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Qualitative reasoning in participatory spatial planning: the use of OSIRIS in the Yellow River Delta

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Abstract: Societies see the emergence of new governance concepts, based on the assumption that processes of planning and decision taking are no longer hierarchical but the product of complex interactions between governmental and nongovernmental organizations, and the general public (the model of 'co-production of knowledge'; Callon, 1999). All involved are seeking to influence the collectively binding decisions that have consequences for their interests. To account for this changing governance and the increased number of stakeholders involved, decisions need to be assessed in an integrated context.

This paper discusses the OSIRIS modeling environment for knowledge rule based reasoning on spatial information. The Yellow River Delta project is used as an illustrative case study to describe how the tool helped to develop a model to determine effects on vegetation and fauna when changing abiotic parameters in the delta and apply different scenarios.

The tool was used in several workshops in which typologies were determined and relationships between them have been defined by means of rules of thumb. Participants needed to think in a structured way following the conceptual framework of spatial strategies and typologies linked with available spatial data and the available expert knowledge.

In the application of scenarios the causal relationships of impacts of spatial plans could be explored by highlighting the decision path in the rules of thumb as defined by participants during the workshop itself. This knowledge transparency makes it possible to have several iterations of fine-tuning the model during a single stakeholder workshop.

***Keywords**:* Participatory modeling, participatory spatial planning, qualitative reasoning

1. INTRODUCTION

Societies see the emergence of new governance concepts, based on the assumption that processes of planning and decision taking are no longer hierarchical but the product of complex interactions between governmental and nongovernmental organizations, and the general public (Callon, 1999). All involved are seeking to influence the collectively binding decisions that have consequences for their interests. To account for this changing governance and the increased number of stakeholders involved, decisions need to be assessed in an integrated context. In the realm of urban, rural and natural resources planning this has led to participatory spatial planning and participatory modeling efforts (e.g. McCall, 2003; Van de Sluis, 2002; Brown Gaddis et.al., 2007; Beal and Zeoli, 2008; Velazquez et. al., 2009).

Participatory modeling is the inclusion of stakeholders and decision makers into a modeling process to support decisions involving complex environmental questions (Voinov and Brown Gaddis, 2008). It may involve scenario development and indicator selection, the use of existing model(s) or jointly created new model(s) and gaining and processing of stakeholder knowledge. Korfmacher (2001) and Voinov and Gaddis (2008) provide helpful guidelines for participatory modeling varying from choosing a transparent(!) modeling approach and tool(s) to gaining trust and acknowledgement of conflict.

Voinov and Gaddis (2008) state that model selection should be based on the goals of participants, data availability, project deadlines and funding limitations. This may lead to the use of complex numerical models, or qualitative techniques. Examples of both can be found in literature (Beal and Zeoli, 2008). The paradox is that it is hard for non-experts to understand complex models, but that the use of a simpler model may detract from the credibility (Korfmacher, 1997, 1998). Walz et. al. (2007) recommend to primary focus on qualitative techniques initially and, only if needed, go through numerical modeling. Especially when there is little information qualitative reasoning provides a means to make knowledge explicit, keep it organized and processable (Salles and Bredeweg, 2006).

Participatory Geographic Information Systems (PGIS) is a tool often used in participatory spatial planning. PGIS gives the public access to spatially distributed phenomena and provides interactive zooming, overlaying, temporal comparisons and many visualization options (McCall, 2003; Jankowski, 2009). By applying participatory modeling in participatory planning impacts and side effects of spatial plans can be analysed.

Potential advantages of participatory GIS and modelling include education, awareness raising, empowerment building, contribution to democratic principles, integrate social processes and it can lead participants to be instrumental in pushing forward an agreed agenda (Korfmacher, 2001; McCall, 2003; Jankowski, 2009). Visualisation and interpretation tools are essential to support the discussion and interaction (Brown Gaddis et. al., 2007). However, participatory processes do not automatically lead to better decisions, nor do the use of IT solutions (Blaschke, 2004). Lack of expertise, risk of biased input, deligitimization or overlegitimization, or insufficient influence are arguments against public participation (Korfmacher, 2001).

This paper discusses the application of qualitative reasoning in participatory spatial planning and modeling supported by the OSIRIS modeling environment (Verweij, 2004). The OSIRIS modeling environment enables the linkage of GIS data to qualitative rules and allows to identify (indirect) impacts of spatial plans, undertake all analysis dynamically and interactively adapt the plans. It will be argued that the use of qualitative modeling is very useful for decision making even in situations where there is more information available. The application of OSIRIS in the Yellow River Delta, China, will serve as an illustrative case.

2. SPATIAL PLANNING AND QUALITATIVE MODELING

2.1 Modeling concept

In spatial planning scenario studies (Harms, 1995) are used to prepare for the future based on possible developments of different factors and to minimize unexpected effects by analysing different solutions and their probable impacts. A scenario is a description of a possible exogenous determined future for which a coping strategy is required. For example for the scenario of climate change and sea level rise, the Dutch can build dikes, or move houses to higher ground. These strategies need to be linked to locations. Finally indicators are selected to measure the impacts (Figure 1).

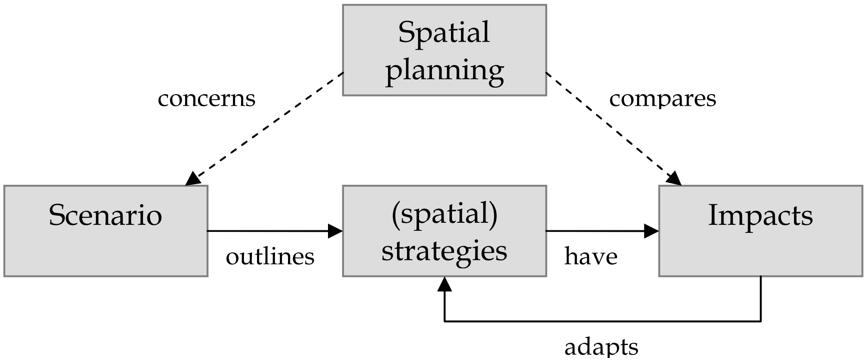
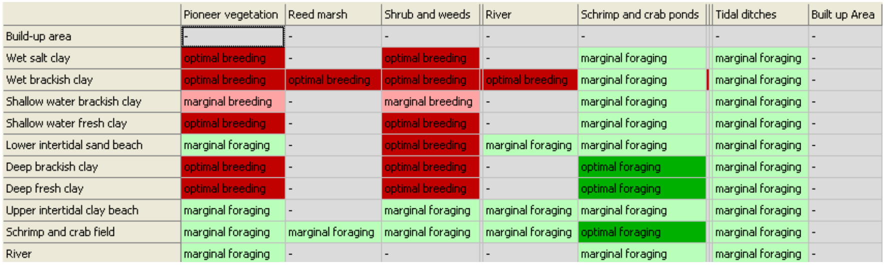


Figure 1 – In spatial planning a scenario describes a coping outline for a possible future for which various spatial strategies are developed. A desired spatial strategy is reached by iteratively adapting the strategy based on its impacts. The impacts of different spatial strategies are compared with eachother for trade-off analysis.

2.2 Qualitative modeling with OSIRIS

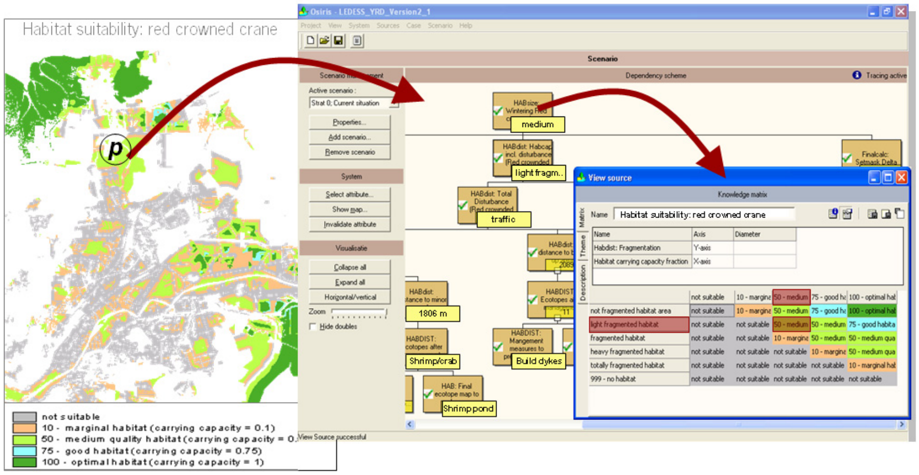
The OSIRIS modeling environment enables the linkage of GIS data to qualitative rules and allows the user to identify not only the direct, but also the indirect impacts of spatial strategies. It enables analyses of causes; dynamically and interactively adaptation of the strategies and/or rules to reach a desired state. OSIRIS is an empty modeling shell, which needs to be filled on a case basis with GIS data, qualitative rules, map algebra (Burrough, 1998), and links between them to model the causal pathway to the impacts (Verweij, 2004). By nature GIS data may be continuous, ordinal, or nominal (Stevens, 1946). Continuous data is classified and ordinal and nominal data grouped into typologies based on characteristic features. Typically, when working with OSIRIS, the types forming a typology depend on original available GIS data which is interpreted and expressed in such a way that it fits the objective of the study best. Often this means clustering the available data and thereby exempting the typology from noise. On the other hand available data may constrain the types in a typology, e.g. for a desired classification of groundwater dependent reed vegetation the accuracy of that data must be of adequate distinction.
Point-based qualitative rules will take a number of classifications and/or typologies and define "if..then..else"-relations between them in decision trees, or knowledge matrices (see Figure 2).



	Pioneer vegetation	Reed marsh	Shrub and weeds	River	Schrimp and crab ponds	Tidal ditches	Built up Area
Build-up area	-	-	-	-	-	-	-
Wet salt clay	optimal breeding	-	optimal breeding	-	marginal foraging	marginal foraging	-
Wet brackish clay	optimal breeding	optimal breeding	optimal breeding	optimal breeding	marginal foraging	marginal foraging	-
Shallow water brackish clay	marginal breeding	-	marginal breeding	-	marginal foraging	marginal foraging	-
Shallow water fresh clay	optimal breeding	-	optimal breeding	-	marginal foraging	marginal foraging	-
Lower intertidal sand beach	marginal foraging	-	optimal breeding	marginal foraging	marginal foraging	marginal foraging	-
Deep brackish clay	optimal breeding	-	optimal breeding	-	optimal foraging	marginal foraging	-
Deep fresh clay	optimal breeding	-	optimal breeding	-	optimal foraging	marginal foraging	-
Upper intertidal clay beach	marginal foraging	-	marginal foraging	marginal foraging	marginal foraging	marginal foraging	-
Schrimp and crab field	marginal foraging	marginal foraging	marginal foraging	marginal foraging	optimal foraging	marginal foraging	-
River	marginal foraging	-	-	-	marginal foraging	marginal foraging	-

Figure 2 – example of a qualitative rule definition in OSIRIS: a two dimensional knowledge matrix to determine the habitat suitability of the gull based on the combination of a physiotopes typology (rows) and vegetation structure typology (columns).

The application of a rule (or a causally linked set of rules) generates a map which is presented for analysis. Often certain locations in the generated maps represent unexpected, or puzzling results. The OSIRIS drill-down feature lets the user trace back into the applied rules by showing the causal relationships between rules and GIS-data resulting in this map and highlighting the decision path in each of the rules as applied for the location of interest. Either this explains the result, or allows to iteratively fine-tune the rules (Figure 3).



Name: Habitat suitability: red crowned crane

Name	Axis	Diameter
Habdist: Fragmentation	Y-axis	
Habitat carrying capacity fraction	X-axis	

	not suitable	10 - margina	50 - medium	75 - good ha	100 - optimal hat
not fragmented habitat area	not suitable	10 - margina	50 - medium	75 - good ha	100 - optimal hat
light fragmented habitat	not suitable	not suitable	50 - medium	50 - medium	75 - good habita
fragmented habitat	not suitable	not suitable	10 - margina	50 - medium	50 - medium qua
heavy fragmented habitat	not suitable	not suitable	not suitable	10 - margina	50 - medium qua
totally fragmented habitat	not suitable	not suitable	not suitable	not suitable	10 - marginal hat
999 - no habitat	not suitable	not suitable	not suitable	not suitable	not suitable

Figure 3 – drill down functionality is initiated by clicking a location '*p*' in map 'habitat suitability: red crowned crane' for which OSIRIS display the cause-effect relationships of qualitative rules and GIS data (orange rectangles) and shows the respective data value (yellow boxes) at point '*p*'. In the opened respective knowledge matrix the decision path for point '*p*' is highlighted

The OSIRIS modeling environment has been used in spatial planning studies by scientists in an inhouse setting. These studies varied in domain from nature (Harms et al., 2000), recreation and landscape attractivity (Roos-KleinLankhorst et al., 2004) agriculture (Boogaard et al., 2003) to integrated approaches (Jongman et al., 2004; Eupen et al., 2007). The interactive capabilities of OSIRIS give it the potential to be used in participatory spatial planning and to jointly define the typologies, setup the qualitative rules, model the causal relationships, calculate impacts and have several adaptation iterations within a workshop.

3. CASE STUDY: THE YELLOW RIVER DELTA

3.1 Area characteristics and objective of the study

The Yellow River Delta (YRD) is located between Bo Sea Bay and Laizhou Bay in China. It is a delta with weak tide, much sediment transport, frequent displacements and forms the most complete and extensive young wetland ecological system in China. On the east-Asian migration routes it offers breeding, wintering and stop-over places for many migratory birds, among which are very rare species like the Red-crowned crane and the Saunders's gull. The YRD is also an important base for aqua-culture and has been appointed as national agricultural development area. The delta faces influences of urbanization, pollution and fragmentation caused by oil development. In recent years regulation of the river course to the delta and decreased sediment loads have led to salinisation and a trend of rapid decrease of wetlands . The freshwater wetland area has decreased with 50 percent in the last 20 years, destroying the connectivity and integrity of the wetland ecosystems. The habitats that are used by rare birds are facing the danger of disappearance.

The YRD Environmental Flow Study (YRD-EFS) aimed at a more balanced water allocation for sustainable development of the wetland nature reserves, dealing with the effects of land use changes and variations in the flooding regime and was primarily carried out for the Yellow River Conservancy Commission (YRCC). YRCC is responsible for the division and quality control of water of the Yellow river in terms of quantity, time and function (e.g. drinking water, irrigation, nature conservation).

3.2 Participatory process

With classic engineering in river management, changes in the landscape and river system are mostly focused on introduction of measures like digging or changing the path of the river. This type of engineering neglects the occupation of floodplains and the interactions with farmers, nature conservation, recreation and forestry risking damage by flooding. The YRD study did include these stakeholders in defining scenarios and strategies to lower that risk.

During one and a half year 5 10-day workshops were organised with YRCC staff, (local) hydrological and (local) ecological experts from the University of Najing and the Chinese Academy of Science, Dutch consultants and stakeholders to define scenarios, spatial strategies, indicators and compare scenario and strategy impacts. Stakeholders were selected by the YRCC based on their dependency of water from the Yellow River and included the Nature Reserve Authority and urban planning of Dongying municipality. Both also representing agriculture and aqua-culture farmers within their territory. Since it was argued that the oil industry predominates all other interests it was decided not to include it in the workshops. Stakeholder presence varied with relevance per workshop.

The YRD-EFS study started with an inception workshop, initiated by the YRCC, resulting in a diagnosis of the problems, defining the boundary conditions and approach of the study in detail including indicators for measuring ecological performance.. Four additional workshops were planned. In each workshop focus groups were formed with a specific objective, such as the definition and refinement of scenarios, spatial strategies, ecological qualitative rule-based modelling and hydraulical-/hydrological modeling (to be denoted as water models). During each workshop the focus groups worked in daily iterations. At the end of each day each focus group presented their progress for plenary discussion and approval of YRCC officials.

In the first workshop the YRCC proposed scenarios, spatial strategies and indicators to open the discussion. Based on these an inventory of required available (GIS) data was made, first water modeling parameters chosen, and the ecological model was setup. In consecutive workshops scenarios, spatial strategies, qualitative rules and modeling were refined.

Each workshop involved modeling. Due to their complexity and data need the water models were run once, or twice during a workshop. At the start of a workshop parameters for scenario (water volume per unit of time) and spatial strategy (location of dams) were chosen to be fed to the models. Resulting ground water level and flood duration maps were discussed afterwards.

The qualitative ecological model was built from scratch with the stakeholders keeping the targeted indicators constantly in mind and using those as a starting point for back reasoning the causal relationship from habitat suitability towards the inputs generated by the water models (Eupen et al., 2007). The ecological know-how was gathered and implemented during the workshops, such as the definition of ecotope-, vegetation and physiotope typologies and rules for vegetation development. Together with the stakeholders causal relationships were made based on typologies and their interrelations in the form of knowledge matrices in OSIRIS (see section 2.2). During a daily session multiple iterations of ecological model adaptation, execution and result analysis were made.

3.3 Resulting model

In the development phase, the tools for the analysis and preliminary solutions to the management problems were developed. Major activities were data collection and data analysis. Throughout the development phase, there was a gradual refinement of the various mechanisms of the study. The first stages started with limited data sets and simplified tools, and progressed to detailed data sets and the full set of models or process descriptions which have been deemed necessary in the inception phase.

Indicators for measuring the overall objective of safeguarding the habitats were chosen to be the ecotope diversity and the habitat suitability of the Saunders gull and red crowned crane. All three indicators are strongly influenced by ecotope quality and -fragmentation. Fragmentation was mainly driven by activity of the not represented oil-industry by building wells and infrastructure. Therefore the alternative to increase the ecotope quality by an increase of discharge from the Yellow River into the delta was adopted as the only plausible scenario to be influenced by the present stakeholders. Three spatial strategies were defined: 1. no extra discharge, 2. put all extra discharge to the southern nature area, or 3. divide it between the northern and the southern areas.

A dynamic ecotope model was developed with the purpose to provide an evaluation of the ecological effects of variations in the flooding regime within the complete delta, while land use changes were restricted to the nature reserve area. This model followed the philosophy of the Landscape Ecological Decision and Evaluation Support System (LEDESS, Harms et al., 2000) and has been implemented in the OSIRIS modeling framework. The LEDESS model compares the impacts of alternative planning scenarios and spatial strategies for the development and management of the landscape. LEDESS confronts GIS maps of the existing landscape with proposed measures or scenarios and ecological know-how. The results of all scenarios are GIS maps and tables of the expected vegetation patterns, the potential fauna distribution and the size of animal species populations.

When defining the ecotope typology a cyclical look ahead to the ultimate goal of the model was needed (the potential fauna distribution). To obtain more information about the quality of the ecotopes themselves, for example, more details were required about the fauna species and their relation with vegetation. As a result, preferably smaller vegetation elements should be distinguished within the ecotopes, but such data was most of the time not available for the total area. As a consequence, all stakeholders agreed on typologies which were a well chosen balance between available GIS data and the extensive knowledge from (local) experts. The basic definition for ecotopes is based on vegetation structure types combined with flooding frequency and soil characteristics (forming the main parts of the physiotopes). Ecotope knowledge tables describe the development of the vegetation for combinations of vegetation types and the changed abiotic conditions (physiotopes).

The physiotopes take hydrodynamics (duration of flooding, as well as the type of the water) and the geomorphology into account. Hydrodynamics were based on the SOBEK hydraulic model (Schwanenberg & Wang, 2007) and a groundwater flow model based on MODFLOW.(Eupen et al., 2007) Current vegetation was defined based on historic monitoring data, SPOT satellite images and (local) expert knowledge. Expert knowledge was also used to model change of vegetation type under scenario conditions.

The results of this study have been taken up in the planning of YRCC and Dongying municipality.

4. DISCUSSION AND CONCLUSIONS

4.1 Adaptability to available data and local knowledge

Heterogeneous availability of process understanding and (spatial) data varying in coverage, scale and actuality hinders the application of complex data-intensive models. Qualitative tools are flexible to combine all these targeted at the decision making objective. This case study shows that qualitative models using typologies and inter causal relationships are highly adaptable to the objective of a study, available data and local knowledge and can play a mediation role in the participatory process. Typologies were targeted at the objective of the study and tuned to fit expert and local knowledge, fit water model and spatial data accuracy, but also condensed information from available GIS data to remove noise.

The YRD study used existing GIS data, but also water models' output. Once the water model' output was imported into GIS it could be seamlessly integrated into the qualitative OSIRIS modeling environment and used as any GIS data source.

A possible drawback of the use of this type of flexible model setup is that important drivers can be omitted if no expertise, or data of the topic is available. In the YRD study the effect of water quality on vegetation development was left out, since there was no spatial explicit data on the subject, making modeled predictions less accurate.

4.2 Transparency and interactivity

Spatial visual representations of model outcomes stimulate discussion especially when unforeseen impacts, or impacts at unexpected locations occur. The ability to support the discussion by showing the modeled cause-effect relation and highlighting the decision path in the qualitative model rules (e.g. knowledge matrix), for that specific indicator and location as supported by the OSIRIS modeling environment increased model transparency, facilitated further discussions and thus speeded up the process.

Many iterative adjustments of typologies and their inter causal relationships based on model outcomes were made within participatory sessions of the YRD study. This was made possible by fast model performance (ranging from seconds to minutes) and interactive qualitative rule editing allowing a continuous discussion based on instant updates of impact visualizations. Although knowledge matrices and decision trees were experienced as clear visualizations of qualitative rules helpful in understanding causal relationships (see Figure 2), they lacked a quality description for each separate 'if..then..else' relationship. Especially when a causal relationship defined in an earlier workshop was under question this lack of quality control could open up a former discussion.

In contrast, the water models' interactivity was relative low as input parameters could only be changed by model experts. The water models took hours to calculate and their intricate internal logic was difficult to explain. There was far less discussion on water modeling compared to the qualitative ecological model. Whether this is due to the Korfmacher paradox (1997, 1998) which describes that it is hard for non-experts to understand complex models, but that the use of a simpler model may detract from the credibility, or that the water models just did not invite for discussion has not been a subject of study.

Like Beall and Zeoli (2008) stated we found that qualitative models which articulate the collaborative vision of the problem can be the most valuable product of the process and essential for group learning. During the many discussions in the short ecological modeling iterations wrong assumptions could be invalidated by analysing model outcomes derived from qualitative rules defined by the same participants who assessed the outcome to be wrong and would be open to explanations from dissentients.

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