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MANAGEMENT OF THE WATER ORGANISED LAND SURFACE

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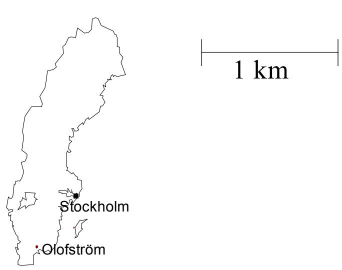
Landscape structures at different scales are the result of non-random water processes. In natural landscapes life uses structured solar energy to control the water cycle and create a stable environment, coherent with locally closed matter cycles and high gross productivity. With human interference, natural stable conditions are severely affected. The cool and moist forest is turned into hot bleeding urban and agricultural landscapes, with large (eroding) fluctuations in temperature and moisture. In the highly non-linear biosphere system loss of stability at one scale can trigger chaotic behaviour and flip-flop changes at other scales. A new water integrated land use planning strategy for sustainability in the spirit of the Brundtland commission and Agenda 21 is needed. Such a strategy must be based on first principles (i.e. thermodynamics), recognising water as the major organising agent of the biosphere life support system (Ripl and Gumbricht, 1996). Synthesis of the symmetries between surface structures and water functions need to be based on heuristic interpretation of encoded high spatial and temporal data, and application of simple and transparent models. Remote sensing (RS) and Geographical Information Systems (GIS) are powerful tools for creating and displaying the necessary data sets. With available GIS and satellite data, land surface modelling of both landscape structures and functions is globally possible. Combined with hydro-climatic time series process and pattern symmetries can be dynamically integrated via GIS coupled models. The article presents three case studies.

Case studies

Within a century urban environments have turned into manufacturing centres heavily dependent on import of structured energy and matter from its surrounding. Considerable areas have been drained or sealed, and unstructured energy is continuously supplied through *inter alia* the transport system and its vehicles and maintenance, the heating and cooling systems with pumping and random release of thermal energy, the water supply and its centralised water production, overexploitation of ground water and disposal of waste water. The balance sheet for irreversible losses from urbanised areas shows ever-increasing trends. Figure 1 shows the town of Olofström in SE Sweden as interpreted from a Landsat TM scene (obtained July 12th, 1994, a date preceded by hot and dry weather). The green forest patches in the town clearly have a higher vegetation density (b), associated with cooler (c), and wetter (d) micro-climate. Larger forest patches and core areas are more cool and moist (cf. Gumbricht *et al.*, 1996a). Open land take an intermediate position, and the lake is the coolest and wettest object.



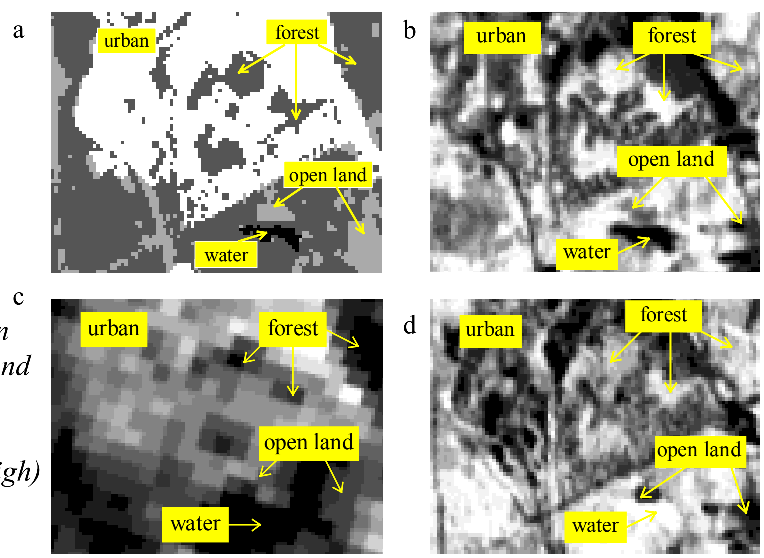
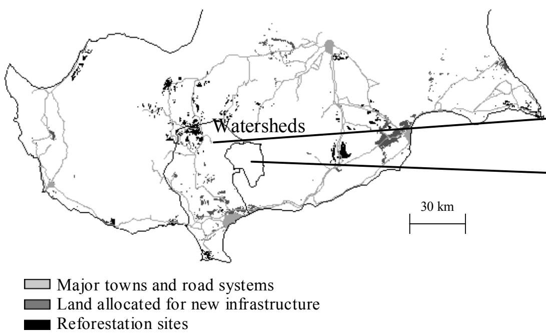


Fig. 1 The town of Olofström in SE Sweden depicted from GIS and satellite data as:
a) object classes
b) vegetation density (light = high)
c) temperature (light = high)
d) wetness (light = high)

Vegetation and its products (e.g. humus) function much like as a sponge, capable of holding large amounts of water. With no or dried out vegetation (sponge), water holding capacity decreases, leading to a simplified hydrograph being controlled by precipitation. Based on the close relationship between water and vegetation, the author developed a simple and transparent hydrological model (PHASE) embedded with GIS (Gumbricht, 1996). The model is semi-distributed and locally parameterised by indexes of leaf area, derived from remotely sensed data, and river basin relief, derived from a digital elevation model. Regional model calibration is done using 3 to 6 lumped parameters for soil moisture accounting and routing. Feedback can be introduced by a fractal water cycle (i.e. a fraction of the evapotranspirated water in one time step is allowed to return in the next), and a vegetation growth and decay function. The model has been tested in Cyprus (*ibid*.), a country suffering from water stress and projected to face water scarcity within 10 to 20 years. As model performance for four differing basins was very stable, the model could be used for evaluation of different future land use scenarios (Fig. 2) (from McCarthy and Gumbricht, 1996). The scenarios were created using GIS as an expert system and a decision support tool (Gumbricht *et al*., 1996b).



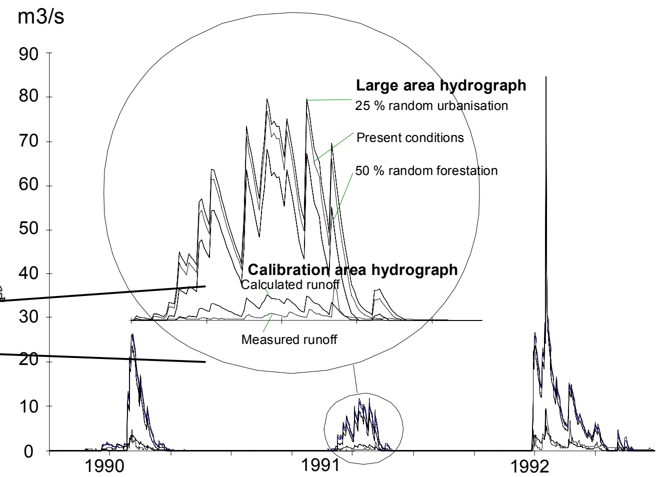


Fig. 2 Scenario of future land allocation in Cyprus (infrastructure and reforestation) generated using GIS as a decision support tool and expert system. The water cycle was modelled using the small (right) watershed as calibration area, and changes in the water cycle was evaluated for the larger (left) area. Runoff decreased with approximately 1 % after both reforestation and infrastructure changes (not seen in the figure). Changes following 50 % random reforestation and 25 % random urbanisation are shown as comparison in the hydrograph.

The ecologically fragile Himalayan region is among the world's poorest, with agriculture dominating the economy. To support a growing population unsuitable land with high erosion susceptibility is cleared and cultivated. With floods and droughts frequently ravaging the region, erosional losses are ever increasing. Innovative approaches are needed for sustainable management of the region. By environmentally adopted hydropower development, a new economic infrastructure could be combined with protection of vulnerable Himalayan ecosystems. One particular problem is to develop models of hydrology and erosion applicable for the Himalayan region, and to mitigate the poor data quality. Gumbricht *et. al*. (1996c) used remotely sensed data and GIS to create a digital data base over the Sutlej river (Fig. 3). Detailed knowledge for a small part (Sangla - fig 3) was extrapolated to the whole Sutlej basin. Precipitation, runoff and erosion was spatially modelled recognising the errors of the data set. Runoff was modelled using PHASE, which could explain between 10-70 % of the variation in flow for 6 different gauging stations (*ibid*.). Erosion was modelled based on field surveys and logical relations between erosion on one hand and water transport, slope steepness and vegetation cover on the other (fig. 3). Relations were inferred in a simple and transparent expert system using ”if ... and if ... then ... ” syntax, and incorporating fuzzy logic. Compared to traditional erosion modelling this highlights relational

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functions at individual sites rather than multiplicative factors as in e.g. the Universal Soil Loss Equation (USLE). Errors and uncertainty can be analysed for improved decision making.

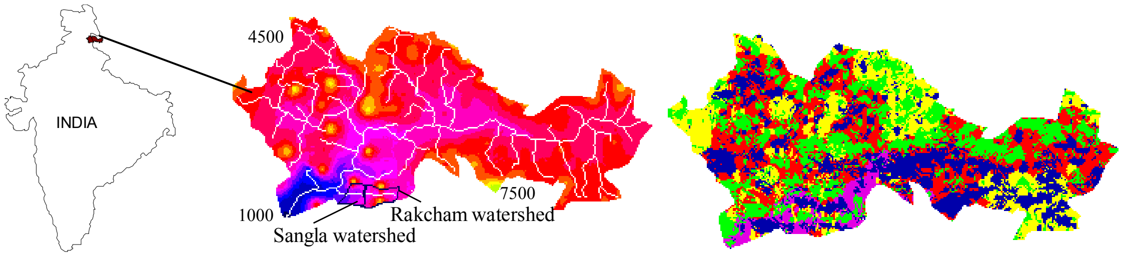

Fig. 3 Sutlej river basin, digital terrain model, and erosion risk map (see text).

Conclusion

The intelligibly human conception of patterns makes GIS a strong candidate for communicating model results to management and policy, and vice versa. The integrated models presented holds promises as management and policy tools in regions suffering from water shortage (e.g. Cyprus), for regions with poor data (e.g. Himalayan), and for regions were traditional models developed in temperate climate do not apply (both sites). From the case studies it is clear that vegetation, relief and water processes are tightly connected. By vegetation clearance water processes become spontaneous and eroding, leading to soil impairments and water quality deterioration. Restitution of the land surface include reforestation and wetland creation at key spots, leading to recycling of water, nutrients and matter. The high (heterotrophic) energy concentration in urban and agricultural areas must be balanced by intelligently managed vegetation restructuring. In the city this could also include greening of roofs and facades, establishment of communicating green lungs of vegetation and high productive moist areas (or green houses) for recycling of waste water.

To be effective the outlined technical (small scale) solutions must be harmonised with societal large scale efforts. A long term solution could be an ecological tax reform with time (energy) and space (land) related taxation in line with first principles (i.e. thermodynamic budgeting). Natural constraints of system efficiency should be price deciding. Land owners should be paid for cooling and clean water produced. Potentially RS data could be used for high resolution monitoring of landscape functions, forming the basis of a new resource related taxation system. The use of market forces for self-organisation of sustainability could lead to a more mature society in harmony with Nature's life support functions.

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