

4.1.2.1 Introduction: The Resiliency Approach and Decision-Making Modeling

Similar to the process of scenario planning, which identifies key drivers and potential future configurations of SES function, a resiliency analysis of key decisions across scales helps in the development of tools to build resilience back into the system or help it maintain current mechanism that can cope with change. Indeed, the decisions of various actors regarding ecosystem use and management govern the mechanisms of the SES that respond to disturbances. Qualitatively modeling these decisions helps to identify the system's threshold and where decision support can assist in making the system function better, thus providing a practical application of the theoretical framework summarized above. Employing the concept of resiliency in the analysis of decision-making allows modeling to take on a more dynamic character, indicating the ability of the SES to respond to different situations. It also identifies the outcomes on system dynamics of certain decisions and the potential gaps in the decision-making process that could in turn lead to the development of various tools that support system performance, maintaining or increasing its resilience. This methodology creates an opportunity to link 'hard system' and 'soft system' approaches into resource management. Qualitative decision-making analysis and modeling is a soft system approach that can be integrated with quantitative hard system research and computer modeling to ensure socially and ecologically sustainable SES function.

Given the stated assumptions inherent in the resiliency framework (See A.1.1.1), applying this theoretical perspective to socio-ecosystem processes allows soft system qualitative modeling of decision-making to indicate effects and outcomes that may threaten an SES's threshold in its current and future configurations, which in turn, may require managers to build resilience into the system through decision support systems. It also allows each decision to be described in relation to the entire linked system in a non-static way, causing the decision support to address the system as a whole—both social and physical environments—and not as disconnected parts.

Before analysis and descriptive modeling, key drivers or stakeholder actions need to be identified as entry points through participatory processes with various stakeholders that reflect the most relevant components or drivers of the socio-ecosystem. Examples include the harvest of non-timber forest products, agriculture, grazing, or tourism. The analysis and modeling framework includes the following components: Socio-Ecosystem Processes Scales, Actors, Functional Areas of the Socio-Ecosystem, Management Practice/Resource Use Pattern, Decisions, Exogenous Factors, Endogenous Factors, Effects or Outcomes, Gaps in the Decision Making Process, Decision Support Tools, and the Vulnerability Context. Each component helps to describe which decisions various actors are making at different spatial and temporal scales, the exogenous and endogenous factors affecting these decisions, as well as the outcomes of the decision on the configuration of the SES. The gaps emerge in relation to the effectiveness of the overall process in adaptively managing resource use, which suggests decision support tools that build resilience, having an impact on making the SES function better. Finally, the vulnerability context helps to prioritize the system components that require more immediate support in relation to others in the same scale.

4.1.2.2 Methodology for a Resilience-Based Approach to Qualitative Modeling of Decision-Making

Before modeling, *policy drivers or key stakeholder actions* need to be identified as entry points that reflect the most relevant components of the social and ecological system. Walker et. al. (2002), suggest that modeling 3-5 key policy drivers or stakeholder actions assists in analyzing a system's resilience, which in turn could be selected as topics for decision-making modeling. Participatory approaches with a range of institutions, local communities, the private sector, and non-governmental organizations, are the best means to properly identify these areas. Focus groups and scenario planning with key collaborators are examples of participatory methods that can assist in the process. See Pretty et. al. (1995) and Lal et. al. (2001) for additional participatory techniques. The modeling process is as follows:

1. Initially, the *scale or levels* of the system require identification from the smallest unit to the largest aspect impacting the SES (Lal, et. al., 2001). For example, when modeling a local community's harvest of non-timber forest products for medicinal purposes, the smallest scale could be the individual/local, followed by the district, province, country, and global levels. Various actors function at different levels, whose decisions affect the SES. When modeling various themes or topics, the scales in the SES do not change, even though the actors involved for each model may differ.

2. For any given topic or theme, a list of all *actors* and their corresponding level needs to be identified. An actor can better be understood as an institution, which is any structure that produces forms of regularized behavior (Soussan et. al, 2001: II). There are two types of institutions, formal and informal. Formal institutions may be thought of as rules that require external enforcement by a third-party organization (such as law courts, prisons, etc). Informal institutions can be internally enforced—they are upheld by mutual agreement among the social actors involved, or by relations or power and authority between them (Leach et al, 1999:237-8).

3. The *decisions* of the actors in relation to the selected topic or theme follow. This component of the modeling is most crucial—it frames the decisions on ecosystem use and management, in addition to beginning the identification of gaps that reflect outcomes that may negatively

impact system function. Each decision of the actor at a given level is different and requires collaborative methodologies to identify the decisions holistically.

4. Once the decisions are listed for each actor, the next step is to identify which the *functional area of the SES*, whether social or ecological, is impacted by each decision. This designation assists in modeling how a particular decision impacts the SES as a whole. The complexity of a linked SES necessitates recognizing the functional area that each actor's decision has on the system as a whole. In the case of energy use, decisions may impact household livelihoods (social) and the forest (ecosystem). Further, certain *management practices or resource use patterns* within a topic may have different effects or outcomes in the SES. In some cases, these practices will be the same as the selected topic or theme, while others may differ. For example, in the case of fuelwood use, the resource use pattern and management practice are the same for all actors, whereas in tourist flow, these aspects can differ by actor.

5. Next is to indicate external and internal forces that impact these decisions. *Exogenous factors* encompass social, economic, political, legal, environmental, and institutional dynamics of the actor's local area, the wider region, their country, and the world as a whole. The increasing globalization in the world affects all actors, and therefore, this entire spectrum of forces is critical to defining the structure and operation of a SES. These exogenous factors are themselves not static; it is their dynamics, the processes of change in the wider natural, economic, and social environments that create the conditions where decisions are made (Soussan et. al., 2001: 9). *Endogenous factors* are the forces that can be controlled internally by the actor. For example, in a particular social system, the distribution of wealth, amount of time spent in the village, subsistence strategy, ecological knowledge, and education levels are all endogenous factors controlled on the household scale. As with the exogenous factors, these forces are not static, causing their dynamics to change separate from and in relation to the exogenous factors. Consequently, both exo- and endogenous forces impact the decision-making of different actors at various spatial and temporal scales.

6. A complete list of exogenous and endogenous factors affecting the decisions of a particular actor, allows the effects or outcomes of the decision to emerge. Each decision has single or multiple *effects or outcomes* that impact the function of the SES in its current and future configurations. For example, the decision of trekking agencies to send groups along the main trekking route causes the outcome that there will be an unequal distribution of wealth off of the main trekking route. Stating the outcomes of a particular decision within a certain system configuration allows identification of the current gaps in the decision-making process to reach a result, to be jointly defined by the stakeholders that interact with the SES, which consequently helps to identify the potential tools that can be introduced by managers to help build resilience into the SES.

7. Outcomes and effects lead to the identification of *gaps in the decision making process*, which in turn can be addressed to build resiliency into the system. Gaps can be a lack of information due to research need, or they can be a lack of entitlements or access of a particular actor. This component reflects when a decision negatively impacts system function at a particular configuration. For example, on a national scale, a resource management entity, such as a department of national parks, may not have adequate information on forest structure, composition and diversity for a specific protected area. Therefore, this formal institution's policies related to the forest may not reflect the needs of the forest, informed by rigorous scientific research. This actor's decisions may be hindering system function, which presents a gap in the decision making process of the SES. These gaps present entry points for decision support tools, facilitating actors to make decisions that build resilience into the SES. The relation between an actor's decision and gaps in the decision-making process will be especially clear in the example of fuelwood use in Sagarmatha National Park below.

8. To correct for gaps in the decision-making process at various scales in a SES, certain *decision support tools* may be employed through a decision support system. These tools differ depending on the functional area of the SES (e.g., socio-economic or biophysical) and the identified gaps. These tools require participatory associations with various actors functioning in the SES, as well as external entities that can offer support, such as international

organizations and academics. It must be noted that just as exogenous and endogenous forces function at different spatial and temporal scales, gaps are not static and change as well. Therefore, decision support tools should adaptively consider all variables spatially and temporally in a given topic or theme to adjust to changes across scales. Tools must also reflect the knowledge, beliefs and practices of certain actors, especially on the local level. This ensures sustainability beyond the initial decision support system development and application. Folke et. al. (2003) present examples of principles drawn from the local level of SES for building resilience. These principles can consequently inform the decision support tools employed. Examples include:

- Using management practices based on local ecological knowledge;
- Designing management systems that 'flow with nature;'
- Developing local ecological knowledge for understanding cycles of natural and unpredictable events;
- Enhancing social mechanisms for building resilience;
- Promoting conditions for self-organization and institutional learning;
- Re-discovering adaptive management;
- Developing values consistent with resilient and sustainable social-ecological systems.

9. A final factor is in the modeling process is the *vulnerability context*. Based on the Livelihood Model outlined by Soussan et al. (2001), vulnerability is the ability of the SES to avoid, withstand, or recover from harmful impacts of shock. Vulnerability is the converse of resilience. A SES's vulnerability context is therefore areas that can structurally disrupt different aspects of the system's processes. In the example of fuelwood use, a vulnerability context may be forests that are closest to the highly visited tourist areas. If tourist flows increase exponentially, the forests around the tourist areas have a higher vulnerability context than those not near tourist areas. Therefore, decision support tools may want to address the vulnerability context differently or by priority, rather than homogenously treating a component of the SES without considering heterogeneous aspects that are vulnerable within the specific functional area of the SES.

4.1.2.3 Sample Qualitative Decision-Making Model: Fuelwood Use in Sagarmatha National Park (SNP)

Table 2 is an example of how to apply the methodology described above into practice. The topic of fuelwood use was selected for the sake of clarity and because it has been identified by various stakeholders from the local to national levels as a resource management issue since before the inception of Sagarmatha National Park (SNP), Nepal, in 1976 (Byers, 2005; Sherpa, 1999; Stevens, 1993; Brower, 1991). Each component will be summarized below for clarification, with the entire description being most clear in Table 2. Only one actor in each scale was selected for the sample model to make it easier to understand methodologically, however, the final model will include all actors and the decisions they make that impact the SES.

Key Driver: Natural Resource Use

Topic: Fuelwood Use

Socio-Ecosystem Processes Scales: In the case of Sagarmatha National Park, the scales include the local/individual, Buffer Zone, National Park and Buffer Zone, national and international/global levels.

Actors: Taking into account the topic and scale, there are various actors that function on the different levels to make decisions affecting the SES. Knowledgeable stakeholders and experts can assist in identifying the actors, which in turn makes them active agents in the model, and their decisions easier to model. Examples of SNP actors that make decisions at various scales in relation to fuelwood use include: households, lodge owner/renters, shinngi nawas (traditional forest guardians), hired laborers, Buffer Zone members, Park staff, the Department of National Parks and Wildlife Conservation (DNPWC), the Ministry of Forests and Soil Conservation, and international tourists.

Functional Areas of the Socio-Ecosystem: In any SES, decisions impact different components of the system, whether in the social or physical environments. In the sample model the two areas that are impacted by the selected actor's decisions are socio-economic and the forest.

Management Practice/Resource Use Pattern: This example only focuses on the harvest of fuelwood, and therefore the resource use pattern is the same across scale and the actors that make decisions in them. This may not be the case with other topics or themes.

Decisions: There are various decisions made by the actors in this model that impact the SES. These decisions range from the harvest technique on the individual/local level to the policy related to fuelwood harvest on the National Park and Buffer Zone level to the decisions made by the DNPWC related to Nepal-wide policies on fuelwood use on the national level.

Exogenous Factors: External forces that differ by scale and actor affect every decision. In the case of the individual/local level lodge owner/renter in SNP, these include the number of tourists, inflation, access to credit, availability of external labor force, tourist type, menu, political stability, and access to alternative energy. The exogenous factors change according to the decision being made. The model format helps to illustrate from decision to outcome how these forces affect the decision.

Endogenous Factors: As with exogenous factors, internal forces that differ by scale and actor impact decisions. In the case of SNP at the national level, the Department of National Parks and Wildlife Conservation (DNPWC) endogenously can control which staff it hires, representing different expertise and ethnicities. This internal factor thus impacts the decisions that the DNPWC makes in regard to SNP's fuelwood policies.

Effects or Outcomes: This field represents the results of an actor's decisions at a certain scale, mitigated by exogenous and endogenous forces. For example, on the Buffer Zone level, adequate patrolling of the forests during the allotted fuelwood harvest period has an outcome of reduced pressure on forests composition.

Gaps in the Decision Making Process: As stated above, gaps represent the outcomes that do not adaptively support system function. For fuelwood use on the household level by lodge owners in SNP, the outcome of a decision to harvest select species may be increased pressure on forest structure due to selective harvest. Conversely, an alternative outcome that maintain or increases resilience could be sustainable harvest or less pressure on select species. Therefore, the gap is knowledge of forest structure and sustainable harvest techniques.

Decision Support Tools: These tools reflect the gaps in the decision-making process and how they could be supported to make the system function better. For fuelwood use in SNP, these could be sustainability workshops for individuals, and ecological research for the Park staff and DNPWC. Tools should be developed in close collaboration with stakeholders, especially on the local level, to make sure that they reflect the nuances of cultural relationships with place, as well as current political-economic circumstances.

Vulnerability Context: This field demonstrates where certain areas within a specific level may have higher vulnerability to shock than other in that level. For example, the sub-alpine forests near the main trekking route may be more vulnerable to an exponential increase in tourism than those not on the route. Therefore, the vulnerable forests should be pointed out in the model in order that they are prioritized if decision support tools are developed.

4.1.2.4 Links with Other Methods in the HKKH Project

A resiliency analysis of decision-making related to key drivers in current and future SES function has many benefits as a stand-alone tool for management across scales. Further, it builds off of and complements the additional soft and hard system techniques employed in the HKKH Project. The following linkages with other methods in the Project are proposed:

- The key drivers for current and future SES configurations can be used as topics or themes to model in the method. Therefore, the participatory approach of identifying scenarios can be used as an iterative process to identify from various scales which system components are the most crucial for its function. Thereafter, this tool can be used to identify the decisions related to these scenarios and can help to identify which tools in the DST can be employed to assist in building or maintaining the resilience of the system under different pressures of change.

- The tool is also useful in identifying outputs that can help to achieve the goal of effective SES function, utilizing the resilience, adaptive management, and IUCN Ecosystem-Based approaches.
- Computer-based modeling, both qualitative and quantitative, can be employed as tools to assist in remedying gaps in the decision-making process that may be evident in this tool's results.
- The DST Software can be employed as a tool to assist certain stakeholders to manage resources or livelihoods more effectively, depending on the key driver and results of the resilience analysis.

4.1.2.5 Conclusion

A resilience-based qualitative model of ecosystem use and management decision-making can be an important tool to understand linked social and ecological system dynamics. It allows the decisions of various actors at differing scales to be analyzed in relation to the internal and external forces impacting them, as well as demonstrating how outcomes impact system function at a particular configuration. The model exposes gaps in the decision-making process and expresses potential tools that build resilience back into the system. Lastly, it reveals vulnerability contexts, which illustrate the heterogeneity within a single level and how to address different components of the system.

Although this type of model could be developed by a small group of technical experts, its true value is in collaboration with the various stakeholders represented in the model itself. This may take more time, but it addresses the true needs of the local people, as well as larger bodies on the regional, national, and international levels. Rather than seeing local communities as the passive recipients of the tools described in this methodology (Pretty et. al., 1995), their voices and views should be part of the modeling and inform the next steps of developing support systems. As all communities are heterogeneous, participatory approaches must be conceived with a keen lens on the peoples addressed in the model and in its outcomes. This process will thus ensure sustainability and applicability of the modeling process beyond the Project period.

Table 2: Sample Qualitative Decision-Making Model: Fuelwood Use in Sagarmatha National Park

Socio-Ecosystem Processes Scale	Actors	Decisions	Functional Area of Socio-Ecosystem	Management Practice/Resource Use Pattern	Exogenous Factors	Endogenous Factors	Effects-Outcomes	Gaps in Decision Making Process	Decision Support Tools	Vulnerability Context
Local/Individual	HH Lodge Owner / Renter	Diversification of source of energy, improving energy efficiency	Forest	Fuelwood collection	Availability of alternative energy	Wealth, building type, education and environmental awareness, gender	Decreased pressure on forest	Improvement and accessibility of sustainable technologies	Workshops on the use of sustainable technologies, micro-credit available to purchase sustainable technologies, green certification program	
Local/Individual	HH Lodge Owner / Renter	Collect themselves, hire, hire and collect	Socio-Economic	Fuelwood collection	Number of tourists, inflation, availability of external labor source	Wealth, location	Increased External Employment	Information on external labor harvesting practices	Sustainable harvesting workshop for hired labor	Forests on the main trekking route (Fungi Tenga, Yarin, around Namche)
Local/Individual	HH Lodge Owner / Renter	Wood type (live or dead wood), amount, location (where to collect), illegal cut, wood species, harvest techniques	Forest	Fuelwood collection	Number of tourists, tourist type, menu, regulations on access to resources	Ecological knowledge, location of accessible forest	Change of forest structure (species composition, biodiversity, age distribution, density) due to selective harvesting, Land cover change (change from more diverse and biomass rich forest classes to less diverse and biomass deficient forest classes)	Information on forest composition, structure and diversity; information on sustainable harvesting techniques	Forest information workshop, sustainable harvesting workshop	Forests on the main trekking route (Fungi Tenga, Yarin, around Namche)
Local/Individual	HH Lodge Owner / Renter	Participation in Buffer Zone organization	Forest	Fuelwood collection		Wealth, education, gender	Increased awareness on sustainable harvest and alternative technology, incorporation of private sector in natural resource management	Knowledge of Buffer Zone system	Buffer Zone outreach meeting with non-participating community members	

Socio-Ecosystem Processes Scale	Actors	Decisions	Functional Area of Socio-Ecosystem	Management Practice/Resource Use Pattern	Exogenous Factors	Endogenous Factors	Effects-Outcomes	Gaps in Decision Making Process	Decision Support Tools	Vulnerability Context
Local/Individual	HH Lodge Owner / Renter	Increase of number of beds	Socio-Economic	Fuelwood collection	Number of tourists, regulations, tourist type, political stability, access to credit, inflation	Number of beds, wealth, location (on or off route)	Increased fuelwood consumption, increased external employment	Improvement and accessibility of sustainable technologies	Sustainable building workshop, green certification program	
Buffer Zone	Buffer Zone Management Committee	Fuelwood collection penalties	Forest	Fuelwood collection	SNP policies, DNPWC policies	Education, wealth, gender	Reduced pressure on forests	Information on successful models for leveraging penalties, research on penalties in SNP over time	Data on impact of harvesting on various community forests, data on best practices for leveraging penalties from other protected areas, GIS assessments	Hired labor in forests on the main trekking route (Fungi Tenga, Yarin, around Namche)
Buffer Zone	Buffer Zone Management Committee	Appointment of Nawas	Forest	Fuelwood collection	Location	Family availability	Sustainable harvest of deadwood in 30 day period	Information on vulnerable forest areas, information on harvest practices and forest impacts of hired labor, information on sustainable harvest levels and techniques for certain species	Assist in creating database of household participation in nawa system	
Buffer Zone	Buffer Zone Management Committee	Patrolling of forests by ward-level Buffer Zone member	Forest	Fuelwood collection	Location	Buffer Zone member availability	Sustainable harvest of deadwood in 30 day period	Information on vulnerable forest areas, information on harvest practices and forest impacts of hired labor, information on sustainable harvest levels and techniques for certain species	Data on impact of harvesting on various community forests, data on best practices for leveraging penalties from other protected areas	
Buffer Zone	Buffer Zone Management Committee	Reforestation projects	Forest	Fuelwood collection	Number of tourists, SNP policies, DNPWC policies	Education, wealth, gender	Increase in forest structure, composition and diversity	Information on vulnerable species, understory priorities, alpine priorities	Workshop on reforestation priorities and techniques	Alpine areas, sub-alpine understory

Socio-Ecosystem Processes Scale	Actors	Decisions	Functional Area of Socio-Ecosystem	Management Practice/Resource Use Pattern	Exogenous Factors	Endogenous Factors	Effects-Outcomes	Gaps in Decision Making Process	Decision Support Tools	Vulnerability Context
Buffer Zone	Buffer Zone Management Committee	Alternative energy projects	Forest	Fuelwood collection	Number of tourists, SNP policies, DNPWC policies	Education, wealth, gender	Reduced pressure on forests	Economic feasibility studies on alternative technologies	Workshops on the use of sustainable technologies, micro-credit available to purchase sustainable technologies	
Buffer Zone	Buffer Zone Management Committee	School curriculum support	Forest	Fuelwood collection	Number of tourists, SNP policies, DNPWC policies, Ministry of Education policies	Education, wealth, gender	Increase in knowledge of sustainable harvest of timber and NTFPs	Examples of place-based curriculum from Nepal and elsewhere, lack of local teachers	Assistance with curriculum development based on literature and new research	
Park and Buffer Zone	SNP	Collection policy (15 Days--2 x/year)	Forest	Fuelwood Collection	DNPWC policies	Warden priorities	Reduced pressure on forests	Information on appropriate times for harvest to reduce pressure on forests	Ecological research on forest composition, structure, and diversity, research on population dynamics of species by age-class	
Park and Buffer Zone	SNP	Guidelines for fuelwood harvest during allotted period	Forest	Fuelwood Collection	DNPWC policies	Conservation awareness and expertise	Reduced pressure on forest composition	Information on forest thresholds for harvest of timber and NTFPs	Ecological research on forest composition, structure, and diversity, research on population dynamics of species by age-class	Forests on the main trekking route (Fungi Tenga, Yarin, around Namche)
Park and Buffer Zone	SNP	Patrolling of forests during collection period	Socio-Economic	Fuelwood Collection	Number of tourists, amount of hired labor, number of headloads per household	Staff Matrix, location of forests, set up of ranger stations	Less livewood cutters, less over-harvest per household (individual, lodge, and tea-shop)	Number of staff, knowledge of local forests, knowledge of local residents, knowledge of hired labor	Cross-cultural communication workshops, data on matrix of harvesters per 15 day period	Hired labor in forests on the main trekking route (Fungi Tenga, Yarin, around Namche)

Socio-Ecosystem Processes Scale	Actors	Decisions	Functional Area of Socio-Ecosystem	Management Practice/Resource Use Pattern	Exogenous Factors	Endogenous Factors	Effects-Outcomes	Gaps in Decision Making Process	Decision Support Tools	Vulnerability Context
Park and Buffer Zone	SNP	Penalties for offenders	Forest	Fuelwood Collection	DNPWC policies	Staff matrix	Less future offenders	Number of staff, information from other protected areas	Data from other protected areas on penalty enforcement and results	
Park and Buffer Zone	SNP	Alternative energy promotion	Socio-Economic	Fuelwood Collection	DNPWC policies, national budget	Staff expertise	Reduced pressure on forests	Information on technology types, expertise on installation and maintenance of technologies	Workshop on alternative technologies	
National	DNPWC	Budget allocation	Forest	Fuelwood Collection	Government priorities, Ministry of Forest and Soil Conservation priorities, National Economy	Staff matrix	Less pressure on SNP forests, more enforcement of fuelwood collection policy, more park staff	Information on Nepal's ecological priorities for sustainable park management, information on international tourist preferences and practices	Research on Nepal eco-regions, research on tourist preferences and practices	
National	DNPWC	Park priorities	Forest	Fuelwood Collection	Ministry of Forests and Soil Conservation priorities, research priorities, external funding	Staff matrix	More resources for parks in priority areas	Information on Nepal eco-regions and their vulnerability, information on international tourist preferences and practices	Research on Nepal eco-regions, research on tourist preferences and practices	

Socio-Ecosystem Processes Scale	Actors	Decisions	Functional Area of Socio-Ecosystem	Management Practice/Resource Use Pattern	Exogenous Factors	Endogenous Factors	Effects-Outcomes	Gaps in Decision Making Process	Decision Support Tools	Vulnerability Context
National	DNPWC	Chief warden appointment	Forest	Fuelwood Collection	Ministry of Forests and Soil Conservation policy	Equal opportunity employment policy	Appropriate leadership and expertise at park level for sustainable park management	Knowledge of local people, knowledge of Nepalese Diaspora	Development of hiring policy reflecting equal opportunity and local knowledge preferences	
National	DNPWC	Park level fuelwood policy	Forest	Fuelwood Collection	Ministry of Forests and Soil Conservation policy	Staff expertise	Less pressure on SNP forests	Longitudinal studies on harvest impacts, information on socio-economic relations with fuelwood harvest	Research on harvesting impact on forest structure, composition and diversity, research on the relation between socio-economic status and fuelwood harvest	
National	DNPWC	Buffer Zone Policy (level of local control and enforcement)	Socio-Economic/Forests	Fuelwood Collection	Ministry of Forests and Soil Conservation policies, number of tourists (Nepal), number of tourists (park-specific)	Staff expertise	Local control of forest management, more community-based resource management, improved park-people relations	Knowledge of local demographics, cross-cultural communication, information on successes in community forestry	Cross-cultural communication workshops, literature review of community forestry movement, data on local demographics	

4.2 Hard System Tools

4.2.1 Introduction to Modeling of System Dynamics

Building on the soft system tools, the hard system tool of computer-based modeling has many useful applications. Following the methodology proposed by Sterman (2001) for system dynamics analysis, the steps involved in an analytical simulation are:

1. Preliminary qualitative analysis (causal diagram)
2. Identification of stocks and flows in the system
3. Identify sources of information that impact the flows
4. Identify the main feedback loops
5. Draw a causal loop diagram linking stocks, flows, sources information
6. Write the equations that determine the flows
7. Estimate parameters and initial conditions
8. Simulate the model and analyze results
9. Test alternative management options and inspect respective system behavior

Further, Binder et. al. (2005: 1-2) explain that causal loop diagrams can be labeled and structured incrementally to create stock and flow system dynamics diagrams. Causal loop diagrams (CLDs) are typical instruments of standard system dynamics practice for purposes of connecting them with simulation modeling. By and large, they are used prior to simulation analysis, to depict the basic causal mechanisms hypothesized to cause the indicated mode of behavior over time. These diagrams also form a connection between structure and decisions that generate system behavior. These models can also be used for detailed system description not related to modeling.

The other common notation for system dynamics are stock-and-flow diagrams (SFDs). Some practioners claim that SFDs are more complicated to lay users that CLDs, whereas, proponents of SFDs criticize the ambiguity and lack of detail in CLDs which prevents the simulation of modeled systems (Binder et. al., 2005: 2). Some also propose to use CLDs for brainstorming and then to switch to SFDs, which model the system exactly. Therefore, Binder et. al. (2005: 2) propose a system dynamics modeling methodology with the following four phases:

(i) The modeler labels the initial CLD in an appropriate way. This means deciding which factors are stocks, and which are flows or auxiliaries, and specifying which links represent flow dependencies and which information dependencies. The resulting *labeled CLD* usually reveals inconsistencies in the initial CLD, such as missing factors or illicit links.

(ii) The modeler then uses manually controlled steps to incrementally transform the labeled CLD. These steps are guided by a handful of constraints which characterize syntactic inconsistencies of the model. For each inconsistency the modeler has to decide on a specific transformation step which best fits the intended meaning of the model. The result of this phase, a labeled CLD which fulfills the constraints mentioned above, will be called a *structured CLD*.

(iii) It is then possible to transform the structured CLD automatically into an SFD.

(iv) The modeler quantifies the SFD, i.e. provides parameters, initial values and formulas for information dependencies. This yields a quantified *system dynamics model* (or *model* for short), which can be simulated.

The HKKH Project will therefore employ the methodology outlined by Sterman (2001) and the modeling technique of Binder et. al. (2005) to produce relevant qualitative and quantitative system dynamics models that can be applied to SES management and integrated into the DST Software (described later).

Before modeling, it is important to take into account that SES can change configurations and that this modeling exercise does not view the system in equilibrium and must therefore employ additional soft system techniques that assist in predicting change. Indeed, modeling can be a very effective tool when used with the over-arching theoretical approaches discussed in A.1.1.1, such as resiliency, adaptive management, and concepts from the field-rested IUCN's Ecosystem-Based technique.

4.2.2 Qualitatively Modeling Key System Dynamics

As Sterman (2001) points out, the first step in this analytical process is the preliminary qualitative analysis of the socio-ecological system of interest, which will be described in this section. In order to effectively model qualitative system dynamics, it is crucial to capture all the causal relationships among the different element of the system or the sub-system analyzed. Causal loop and stock and flow diagrams provide a language for articulating our understanding of the dynamic, interconnected nature of our world. Given an interest in modeling the dynamics of the mountain socio-ecosystem, where the human dimension interacts daily with the ecological system dynamics, and where local knowledge plays a key role in the management of natural resources, the overall analytical process carried out must benefit from the participation of key stakeholders.

In order to ensure an appropriate characterization of the SES, all the steps of the process, from the goal identification to the qualitative analysis, are made through:

- Multiple focus groups and intensive sessions of the technical team together with representatives of relevant stakeholders.
- Scenario planning workshops.
- Multiple sessions carried out with key local stakeholders (mainly researchers) to validate the analysis conducted until that moment.

The process starts with the identification of the main purpose of the analysis, followed by the identification of the potential users, issues, indicators of performance and management levers:

1. Aim: what is the main aim of the exercise?
2. Users: who is going to use the tools?
3. Issues: what issues the analysis wants to tackle?
4. Thematic Areas: what sub-systems of the overall socio-ecological system shall we focus on and how?
5. Indicators of performance: how to capture and quantify the critical factors of the system dynamics?
6. Management levers: how the decision makers can influence the sub-systems identified?
7. Tools for Analysis: what tool shall we use for the qualitative analysis?

4.2.2.1 Sample Qualitative Model: Environmental Quality

The following model of environmental quality will be used as an example to illustrate the methodology and the outcome of a system analysis session. In the context of In Sagarmatha National Park, the issues of solid waste and deforestation have been extensively investigated, often creating excessive alarmism. Starting with the acknowledgement of this potential harmful impact, however, it is now accepted that tourism can provide an economic rationale for conservation. Capturing these two tendencies is not easy. However, a better understanding of the relationships between tourism and environment through qualitative and quantitative modeling could provide a base upon which to set in place an effective sustainable decision-making process, able to protect as well as to valorize natural resources and the life and traditions of mountain communities. The first step in this process is to develop a preliminary qualitative analysis of the socio-ecological system of interest, capturing all the causal relationships among the different elements of the system or the sub-system analyzed.

Following an agreed upon language, a first diagram was created with the idea of providing a general comprehensive overview of the issues connected to environmental quality (see Figure 3). To make the analysis more "readable", the green color was used to identify quantifiable factors (indicators of performance), while the orange color was used to identify factors that are linked to a hub.[1]

The majority of the issues, identified through focus groups and an extensive literature review, are relevant in the SNP context. However, it is important to point out that some issues may not be as relevant from an analytical point of view, such that they may not have an important role in the socio-ecosystem system dynamics. The relevance of these issues in this respect will have to be assessed through the scenario planning, focus groups and fieldwork.

The identified issues are:

Water body pollution: water body pollution affects human health as well as animal health. It is thus important to investigate the level of pollution in rivers and lakes, taking into consideration all the possible source of pollution (from human to animal waste).

Noise pollution: though benefiting from the transport of cargos and tourists by helicopters and planes, a number of tourism and trekking agencies complain about the frequent flights and the potential impact on tourist flow, the environment and especially the fauna.

Solid waste pollution: the problem of solid waste has been widely publicized and acknowledged by the media and represents one of the major issues to tackle. The initiatives set in place in the last few years have improved the situation, but there is still much to do.

Air pollution (indoor and outdoor): in certain circumstances, burning fuel-wood in traditional stoves could represent a harmful activity for the household members, besides representing a threat for the fragile forest function in current and future states. Also, from a macro perspective, it is important to investigate the possible consequences that the air pollution can cause especially in the Khumbu valley by lodges and by the effect that burning solid waste may have on the climate dynamics that are affecting the Himalayan glaciers.

Visual pollution: with the increase in tourism industry, there is the risk of degrading the cultural/natural landscape (e.g., through littered solid waste), as well as the rich Sherpa culture (e.g., through the construction of non-traditional buildings).

According to experts, soil contamination should not be included in this list, given its scarce relevance in the SNP. However, the issue has been included and analyzed in one of the sub-diagrams, as to give the researchers the chance to validate this hypothesis in the field.

All the issues identified have a precise geographical (i.e. valleys) and temporal (i.e. seasonal) dimension. The tourism sector plays a crucial part in both of these dimensions. From a geographical point of view, for example, the concentration of tourist-flow in the Khumbu Valley worsens the problem of solid waste and water pollution. It is thus crucial from an analytical point of view to differentiate these effects spatially. From a temporal point of view, it is clear that the greatest environmental impact occurs during the two peak tourist seasons, which is to say in March-April and October-November. Again, it is important to capture these dynamics, in order to make the analysis reliable, credible and closer to the actual reality.

The analytical language identified helped in the process of capturing these links and dynamics. Water bodies pollution, noise pollution, solid waste pollution, air pollution, visual pollution, are seasonal and they occur in specific valleys. The arrows going out of the various boxes "pollution" into the two boxes "seasonal" and "valleys" have captured these phenomena. The color of these two boxes is orange, since through clicking on the little arrow on the bottom right of the box it is possible to be transferred into the Geographical Dimension hub and into the Spatial Dimension hub respectively.

[1] Also these factors are often quantifiable. However, it was important to highlight the link to the hub.

All the different kinds of pollution are used to identify a unique Environment Quality Index (EQI). Looking at the arrow going out of the "Index" box into the "Tourists" box, it is possible to read that this index affects the number of tourists, in a positive way. The assumption underlying this statement is that the better the environment, the higher the number of tourists will be.

It is now possible to identify one of the main feedback loops of the system. If it is true that a better environment attracts more tourists, it is also true, as already stressed, that a higher number of tourists may affect the environment negatively. In other words, the higher the number of tourists, the higher the potential negative impact on the environment, the higher the possibility that the number of tourist will decrease. This feedback loop will be explicitly represented in other sub-diagrams. It is worth pointing out that this loop does not consider that tourism can provide an economic rationale for conservation. Following this reasoning, also the potential positive impact of tourism on the environment is considered, which could mitigate the negative impact described above.

This analysis does not go that far. However, it does attempt to capture this additional dynamic of inserting management levers, i.e. decisions that can influence or affect the relationships and links of a sub-socio-ecological system. In this specific case, for example, a management lever could be the launch of an awareness campaign on pollution (in general). If the awareness campaign is effective, the level of pollution shall decrease, mitigating the negative impact of tourism on environment. Clearly, this is not very accurate—while the rationale for conservation can stem naturally from the increase of tourism (i.e., tourists come attracted by the environment and therefore improving the environment will bring more tourists), management levers are here thought more as reactions to a problem (i.e., the first assumption is that tourism affects negatively the environment). However, given the difficulties in capturing the potential mitigation effect in the first place, even the acknowledgment of these dynamics represents an important step at this stage of the qualitative analysis.

Solid Waste Pollution

All the issues identified (i.e. water pollution, noise pollution, solid waste pollution, air pollution, visual pollution) define environmental quality. As already explained, the diagram as such provides a general comprehensive overview of this theme. However, the diagram fails in answering more specific questions. For example, a reader could be interested in knowing how water pollution is measured, or in the consequences of the accumulation of solid waste, or in the definition of visual pollution, or in the identification of the main polluters.

To answer these questions, each and every issue (or element) of the diagram is linked to another sub-diagram, where new links and relationships attempt to provide the answers.

Clicking on the link positioned at the bottom right of the "Solid Waste" box, for example, another sub-diagram appears. This sub-diagram provides many of the answers to the questions listed above. In particular, the sub-diagram tries to:

- identify the causes of solid waste;
- define the categories of solid waste;
- measure solid waste (i.e. providing a unit of measurement);
- link solid waste pollution to other issues;
- highlight the consequences of solid waste;
- find possible solutions.

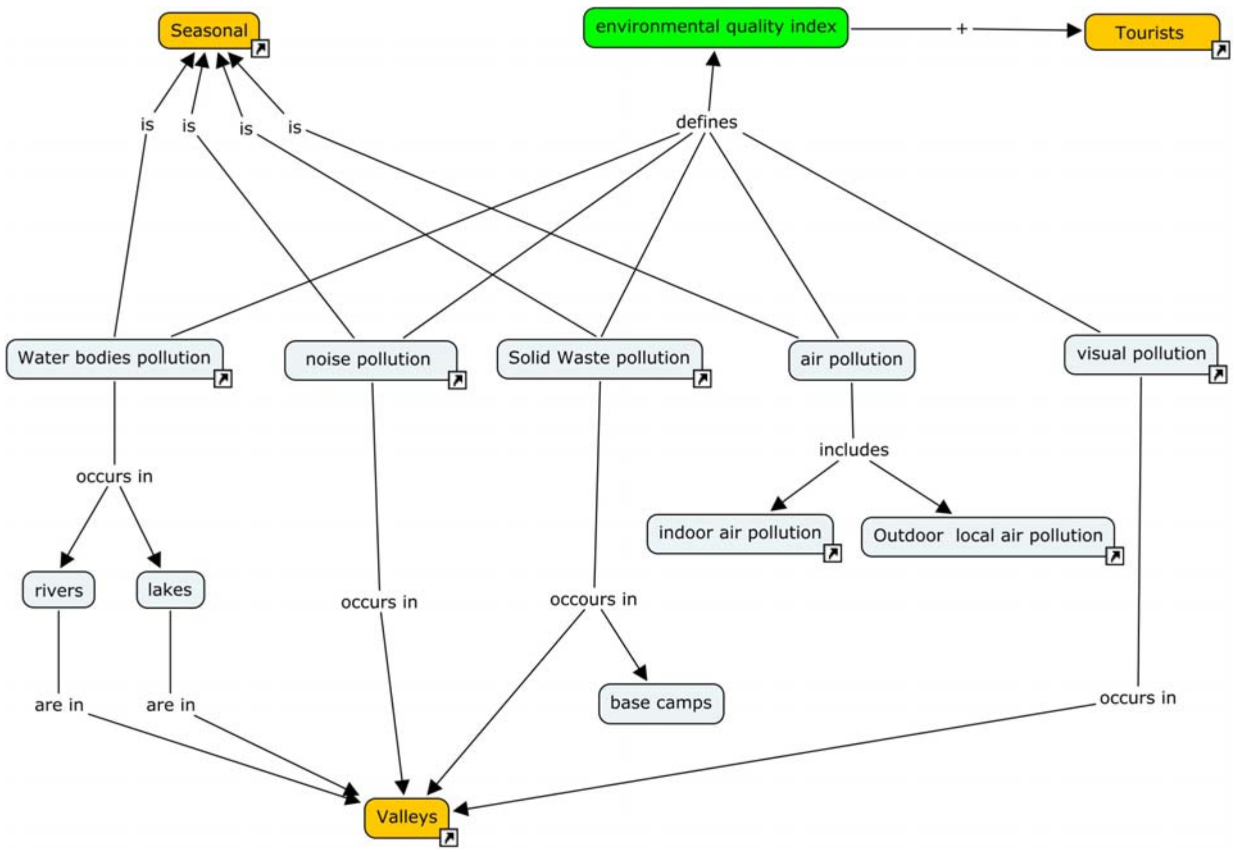
Who causes solid waste?

As for the causes of solid waste, a number of actors, or potential polluters, have been identified, namely:

- Tourists (3 categories)
- Tourists Staff
- Resident population

These three categories of actors are linked with the Solid Waste box through an arrow that goes from the former to the latter, with a positive sign. The logic is simple: the more the tourists, the higher the production of solid waste; the more the tourist staff (which is strictly correlated to the number of tourists), the more the production of solid waste; the higher the resident pollution, the higher the production of solid waste.

Figure 3: Diagram of Environmental Quality



The links as such are not complete. From a modeling perspective, it is necessary to identify a factor that facilitates the calculation of the actual amount of waste produced. In this case this passage is fairly simple:

What do we have to multiply the number of tourist for, in order to obtain the actual production of solid waste (in, say, kilograms, or tons)? The answer is straightforward: the per capita production of solid waste, per category of polluter. Following this line of reasoning, few additional elements are added (see Figure 4), namely:

- per capita tourists solid waste production (differentiated per the 3 categories);
- per capita tourists staff solid waste production (to be differentiated, if necessary, in per capita trekkers staff solid waste production and per capita mountaineers staff solid waste production);
- per capita resident population solid waste production.

In this sub-diagram, there is an underlying simplification, since the "Tourists" box should be broken into the sub-categories of tourists identified in the Tourism Hub (i.e., trekkers – independent and organized, and mountaineers). To be consistent and to make the reasoning simpler, the tourists box shall thus be broken into two, which will allow an easy and immediate calculation of the solid waste produced by trekkers and mountaineers respectively.[2]

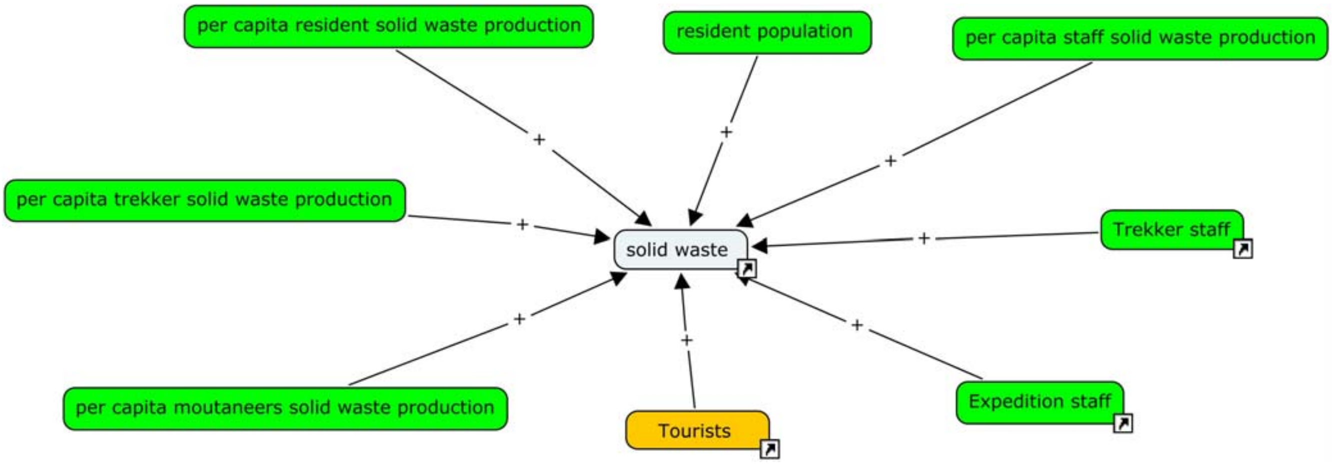


Figure 4: Identification of the Main Polluters and Calculation of the Total Amount of Solid Waste per Polluter

With the identification of the main polluters, having set in place the main relationship between polluters and solid waste, and after having had a first feeling about how to structure the analysis in order to facilitate the modeling process, it is now possible to analyze the consequences of solid waste on the environment (which, according to the original assumption, shall affect the number of tourists). Before getting to that point, though, it is important to break down the general category "Solid Waste" in a number of specific categories and sub-categories, in order to define solid waste in a more specific way (i.e., in all its different aspects). These categories shall reflect reality as much as possible, i.e., shall mirror the real dynamics of solid waste that characterize the Sagarmatha National Park.

Solid waste and Its Sub-Categories

Starting from a very basic categorization, it is easy to break the category "Solid Waste" into two sub-categories: Littered and Collected. These two sub-categories are characterized by different dynamics, and shall be dealt with in different ways. The collected solid waste, in particular, includes:

- Burnable solid waste burnt[3]
- Non-disposable exported[4]
- Organic (further sub-categorized in composted and dumped)
- Non-burnable (disposable and non disposable) buried

The non-collected solid waste includes:

[2] In the final version of the diagram, only the sub-category of tourists will appear. However, since one of the objective of this document is also to explain the logic underlying the analysis, this passage has been explained in detail.
[3] Burnable Waste is defined as Material free of any apparent or actual pathological/infectious, radioactive or hazardous chemical contamination (Note: Some Biological Waste can be decontaminated and then discarded as general waste. Some general waste material can be recycled). Disposable Waste is defined as a product designed for cheapness and short-term convenience rather than medium to long-term durability, with most products only intended for single use. The term is also sometimes used for products that may last several months (ex. disposable air filters) to distinguish from similar products that last indefinitely (ex. washable air filters). Disposable products are most often made from plastic, paper, cotton or polystyrene foam. The relevance of these sub-categories in SNP will have to be validated through field work.
[4] According to the regulation implemented by the Sagarmatha Pollution Control Committee, the non disposable solid waste produced (especially during the expeditions) shall be brought down the valley and flown outside Kathmandu. The underlying assumption in this case is that all the non-disposable waste collected is exported. This assumption will have to be validated through fieldwork.

- Plastic
- Heavy metal
- Organic

These sub-categories, when quantified (the more plausible unit of measurement will probably be tons), will represent nothing but the indicators of performance, i.e., quantifiable measurements that reflect the critical factors of the sub-system.

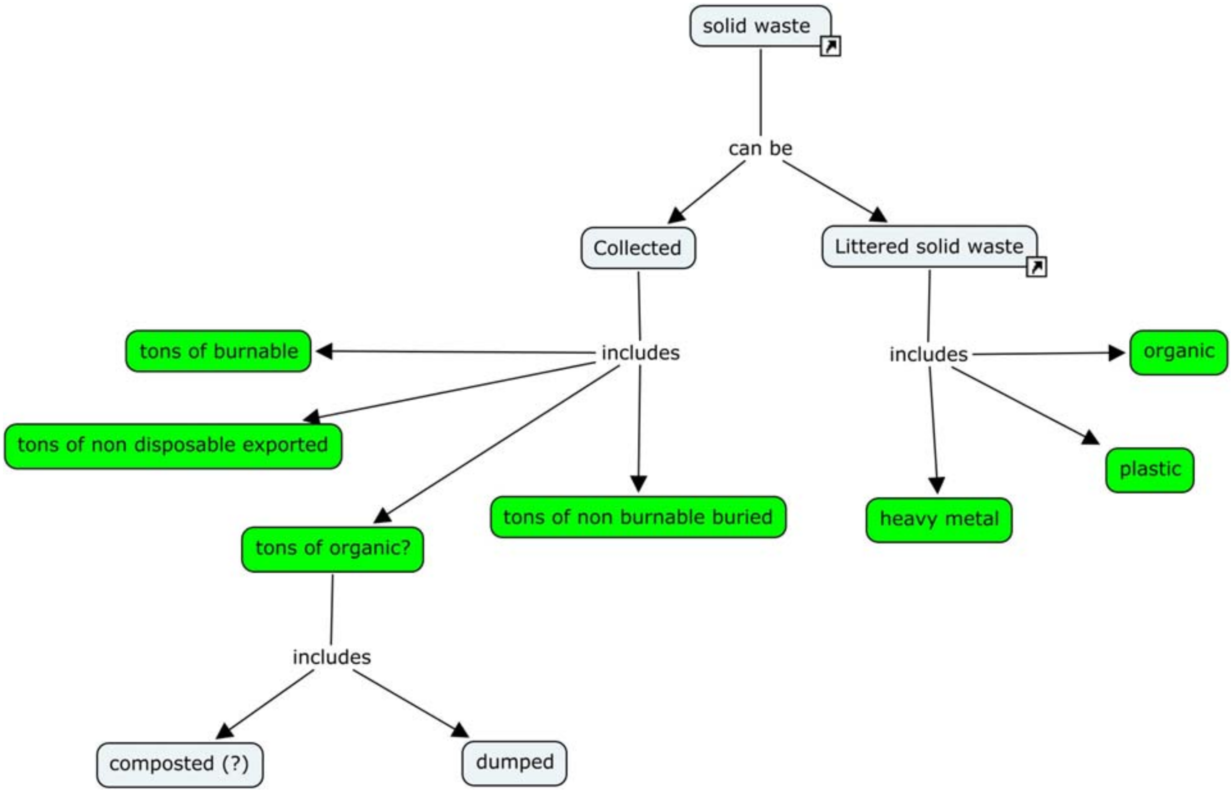


Figure 5: Solid Waste and its Sub-Categories

Note: the question marks indicate uncertainty in the statement. In this specific case, it is not known if household in the SNP collect organic for compost.

Clearly, collected and littered solid wastes include similar components. However, the definition of the two sub-categories, apparently different, stems more from an analysis of what is more relevant in the Park, rather than from a selection and description of items. In this case, for example, the collected waste is defined more in term of actions rather than in terms of items (i.e.. Tons of burnable burnt, tons of non disposable exported, tons of non burnable buried), while the littered solid waste is defined in terms of specific items (i.e., plastic, heavy metal, organic). This shall make the data collection analysis easier to conduct, since while the actions can be connected directly to specific indicators of pollution, the specific items will have to be further analysis.

The Indicators

Once the main actors causing solid waste and the solid waste itself are defined, it is possible to focus on the impact of solid waste on environment. In particular, each and every single factor identified in the analysis of the sub-categories can impact the environment, causing different kinds of pollution. Before linking directly the possible pollutants with the problems, or issues (i.e., the different kinds of pollution identified in the Environmental Overview sub-diagram), however, it is necessary to understand how the problem is measured. To achieve this goal, each issue (i.e., the different kinds of pollution) is defined through one or more specific indicator. For example, water pollution (which can be caused by a number the sub-categories of solid waste identified) can be measured through biological, physical or chemical indicators.

Solid Waste Pollution Factors and Links to Other Types of Pollution

The next step in the analysis is to understand how the pollution factors identified (e.g., the heavy metal identified as possible littered solid waste) impact/influence the selected indicator of pollution. This will be carefully quantified through the quantitative analysis, when the relationship will be clearly defined with the selection of specific indicators. Still, at his stage, it is important to capture the possible link between the factor and the indicator of pollution (which will capture the effect of the factor on the pollution type). Thus, as this time, it is important to know, among other things:

- Littered solid waste influences the indicator of visual pollution, affecting, together with other factors, visual pollution;
- Heavy metal influenced the indicator of water pollution, affecting, together with other factors, water pollution;
- Tons of burnable, if burned, influence the indicator of outdoor air pollution, affecting, together with other factors, outdoor air pollution;

The diagram will show a number of arrows going from the polluter to the indicator of the pollution. This indicator, in turn, will define the specific type of pollution. Figure 4 illustrates the case of outdoor air pollution. Among the potential pollutants identified above, "Tons of burnable" certainly represents the main factor to consider. However, the tons of burnable as such do not affect air pollution. They do so only if they are actually burnt. This passage may see trivial. However, as already stressed, it is necessary to show it explicitly in order to ensure consistency and to facilitate the subsequent modeling process.

"Tons of burnable", combined with "Direct burning", impact the indicator of outdoor air pollution, which in turn defines air pollution. Following the same logic, air pollution, defined by a specific indicator, will be measured through specific parameters, such as CO, SOX, NOX, PM10.

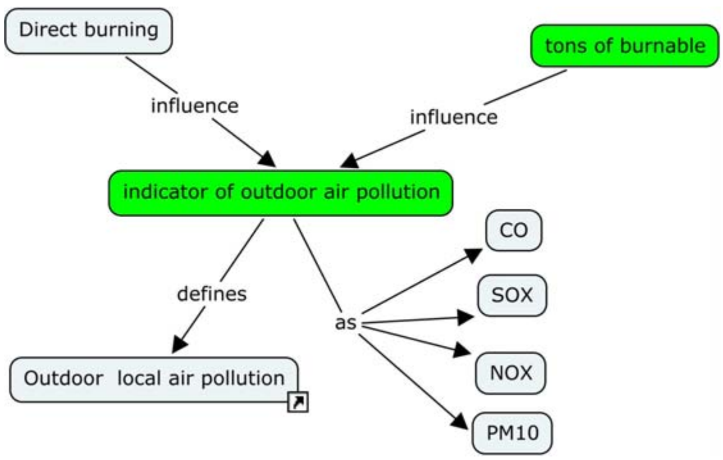


Figure 6: From Solid Waste to the Case of Outdoor Air Pollution

At this stage of the analysis, it is not necessary to know exactly what king of indicator will be used (in the case illustrated, it may be CO, SOX, NOX, or all of them together). This gap will be filled with the launch of the research activities in the field, when the specific indicators that will be used will be inserted. This will allow completing the analysis, using the appropriate linking statement (in the case of air pollution, for example, a higher level of PM10 will be associated to the box "Air pollution" with a + sign. This, in turn, will be captured by the general EQI).

Further, following the logic explained above, the links as such are not complete, since from a modeling perspective it is necessary to identify a factor that facilitate the final calculation of the indicators. These factors will have to be clearly and quantified during the through the filed work.

Possible Interventions

As explained above, one of the main goals of the qualitative analysis is also to identify management levers, i.e. those actions that could be implemented by decision makers at different levels, that can influence or affect the relationships and links of a sub-socio-ecological system. In other words, a management lever is a policy instrument that can influence the issue analyzed, thus affecting the links between elements of a specific sub-system and elements of another (or the same) sub-system in a controllable direction.

At this stage, the analysis specifies who are the actors causing the problem and a fair amount of knowledge on the nature of the problem. An in-depth knowledge of the decision making processes at different managerial levels in the SNP can help in identifying possible actions to either affect the behavior of the actors (i.e., of the polluters) or decrease the impact of the pollutants (i.e., of the pollution factors identified).

Management levers could be identified for a number of elements in the diagram. In the case of littered waste, for example, possible management levers are:

- increase of effectiveness of collection (e.g., though better location of bins, or better collection shifts);
- launch of awareness campaigns

.

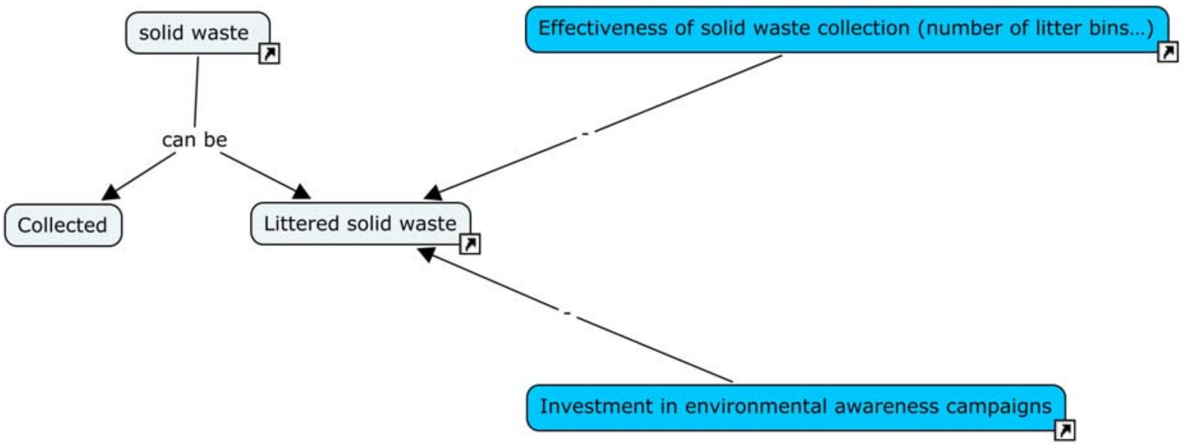


Figure 7: Possible Management Levers

Both of these levers are controllable, realistic and feasible, and could be implemented by a number of local stakeholders (e.g., SNP, BZ committees, SPCC, women groups, etc). Both of them influence the indicator of performance—amount of littered solid waste—through a negative relationships (e.g., with the launch of a massive awareness campaign, the kilograms or tons of waste dumped locally is very likely to decrease). This, in turn, shall impact the total amount of solid waste, and thus shall affect the environmental index, that is calculated as a composite index taking into account all the sources of pollution. If the assumption that a good environment attracts more tourists is valid, this, in turn, shall affect the number of tourist, through a change in the intensity of the relationships in the feedback loop.

4.2.2.2 Links with Other Methods in the HKKH Project

The qualitative modeling of key system dynamics can both stand-alone as a tool and contribute to the quantitative modeling described in the next section. It also helps to illustrate current system function in order that tools can be developed to adaptively maintain or increase resilience in the system. Further, it links with other methods in the HKKH Project in the following ways:

- In addition to the key stakeholders involved in the modeling process, it can incorporate the results of the scenario planning exercises to identify key drivers affecting SES function and therefore help to shape the topics and content for modeling. The 'system description' component of SP is especially useful in this respect. SP also affords the potential to view future configurations of the SES in order that management can adapt to non-linear, uncertain, and heterogeneous system characteristics.
- The decision-making modeling can be employed to reify the results of this modeling exercise in order that management levers take into account the spectrum of decisions that stakeholders make across scales. These models can also be used in tandem with the quantitative system dynamics simulation models (described in the next section) to create tools that help the SES function better now and in the future across scales, achieving the objective of supporting decision-making.
- The results of this activity and the following quantitative activity will be utilized in the DST Software described later.

4.2.2.3 Conclusion

This description attempts to illustrate an application of the tool in a specific analytical context. In particular, the case of Environmental Quality was presented. The analysis relies on experts' opinion, field experiences, and an in-depth literature review. Once the indicators of performance are identified and represented, the analysis will be quantified through fieldwork, which will clarify how the sub-systems (i.e., sub-diagrams) interact with each other. In particular, it will be crucial to understand the thresholds of a specific indicator that could reconfigure the system, expressing the SES abilty to withstand various disturbances.

4.2.3 Quantitative Modeling of Key System Dynamics

4.2.3.1 Simile as a Tool for System Dynamics Modeling

Recall from the discussion above on the methodology for system dynamics modeling, Sterman (2001) and Binder et. al. (2005) point out processes to link qualitative to quantitative modeling in order to create comprehensive models. These methods integrate qualitative and quantitative strategies with causal loop and stock and flow diagrams to describe and simulate SES dynamics. In order to integrate the qualitative system description explained above with computer simulation, the tool of Simile will be utilized as a cutting-edge social and ecological system management tool to view potential scenarios across spatial and temporal scales. The following is an introduction and description of this tool.

Simile is a software tool for computer simulation of complex dynamic systems in the earth, environmental and life sciences. Simile uses a 'visual modeling environment,' meaning that it uses a diagram-based language for designing models, including both system dynamics and object-based concepts. An even more fundamental feature of Simile is that it is a declarative modeling environment, employing a logic-based declarative modeling. In other words, this is a model which is seen primarily as being a specification rather than as a piece of computer programming to represent the interactions in these systems in a structured, visually intuitive way. Simile also supports modular model construction, which can be nested to any depth. The resulting models can be run as compiled C programs, and delivered to others as standalone models (Muetzelfeldt and Massherder, 2003).

The main features of Simile are as follows:

Visual Modeling: a two-phase approach that involves drawing diagrams that show the main features of the model and fleshing out the model-diagram elements with quantitative information, such as values and equations.

System Dynamics: expresses compartments (stocks or levels) whose values are governed by flows in and out—it is a visual language for representing differential equation models, with a compartment representing a state variable, and the rate of change being the net sum of inflows minus outflows.

Disaggregation: illustrates values forms such as age/size/sex/species classes. This is defined by how one class behaves, followed by the specification that there are many such classes.

Object-based Modeling: populations of objects can be modeled, such as animals or trees.

Spatial Modeling: a special form of disaggregation, in that one unit is modeled and then many such units are specified.

Modular Modeling: represents the ability to have any model to be inserted as a sub-model in another model.

Fast Simulation: the program can perform the running of 100s of equations and 1000s of object instances in complex systems.

Customizable Output Displays and Input Tools: users can design and implement input/output processes beyond those created by the program developers.

Declarative Representation of Model Structure: allows other groups to produce software to process Simile models in the future (Muetzelfeldt and Massheder, 2003: 347-8)

In order to illustrate how the Simile modeling program works and to justify its utility to the objectives of the HKKH Project, Figure 8 demonstrates a sample diagram of how the software can represent system dynamics of complex social and ecological systems. The model is based on the one described in Muetzelfeldt and Massheder (2003: 351-2) and will employ the authors' direct description to describe the model:

> The model consists of a fixed number of fields and a possibly-varying number of farmers (note the visual difference between the two sub-models). There is an ownership association between the farmers and fields (i.e., we know which farmer owns which fields). Each field can contain a grass and/or crop. (We cannot tell from the model diagram whether these are mutually exclusive, but we can see that the existence of each sub-model—i.e. the presence of grass and the presence of crop—is conditional on the variable 'field type.') The growth model for the grass is based on a single state variable, while that for the crop has separate state variables for the green biomass and the grain. Each field contains a multiple-layer soil water sub-model, with a state variable (water content) for each layer. Grass and crop growth are dependent on aggregate soil water, and in turn influence transpiration losses from the soil water compartment. Information on crop harvest is passed back to the farmers via the ownership sub-model (so each farmer has access to the values on the grain harvest from the fields that he owns): this is used to build up the farmer's grain store, which is reduced by sales.
>
> Note that we can produce this narrative simply by reading the diagram: we need no prior knowledge about the system. Note also that this diagram is not merely a presentational device. Rather, the diagrammatic notation, combined with the simple setting of properties for some sub-models contributes significantly to the mathematical structure of the model, just as (in a much more limited way) drawing a compartment – flow diagram tells a model interpreter what are the state variables, and what terms contribute to the rate-of-change expressions. This dramatically reduces the amount of information that the user needs to provide to complete the model: in this simple case, most elements needs only a value or a simple algebraic expression.

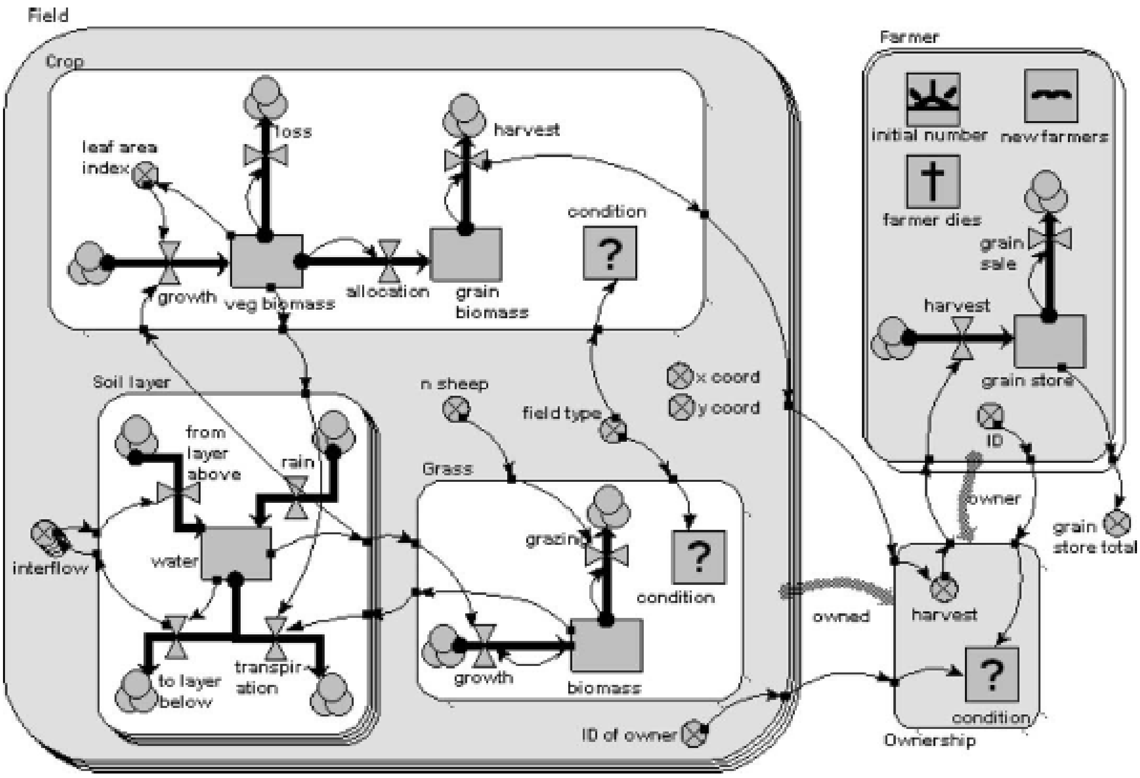


Figure 8: Sample Simile Model Diagram (Muetzelfeldt and Massheder, 2003)

Simile has already been applied to projects that have proven its utility. Prabhu et. al., (2003) explain that the ZimFlores project utilized participatory modeling with Simile to provide a shared factual basis for exploring land-use options for the communal lands surrounding the Mafungautsi forest, Zimbabwe. The authors conclude that participatory modeling with Simile proved an effective way to consolidate a diverse body of knowledge and make it accessible. The results demonstrate the importance of model outputs that are diagnostic, and which offer insights into the identified issues.

4.2.3.2 Links with Other Methods in the HKKH Project

Simile was selected as the most cutting-edge software that can express through simulation casual and stock and flow diagrams in a user-friendly way. If used with the appropriate theoretical framework, it is a hard system tool that can utilize the results of the soft system techniques to express system dynamics at different SES configuration across spatial and temporal scales, employing management-oriented research into simulations of current and future system configurations. Simile serves as a tool that can capture the complexity of social and ecological systems in a descriptive and systemic manner, assisting stakeholders to make decisions that support sustainable environmental practices and choices, as well as development. As Sterman (2001) points out, rather than being independent of the qualitative modeling, this technique is a natural next step after the initial models are created and evaluated, serving as repositories of data collection in ways that have been evaluated by stakeholders using participatory techniques reflecting the values of post normal and the new sciences, as well as management-oriented research. The models can be used with a resiliency and adaptive approach, helping the system function better in the present and future. The outputs of these models will also be integral components of the DST Software described below.

4.2.3.3 Conclusion

Qualitative and Quantitative modeling of socio-ecosystem dynamics will therefore be an integral hard system tool in the DST. Each method builds off of the other, to create system dynamics models that are both descriptive and simulate the complex system processes. Each has utility on its own, and combined, can create simulations that are useful to support the decisions of multiple stakeholders across scales. Simile has been selected as the tool to create the simulations because it reflects both the descriptive characteristics of the qualitative models and the ability to simulate phenomena using aggregated data sets from rigorous participatory research and consultation. The outcome will be cutting-edge and innovative with respect to SES management, and in tandem with the soft system methods, encompasses many of the components that will inform the models, producing a management toolkit that will sustain well beyond the Project duration.

4.2.4 Decision Support Toolbox Software

4.2.4.1 Introduction to the DST Software

One of the major objectives of the HKKH Partnership project is to develop a system to support SES management and the related decision-making process. For this, Decision Support Toolbox (DST) Software will be designed and developed to provide a set of integrated and self-contained tools that will be available to key stakeholders to support their specific tasks related to the management of the socio-ecosystems (i.e. assessment, planning, managing and monitoring). The Software includes a multi-component system which combine simulation modeling, optimization techniques, heuristics and artificial intelligence techniques, geographic information systems (GIS), associated databases for calibration and execution, and user interface components.

The DST Software development is guided by the following objectives:

1. Easy access to the existing data, information, and knowledge of the targeted socio-ecosystems. It will:

- serve as a repository of existing knowledge, information and data related to a socio-ecosystem management.
- provide easy access to the above information to different user groups.

2. Provide tools for systemic analysis of key management issues and natural processes in the targeted socio-ecosystems. It will:

- provide an environment for system dynamics modeling of socio-ecosystem behavior and simulate the possible effects of alternative management options.
- provide tools for spatial and temporal analysis of different thematic areas.

3. Promote the use of scientific knowledge in the management process. It will:

- support the analysis of different management scenarios and alternative options.
- support the development of a shared understanding of socio-ecosystem dynamics and behavior among different stakeholders.
- facilitate the process of building consensus on a selected management options among different stakeholders accounting for different sets of values

4. Assist in developing a framework for monitoring and new research. It will:

- catalogue past and ongoing research.
- provide a framework to highlight gaps in knowledge required for decision-making and prioritize research initiatives towards management priorities.

4.2.4.2 Sample Use Case: Sagarmatha National Park

Below is a sample use case illustrating specific issues and dynamics of Sagarmatha National Park. Although the individual stakeholders may be different in the three case studies, they will generally belong to one of the broader groups presented in the table below.

Actors

The analysis of the stakeholders in SNP came up with the six major groups. The stakeholder groups and their values and concerns are summarized in Table 3:

Table 3: Stakeholders and Their Concerns in Sagarmatha National Park

Stakeholder groups	Values and concerns
Government agencies Central level Local level	Legislative framework Livelihood of the population Conservation of NR Partnership
CBOs formal governance bodies resource management bodies public interest bodies	Participation in planning Participation in management Livelihood
Business organizations	Stable environment Facilities and infrastructure Business
NGOs	Participation Local culture Conservation Environment Women empowerment Education
Research and academic institutions	Research Technology development and transfer Information and dissemination
Cultural and religious organizations	Religion Culture and tradition Historical heritage

The stakeholders listed in the above table are involved at different levels of influencing management decisions. Some of the local level stakeholders, such as cultural and religious groups, CBOs and business organizations, will be involved during the participatory processes. The most likely users of the DST Software are the government agencies at central and local levels, NGOs and research and academic institutions. There will also be a group of external users who are not direct stakeholders, but will interact with the knowledgebase and analytical outputs of the system.

Roles

During the interaction with the DST Software, these stakeholders will play different roles. The relationship between stakeholders is diverse, with one stakeholder potentially playing many roles, and conversely, many stakeholders playing one role. The different roles played by the stakeholders are identified as follows:

1. Decision Maker

The major decision makers in park management are the government institutions. These can be at the following levels:

- Central level (national level conservation policies and decisions) or

- Local government bodies at the park level (park office, local councils).

Table 4: Stakeholders Roles and Interaction with the DST Software

Stakeholder	Role	System Interaction
Government agencies Central level Local level	✓ Decision maker/ planner ✓ Thematic expert ✓ Technical user ✓ Researcher ✓ External user	✓ Build model ✓ Run model ✓ Edit spatial data ✓ Perform spatial analysis ✓ Assess alternate scenario ✓ Query map ✓ Edit data/ knowledgebase ✓ Query data/ knowledgebase
CBOs formal governance bodies resource management bodies public interest bodies	× Decision maker/ planner × Thematic expert × Technical user × Researcher ✓ External user	× Build model ✓ Run model × Edit spatial data × Perform spatial analysis × Assess alternate scenario ✓ Query map × Edit data/ knowledgebase ✓ Query data/ knowledgebase
Business organizations	× Decision maker/ planner × Thematic expert × Technical user × Researcher ✓ External user	× Build model ✓ Run model × Edit spatial data × Perform spatial analysis × Assess alternate scenario ✓ Query map × Edit data/ knowledgebase ✓ Query data/ knowledgebase
NGOs	× Decision maker/ planner ✓ Thematic expert ✓ Technical user ✓ Researcher ✓ External user	✓ Build model ✓ Run model ✓ Edit spatial data ✓ Perform spatial analysis ✓ Assess alternate scenario ✓ Query map ✓ Edit data/ knowledgebase ✓ Query data/ knowledgebase
Research and academic institutions	× Decision maker/ planner ✓ Thematic expert ✓ Technical user ✓ Researcher ✓ External user	✓ Build model ✓ Run model ✓ Edit spatial data ✓ Perform spatial analysis ✓ Assess alternate scenario ✓ Query map ✓ Edit data/ knowledgebase ✓ Query data/ knowledgebase
Cultural and religious organizations	✓ Decision maker/ planner × Thematic expert × Technical user × Researcher ✓ External user	× Build model × Run model × Edit spatial data × Perform spatial analysis × Assess alternate scenario ✓ Query map × Edit data/ knowledgebase ✓ Query data/ knowledgebase

2. Thematic Expert

The role of thematic expert is to provide thematic inputs to the DST Software, contributing to the qualitative model development and knowledgebase, as well as identifying indicators and defining spatial analysis procedures, among other assistances.

3. Technical User

The technical user can have different functions requiring different expertise. These include:

- Data entry operators update the system database, both spatially and non-spatially.

- GIS analysts perform spatial data editing and analysis.
- Modelers build computer models based on the qualitative models.
- Database administrators build and perform queries on databases and knowledge bases.
- System administrator maintains the regular functioning of the system.

4. Researcher

Researchers are typically associated with academic or research institutions, and therefore, contribute to the knowledgebase, model development, spatial and non-spatial database development in different thematic areas of research.

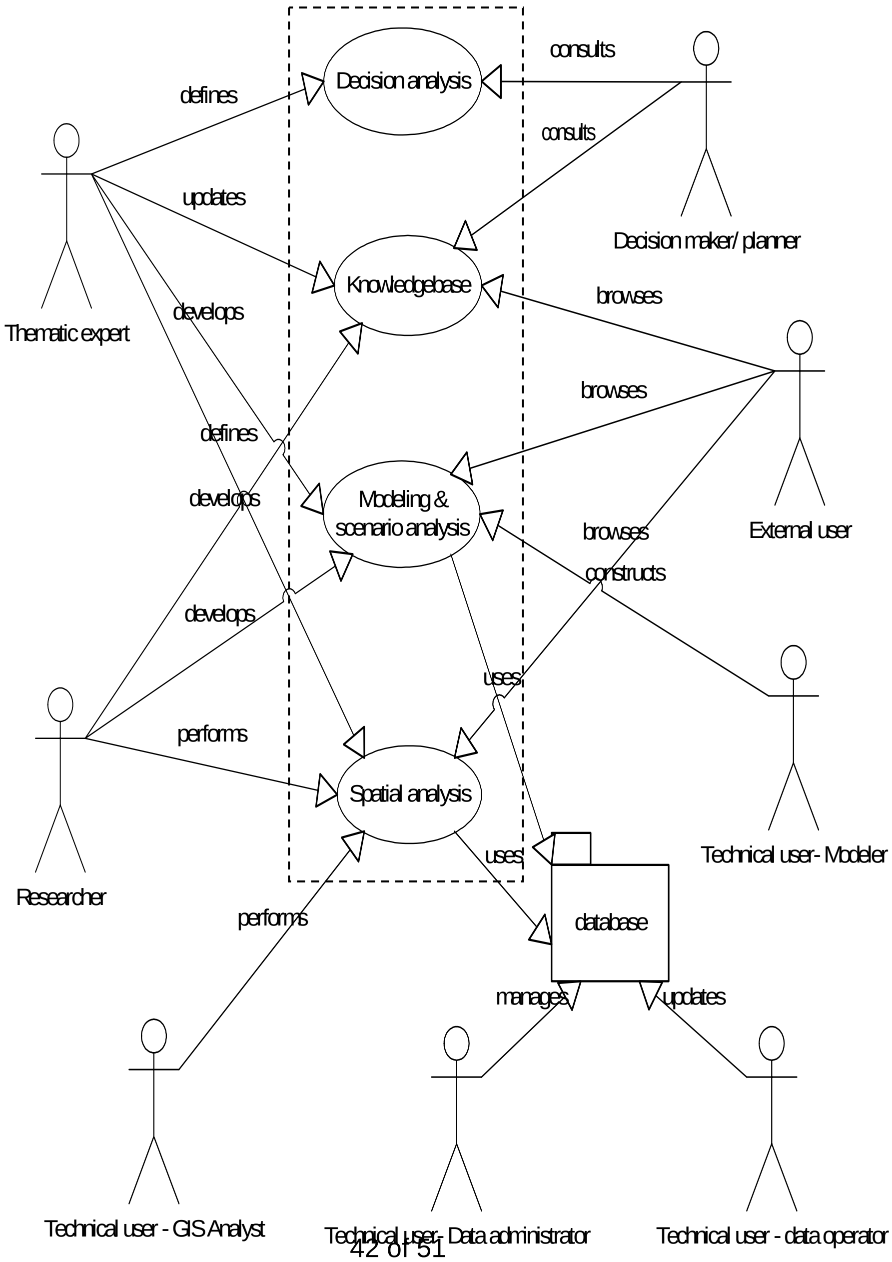
5. External User

The role of the external user is mainly consulting the knowledge base, qualitative models, outputs of analyses, and maps.

The different roles that can be played by the stakeholders and their interactions with the DST are provided in Table 4:

The following use case diagram illustrates the main use cases in the Unified Modeling Language (UML):

Figure 9: Main Cases in Unified Modeling Language



4.2.4.3 System Requirements

Based on the requirements expressed in the GOP and the analysis of the different functions involved in the analysis, assessment and management of socio-ecosystems, the following system requirements have been identified:

1. Data Management

- Organize, store and manage data, information, and knowledge in electronic format.
- Query and display data, information, and knowledge in electronic format.
- Provide easy access to these data, information, and knowledgebase.

2. Modeling and Scenario Analysis

- Support drawing the causal relations/influences among system elements for qualitative modeling.
- Develop a dynamic computer model (DCM) capable of simulating system behavior on different temporal scales over time in different system configurations.
- Browse interactively the dynamic computer models.
- Represent the dynamic system behavior over time through intuitive representations (charts and tables).
- Integrate model inputs and outputs with spatial analysis environment.

3. Spatial Analysis

- Support browsing and display of spatial information through map representations.
- Support query of spatial data.
- Spatial editing and analysis in different formats (raster and vector).
- Linkage with system dynamics model for visualization of model outputs.

4. Decision analysis

- Support the identification of management issues.
- Analytically compare and rank alternate management options.
- Store “measured” baseline data that describes the system state at a given point in time for monitoring.
- Compare “measured” data with simulated data.

5. Publishing and Outreach

- Disseminate the information available to a wide audience in an interactive format not requiring high computer proficiency (user friendly)

4.2.4.4 Design Considerations

The approach used by the project will be gradual and participatory. Key stakeholders will be involved in the iterative process of system conceptualization, development, and implementation to assure that real user needs are answered and a sustainable process of improved natural resource management is established. Modular decision support tools will be developed and provided to users progressively, starting with simpler applications containing geographic background layers, environmental and socio-economic data and gradually integrating modeling and analytical components to support systemic decision-making. Such an approach will allow to smoothly build the capacity of the stakeholders while gradually institutionalizing the new tools developed in various stages of project implementation.

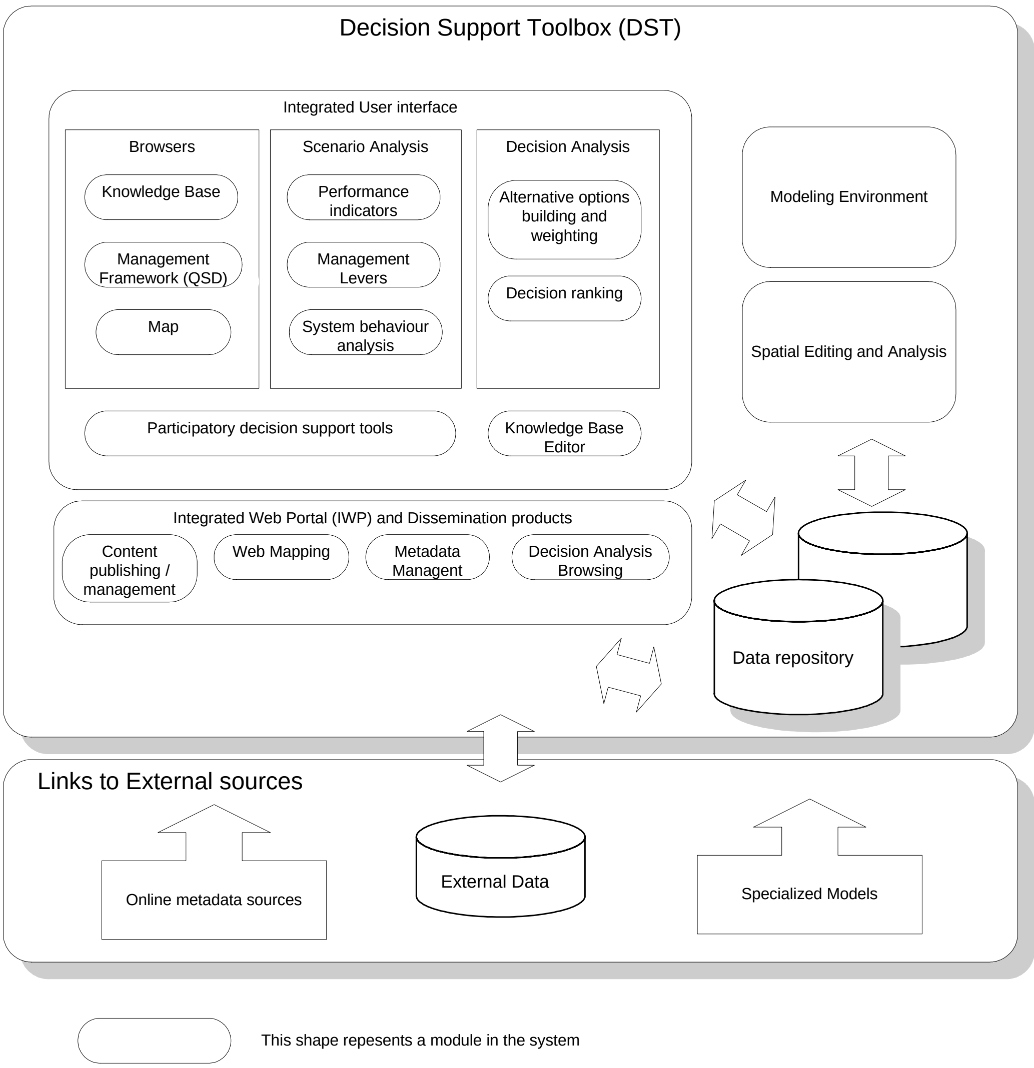
From a technological point of view the modules will be seamlessly integrated into a common environment to provide for a unique systemic management oriented model. The modular architecture of the toolbox will allow the development and the progressive delivery to final users of self-contained complementary modules. At the first stage a more simple, yet indispensable, functionalities of data consultation will be provided; followed by more complex and analytical components, as they are ready. The deployment of new modules will be an upgrade of the toolbox with new functionalities designed as an extension to the earlier user interfaces.

This development and deployment approach is expected to gradually raise the capacities of end users and institutionalize the use of the toolbox—starting from the early stages of the project with useful tools to be applied during ordinary tasks to improve efficiencies and effectiveness will provide the foundation to evolve towards more complex applications, such as modeling, scenario analysis and prioritization of management options.

4.2.4.5 General Architecture

From the requirements identified above through an iterative process by the technical team, an outline of the Decision Support Toolbox Software is summarized in Figure 9:

Figure 10: Decision Support Toolbox Software General Architecture



The DST Software is based on a modular architecture that integrates multiple applications and technologies. A main application characterized by a unique working environment (user interface) will contain the key functionalities outlined above. The other modules will communicate with the main application through custom procedures, appropriate intermediate application layers or interchange file formats.

The following is a functional description of the modules presented. Depending on the technical solutions identified for software development, the following structure could result in separate modules or in logical grouping of functionalities within the same module/application. Crucially, there will be inter-linkages between the different modules, such as spatial analysis, modeling and scenario analysis, and decision analysis.

Integrated DST Software User Interface

The different modules and functions of the DST Software will be accessed through an integrated user interface. It will provide a seamless environment for the modular development approach, which will allow additional functionalities and modules to be added gradually with the progress of the project activities.

Spatial Analysis

The spatial analysis module will provide the following functions to work with spatial data:

- Spatial data viewer: spatial data, both in vector and raster formats.
- Spatial data editor: basic editing functions for point, line and polygon features.
- Spatial analysis: basic classification and overlay operations on vector and raster data.
- Map composer: compose map layouts for printing.

Modeling and Scenario Analysis

This will provide the functions to browse and execute the system dynamics models. It will allow the users to select parameters (elements of the system that influence its behavior, but are not influenced by the system) that will constitute the levers to manage the socio-ecosystem. System behavior analysis will be possible through a set of displays in the form of charts, tables, and maps that can be interactively customized by the user to analyze SES behavior over time and intuitively compare alternative management options.

Decision Analysis

This module is aimed at ranking and selecting the most appropriate options out of the alternatives identified. These include:

- Alternative options building and weighting: the evaluation criteria will set forth by the user(s) and the respective weighting will be developed.
- Decision ranking: alternative options are compared through visual representations and ranked according to the criteria set. The best option is therefore identified

Knowledgebase

- Knowledge base: meta-data based catalogue storing relevant electronic objects (documents, hyperlinks, static maps, photos, videos, data sets, models).
- Knowledge base editor: allows the creation, editing and publishing of metadata as well as of associated electronic objects.

Data Repository

All the spatial and non-spatial data used in the DST Software will be stored in the data repository.

Modeling and Scenario Analysis

A modeling environment for qualitative and quantitative modeling will be implemented using the commercially available software engines as external modules that support visual modeling and run the simulations of socio-ecosystem behavior over time. The main functionalities are:

- Development of Qualitative System Diagram (QSD): in a visual modeling environment the user will develop a diagram containing the elements that describe the system and their respective influences. Relevant information in the form of electronic objects (hyperlinks, documents, photos) can be attached to the diagram to facilitate multidimensional and interactive interaction with the QSD.

- Development of Dynamic Computer Model (DCM): in a visual modeling environment the user will translate the QSD in a DCM. This will involve identifying and defining variables, parameters, stock, flows as well as mathematical relations among system elements. The model will support spatially explicit and implicit representation of the system.

- Running the simulation: the user will simulate system behavior over time through the modeling environment engine.

- Connection to external data sources: the simulation will use external data drawn form the data repository to set initial values for system variables and parameters and will output multi-temporal simulated data to the same repository.

Advanced Spatial Analysis

For the advanced spatial analysis functions, an external GIS software engine will be used, which will in turn be linked with the DST Software. It will thus be possible to use the outputs of the analysis by the appropriate modules of the Software.

Integrated Web Portal

The Integrated Web Portal constitutes the backbone of the Software in relation to online access. This component includes:

- Content publishing/management: a user-friendly system to support collaborative online content management and browsing.

- Web mapping: interactive dynamic display of predefined map collections issued by the DST Software, including the functionalities of changing layers, panning, zooming, consulting legend, querying and exporting/printing of maps created

- Metadata management: online access to the knowledgebase with searching of meta-data. Editing is also available for selected authorized users.

- Models and decision analysis browsing: online access to the QSD, DCM, outputs of simulations and decision analysis will be provided through the thematic content component of the IWP.

- Discussion forum: a platform for discussions and postings on subjects relevant to the project partners and stakeholders.

4.2.4.6 Links with Other Methods in the HKKH Project

It is clear that the DST Software is an innovative tool that has many broad ranging uses for many stakeholders and can benefit even more. It can be considered a clearinghouse for the hard and soft system tools described in this document. The soft system tools of scenario planning and resiliency analysis of decision making can help to inform the content of the models that will be available in the various components of the software package. Both the qualitative and quantitative models of system dynamics across scales are integral to the Software, and will be seamlessly integrated into the system upon completion. Further, the participatory methods that engage stakeholders at various scales can later be trained to use the system, building capacity, which may have been absent prior. Efforts described throughout this document to integrate systemic thinking of complex socio-ecosystems will be evident throughout this Software.

4.2.4.7 Conclusion

The DST Software is a cutting-edge user-friendly tool that can assist many stakeholders to improve their management of socio-ecosystems. It aims to bridge the technical divide by having easy interfaces that provide relevant information to many different people and institutions. It will incorporate the outputs from the hard system tools and the recommendations of the soft system tools. Even though some stakeholders will not be able to utilize the Software as it stands, there are opportunities for capacity building and training to increase the user audience beyond its current state in the Project period. Indeed, this computer-based software, developed through participatory approaches and reflects the theoretical roots of resiliency and adaptive management, has the potential to assist in SES management for years to come, especially in close association with soft system tools, therefore representing the spectrum of stakeholders in the targeted areas.

5 Synthesis of Hard and Soft System Tools in the HKKH Project

As stated in the introduction and in document A.1.1.1, socio-ecosystem management requires a holistic approach that engages multiple stakeholders across scales, providing pragmatic tools. The HKKH Project methodology attempts to integrate cutting-edge theoretical concepts and approaches into functional methodologies, which adaptively address SES function, accepting the non-linear, uncertain, and heterogeneous nature of these complex systems. The participatory method of scenario planning, and its linked counterpart resiliency analysis of decision-making, assist in engaging multiple stakeholders, especially on the local level, to represent their perspectives of current and future configurations of the SES, as well as what outputs could assist them to help it maintain or increase resilience to disturbances.

Further, the hard system tools of qualitative and quantitative system dynamics modeling comprehensively illustrate how different variables affect SES function at various spatial and temporal scales. The models will provide various stakeholders the ability to view how the system will function under various configurations and therefore make decisions that benefit both the environment and livelihoods. Finally, the DST Software integrates the outcomes of the various techniques, as well as much more, into a user-friendly interface that could serve diverse stakeholders to govern and manage resources in sustainable ways, benefiting livelihoods and the environment. In sum, the entire range of hard and soft system tools in the DST will assist in developing outputs that meet the Project objectives and will be tangible to the targeted SES, making the initiative not only important to the case studies, but to the general discourse of social and ecological system management.

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