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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, is 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 on the integration of quantitative and qualitative analysis, combining tools of quantitative analysis with methods of environmental, socio-economic and policy impact assessment using rule-based expert systems technology. Indicators and indices are used to link a cascade of modelling tools including land use change modelling, water resources modelling, and a coastal water quality model. The model system is used to obtain a realistic and detailed representation of spatially distributed and dynamic resource management strategies and development scenarios. In a final step, a discrete multi-criteria optimisation methodology is used to provide input to an interactive and participatory policy and decision making process, involving local actors and stakeholders.

1. INTRODUCTION

To study the sustainable management of scarce resources in the coastal zone, and water in particular, requires a complex and interdisciplinary methodology. The approach described here is based on the integration of socio-economic analysis and indicators, defining scenarios, and a set of quantitative simulation models to explore the impacts and outcomes of these possible development scenarios. The main components are data bases and GIS to compile consistent data for the case studies, including the socio-economic data that are summarised in a set of indicators, a set of models that describe the coastal zones including: a dynamic land use change model, a water resources model with embedded estimation tools for rainfall-runoff modelling, irrigation water demand estimation, water allocation, surface and groundwater quality, and coastal water quality; the model results are in turn summarised as indicators and derived indices, and used for a multi-criteria comparative assessment of alternative scenarios, and a discrete optimisation multi-objective multi-criteria methodology that is designed for participation of a wide range of actors and stake holders.

As a final element, the data and tools are designed to be accessible over the Internet, adding a public information component to the basic analytical approach.

1.1 Projects and Case Studies

The projects SMART and OPTIMA address the case studies around Mediterranean, including Cyprus, Turkey, Lebanon, Jordan, Palestine, Egypt, Tunisia and Morocco. These cases provide a broad range of examples to test a common methodology under a range of physiographic settings (Table 1).

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. OPTIMA concentrates on water resources at the river basin scale, 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.

Table 1: Case study characteristics.

Case study	country	Avg. monthly max temp	Avg rainfall
Gediz river, Izmir	Turkey	22.99	652
Dhiarzos river	Cyprus	25.27	439
Aqaba SEZ	Jordan	31.29	37
Zarqa river	Jordan	23.43	279
Tripoli, Badroun	Lebanon	24.33	286
Litani, Tyr	Lebanon	24.50	229
Mount Aquifer	Palestine	23.14	533
Abu Kir bay, Alexandria	Egypt	24.08	191
Hammamet	Tunisia	23.00	415
Gulf of Tunis	Tunisia	23.00	461
Ceuta-Tetouan	Morocco	22.25	895

1.1.1 SMART

The coastal zones of the Mediterranean are at the same time undergoing rapid development with growing and conflicting demands on the natural resources, and at the same time subject to often irreversible degradation of these resources and thus the very basis for 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. This project will explore 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.

The approach is based on a multi-sectoral integration of quantitative and qualitative analysis, combining advanced tools of quantitative systems engineering using numerical simulation models, with methods of environmental, socio-economic and policy impact assessment using rule-based expert systems technology and interactive decision support methods (Fedra, 2002).

Water resources modelling including both quantitative and qualitative aspects will provide the framework for policy scenarios, exploring different development strategies, the consequences and implications of demographic, socio-economic, and technological development, and the interaction of these driving forces towards long-term sustainability of the coastal regions and their hinterland.

Aiming to support a participatory approach to policy making and impact assessment, the approach also foresees the extensive use of the Internet to facilitate broad participation and a shared information basis to empower the various actors and stake-holders in the decision making process, contributing to the development of a civic society. The integration of advanced quantitative methods and models with qualitative assessment aggregated into policy relevant indicators of sustainable development will add scientific rigor to the interactive and participatory political process. This will make it possible to focus the debate on policy issues, objectives and values rather than the underlying physical based data and information describing better quantifiable constraints and dependencies of the physical world.

A common methodology for policy design, evaluation, and decision making is being developed and tested in a set of parallel case studies in each of the participating Mediterranean countries, and compared with the corresponding EU policies. Lessons from the comparative analysis of these case studies will help to ensure a generic and generally applicable methodology, and at the same time help to foster inter-regional contacts and the exchange of experience.

Integrated management of the coastal zone requires a balanced consideration of numerous aspects including both the socio-economic and physical, environmental domain. While this principle is well understood and 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 innovative 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

The overall aim of OPTIMA is to develop, implement, test, critically evaluate, and exploit an innovative, scientifically rigorous yet practical approach to water resources management intended to increase efficiencies and to reconcile conflicting demands. 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.

The project also aims at building a wide dissemination network of expertise and knowledge exchange sharing its findings, generic data, and best practice examples.

For a broad geographical coverage and a good basis for comparative analysis, OPTIMA brings together partners from Austria, Italy, Greece, Cyprus, Malta, Turkey, Lebanon, Jordan, Palestine, Tunisia, and Morocco,

OPTIMA is extending classical optimisation and mathematical programming methodology in several respects, by:

- 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.

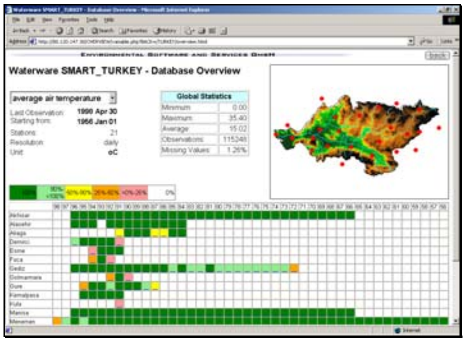
1.*2 MODELS AND TOOLS*

For the analysis, a set of integrated models is used, based on a set of shared data bases and GIS (Figures 1,2). This includes:

- A dynamic land use change model (http://80.120.147.30/LUC/, Figure 3)
- A water resources modelling system (http://www.ess.co.at/WATERWARE) that includes also models for rainfall-runoff and irrigation water demand estimation (Figure 4,5);
- Water quality models for surface and groundwater, linked to the water resources management information system
- A coastal water quality model, TELEMAC (Figure 6).

The models are linked to data bases that describe each of the cases in terms of GIS layers (Figure 3), monitoring time series of climatic (Figure 4) and hydro-meteorological data (Figure 5), 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.



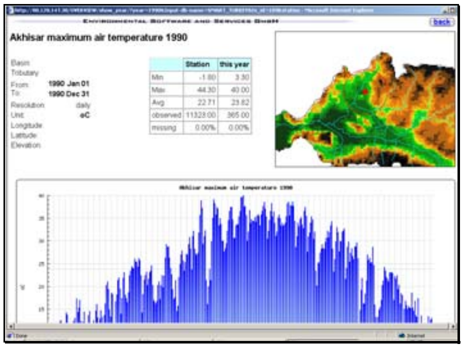
Waterware SMART_TURKEY - Database Overview

average air temperature

Last Observation: 1990 Apr 30
Starting from: 1956 Jan 01
Stations: 21
Resolution: daily
Unit: oC

Global Statistics	
Minimum	0.00
Maximum	35.40
Average	15.02
Observations	115248
Missing Values	1.26%

Figures 1,2 : Monitoring data and GIS linkage



Akhisar maximum air temperature 1990

Basin:
Tributary:
From: 1990 Jan 01
To: 1990 Dec 31
Resolution: daily
Unit: oC
Longitude:
Latitude:
Elevation:

	Station	this year
Min	-1.80	3.30
Max	44.30	40.00
Avg	22.71	23.82
observed	11323.00	365.00
missing	0.00%	0.00%

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 models in SMART 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.

LUC is a dynamic land use change model based on

- A set of well defined land use classes;
- A matrix of a priori transition probabilities;
- A set of RULES, one set for each possible transition, that can modify the *a priori* probabilities using
- A set of operators that use spatial and temporal aggregate and neighbourhood properties to modify the transition probabilities.
- 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.
- Properties of spatial units other than the land use itself can be used to model the evolution of related 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, 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: REL-INCREASE, REL-DECREASE, ABS-INCREASE, ABS-DECREASE, ABSOLUTE (set);

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) RE-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

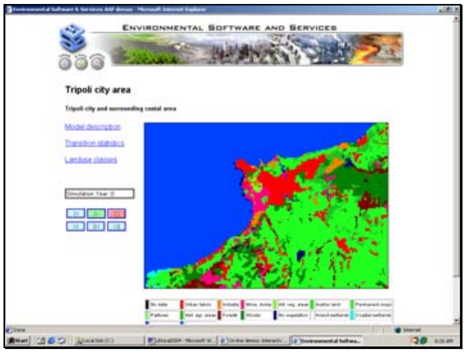
IF more than 95% of the neighbours in a 5x5 area around a cell are already city, decrease the probability of transition of the last cells into city.

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;
- 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. The predictor-corrector method is controlled by a maximum number of iterative trials.

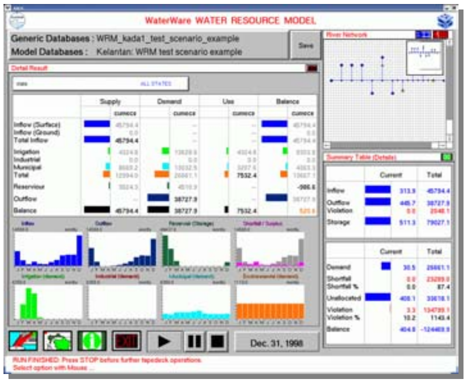

Tripoli city area

Tripoli city and surrounding costal area

Figure 3: Interface to the LUC model

1.2.2 Water Resources Model

The water resources model WRM is one of the core components of the WaterWare system. It describes the water flow 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).


Generic Databases : WRM_kada1_test_scenario_example

Model Databases : Kelantan: WRM test scenario example

Dec. 31, 1998

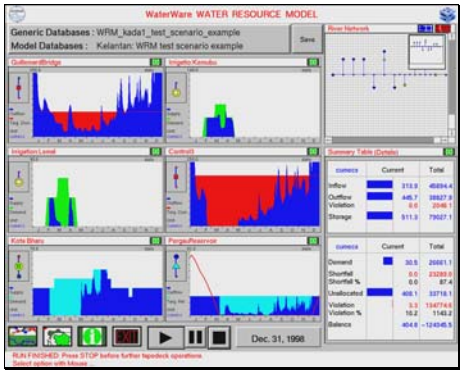
RUN FINISHED: Press STOP before further tapedeck operations.

Select option with Mouse ...

Figure 4; water allocation summaries

In order to simulate the behaviour of a river basin over time the river basin is described as a system of nodes and arcs. 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.

The WRM calculates demand and supply over time at these nodes.


Generic Databases : WRM_kada1_test_scenario_example

Model Databases : Kelantan: WRM test scenario example

Dec. 31, 1998

RUN FINISHED: Press STOP before further tapedeck operations.

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Figure 5: demand-supply at different nodes.

1.2.3 TELEMAC coastal water quality model

The TELEMAC system 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 high-capacity algorithms based on the finite-element method. Space is discretised in the form of an unstructured grid of triangular elements, which means that it can be refined particularly in areas of special interest.

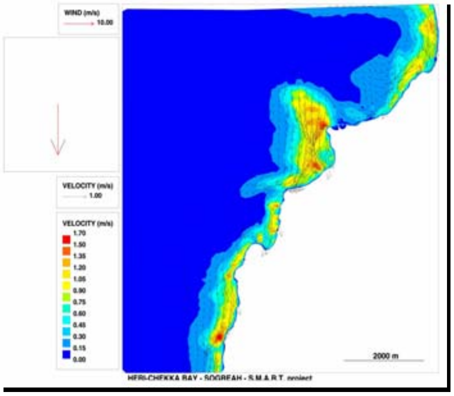

Figure 6: Model output: Heri-Chekka Bay, Lebanon

2. SCENARIO ANALYSIS, OPTIMISATION

The basic scenarios in SMART 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;
- Pessimistic, where all possible negative developments are assumed.

These three scenarios, for each of the indicators used, now define a possible and 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 described below.

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, an integration of qualitative and quantitative tools for rational and scientifically based design and analysis of options and alternatives, and the support for wide participation 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. Their practical applicability for complex problems, however, is limited by the fact that efficient optimisation requires a sometimes gross simplification (usually based on linearisation) 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 thuds often generates barriers to the actual implementation of technically optimal solutions. Brute forward 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. 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 innovative 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 to simplify the expression of preferences and trade-offs, this combined method supports interactive, exploratory use and aims at easy integration 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., the public.

ACKNOWLEDGEMENTS

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REFERENCES

Fedra, K. (2002) GIS and simulation models for Water resources Management: A case study of the Kelantan River, Malaysia. 39-43 pp., GIS Development, 6/8.

Fedra, K. and Feoli, E. (1998) GIS Technology and Spatial Analysis in Coastal Zone Management. *EEZ Technology*, Ed. 3, 171-179.

Fedra, K., and Jamieson, D.G. (1996) An object-oriented approach to model integration: a river basin information system example. In: Kovar, K. and Nachtnebel, H.P. [eds.]: IAHS Publ. no 235, pp. 669-676.

Jamieson, D.G. and Fedra, K. (1996) The WaterWare decision-support system for river basin planning: I. Conceptual Design. Journal of Hydrology, 177/3-4, pp. 163-175.

Post, J.C and Lundin, C.G [eds.], (1996) Guidelines for Integrated Coastal Zone Management. ESD Studies and Monograph Series No.9, 16 pp., The World Bank, Washington, D.C.