Coastal zone resource management: tools for a participatory planning and decision making process

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Abstract

Coastal zones around the globe experience rapid development and change, and the Mediterranean, and in particular the Southern and Eastern parts, are undergoing dramatic demographic and related socio-economic development with growing and conflicting demands on natural resources. This leads to often irreversible degradation of these resources including the littoral and sub-littoral zones and thus the very basis for development. Two ongoing projects sponsored by the European Commission under the INCO framework address these issues with a combination of information technology, environmental sciences and engineering, and socio-economic analysis. The projects develop and explore methods and tools for long-term policy analysis and strategic decision support for integrated and sustainable coastal development with special emphasis on land use and water resources including coastal water quality. Parallel case studies in Turkey, Cyprus, Lebanon, Jordan, Egypt, Tunisia and Morocco are used to test the methodology. The approach is based upon close and direct cooperation with the local and regional stakeholders who define the problem issues, criteria, objectives, constraints and instruments for policy options. This provides the basic inputs for an integrated set of tools for quantitative analysis together with methods of environmental, socio-economic and policy impact assessment using both models and rule-based expert systems technology. Indicators and indices provide the common language between stakeholders and analysts, and are used to link a cascade of modelling tools including land use change modelling, water resources modelling, and coastal water quality modeling. The model system is used to obtain a realistic and detailed representation of spatially distributed and dynamic resource management strategies and development scenarios and generate feasible policy alternatives. A discrete multi-criteria optimisation methodology is used in an interactive and participatory policy and decision making process to identify acceptable compromise solutions.

1. INTRODUCTION

To study the sustainable management of scarce resources in the coastal zone, and water in particular, requires a complex and interdisciplinary methodology (Fedra, 2004 a, b) . The approach described here is based on the integration of socio-economic analysis identifying the main issues, and possible policy scenarios to address them, and preference structures to select an optimal, or more realistically, generally acceptable compromise solution. Quantitative simulation models are used to generate and then explore the impacts and outcomes of development scenarios. The main components are databases and GIS to compile and analyze consistent data, including socio-economic information summarised in a set of indicators. A set of models describe the coastal zone including: a dynamic land use change model linked to resource consumption patterns, a water resources model, including economic assessment, with embedded tools for rainfall-runoff modelling, irrigation water demand estimation, water allocation, surface and groundwater quality, and coastal water quality, together with the economics of water supply and use, and water quality. The model results are in turn summarised as indicators and derived indices including economic concepts such as benefit/costs ratios. These outputs feed into the next round of participatory decision making processes: a multi-criteria comparative assessment of alternative scenarios leads to a discrete multi-objective multi-criteria optimisation methodology that is designed for the direct participation of a wide range of actors and stake holders to identify optimal or generally accepted solutions. The data and tools, models and results are accessible over the Internet, adding a public information component to the basic analytical approach to provide a common information basis for the participants in the decision making processes, implementing Agenda 21, chapter 40 concepts of empowering stakeholders and actors through easy access to information.

1.1 Participatory planning and decision making

Integrated coastal zone management and natural resources management in the coastal zone as one of its central components are ultimately about conflict resolution. Resources such as space and water are limited, in part due to the characteristics of the coastal location itself that limits the physiographic catchment and useable land area and thus its natural resources, in part due to the rapid development of the coastal zone in most areas around the world. The basic thesis motivation and rationale of the approach described here and the projects that develop and test it is the firm believe that the overall function and performance of coastal regions and river basins under stress, measured in terms of economic results, equity, and environmental quality, and thus eventually human well being, quality of life, and sustainability can be improved with a more rational allocation of shared resources, leading to increased efficiency. This in turn needs better communication, understanding and coordination between the major actors and stakeholders, and an institutional and regulatory framework that facilitates participatory policy and decision making.

Conflict resolution is only in part a scientific exercise: it involves politics as much as psychology, values, preferences, believes and fears, more or less realistic perceptions and expectations, more or less hidden agenda, and is usually constrained by regulatory and institutional frameworks that do not necessarily support direct stakeholder involvement. To make the planning and decision making process more open requires an approach and tools specifically designed to bridge the gap between science and policy making. Stakeholders and major actors must be involved, early on, continuously, and actively. This needs a language that makes communication possible, and easy. It also needs an approach that demonstrates the advantages of participation by making it obvious that any contribution counts towards the outcome. Active involvement is the basis for acceptance, responsibility and ownership, which in turn is a basic requirement for any sustainable use of formal planning and decision support tools.

While intuitively the idea of “optimal” is easy to grasp, the practical solution for a multi-objective, multi-criteria problem is anything but easy. We therefore propose an approach based on the concept of satisficing that lends itself more easily to stakeholder participation. Rather than trying to find a consistent preference structure in a group of usually competing stakeholders with conflicting objectives, that needs sets of weights for trade-offs, pair-wise ranking, or any number of complex and abstract specifications of decision analysis, we simply collect all aspirations or expectations in the form of equivalent constraints: minimal levels of desired system performance that any stakeholder can freely define for her domain of interest, in natural language, with concepts measured in natural units like ha, m^3, or monetary units. These *a priori* constraints may well be naïve, unrealistic, even contradictory, but they represent the stakeholders' initial preferences. These are the starting point for a collective learning exercise. Examples can be at a generic policy level like a minimum family income, compliance with coastal water quality targets for at least 99% of the season, or very specific, like a minimum amount of water available to an individual farmer, or a maximum price he is willing to pay for the water. An optimal outcome is reached when all constraints (and thus all stakeholders) are satisfied, an optimization paradigm called satisficing. According to Simon (1957, 1969), real decision makers in practical situations do not optimize their utility when making decisions, for many reasons. Simon postulated that actual decision makers, through learning, adaptively develop aspiration levels (their expectations or requirements) for various important outcomes of their decisions. Then they seek decisions that would result either in outcomes as close as possible to the aspiration levels, if the latter are not attainable (which corresponds to an optimization of decisions, but in the sense of the distance from aspiration levels, which can also be understood as the distance from a reference point), or in outcomes equal to aspiration levels, if the latter are attainable. This then leads to stopping improvements in this case: Everybody gets at least what the minimally want, so everybody should be satisfied, accept and subscribe to the proposed solution.

A naïve second look at the satisficing paradigm will yield some suggestions for the implementation of DSS and their use in a participatory decision making process. The first step is to structure the problem and its model representation so that everybody feels their concerns or issues are sufficiently well represented. This is guided by the initial scoping questionnaire that identifies the perceptions of issues and their relative importance by all stakeholders. The resulting problem structure and model representation is then presented to the stakeholders in dedicated workshops or individual meetings between analysts and stakeholders, where further changes to the model structure are discussed. The second step is to identify initial constraints expressing the stakeholders' *a priori* expectations and requirements together with the policy and management instruments proposed to address the issues identified. These include both regulatory and policy level instruments like land use master plans and zoning regulations or awareness raising educational campaigns as well as specific technical solutions like wastewater treatment plants, different crops and irrigation technologies. For each instrument, we need to estimate its costs (investment and operations) as well as its effectiveness in changing some aspects of the function of the overall system. On this basis, the modeling tools can now be used to generate feasible alternative futures for the system, coastal zone or river basin, in question. If no feasible solutions can be found, the constraints need to be relaxed in negotiations of the stakeholders. As a guidance, the system in generating a set of alternatives identifies the most stringent constraints, i.e., those that are always or most often violated.

We conceptualize the set of alternatives (existing plans or to be generated by the model system) as described by a attribute vector X_i, in terms of criteria that are directly relevant to the stakeholders, in fact identified and selected by them, and expressed in their natural units including monetary units. This includes land use patterns, water demand and supply, reliability of supply, compliance with environmental quality standards, and the economics of the region, costs and benefits for the individual economic sectors or major actors. The decision makers (our stakeholders) can now refine their aspirations in terms of these criteria, adjusted to the repertoire of possibilities generated by the models and the increasing experience of the users with the function and interdependencies of the system. Examples would be economic costs and benefits, actual amounts of natural resources like water available for specific activities, and compliance with environmental standards. For each, the requirement expressing the actors or stakeholders aspirations can be to:

1. Minimize or maximize the value of the criterion;
2. Meet a constraint, i.e., a minimal or maximal allowable value.

In the optimization case (1), there are implicit trade-offs between the objectives, expressed in terms of the criteria implied, when we try to improve more than one at a time, conjunctively. Since there are always multiple stakeholders with multiple and usually conflicting objectives, this is always the case in any practical application. Much of the multi-attribute decision theory literature revolves around how to best elicit and implement these relationships, for example as weights on individual criteria expressing relative importance, or as a reference point defining scaling for all of them simultaneously, and implicitly. However, both the procedure and the underlying concepts are somewhat complex, involved, and not easily used other than with a captive audience of students of decision theory. For an efficient involvement of real world stakeholder with divers and almost always non-technical backgrounds, we must find a better approach.

In the case (2) of expressing aspirations as a set of constraints that are easy to understand and directly relate to everyday activities, the procedure is simple, intuitively understandable, and lends itself well to a participatory approach as chosen in the projects described below. The steps are easily described, and can be communicated to the stakeholders in dedicated workshops or individual meetings, or explored interactively through web access to the tools, with or without the help of facilitators.

- An initial set of reasonable constraint values are defined reflecting the collective expectations or a shared vision in the natural units of the criteria. This makes the procedure easy to understand and facilitates discourse and negotiation between the stakeholders. Extreme bargaining positions set up as straw men only to be given up graciously later are easily identified as they will make it impossible to find feasible solutions, and are identified by the model process, if not common sense.
- A solution or set of solutions that meets all the current constraints (a feasible solution) is found in the set of available alternatives.

- If the set is empty, i.e., no feasible solution meeting all constraints can be generated, the constraints are relaxed, extreme positions have to be given up – the sequence and degree of relaxation are a reflection of the DM's collective preferences and very much subject to group dynamics, which makes the role of a skillful mediator an important one. But at the same time an understanding of tradeoffs, possibly the results of a negotiation process between several decision makers with conflicting objectives emerges as one of the valuable results of the approach.
- If the set of feasible solutions includes more than one solution, the constraints can be tightened in the same interactive and iterative procedure as above, but in the opposite direction.
- The procedure ends whenever the decision makers (all or an agreed majority, depending on the rules of the process agreed upon) are satisfied, possibly with a single remaining solution (Hobson's optimality).

From a game theoretical point of view (e.g., Gibbons 1997), the interactive adaptation of constraints but also possible instruments is where the transition from a perceived zero-sum game or a version of the prisoners dilemma with dominant strategies with a possibly suboptimal equilibrium to a cooperative game should be introduced. In terms of water use, while allocation for consumptive use may indeed be understood as a zero sum game, total extractions are not. The possibility for shared and highly diversified land use or the recycling and re-use of water, or water markets moving allocation to uses of higher overall value generated (which includes social and environmental criteria as much as direct economic ones) clearly shows the potential for a cooperative game approach.

The idea of a cooperative game approach, however, requires the introduction of the appropriate coordination and exchange mechanisms: without the possibility to trade resources in some sense so that the overall benefits of use can be increased together with individual user benefits, this is difficult if not impossible to implement. While there usually is a well structured and functioning real-estate market, water is treated differently with new approaches to water pricing reflecting realistic and full costs are only slowly emerging. The social equity of water pricing between domestic, industrial, and agricultural uses is another contentious issue. Similarly, the consideration of the full external costs of pollution affecting shared resources like coastal water quality is a difficult and politically and economically sensitive issue, consider, for example the potential conflicts between aquaculture and tourism.

More efficient and equitable allocation of resources not only requires the institutional structures or market mechanisms to make this level of cooperation and coordination, i.e., a truly integrated coastal zone and water resources management, possible. Improved overall efficiency and thus sustainability also needs tools and mechanisms to facilitate participation in more open policy and decision making processes to increase the awareness for such strategies in the first place.

1.2 Projects and Case Studies

The EU funded INCO projects SMART and OPTIMA address issues of natural resources management in the coastal zone and river basins in a total of 11 case studies around the

Mediterranean, including Cyprus, Turkey, Lebanon, Jordan, Palestine, Egypt, Tunisia and Morocco. This provides a broad range of examples to test a common methodology under a range of physiographic but also socio-economic settings (Table 1) and facilitate comparative analysis.

The main emphasis of SMART is on integrated coastal zone development (Fedra and Feoli, 1998, Post and Lundin, 1996) and water resources in particular, using a scenario analysis approach (http://www.ess.co.at/SMART/). Sharing the same models and concepts, OPTIMA goes one step further towards decision support by including explicit optimisation with participatory elements: we extend the original WHAT IF questions to HOW TO, given the set of objectives and constraints defined by the stakeholders, but also including the final evaluation and choice between alternatives in the formal DSS process. OPTIMA concentrates on water resources at the river basin scale as a key resource for coastal zone development, going beyond scenario analysis by a multi-criteria optimisation approach (http://www.ess.co.at/OPTIMA/). Based on concepts of the EU Water Framework Directive (2000/60/EC) this combines economic efficiency with meeting environmental targets and constraints under the overall umbrella of sustainable development.

Case study	country	Area (km2)	Avg. monthly max temp	Avg. rainfall
Gediz river, Izmir	Turkey	18,000	22.99	652
Dhiarzos river	Cyprus	260	25.27	439
Aqaba SEZ	Jordan	500	31.29	37
Zarqa river	Jordan	4,120	23.43	279
Tripoli, Badroun	Lebanon	300	24.33	286
Litani, Tyr	Lebanon	600	24.50	229
Wadi Zeimar/Alexander	Palestine Israel	500	23.14	533
Abu Kir bay, Alexandria	Egypt	1,339	24.08	191
Hammamet	Tunisia	155	23.00	415
Melian river, gulf of Tunis	Tunisia	553	23.00	461
Martil, Tetouan	Morocco	1,129	22.25	895

Table 1: Case study characteristics.

1.1.1 SMART

The coastal zones of the Mediterranean are undergoing rapid development with growing and conflicting demands on the natural resources, endangering the resource basis for this very development. Water resources and the related land use issues are a key element for the sustainable development of coastal regions. They illustrate the dependency of the usually dynamic and fast growing coastal areas on their resource catchment or ecological footprint. SMART has developed and tested methods and tools for long-term policy analysis and strategic decision support for integrated coastal development with special emphasis on water resources and land use, and the resource balance between the coastal region and inland areas (http://www.ess.co.at/SMART).

Integrated management of the coastal zone requires a balanced consideration of numerous aspects including both the socio-economic and the physical, environmental domain. While this principle is well understood and widely published, it is rarely implemented in practice. The scientific literature in the domain is voluminous; while classical texts have often stressed the engineering aspects of the problem, the importance of the socio-economic participatory policy and decision making processes need informed participants, actors or stake holders - this empowerment through information and the role of information for policy and decision making are important topics addressed in the Agenda 21, and related European policy documents and directives.

For the SMART project this means the smooth integration of advanced quantitative tools based on applied systems analysis and information technology such as state-of-the art simulation and optimisation models and expert systems technology into the socio-political and economic framework of regional development planning and public policy with its uncertainties, qualitative criteria, and conflicting objectives.

The main characteristic elements of the project include:

- Integration of advanced spatially distributed and dynamic numerical simulation and optimisation tools with socio-economic elements through rule-based expert system technology for qualitative analysis;
- Explicit consideration of multiple criteria and conflicting objectives, uncertainty, and the necessary political trade-offs and adaptive strategies;
- Direct involvement of end users including the concerned public through the use, *inter alia*, of the Internet and the support of remote clients;
- Smooth integration of existing information resources and data through a distributed client-server architecture and a common framework of indicators for sustainable development;
- Integration of technical analysis with educational, awareness-building elements for a broad target audience, aiming at the empowerment of a broad range of actors and local stake holders;
- Long-term sustainability of the project results through direct integration in existing institutional structures including governmental, NGO, and academic institutions as well as the concerned citizen at large.

1.1.2 OPTIMA

Starting with the scenario analysis developed in SMART, OPTIMA is developing and testing a scientifically rigorous yet practical approach to water resources management intended to increase overall efficiencies and to reconcile conflicting demands (http://www.ess.co.at/OPTIMA). Based on the European Water Framework Directive

(2000/60/EC) the approach equally considers economic efficiency, environmental compatibility, and social equity as the pillars of sustainable development.

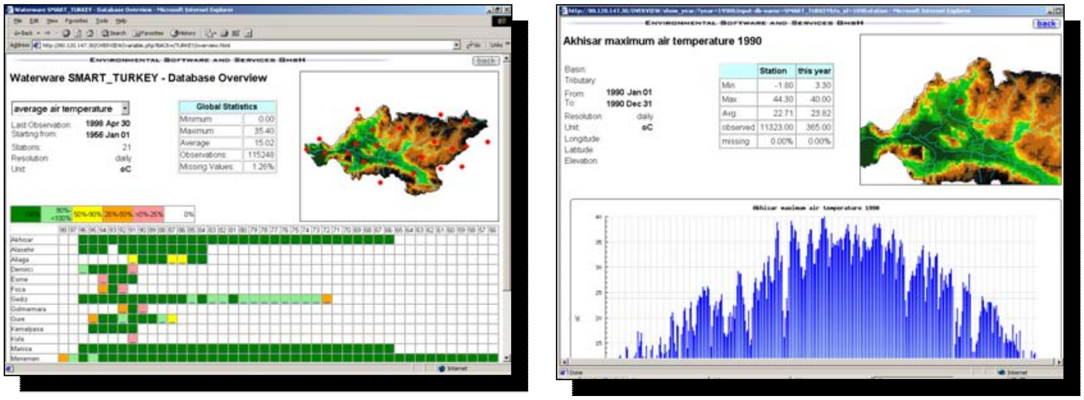
In OPTIMA, we extend the classical optimisation and mathematical programming methodology in several respects, by:

- Including tools for the direct involvement of stakeholders, elicit preference structures in terms of general issues, criteria, objectives and constraints with a set of structured questionnaires that directly feed into the optimization tools;
- Using a full-featured dynamic and distributed simulation model and genetic programming as the core to generate feasible and non-dominated alternatives. Water technology alternatives including their cost structure, and up-to-date remote- sensing derived land use information are primary inputs;
- Extending the set of objectives, criteria and constraints through expert systems technology to include difficult to quantify environmental and social dimensions;
- Putting specific emphasis on local acceptance and implementation through the inclusion of stake-holders in an interactive, participatory decision making process carefully embedded in institutional structures, using a discrete multi-criteria reference point methodology;
- Comparative evaluation and benchmarking across the set of local and regional case studies in 7 countries, namely Cyprus, Turkey, Lebanon, Jordan, Palestine, Tunisia and Morocco around the Southern and Eastern Mediterranean.

1.2 MODELS AND TOOLS

For the analysis, a set of integrated data bases and models is used:

- An on-line web accessible database of stakeholder institutions with their profiles, including a dynamic CRM component to log all interactions;
- An on-line questionnaire and database for the definition of problem issues by the stakeholders, web accessible but also used in hardcopy at stakeholder workshops;
- Georeferenced databases for physiographic, hydrological, and socio economic data, managing time series of monitoring data (Figure 1) but also the attributes of all structural and functional objects described in the models, as well as the model scenarios themselves;
- An on-line database of water technologies and policies including their economic costs and benefits, web accessible;
- A web-enabled GIS, map catalogue and map server providing background and display tools for all georeferenced data;
- A dynamic land use change model (http://80.120.147.30/LUC/, Figure 2) that combines a classical Markov state-transition model with rule based spatial and temporal context sensitive transition probabilities; resource consumption and economic estimates are based on the land use patterns as an alternative to the process oriented mass budget models;
- A dynamic basin-scale water resources modelling and optimisation system (http://www.ess.co.at/WATERWARE) that includes also models for rainfall-runoff and irrigation water demand estimation (Figure 3);



Figures 1 : Georeferenced monitoring stations and time series display

- Water quality models for surface and groundwater, linked to the water resources management information system that provides the hydraulic driving forces;
- A coastal water quality model, TELEMAC, developed by SOGREAH.

The models are linked to data bases that describe each of the cases in terms of GIS layers monitoring time series of climatic and hydro-meteorological data (Figure 1), and the main components of the water resources system like major demand nodes. Linkage between the models is by means of indicators that summarize the output from one model as boundary conditions for another, translating differences in dimensionality and resolution in time and space.

The data and related analysis tools are accessible through the Internet to facilitate the dissemination of project results, but also to make it easier for the various actors and stakeholders in each of the regional cases to share a common information basis. Empowerment through information as foreseen by Agenda 21's chapter 40 is the underlying concept.

1.2.1 Land Use Change modelling

One of the main driving forces and at the same time a most obvious manifestation of coastal zone development is changing land use. One of the main data sets and models in SMART and OPTIMA is therefore a dynamic land use change model to analyse impacts and consequences of the various socio-economic scenarios on land use and related resource issues, based on the comparative analysis of remote sensing data.
LUC is a dynamic land use change model based on

- A set of well defined land use classes, using the EU CORINE classification scheme as a starting point;
- A matrix of a priori transition probabilities, derived from the analysis of sequences of remote sensing data sets;
- A set of RULES, one set for each possible transition, that can modify the *a priori* probabilities using

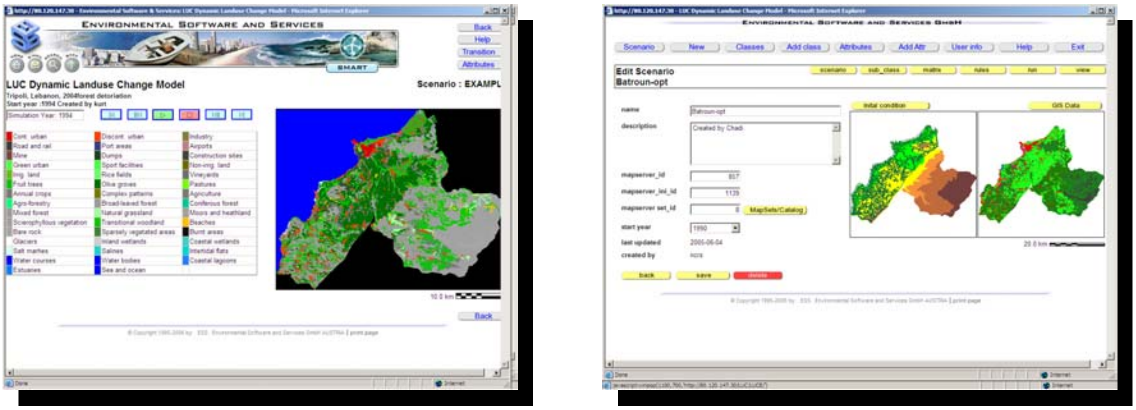


Figure 2: Interface to the Land Use change model

- A set of operators that use spatial and temporal aggregate and neighbourhood properties to modify the transition probabilities and thus impose strong and realistic spatial patterns;
- Other rules can be based on any attribute or property a given spatial unit has such as soil, geology and terrain features, climatic variables, infrastructure, and population that can modify its transition probabilities based on the feature-related suitability for a given target use.

- Properties of spatial units other than the land use itself can be used to model the evolution of related resource economic variables describing the area, such as regional product, income and revenues, employment, resource consumption (in particular water and energy), waste generation, and effects on population growth and migration.

Transition probabilities are expressed as a complete matrix of land use classes, where the rows of the matrix sum to 1.0 (or 1000 ‰ in our implementation), and the diagonal cells represent the probability that a class remains what it was (i.e., does not change).

RULES are first order production rules:

IF condition AND/OR condition
THEN p(n,m) CHANGE-OPERATOR VALUE

where

condition: a function return value of the type: TRUE/FALSE for the functions FRACTION (spatial neighbourhood), FREQUENCY (temporal neighbourhood), and LAST (history of state) and p(n,m) is the probability of a transition from class n to m.

CHANGE-OPERATORs are: RELATIVE INCREASE and DECREASE, ABSOLUTE INCREASE and DECREASE, ABSOLUTE (setting a value);

The following functions are used in the model:

1. FRACTION (N,i) is the local fraction of LUC N in a neighbourhood of size i (i= 1, 2, 3, 4,..) where the number describes a radius in terms of cells around the current cell: i.e., 1 refers to a total area of 3x3=9 cells, 2 is 5x5, 3 is 7x7 i.e., 2*r+1; FRACTION (N,0) is the global fraction.

2. FREQUENCY (N,i) is the temporal equivalent, i.e., frequency of class N over i previous time steps. FREQUENCY (N,1) = 1 would imply that the cell was of class N in the previous time step.
3. LAST(i) returns the LUC value of a cell i steps back.

Rule examples:

IF FRACTION(1.1,1) > 500 THEN P(*,1.1) REL-INCREASE 500

IF more than half the immediate neighbours of a cell are city (1.1), then the probability of transition to city increases by 50%; the same principle of contagion can be expressed differently as well:

IF FRACTION(1.1,1) < 100 THEN P(*,1.1) REL-DECREASE 950

with somewhat different behaviour.

IF FRACTION(1.1,2) > 950 THEN P(*,1.1) REL-DECREASE 900

IF more than 95% of the neighbors in a 5x5 area around a cell are already city, decrease the probability of transition of the last cells into city, thus maintaining a minimum level of green or mixed use areas.

The model is driven by the internal transition probabilities. This can be extended by a set of possible external driving forces that represent factors such as:

- demographic development;
- regional development policies, regulations, zoning rules;
- global effects (energy prices, demand for specific regional products).

Each cycle is executed in a two-step procedure: a naïve run, that uses the values of the last state for all rules and adjustments. On the basis of the naive run, all FUNCTION values are re-calculated in several rounds of iterative adjustments that reflect shared information and possible cooperative strategies. The predictor-corrector method is controlled by a maximum number of iterative trials.

The land use pattern at any point in time is used to estimate a number of resource and economic indicators, such as water consumption, waste generation, energy demand, or employment and gross regional product. These estimates a re arrived at in parallel and independently from the water resources and water quality models and can thus serve as a very basic check of model performance and the consistency and plausibility of results.

1.2.2 Water Resources Model

The water resources model WRM is one of the core components of the WaterWare system (http://www.ess.co.at/WATERWARE). It describes the water flow, storage and availability, demand and supply balance on a daily basis across a river basin and its elements, based on conservation and continuity laws (Jamieson & Fedra, 1996; Fedra & Jamieson, 1996).

In order to simulate the behaviour of a river basin over time the river basin is described as a system of nodes and arcs (Figure 3). These nodes represent the different components of a river system such as inflows (well fields, springs, sub-basins) demand points such as irrigation areas, cities, reservoirs, and control structures. The nodes are connected by arcs which represent natural or man-made channels which carry the flow of water.

The WRM calculates demand and supply over time on a daily basis with annual summaries at these nodes. Costs are accounted for all elements of water supply, penalties for missing target flows, or for flooding conditions. Benefits accrue from useful demand satisfied including environmental demands e.g., for wetlands, and meeting constraints at control nodes, e.g., low flow constraints for navigation or recreation.

The results are summarized in policy relevant terms, such as the ratio of supply and demand, global and by economic sector, reliability of supply, flooding conditions, but also economic data such as benefit/cost ratio for direct and indirect costs, net benefit, and economic efficiency, as well as environmental impacts for individual nodes, arcs, and by economic sector.

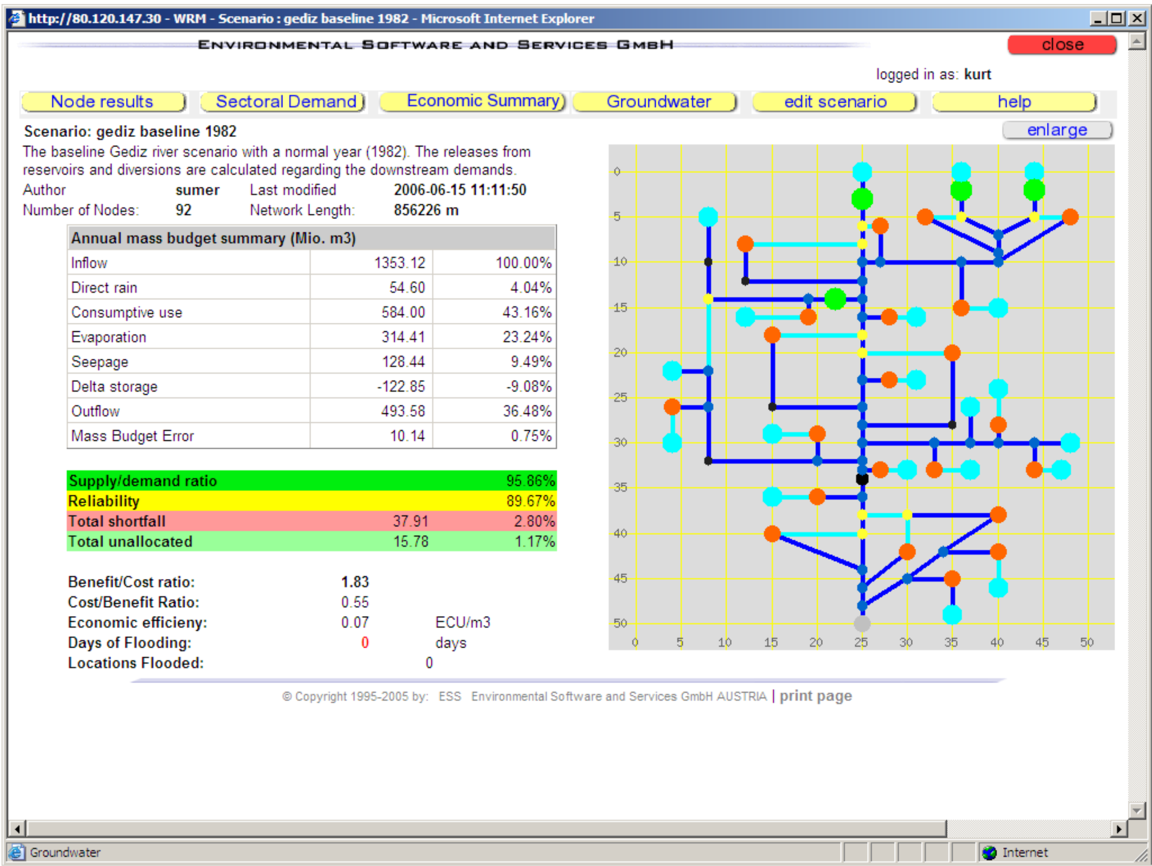


Figure 3: water allocation summaries and economic assessment

1.2.3 River water quality model

The daily hydraulics generated by the water resources model directly feed into a dynamic, distributed river water quality model that operates on the same network representation as the water resources model. Start nodes input water of defined quality, demand nodes representing all kinds of water use release pollutants (BOD, conservative and first-order decaying user defined substances) depending on their economic activities, production technologies and any pollution control technologies with their associated investment and operating costs. Benefits are accumulated for the supply of water meeting the use specific quality constraints at each individual demand node. Specific treatment nodes represent waste water treatment plants and their economics, and affect water

quality according to the treatment levels and hydraulic capacities of the plants. Further costs and benefits can be associated control nodes where penalties for violating standard can be considered, and with individual river reaches. This can include in-stream recreational benefits and environmental benefits. Non-point source pollution can be ascribed to lateral inflow at these reaches. Annual summaries for water quality and economics are calculated and reported as criteria for the decision making process.
The outflow from the basin, i.e., the pollutant loads (flow and concentrations) at the end points represent input to the coastal water system and its model, described below.

1.2.4 Coastal water quality model

As a final step of the model based analysis, the basin outflow from the water resources model and its companion water quality model, as well as waste loads estimated by the land use change model are fed into a coastal water quality model to obtain estimates of local pollution.

In SMART, The TELEMAC model system developed by SOGREAH (2001) was used to translate pollutant loads from the watershed into coastal water quality. TELEMAC is a powerful integrated modelling tool for use in the field of free-surface flows and related transport phenomena (http://www.telemacsystem.com/). The various simulation modules use algorithms based on the finite-element method. Space is represented in the form of an unstructured grid of triangular elements, which means that it can be refined particularly in areas of special interest such as in the immediate coastal zone or close to the river mouths or estuaries.
For a specified coastal water quality standard, the model keeps track of violations in space and time, and thus generates yet another set of criteria for the multi-criteria optimization and decision making process.

2. SCENARIO ANALYSIS, OPTIMISATION

The basic scenarios of coastal zone development are expressed in terms of indicators of socio-economic, institutional, and regulatory development. In addition to the baseline scenario representing the status quo, three common scenario types looking 25 years into the future have been defined:

- Business as usual, based on an extrapolation of current trends;
- Optimistic, where all reasonably possible developments towards a sustainable development of the coastal zones are assumed to be implemented;
- Pessimistic, where all possible negative developments are assumed to happen.

These scenarios, for each of the indicators used, define a plausible range of possible futures, but at the same time they illustrate the scope for improvements, and define nadir and utopia for the discrete multi-criteria approach. They also define the starting points for the optimization approach.

2.1 DECISION MAKING PROCESSES

The primary objective of both projects is to contribute to better policy and decision making for resource management in the coastal zone. The basic elements are reliable data and information, exploiting modern information technology, direct involvement of stakeholders and actors, the integration of qualitative and quantitative tools for rational

and scientifically based design and analysis of options and alternatives, and the support for wide participation of the stakeholders in the decision making process.
DSS based on optimisation technologies are a central element of operations research, and an established technology in water resources research (Loucks et al., 1981). Their practical applicability for complex problems, however, is limited by the fact that efficient optimisation requires a sometimes gross simplification (usually based on linearization) of the problem to arrive at an optimal solution with guaranteed convergence. A secondary problem is that the formalisation and related abstraction and simplifications make assumptions and results difficult to understand and communicate, which hinders broad participation in the decision making process and thus often generates barriers to the actual implementation of technically optimal solutions. Numerical optimisation, based on simulation modelling can retain a sufficiently detailed, realistic description. However, the combinatorial explosion of alternatives makes an exhaustive search of the decision space impossible for even moderately complex problems. An alternative is the introduction of domain specific heuristics in a multi-tiered approach, using rule-based expert systems, and genetic algorithms, which can make the search much more efficient than traditional methods (Fedra, 2000). Iterating between different levels of aggregation and representation, evolutionary strategies and local stochastic gradient search, a screening level approach and the use of evolutionary concepts of good enough rather than optimal can lead to efficient solutions even for very complex and large-scale problems.
This approach to the optimisation of complex, non-linear, distributed and dynamic systems is embedded in a framework of interactive, participatory decision support based on a secondary layer of discrete multi-criteria optimisation. Using a reference point approach and constraints in a satisficing paradigm to simplify the expression of preferences and trade-offs, this combined method supports interactive, exploratory use in the planning and policy making process, facilitating the participation of all major institutions, actors and stakeholders in water resources, which is more or less everybody, i.e., from government to the general public.

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