SAF Handbook
GUIDE TO SYSTEM DESIGN
v.3.04

Spicosa WP3

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Contents

1 Introduction

What you are reading is a product of the SPICOSA research project, funded by the European Commission from 2007 - 2011. SPICOSA stands for '**S**cience and **P**olicy **I**ntegration for **CO**astal **S**ystem **A**ssessment'. Its research was aimed at developing and testing a toolbox of methods for providing multidisciplinary advice to 'stakeholders' and 'governance' concerning environmental problems in the coastal zone, in order to improve the zone's ecological *sustainability*, economic *efficiency*, and social *equity*. **Sustainability** relates to the capability of an ecosystem to go on supplying humans with 'goods and services'. **Efficiency** is about making the best use of those resources for the satisfaction of human needs, and **equity** is about the fair distribution of such satisfaction.

It was in response to the need for such a methodology, that the SPICOSA project developed and tested the 'Systems Approach Framework' or SAF. As explained in section 9, a SAF application has four main steps:

1. System Design
2. System Formulation
3. System Appraisal
4. System Output

Each step of the SAF has a handbook to describe its implementation. This handbook is a guide to step 1, 'System Design'. It also introduces the SAF as a whole.

2 Who are 'you' and who are 'we'?

The first drafts of the material contained in SAF handbooks were written for members of the Spicosa project to test during a set of 'Study Site Applications', or SSA, at sites as diverse as a Swedish fjord, a Spanish beach, or a Turkish estuary. Based on SSA experience, we have re-written this guide to the first step, 'System Design', for a wider audience. We assume that you, the reader, are an environmental researcher or regulator, or a member of the public; that you have a concern about an environmental problem arising from human activity in the coastal zone; and that you want to help find a solution to this problem that optimizes human well-being whilst preserving environmental sustainability. We also assume that you have a general knowledge of coastal zone ecology and geography.

The Spicosa method involves three main groups of actors:

'stakeholders': people or institutions that have an interest in the environmental problem because they cause it, or are impacted by it, or might be affected by the solution

'governance': people or institutions who make laws or policy regarding environmental problems, or who implement those laws or policy;

'scientists': the technical experts, including ecologists, economists, mathematical modellers, political scientists, social scientists, and systems analysts, who will apply the SAF to provide stakeholders and governance with the information they need for better deliberation of management or policy options.

When we address 'you' in this guide, we sometimes mean 'you' in the general sense of 'you, dear reader, from any of the three groups of actors', and sometimes in a more focussed sense of 'you, someone who will implement the steps of the SAF, or who will manage a team doing this'.

When we write 'we' in this guide, the pronoun is meant to refer to the team that assembled the material for the first drafts of the 'System Design' handbook, from which this short guide has been abstracted. Members of this team are listed at the end of the guide: 'we' include oceanographers, marine ecologists, modellers, social scientists and economists, who learnt interdisciplinarity and 'systems theory' during the writing of these drafts and from the experience of our Spicosa colleagues in applying the SAF.

3 How to use this Guide

This document gives an overview of the 'System Design' step. It is a short guide, in essence a set of lists of things to do, with brief explanations of key ideas. We recommend that you:

1. read the Guide once through completely, to understand the nature of 'System Design' and of how to start an application of the 'Systems Approach Framework';

2. subsequently, work from the 'to-do' lists (in Tables 5, 7, 8, 9, and 10), referring to separate and more detailed handbooks when you need further guidance in technical tasks.

There are a number of words, such as 'stakeholder', that we use, and want you to understand, with a particular technical meaning. These words are often highlit in various ways - by the use of 'inverted commas' or *italic font* - and are briefly defined at points where the word appears in **bold font**. The *SAF web-site* a more complete and more detailed glossary of Spicosa-related terms. There are a few ideas that require more than simple definition, because they are so important to understanding the SAF, that we outline them in sections 5 to 8. Following these is a section (9) giving an overview of the SAF as a whole and of the tasks of 'System Design'. Detailed instructions for 'System Design' start in section 10 dealing with the 'Issue Resolution' task.

4 Assembling and managing an interdisciplinary team

This section is addressed to those who are carrying out the technical work of implementing the 'Systems Approach Framework' in a particular case - i.e. to the actors that we refer to as 'scientists'. An application of the SAF needs knowledge of ecology, economics and social and political sciences, together with skills in numerical modelling and the management of relationships with stakeholders and governance. It will be unlikely that one person has all the necessary knowledge and skills, and a SAF application is therefore usually made by a multidisciplinary team. The section heading refers to an 'interdisciplinary' team, because we hope that, during a SAF application, team members will learn sufficient of each others' technical language for the team to function as a unit, so that the team's work will describe the behaviour of an 'EcoSocialEconomic System' as an entity.

The first task for the manager of a SAF application is this: consider your human resources: what people and skills can you draw on? How much of their time is available? How does this fit with the magnitude of the problem with which you are dealing and the deadline by which your stakeholders/customers need answers? Actually, you may not be able to answer these questions in full until the end of the 'System Design' step. See section 14 concerning how to better match your problem and resources when you reach that stage. Meanwhile, you need an initial team to identify and meet with stakeholders and to explore with them the environmental problem of concern.

When you have finished reading this guidebook, get your team together and ask them to read it also. And finally, keep this in mind: the team should see itself as part of a self-organizing human-environment system: it is to be expected that its members will learn, and change, and that methods will evolve, as a result of experiences during the application.

5 The problem: human activities lead to impacts on ecosystem goods and services

Members of the species *Homo sapiens* are, of course, components of **ecosystems**, where communities of animals, plants and micro-organisms interact amongst themselves and with the non-living environment. Nevertheless, it is common to distinguish between, on the one hand, ‘humans’, and, on the other hand, ‘the environment’, the milieu in which humans live. It is the second perspective that is adopted in the acronym **DPSIR**, which refers to the chain of links between the driving forces within society (D), the pressure on the environment (P), the state of the environment itself (S), the impact on people and nature (I) and the desirable response (R). [1]

One criticism of DPSIR is that it suggests a linear flow of cause and effect from Driver to Response. Thus, some users link Response back to (a change) in the Driver. It is such a feedback loop that is at the heart of the SAF analysis of coastal zone environmental problems (table 1). The starting point of a SAF application is the identification of a ***H****uman* ***A****ctivity* that results in a ***F****orcing* that brings about a change or ***R****esponse* in ***S****ystem* ***S****tate*, causing an ***I****mpact* on the *ecosystem goods and services* used by humans. In the context of the SAF, a **Human Activity** is something that humans do (in the physical world) that does, can, or might, cause a significant change in ecosystem state, whether by design or unintended consequence, and which thus significantly alters the ecosystem’s capacity to provide goods & services.

The SAF seqence ends with a ***P****olicy* ***C****hange*, also called a *Management Option*, a choice amongst things that might be done. For example, in the case of eutrophication in a Swedish Baltic fjord, the choice could include: doing nothing; augmenting local sewage treatment to remove more nitrogen or phosphorus; closing private sewer discharges; flooding coastal land to create marshes to remove nitrogen by natural means; persuading Swedes to use low-phosphate detergents; and, paying Poles or Russians to reduce their nutrient emissions, thus reducing background levels in the Baltic Sea.

The Policy Change is expected to feed back to changes in Forcing, leading not only to an improvement in System State but also to more sustainable provision of goods and services by this part of the coastal zone. The local choice of management options is often constrained: in the example, by the Swedish transposition of the European Urban Waste Water Treatment Directive and the Water Framework Directive. At a higher level of governance - for instance, in the European Parliament and Council of Ministers, the choices relate to the sort of policy to make, and the issuing of these Directives could be the Policy Change.

[1] Luiten, H. (1999). A legislative view on science and predictive models. Environmental Pollution, 100, 5-11.

Table 1: The DPSIR, and equivalent SAF, cause-&-effect, chains, or loops, exemplified for the 'Issue' of eutrophication in a fjord in Sweden.

DPSIR	Example	**SAF**	*Comment*
Driver:	Generation of urban waste water	**H**uman **A**ctivity	*As we use the term, HA refers to a deliberate or unintentional human intervention in the function and structure of natural systems.*
giving rise to a ...		*which results in a ...*	
Pressure,	from loading of the fjord with nutrients in the waste water,	**Forcing**	*(Pressure - in physics, a force per unit area - is too specific. Forcing is more general.) The SAF sees forcing as a change relative to a 'natural' level, as exemplified here by anthropogenic nutrient loading.*
resulting, perhaps, in a shift in the ...		*which acts on ...*	
State	of the fjord's ecosystem, with increases in concentrations of nutrients, abundance of phytoplankton, and amount of primary production,	**System State**	*where 'State' or 'Status' represent the situation at a specific time.*
		to bring about a ...	
		Response	*a forced change in the ecosystem. Eutrophication would be seen as part of this.*
which may be diagnosed as an ...		*perhaps causing an ...*	
Impact,	the 'undesirable disturbance' of eutrophication (including, e.g., decreased water transparency, harmful algal blooms, deep water hypoxia, and fish deaths),	**Impact**	on ecosystem goods and services: *the end-result in a cause-&-effect chain, with direct consequences for ecosystem users, such as reduced attractiveness of the fjord for recreation.*
causing a ...		*perhaps requiring a ...*	
Response	such as the 'more stringent treatment' of waste water required by the Urban Waste Water Treatment Directive.	**Policy Change**	either a choice amongst local management options or general action at a higher level of governance. *The SAF aims to forecast the results of different options or scenarios, not to dictate the choice amongst them.*

6 Understanding systems and models

An ecosystem is made of of living and non-living things interacting together. By analogy with this, we call the human part of the Coastal Zone a 'socio-economic system', and the whole thing an 'ESEsystem', where 'ESE' stands for 'ecological, social, and economic'. All this is compatible with the typical dictionary definition that a **System** is *a set of things working together as a mechanism or interconnecting network*. However, there is more to **Systems Theory** than this: systems have general properties (Table 2) above and beyond the properties of the 'things' that make up a system. An example is to be found in most houshold heating systems: the *emergent* property of temperature regulation derives from the system and not from the thermostat alone.

Table 2: A descriptive definition of 'System'

A **system**:
– consists of parts and relationships or interactions amongst these parts;
– often contains feedback loops which create *emergent* properties additional to those of the individual parts and relationships;
– has *boundaries* in space and time, which define system *extent* and *scale*;
– has an internal *state*, which responds to internal dynamics and trans-boundary processes;
– can contain a *hierarchy* of sub-systems; emergent properties of one level appear as relationships at the next higher level.

Systems modelling is one of the main tools of the SAF. Several centuries ago, Adam Smith wrote: [2]

> *Systems in many respects resemble machines. A machine is a little system, created to perform, as well as to connect together, in reality, those different movements and effects which the [maker] has occasion for. A system is an imaginary machine, invented to connect together in the fancy those different movements and effects which are already in reality performed.*

The core idea here is that *a system is an imaginary machine*, something that captures the essence of reality but is less complicated. In the SAF, the imaginery machine, or the *model*, or the *virtual system* as we'll sometimes call it, is constructed in three stages:

[2] The quote is from Smith's essay on 'Astronomy' in *Essays on Philosophical Subjects*, 1795, as given in the Introduction by A.Skinner to Smith's *The Wealth of Nations*, Penguin Books, London, 1986 reprint; the word 'maker', here, replaces 'artist' in the original.

1. a **conceptual model**, typically, a drawing of system parts connected by arrows showing functional or cause-& effect relationships between the parts (as in fig. 4);

2. a **mathematical model**, a set of equations that specify how each relationship works: exemplified on page 10;

3. a **numerical model**, in most cases made using computer software to solve the equations and make quantitative predictions about the behaviour of the virtual system (and, hopefully, the real system that it mimics).

Your 'imaginery machine' does not need to take account of all reality in your coastal zone: it only has to capture the key features of the real system's behaviour in relation to an identified problem, so that it can predict the outcome of different management options. Making the model is helped by recognizing that systems have boundaries and that these define the *scale* of internal dynamics. As Figure 1 emphasizes, the 'system' is what is within the boundaries; the 'rest of the world' is apparent to the 'system' as *boundary conditions*, which act on the 'system' but are not themselves influenced by it. Furthermore, the boundaries define what is to be included and on what scales: a coastal zone model need not start at the origin of the Universe in the 'Big Bang', nor does it need to include quantum dynamics.

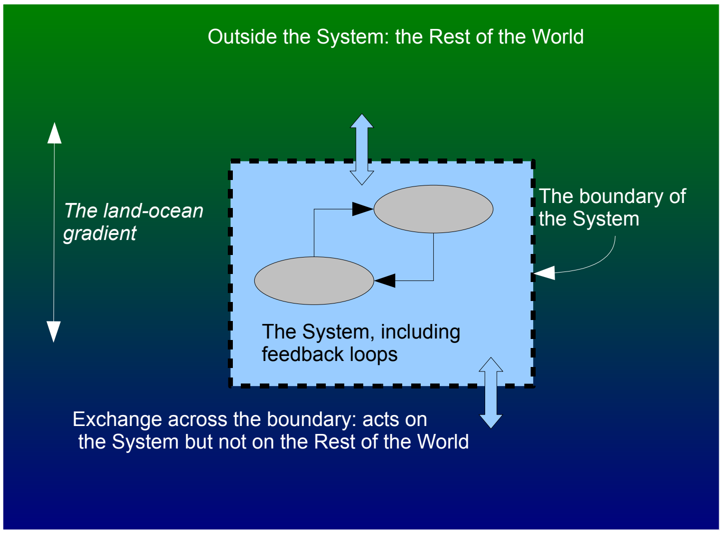
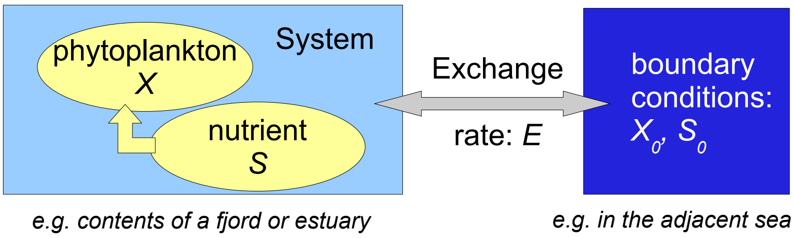


Figure 1: A coastal zone system and its boundaries.

Box: a simple ecological model illustrating key terms

This example shows the conceptual model of a simple pelagic ecosystem as a single box with two *state variables*.



The mathematical model includes a pair of differential equations, and the **state variables** are the subjects of these equations:

	rate of change:	is defined by the equation	where the *state variable* is:	
(phytoplankton)	$\frac{dX}{dt}$	$= r \cdot X + E \cdot (X_o - X)$	X	(1)
(nutrient)	$\frac{dS}{dt}$	$= -\frac{r \cdot X}{q} + E \cdot (S_o - S)$	S	(2)

Change in the system depends on *internal processes* and on the effect of **boundary conditions**. Water exchange between the system and conditions at or outside its boundaries brings influxes $E \cdot X_o$ and $E \cdot S_o$; the boundary effects are included in the model by providing data either for these fluxes or for the exchange rate E and the boundary concentrations X_o and S_o. The outfluxes $E \cdot X$ and $E \cdot S$ are supposed to have no influence on the boundary conditions. The **internal processes** include the effects of phytoplankton increase rate, r, on amount of phytoplankton and, taking account of the coupling constant q, on amount of nutrient. Feedback from nutrients and phytoplankton to r can be provided by an equation such as:

$$r \quad = \quad r_{max} \cdot (1 - \frac{X}{X_{max}}) \cdot \frac{S}{k_S + S} \qquad (3)$$

Like q, X_{max} and k_S are likely to have constant values in any one application of the model. It is, however, better to refer to each as a **parameter** (Greek: 'auxilary measure'), because their values may depend on the type of phytoplankton or local conditions, rather than being universally constant.

The **scale** of the model is set by its *extent* and *grain*. In this single-box model, spatial extent (the distance between boundaries), and grain, are the same. Thus, exchange rate, the probability that, in a given time, any small packet of water inside the box may be swopped with a packet from outside the boundary, combines - and therefore does not distinguish as more detailed models might - the effects of smaller-scale water movements. If the model is used to simulate day-to-day changes during a year, then temporal graininess, such as hour-to-hour changes in exchange due to tide or wind, need not be explicitly represented, net effects being averaged over 24 hours. The parameter r_{max} might vary during a daily cycle because of the effect of changing illumination on phytoplankter photosynthesis, but this high-frequency variation could be neglected in a seasonal cycle model by expressing r_{max} as a simple function of 24-hr mean illumination.

7 Understanding stakeholders, institutions, governance, laws and environmental management

Stakeholders, and people representing governance, are key players in a SAF application. The two groups may overlap. Furthermore, they are also part of the real Coastal Zone system, and may enter into the 'virtual system' that is to be described in a model. In order to explain them further, we need to say something about 'society' (in the Coastal Zone).

Society is made up of people and the links between them. Some of these links are transient and small-scale: peoples' relationships with their neighbours, for example. In addition, the pattern of, or the information in, links has some existence in its own right, and is built up, handed on, and evolves, from generation to generation. We're speaking of 'culture' and 'norms' here, the kind of rules that people obey when, in certain cultures men raise their hats to ladies, and in others, women cover their heads in the presence of males. Sets of rules that become formalized are called **institutions**, a word also used for the organizations and the buildings where people work under these rules. Societies can be mapped or modelled in terms of the relationships between institutions, as we'll see, and the 'social capital' of a society lies in its institutions and its local networks of trust.

Churches, fishermens' co-operatives, and industrial businesses are all examples of institutions. Over-arching all of these, in an ordered society, is 'Government', made up of deliberative, executive, legal, and police, systems. These ruling institutions are collectively called **governance**, defined as *the act or manner of, or the system for: ruling or controlling the subjects or citizens of a State; or, conducting the affairs of an organization.* The word derives from the Latin 'gubernator' and that from a classical Greek word for the person who steers a ship - who is helmsman, navigator and captain.

In modern states, and other large institutions, governance takes place on several scales. We distinguish three of these. The *operational level* is, in our context, the level at which the direct interaction between human activity and the biophysical resources takes place, and at which stakeholders or public officials implement rules dealing, for example with public access to the shore or the contents of individual sewage discharges. Rules on the *collective level* govern the management of coastal resources; they tell how the decisions leading up to rules on the operational level are to be made: for instance, who is in position to make decisions, who can block decisions, how decisions are made (unanimous or simple ma jority), the amount of information required etc. At the *constitutional level*, rules specify how changes in the management of coastal resources can be made - e.g., how lower level rules or governing bodies can be changed.

We define **environmental management** as *'governance' extended to ecosystems, with the aim of sustaining an ecosystem's ability to provide goods* *and services; it includes the prevention of pollution, the conservation of species and habitats, and the remediation of damaged ecosystems.* An 'environment manager' is a public official who carries out environmental management; on the operational level, managers plan or consent individual Human Activities (HAs) taking account of their likely environmental impact; at the collective level, they make environmental plans or oversee the implementation of environmental policy, at the constitutional level they decide policy or support legislators who make environmental law. It is likely that some of these managers will play an important part in a SAFapplication.

In a democracy, of course, all citizens have a stake in their Governments, but there is a difference between 'citizen-voter' and 'stakeholder' as we will use the words here. Governments are elected to deal with many aspects of society. In the SAF you will focus on just one 'Issue', meaning a set of matters related to a coastal zone problem (or group of related problems) arising from a Human Activity. A **stakeholder** is *an organisation, community or individual who has a 'stake' in that 'Issue' because they are concerned about it, potentially or actually affected by it, or have or want a voice in the making of decisions about it.* The words 'stake', 'interest' and 'concern' are interlinked, and carry with them, in our usage, some sense of a moral right to be consulted about any proposal or plan than might have an effect – for better or for worse – on the stakeholder. Some stakeholders carry out the harmful HAs and others are affected by consequent impacts. A third group might presently be unaffected but might be affected by remedial measures - for example, they might have to pay the cost of these, or suffer a new sewage treatment works to be build close to their houses.

In implementing the SAF you will need to know something about the institutions, and the categories of stakeholders, in your coastal zones, relevant to the problem you address. There are tools for getting this information:

institutional mapping : *a process of analysis for identifying the rules governing the relations between organisations, groups and individuals, optionally resulting in a diagram*; in a hierarchical system this analysis may focus on the relationships between institutions, including governance; all of which are themselves sub-systems;

stakeholder mapping : *a subset of institutional mapping that involves the identification of stakeholder groups relevant to a particular matter*, such as a HA, impact, public environmental policy, or 'Issue'.

Methods are described in a separate guide to *Institutional & Stakeholder Mapping*. Environment managers, members of governance institutions, might also be seen as stakeholders. We prefer to distinguish them because of their specialized role in a SAF application.

8 Understanding ecological economics

The 'eco' components in 'ecology' and 'economics' have a common origin in the Greek word *oikos* for 'house', and so 'economics' may be thought of as 'rules for housekeeping' in human society, and 'ecology' the 'study of (nature's) household'. However, there is a difference between the real world in which ecosystems are to be found, and the world of economics and money that some people refer to as 'real', but isn't. To explain the difference, we will introduce the three 'worlds' postulated by Karl Popper. [3] They are:

1. the real, physical, world, in which exist ecosystems including their fleshy human component;
2. each human mind (Descartes: *"cogito ergo sum"*);
3. the world of information, shared amongst humans in the form of narratives, pictures, computer programs, cultural norms, laws, etc.

Ecology is world 1 (but understanding of it is in world 2 or 3, and system models will be made in world 3). Economies, defined in money terms (for example when Gross National Product is cited), are in world 3. If we define the purpose of an economy as the 'efficient satisfaction of human well-being needs' then those needs are, properly, in world 2. People need food, drink, etc for their corporeal bodies, of course, but their perceived needs are in their minds. As figure 2 shows, there are three routes to satisfying these needs: by central allocation of resources ('hierarchies'), by local social networks ('collective arrangements'), or by way of the impersonal market.

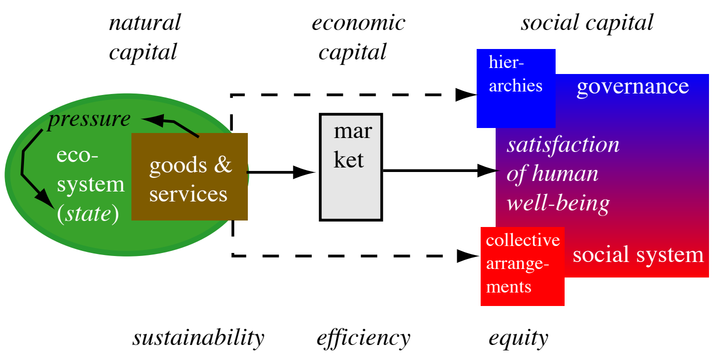


Figure 2: An ecological-social-economic (ESE) system

[3] Popper, K. (1972). Objective knowledge: an evolutionary approach, Oxford University Press.

Modern markets operate with the aid of money. The 'use-value' of objects can lie in any of the three worlds, but the 'exchange-value', or monetary worth, of a good or service is strictly a world 3 entity. Money is both information (about this valuation) and institutionalized trust, a promise to provide some use-value on demand. The idea of **ecosystem goods and services** provides the link between world 1 ecosystems and world 3 societies and economies. We define them as *the material and non-material things that ecosystems supply to humans, including ecosystems' capacities to assimilate wastes as well as provide tangible and intangible resources.* They are categorized in Table 6, where we follow standard practice and refer only to services, classing 'goods' as a *provisioning service.*

Ecological economists make several criticisms of classical economics. One criticism is that it deals only with what humans do to satisfy well-being needs: what we spend, what we pay each other. A second is that it recognizes only the several sorts of human capital that have been amassed to make the production of goods and the supply of services more efficient: durable capital, intellectual capital, financial capital. Thus, classical economics does not take account of natural capital, which needs to be maintained if a system is to be sustainable, and it does not take account of 'externalities' - the uncosted effects of human activities on other humans and the environment. Ecological economics takes these into account in seeking to ensure that 'goods and services' are used both efficiently (the aim of economic management) and sustainably (the aim of environment management).

As an example of this, let's look at eutrophication in a Swedish fjord. 'All flesh is grass': food webs depend on primary production, and that on nutrients. These are compounds of nitrogen and phosphorus; their scarcity in most pristine coastal seas restricts the amount of organic matter that phytoplankton, seaweeds and seagrasses can manufacture using the energy of sunlight, and so set a limit to the number of animals that can be supported by the plants and algae, and the amount of fish that can be harvested. Human activities (such as the production of sewage, or the fertilization of farmland) increase the supply of nutrients reaching the sea, and so increases primary production. Although this may give rise to more fish, it also results in problems such as decreases in water clarity, or hypoxia in deeper water.

Nutrient enrichment might increase the potential harvest of fish or shellfish or might decrease the attractiveness of recreational waters to visitors; de-oxygenation might kill fish; etc. Behind such obvious effects, there is hidden service provided by the sea: that of recycling nutrients safely. Until recently, humans took no account of most of these goods and services: fish could be freely taken from the sea (subject only to the costs of running boats and paying fishermens' wages), and the use of the sea as a dumping place for sewage seemed a much cheaper option than that of building and operating a costly sewage treatment plant.

9 'System Design' starts a SAF application

Each step of the 'Systems Approach Framework' has its own guide, but we need to provide an overview in this 'System Design' guidebook so that you know what's coming next! Here are the steps:

System Design : consult with stakeholders and environment managers to identify the 'Issue', a Coastal Zone 'problem' involving a cause-&-effect chain from a *HA* to its *impact* on ecosystem goods and services; thus, identify a 'virtual system' that embodies sufficient real-world behaviour to allow this problem to be explored through modelling; agree remedial 'scenarios' or management options with stakeholders;

System Formulation : build conceptual, mathematical and numerical models for use in simulating system behaviour or its ecological, economic and social components; get data needed by these models;

System Appraisal : test your model(s) against observations on the real system; where necessary link the separate components and use the final model to explore the implications of the management scenarios;

System Output : take your results back to the stakeholders, explain what has been done and help the stakeholders to deliberate on their choice amongst options, using the results simulated for each scenario.

The **System Design** step is set out in table 3, and described in more detail in sections 10 through 14. Before you start it, here are a few remarks. The SAF itself is a system, and may be adapted to, or evolve in response to, particular applications, so long as it remains informed by 'systems thinking'. Some 'Issues' are too simple to justify the time and resources required for a SAF application: see Figure 3. Others might seem too demanding: see section 14 about scaling the application to the available skills and time. The *System Formulation* and *System Appraisal* steps make heavy demands on the time and skills of modellers. Spicosa has made a library of model blocks, using ExtendSim software, to help them. In other cases it may be possible to go directly from 'Design' to 'Output', the design of a 'virtual system' in consultation with stakeholders being sufficient in itself to help stakeholders' deliberations. Finally, a caution. The SAF is a rational, 'Enlightenment', method. Given adequate data it should point to an optimum choice amongst management options. However, what will be chosen by a particular group of stakeholders will be constrained by law, culture and the existing distribution of power in the coastal zone society. 'System Design' tasks include a study of these constraints, but it should not be the aim of the SAF application to change them, except insofar as the provision of knowledge is empowering. You should be satisfied with any outcome that increases coastal zone sustainability.

Table 3: The tasks and subtasks of the 'System Design' step of the SAF

1	**Issue Resolution**: section 10, table 5. *a. Reach agreement on Policy Issue(s) and associated scenarios, ...* *b. Identify what dysfunction in the natural system is implied by this Issue ...* *c. Identify social concerns and public perceptions relative to the Issue.* *d. Identify relevant economic activities ....*
2	**System Definition**: section 11, table 7. *a. Define the Coastal Zone System to be studied by ascertaining that all primary functionality is within the boundaries of the specified 'virtual system'* *b. Specify boundary conditions ... [and] relevant internal inputs, controls, constraints, and social and economic demands relative to the Policy Issue(s).* *c. Anticipate potential risks ....* *d. Synthesize the state of the impacted ecosystem ...*
3	**Conceptual Models**: section 12, table 8. *a. Construct conceptual models of the CZ systems response to the Policy Issue(s) that will allow visualization of its primary characteristics ...* *b. Use these models to indicate the primary (ecological) cause & effect relationships; specify the key forcings and social and economic interactions ...* *c. Use standard formats to provide examples for these conceptual models.* *d. Specify the outputs of the conceptual model's 'virtual system'.*
4	**Methods & Information required**: section 13, table 9. *a. Identify the modelling software and analytical methods to be used.* *b. Acquire existing information on the major (relevant) HAs .* *c. Obtain data for external forcing.* *d. Indicate the format for storing the CZ relevant data.* *e. Specify any auxiliary models needed to link with the systems model.*
5	**Problem Scaling**: section 14, table 10. *a. Scale all processes and streamline the problem to the first-order ... cause-&-effect chain; simplify methods to bring them in balance with the overall effort.* *b. Iterate on the scope of the problem to ensure feasibility and reduce if needed.* *c. Begin to think about the outputs of the SAF in terms of publications in the natural, economic, social sciences ....* *d. Begin to think about the format for presentations and visualizations (for policy-makers, stakeholders, and public) ....*

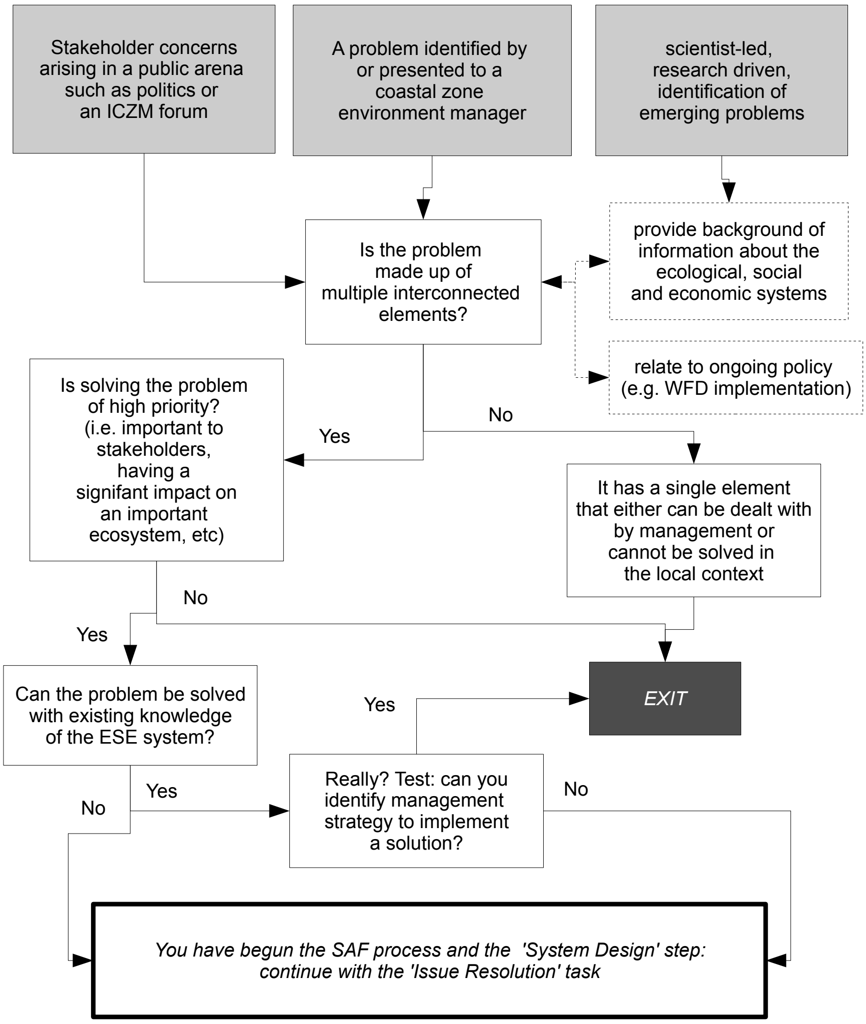


Figure 3: Is a SAF application necessary? A decision diagram.

10 Discussing and agreeing the ‘Issue’ with stakeholders

A SAF application starts with the task called ‘Issue Resolution’. *‘Once upon a time,’* our tale might begin, *‘scientists were talking together, when a stakeholder rushed into the room and said, “I’ve been impacted by a Human Activity, and something must be done!”. Whereupon the scientists got together with other stakeholders and with environmental managers, identified the cause-&-effect chain from HA to impact, who was responsible for the HA, who was affected by it, what the economic consequences were, and some management options for ameliorating the impact. And thus ‘Issue Resolution was accomplished and the SAF application got underway.’*

In reality, the application might be initiated by stakeholders who seek better information to help them choose amongst management options already proposed, for example, by regional planners. Or the starting gun might be fired by local environment managers, who have themselves identified an environmental problem, or know that they soon have to implement a new law, and would like more information about the consequences of their planned actions. Or scientists themselves may start the process, through their own concern about an environmental problem, or their need to fund their work. In many cases the kick-off will be a messy process, involving repeated meetings between the three groups of actors, during which the essence is slowly distilled from of an initially confusing set of problems, perceived impacts, and potential solutions

This essence should be a well-defined HA-forcing-impact problem and its management options. We call the set of problem and options, the **Issue**, and the process of identifying it is called **Issue Resolution**. Note that this task is about *defining* the Issue, as if by focussing a telescope, and not about *solving* the HA-impact problem, either now or later. A SAF application does not aim to solve problems, merely to give advice to stakeholders and environment managers, so that they can better deliberate about the options available to them. Sometimes solution will be achieved by the discussion that starts ‘Issue Resolution’ (Figure 3). The SAF application need continue only if there remain uncertainties or disagreements that can be ameliorated by scientific study.

Questions may arise about who pays for that scientific study: we don’t address those here but see section 14 about adjusting the SAF application to fit within the resources of time, people, skills and equipment available to the scientific team. Consider, also, the stakeholder’s own deadlines. If a decision has to be made about a choice of management options within 6 months, then later information will be no use.

It is usually not feasible to engage with large groups of stakeholders during Issue Resolution. Instead, aim to work with a small group of environment managers and representatives of stakeholder concerns. We'll call this the **Reference Group**, because matters are *referred* to them. [4]

Table 5 lists sub-tasks and action points, and Table 4 presents a summary of an example 'Issue'. The subtasks include the identification, not only of the environmental problem, but also of who is involved and what is likely to determine the economic costs and benefits of the problem and the options for dealing with it. Additionally, indicators of ESEsystem state will be needed. The table shows 'water transparency' as an example of an environmental indicator. It is easy to measure, widely understood, clearly relevant to the Issue of Eutrophication, and allows the success of management options to be assessed. The socio-economic indicators will depend on stakeholder preferences. Is the aim to maximize local income, for instance? Or to maximize employment?

Finally, note that the SAF requires simulation and appraisal of ESEsystem state under several **scenarios**. Think of these as *'what-ifs'*. What would happen if management option B were chosen instead of A? [5] A SAF application aims to compare consequences in a safe 'virtual' world.

Table 4: Example Policy Issue, based on a completed SAF application

Site:	A fjord in Sweden, south of Stockholm
Reference group :	About a dozen, including farmers, private citizens, elected representatives, officials from municipal authorities and the Environment Protection Agency
Human Activities:	Discharges from Sewage Treatment Plants, agriculture, and private sewers
Forcing:	Enrichment of the fjord with nutrients
Impact:	Degradation of water quality which can deter tourists
(Policy) Issue:	Eutrophication
Management options (scenarios):	(i) increased stripping of nitrogen from STW discharge; (ii) connection of private sewers to public STW plant; (iii) change in farming practices so that small er amouts of nitrogen compounds enter the fjord
Social concerns:	Desire for 'clean' water in fjord, distribution of costs amongst stakeholder groups.
Economic aspects:	Costs of sewage treatment, benefits of leisure visits
Provisional Indicators:	Water transparency, number of visitors during year

[4] In earlier drafts the term 'Stakeholder Participant Group' was used

[5] Previous versions of this handbook referred to 'policy option'. 'Management option' seems the better term when dealing with choices at the operational level of governance; 'policy option' could be used when working at collective or constitutional levels.

Table 5: Subtasks and Action Points for Issue Resolution task.

Sub-task Action Point	Notes
Preliminary (before meeting with stakeholders) – Make a preliminary list or map of human activities (HAs) and associated stakeholder groups – Make a preliminary Institutional Map to understand Governance in relation to these HAs and stakeholders	
a. Reach agreement on Policy Issue(s) and associated scenarios, indicators, descriptions and criteria. – If necessary help form, and then meet with, the 'Reference Group' of stakeholders and environment managers – Discuss HAs, Impacts, and management options and indicators, with this group – Reach consensus on the 'Issue'	*see:* *Working with Stakeholders; Scenarios for Management; Identifying the 'Issue';*
b. Identify what dysfunction (impacts) in the natural system is implied by this Policy Issue and prioritize them in the case of multiple impacts. – Analyse available information on the (ecological) cause-&-effect chain from HA to impact and evaluate the importance of different HAs and impacts in relation to the Issue – Agree ecological indicators to use in comparing the outcomes of management options	
c. Identify social concerns and public perceptions relative to the Policy Issue(s). – Carry out stakeholder mapping to identify the main groups of stakeholders in relation to the Issue – If resources permit, survey opinion amongst these stakeholders and list their main concerns in relation to the Issue – Agree social indicators for use in the comparing the outcomes of management options	*Institutional & Stakeholder Mapping;*
d. Identify economic activities directly impacted and those potential economic effects including non-market impacts. – List or map the main economic activities that have a relevant HA and Impact within the ecosystem – List the main ecosystem Goods and Services that are relevant to the Issue – Agree economic indicators for the Issue – List the main economic drivers of change within the CZ system (relevant to the Issue)	*Defining a Coastal Zone Economic System.*

11 System Definition: describing the real coastal zone system, defining a 'Virtual System'

This task requires *description* of relevant features of a Coastal Zone and *definition* of a 'Virtual System' that contains only features relating to the identified 'Issue'. The distinction between, on the one hand, the complicated 'real' Coastal Zone system, which includes both 'world 1' ecosystems (with their human populations and physical infrastructure) and 'world 3' economies and social institutions, and on the other hand, the 'world 3' 'virtual machine' that will enable you to predict the outcome of management options or policy scenarios, is crucial to the SAF. In 'System Design', it is, of course, the 'virtual system' that is being designed: the 'real' world can only be described. As you move on to 'System Formulation', the 'virtual system' that you have designed will be implemented as one or more mathematical and numerical models.

During the 'System Definition' task of 'System Design', however, your main tools are written words, arranged in lists of key features and in narratives of the relevant history and geography of the study area. A good narrative links the items of a list in an explanatory, sometimes causal, framework. Maps play a useful supporting role. There are two sorts of maps: those that show a territory realistically but at a much smaller scale - for example showing 50 km of a river and its delta at 1:100,000 on a 50 cm surface; [6] and those, like most maps of city transport networks, emphasize functional links rather than exact spatial relationships. It is a small step from such simplified maps to those that are purely conceptual, such as those that show power relationships between institutions.

Spatial averaging, categorization and typification are further aids to simplification. For instance, real world systems can often be mimicked by a small set of boxes, or even by one box, in a virtual system, as illustrated in by the simple model on page 10. 'Stakeholder mapping' involves grouping stakeholders, and is aided by recognizing 'essential' features to allow use of prior knowledge of types. 'These are farmers, therefore they plough and sow ...'. In the case of eutrophication as an Issue, it may be acceptable to define all phytoplankters as a single entity in the virtual system. But take care not to neglect heterogeneity within physical-ecological, economic or social categories - think of standard deviations as well as means of properties. And do not homogenize two categories whose distinction is of the essence of the 'Issue'. For example, the definition of eutrophication includes the idea of 'disturbance to the balance of organisms', and the relevant 'virtual system' may thus need at least two phytoplankton components.

As shown in the list of subtasks (Table 7), 'System Definition' starts with

[6] In some cases it will be necessary to take account of the third dimension and consider, for example, stratification in an estuary or coastal sea.

the impacted ecosystem and related features of the physical world. The 'virtual system' that you are designing is, however, an ESEsystem, and so you need also to identify the relevant economic and social features in 'world 3'. Table 6 brings an economic perspective to ecological and social components together. 'Stakeholder Mapping' and 'Institutional Mapping' will help to complete your lists, which should include relevant organs of government and their roles. Key questions here concern the interaction between services and capitals, the ownership of capitals and access to services by different stakeholder groups, the role of laws and cultural norms in determining this at the operational and (local) collective levels. How do these relate to the Issue, which will change, or need to change, in the different management options? Some of them might become components of the models, others used to appraise the outcomes of the different scenarios.

You need to identify the boundaries of your 'virtual' Coastal Zone. These may be administrative boundaries, or those set by topography, in the 'real' world. The essential feature of the boundaries of a 'virtual system' is that they separate a domain in which modelled processes can interact, from an 'outside' which will be represented by **boundary conditions**. As illustrated on page 10, boundary conditions can be set either as state of the external world at the 'virtual system' boundary, or the fluxes across that boundary. As an example, consider the rivers that drain into a coastal sea. Does the river catchment need to be part of the 'virtual system', or can it be placed outside the boundary and its effect simulated by data about discharge of water, sediments, dissolved substances, etc.?

A final idea is that multiple representations of the 'real' system are possible; it may be understood, and defined in the 'virtual system' in more than one way. This does not mean that 'truth' is relative to the observer. A defined 'virtual system' must be compatable with existing information about the 'real' CZ system, and the simulations of the mathematical and numerical models made from the description of the 'virtual system', must agree with observations in the 'real system'. This agreement will be explored in the 'System Appraisal' step of the SAF application.

Subtask 3 concerns 'Risk'. Think about what might go wrong as a result of events beyond the boundaries of your system. What are the likely major hazards, and what is the likely probability of their occurrence? Around the Mediterranean basin, for example, and in other tectonically active zones, the hazards include earthquakes or volcanic eruptions, and, as recent history has shown, the probability of these phenomena is sufficiently high that they may influence choice between management options. Some may be more resilient against physical damage. What about socio-economic hazards, such as collapse in governance, or global economic recession?

Table 6: Capitals and services in ecological economics, exemplified by the clam fishery in the Lagoon of Venice

(a) Capitals

category	subcategory	contents	examples
physical	fixed	buildings, fixed machinery, roads, harbours, etc	buildings for storing and processing shellfish
	movable	equipment	fishing boats
	working	stocks of raw materials and products for sale	dredged clams (which might be relaid)
human	individual	skills and knowledge	boat operation, clam dredging, etc
	intellectual	patents, books, software, etc	training courses in fisheries management; traditional ecological knowledge
	social	networks, institutions	fishing co-operatives, government fisheries office, etc
natural	renewable*	stocks of living things, soil etc	the stock of wild clams in the lagoon
	non-renewable*	fossil fuels, minerals, biodiversity	marine biodiversity

* renewability is a matter of timescale: fossil fuels need millions of years

(b) Human activities

economic sector	contents	examples
primary	exploiting natural resources (mining, fishing, forestry, some farming)	harvesting wild clams, or using lagoon to grow them
secondary	processing and distributing these resources or things made from them	shellfish processing
tertiary	supplying services to other people or institutions	insuring boats, licensing shellfisheries, fish restaurants

(c) Ecosystem services*

category	contents	examples
supporting	necessary for other ecosystem services	primary production by lagoonal phytoplankton
provisioning	products or goods, e.g. food, materials, medicines, biofuels	wild or farmed clams from the lagoon
regulating	climate and water regulation, erosion control, storm protection etc	waste removal as a result of lagoonal flushing
cultural	nonmaterial benefits: spiritual, recreational, aesthetic	'sunset over the lagoon of Venice'

* Millennium Ecosystem Assessment, 2003. Ecosystems and Human Well-being: A Framework for Assessment. Island Press, Washington, D.C.

Table 7: Action Points for System Definition task

Sub-task Action Point	Notes
a. Define the CZ System to be studied by ascertaining that all primary functionality related to the 'Issue' is within its boundaries. – Draw a geographic map showing the main features of the CZ to be included in the 'virtual' System; include the 'real' boundaries if known, and the 'virtual' System boundaries. – Identify vertical structure that is important to the ecosystem's functioning, and include in the 'virtual' System. – List the main ecosystem components, and their main internal transformations, to be included in the 'virtual' System.	
b. Specify the necessary boundary conditions, i.e. identifying information/data needed for prescribing the external boundary conditions, anthropogenic drivers. Specify the relevant internal inputs, controls, constraints, and social and economic demands relative to the proposed Policy Issue(s). – List or map the main transboundary exchanges that should be included in the 'virtual' System. – List or map the main (natural & anthropogenic) within-system inputs or withdrawals of matter & energy to be included in the 'virtual' System. – List the steps from HA to impact relating to the ecosystem dysfunction that provides the 'problem'. – Identify the main property rights and Goverance structure relating to the Issue, and draw an Institutional Map. – List the present and potential economic demands likely to be made in the 'real' system in relation to the Policy Issue, and which should be included in the 'virtual' system.	*for detailed guidance, see:* *Institutional & Stakeholder Mapping;* *Defining a CZ economic system;*
c. Anticipate characteristics of potential risks (e.g. geological, ecological, social, economic) that should be evaluated and estimate the resources required. – List the main external hazards that pose a risk to the 'real' system, and estimate the work required to evaluate the level of hazard, the probability of its occurrence, and its consequence for each management option	
d. Synthesize the state of the impacted ecosystem relative to its function, knowledge gaps, and major component interactions. – Include the above information in an illustrated narrative that defines the 'virtual' ecosystem in relation to the Policy Issue, and add a preliminary assessment of the impact of relevant HAs. – Discuss this narrative with other scientists and the Reference Group in order to identify knowledge gaps.	*Examples on website*

12 Making a Conceptual Model

'Conceptual Modeling' continues to formalize the description of the 'Virtual System'. Whereas 'Issue Resolution' was largely about discussion with stakeholders etc, and 'System Definition' mostly about written lists and narratives, 'Conceptual Modelling' is mainly about diagrams.

We recommend starting with a blackboard, whiteboard or flipchart as a focus for discussion, and then switching to electronic tools to make the conceptual model more precise. During the Spicosa project we explored a a range of software. Microsoft PowerPoint can be used to draw boxes and arrows and add annotations. Some of the diagrams in this Guide were made with the similar program, OpenOffice.draw, part of the freeware package OpenOffice.org. [7] EmergySystems.org hosts a set of symbols that can be used in such diagrams to characterize a range of systems properties. [8] The modelling software Stella enables conceptual models to be made using a simple set of icons for state variables, fluxes, parameters and information flow. [9] This can be done without adding the quantitative equations required to make the model work. However, we found the freeware Cmap to be most useful at this stage, being easy to learn, and offering a good combination of flexibility and precision. [10] As the example in Figure 4 shows, its boxes can be used to represent system 'nouns' or things, and its linking arrows, 'verbs' or relationships.

The example demonstrates several general points. A box has been drawn to include the major components and main relationships of the ecosystem relevant to the Issue. Within this the component labelled 'balance of organisms', included to take account of a key feature of eutrophication, may become superfluous in the final model, because this needs only include components that relate to the costs and benefits of nutrient removal by way of water transparency. Inside the 'phytoplankton' box is a sub-system dealing with the effect of light as well as nutrients on the growth, production and amount of phytoplankton. Several arrows cross the left-hand side of the ecological box, and these represent the boundary fluxes (the 'external inputs'). All are relevant to the issue, but the arrows for discharges and leaching are directly involved in the HA-forcing link, whereas the arrow for exchange represents a natural process that continues irrespective of the HAs but is essential to quantifying the effect of the human forcing.

The diagram includes key social and economic features of the coastal zone system as related to the locally defined Issue (table 4). There is a

[7] http://www.openoffice.org/

[8] The symbols were proposed by Odum., H.T. 1994. Ecological and General Systems: An Introduction to Systems Ecology. University Press of Colorado. They can be copied from: http://www.emergysystems.org/symbols.php.

[9] isee systems: http://www.iseesystems.com/

[10] IHMC Cmap Tools: http://cmap.ihmc.us/

feedback loop from water transparency by way of Environment Managers to control of nutrient discharges. The managers, plus householders and farmers, are parts of the socio-economic system within the boundaries of the conceptual model. Whereas the ecosystem model is very likely to become a mathematical model, this may not be true of the socio-economic components. But these have to be understood to make sense of system behaviour. The local income resulting from visitors is in our example one of the agreed management indicators (and thus a 'system output'), so it will be necessary at some stage to have a means to estimate this as a function of simulated changes in transparency. Finally, the two EC directives mentioned here may be treated as boundary conditions for governance: they influence what happens in the 'virtual machine' but are not influenced by it.

Now turn to the subtasks in Table 8.

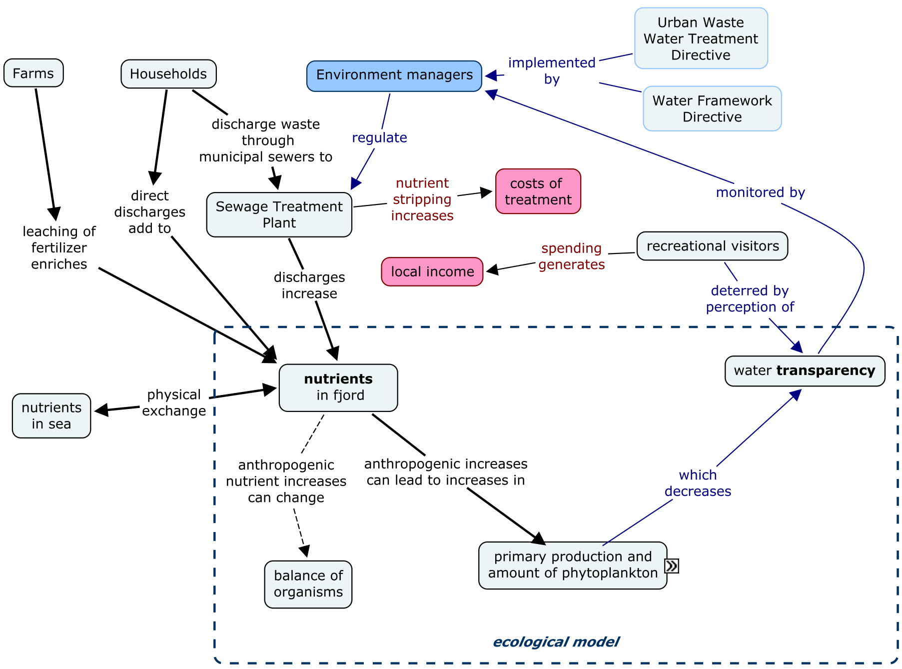


Figure 4: Example conceptual model, based on Eutrophication as an 'Issue' (Table 4). This example uses Cmap Tools to show ideas about the contents and causal relationships of the 'virtual system' as they might emerge from a preliminary discussion; it is not yet a full specification for the mathematical model, although suggests that 'nutrients' and 'transparency' might become *state variables* in this model. An attempt has been made to distinguish actual flows of nutrients (thicker lines) from less well-defined cause-&-effect relationships or information flows. Cmap allows a hierarchy to be set up within the conceptual model, with complex low-level objects collapsing into simpler objects when viewed at a high level. The tab on the 'phytoplankton' box indicates that it can be expanded in this way.

Table 8: Action Points for Conceptual Modelling task

Sub-task Action Point	Notes
a. Construct conceptual models of the CZ system's response to the Policy Issue(s) that will allow visualization of its primary characteristics in relation to each other, e.g. external boundary conditions, major compartments, and those internal processes that control the flow of mass, energy and information through the system. – Sketch diagrams showing relationships amongst system components, and system boundary exchanges, for the parts of the 'natural ecosystem' that are relevant to the Issue and thus which need to appear in the 'virtual system';	*see:* *Introduction to SAF Modelling*
b. Use these models to indicate the primary cause & effect relationships; specify the key forcings, variables, and processes; identify external inputs (mass, energy, & information), internal inputs; and indicate the social and economic interactions, controls, processes, and components and their interactions relative to the cause & effect chain; and specify expected CZ system outputs. – Add to these diagram(s) the cause-&-effect chain from the HA(s) to the impact(s) identified during 'Issue Resolution'; this will include propagation of the effects into the human socio-economic system by way of 'goods and services'; – Take care that relevant feedback loops are included both within the ecosystem component and by way of the socio-economic (including governance) components;	
c. Provide a sample format in the form of examples for these conceptual models by adapting various in-use methodologies. – Of currently available formats, Cmap Tools has been widely used in Spicosa applications, and seems to offer a good compromise between flexibility and specificity; – Formalize the model diagrams using the selected tools; where appropriate, make use of Cmap's facility for displaying different levels in a hierarchy of subsystems;	*examples from Spicosa study sites*
d. Specify the system outputs for both qualitative and quantitative analyses. – Ensure that the diagram has a place for the information that is expected to be output from the model of the virtual system, as agreed during Issue resolution – Include in the diagram suggestions for other outputs (e.g. time series of state variables or rates that can be compared with observations) that might be used to demonstrate reliable modelling of the CZ system	

13 Thinking about the information you will need

Now you have an 'Issue' and a conceptual model of the relevant 'virtual' ESEsystem, the next task is to think about what data will be needed to complete the mathematical and numerical modelling, to run numerical simulations, and to appraise or interpret the results, in later steps of the SAF. Experience has shown that it's best to begin data gathering as early as possible. That's what this task is about, and we hope that you find it straightforward to work through the list in Table 9.

A few comments. 'Actions to acquire data' should start by querying public data bases (such as those of meteorological information). After this, consult any other source, including the scientific literature, available to you. If needed data don't seem to exist, can you simulate them with an accessory model (e.g. using an astronomical model to calculate sunshine as a function of latitude and day of the year), or adapt information from a similar coastal zone? Only if all else fails, should you consider the expensive and time-consuming process of measuring what you need. And even in this case, some stakeholders or environment managers might already be taking observations that can be adapted to your needs.

'Storing the data' is worth thinking about as you start. If the data sets prove to be are large, how might your institution store and access them? Might they be useful again, once this application is finished? If so, store them in a non-proprietal format for ease of later access (e.g. comma separated columns of ASCII text instead of the latest Microsoft Excel format).

'Methods for modelling' refers to your tools for making the main systems model. Will your modellers write code in languages such as Fortran or C++ ? Will they use specialized modelling software such as Stella, or a tool like Matlab[11] that has some of the advantages of a generalized languages as well as specialized modelling tools? The Spicosa project used the modelling software, ExtendSim[12], as its standard tool, and is publishing a library of coastal zone model building blocks for ExtendSim. The software is versatile, but as it works by linking blocks together, it cannot easily deal with simulations that involve grids in 2 or 3 dimensions. It can take data from, or output data to, more specialized models. We suggest that you examine some of the ExtendSim models that Spicosa has placed on its website in order to understand better its abilities and limitations. In any case, be aware of training needs if a new type of software is to be used.

[11] The MathWorks, Inc. http://www.mathworks.com/
[12] Imagine That Inc. , http://www.extendsim.com/

Table 9: Action Points for Methods & Information task

Sub-task Action Point	Notes
a. Identify the methods suitable for resolving the various quantifications and qualitative interpretations needed. Identify methods for: – conceptual modelling and numerical simulation – analyzing initial, comparison, and boundary data, and for supply missing values numerically – measurements to provide missing data and parameter values, where necessary and affordable – acquiring new economic data, where necessary and affordable – acquiring new qualitative and quantitative social data, where necessary and affordable	
b. Acquire existing information/data on the major HAs relative to their controls and constraints on the ecosystems. – Identify the relevant HAs and set in motion actions to acquire relevant 'pressure' or 'forcing' data – Identify existing economic data relating to these HAs and set in motion actions to acquire these data – Identify existing demographic and social attitude data relating to these HAs and set in motion actions to get these data – If CZ Governance structure relative to HAs not clear from previous tasks, set in motion actions to identify relevant laws and governance institutions in place	
c. Obtain data inputs for external forcing (not having strong interactions) . – List variables for which data needs to be acquired, identify sources, and set in motion actions to acquire these data	
d. Indicate the format for storing the CZ relevant data – Set in motion actions to identify data storage format for existing data sets available for the CZ System	
e. Specify any auxiliary models needed to link with the systems model considered necessary – List auxilary models that are available to you, and that are feasable to use with available resources.	

14 Reflecting on progress so far

'System Design' is a tool like a microscope or telescope; the sequence of tasks in this guide can be likened to the process of bringing the object of attention more sharply into focus. That object is the 'virtual system' that connects the Issue-related HA to its impact on ecosystem goods and services and their contribution to the 'well-being needs' of groups of stakeholder. Seen in the light of this analogy, the 'Problem Scaling' task is simple: it is to consider whether the 'designed system', in the form of the conceptual model, is too simple or too complicated. You do this so that you can scale - i.e. adjust the number of model components and the data requirements - for relevance (to the Issue), for resources (of skills and time available to you), and in terms of scientific understanding. Additionally, this is a good time to think over the work that has led you to the conceptual model.

'Occam's razor': *it is vain to with more what can be done with fewer*, suggests starting with a simple model, and adding extra components only when it proves impossible to get realistic results from the simple model. In the face of a very complicated 'real' - i.e. physical and human-social - world, Occam's razor is helpful. When applied to models of systems, however, it may slice away something that appears minor but which actually plays a critical part in a feedback loop. We've found it helpful to use the word 'complex' for system models. Linear models, such as those simulating cause-effect chains, can be made simple; but most systems have feedback loops from which arise emergent properties that we (and you) may want to simulate. Thus they are complex, neither too simple nor too complicated.

'Problem Scaling' can lead to removal of some existing parts of the conceptual model, and the addition of new parts. In ideal circumstances, such adjustment may go on for some time, as your team debate amongst themselves and with stakeholders. In practice, your application will be restricted by the resources of people, skills, time and information available to you, and by the stakeholders' time-constraints. So the 'virtual system', and the 'Issue', need to be reconsidered in relation to those constraints, and a decision reached, in consultation with stakeholders, as to what can be done. If your modellers are experienced and already have portfolios of model components (or can take these from the Spicosa website), then will be possible to build, quickly, an adequately complex model. If that is not possible, do as much as you can! Our experience in Spicosa suggests that even simple models, simulating only parts of the system, can be useful, and that, on its own, the business of resolving the Issue and creating a conceptual model can help by clarifying understanding of ecological, social and economic constraints on the management solutions, even if no numerical model is built.

Now you should be ready to work through the action points in Table 10, before moving on to the SAF's next step of 'System Formulation'.

Table 10: Action Points for Problem Scaling task

Sub-task Action Point	Notes
a. Scale all processes and streamline the problem to the first-order linkages and interactions of the cause-&-effect chain; Simplify methods if the effort required to utilize them is out of balance with respect to the overall effort. *b. Iterate on the scope of the problem to ensure feasibility and reduce if necessary.* – Consider: — reductions in the list of model state variables — re-adjusting 'virtual' System extent to simplify boundary condition description whilst retaining all relevant functionality — simplifying the representation of spatial heterogeneity within the model-to-be — removing or simplifying subsystems from the model-to-be — focussing on a single space and time scale, so eliminating some process descriptions — adding variables, feedback loops, and process descriptions in order to include relevant key system features hitherto omitted – Prioritize, on grounds of relevance and cost-effectiveness, the activities of data acquisition, new measurements, and use of auxilary models – List the human resources available to you (in terms of skills and person-months) for this project; estimate how much has been used so far	*see:* *Problem Scaling: the movie*
c. Begin to specify the format for scientific results: simulation output, qualitative information, and the formats required by the natural, economic, social sciences, and public users interfaces. – Begin to think about needs for a peer-reviewed scientific publication from your application results	
d. Begin to specify the format of output for presentations and visualizations (for policy-makers, stakeholders, and public) recommended for use 'System Output'. – Discuss with stakeholders the outputs they would like	
Finally: – Write a 'Designed System Report' to summarize results	

15 Appendix: Authorship, history and citation

The original 'System Design' handbook was the responsibility of SPICOSA's Work-Package 3, which began work at the first SPICOSA meeting in Rome, 20-22 February, 2007. The handbook went through several drafts, culminating in v.1.26 of 13 November 2007, which took account of feedback received at the workshop in the University of Plymouth, 12-14 September 2007.

Further revisions were drafted in 2008, until in Brest in October 2008, it was decided to use a web-based and layered approach to the SAF handbook. Thus, the original v.1.26 was split into sections, which were worked on to a plan developed in Rome in June 2009. v.3.02 of this 'Guide to System Design', a summary of key ideas and a list of tasks and subtasks, was written by the WP3 leader, drawing on material from v.1.26 and incomplete drafts of other sections of the 'e-handbook', and the reported experiences of SSAs. It was finished in February 2010, at which time WP3 was brought to an end, its work done. Work on completing other sections for the web-site continues in Spicosa WP6.

Table 11: Contributors to 'System Design' handbook and Guide

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