Modelling Biocomplexity in the Tisza River Basin within a Participatory Adaptive Framework

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Abstract: The erosion of biocomplexity in the Tisza River Basin developed slowly and incrementally over the past 130 years since implementation of the original Vásárhelyi river engineering plan. The Hungarian public view, blinded by flood and toxic spill catastrophes, missed the slow and subtle changes to natural, social and human capital precipitated by the reshaping of the TRB landscape and its agriculture for flood defence and grain production. While conversion of the TRB from a fruit/nut/ fishery polyculture to a wheat monoculture produced a great deal of financial capital for an aristocratic minority, the gradual drain of alternatives forms of capital left the region less and less resilient in the face of ecological (floods), economic (globalization) and political (war) shocks. Domination by central authorities over the past 50 years reduced local civic capacity to levels of passivity that make most communities incapable of innovating to find sustainability solutions, and this trend is reinforced by on-going paternalistic attitudes in the Hungarian national government. Poverty, passivity, apathy and the severe consequences of failure in the event of flooding have severely reduced Adaptive Capacity, the potential to innovate and adapt to uncertainty. Both Nature and Society have evolved considerably since 1870, so simple reverse engineering futilely aims to resurrect a system that no longer exists. Since the knowledge to un-straighten and reflood a river basin is in its infancy, we must learn as we go along, humble in the knowledge that management interventions often only increase uncertainty and can push the system further into a degraded state. This paper describes an initiative to use conceptual and formal modelling within an Adaptive Management framework to facilitate a regional discussion on how to manage the TRB while inventing a pathway back to a more resilient socio-ecosystem, linking natural and social processes.

***Keywords**:* Adaptive management, Vulnerability, Resilience, system dynamics models

1. INTRODUCTION

Managing a river basin is less certain than it was a century ago when flooding was the prime concern and engineering the solution. Rising damage trends witness the repeated failure of flood control, but parallel crises with river valley economic, social and cultural assets reveal a deeper, more entangled dilemma. *Biocomplexity* is an attempt to convey the uncertainty emerging not only from complex interactions within these sectors, but also from the tangle of relations *across* ecological, economic and socio-political domains. The challenge to understand and manage biocomplexity emerges in a history of surprising reversals of initial policy success, "policy resistance" (Sterman 2000, 2002). Attempts to eliminate, at first, and then to merely control disturbances (flood, fire, pests) have only promoted larger and more profound disturbances. Stubborn resistance to most policy remedies has earned such problems the title of "wicked problems" (Rittel and Webber 1973), as if evil intention is a metaphor for how intractable, unknowable and uncooperative the world is.

Wicked policy resistance has become increasingly evident in Tisza River Basin (TRB) as rising flood crest trends overtop every effort to raise and fortify the dikes, and regional agriculture and communities struggle to hold on (Sendzimir et al. 2004). Blame for rising flood statistics or declining river valley economies and societies cannot simply be pinned on "the usual suspects": exogenous drivers or ignorant human actors or policies. Analysis of the underlying complexity continues to improve (Linerooth-Bayer and Vári 2003, Molnar 2003, Sendzimir et al. 2004), but understanding, and more importantly the capacity to adapt, remains woefully behind the evolving reality. The move from the "hard" and narrow technical approach to a more adaptive and comprehensive "soft" path (Gleich 2001) requires not so much better understanding or methods of analysis or management intervention, but their integration.

Adaptive management offers a framework to integrate research, policy and local practice into a structured learning cycle (Walters 1985, Gunderson et al. 1995, 2002). Research, policy and public debate have been meshed with some success in AM-inspired initiatives to renovate the Kissimmee (Light and Blann 2000) and Colorado rivers (Walters et al. 2000). As with the TRB, the historical causes and resultant problems were far better, if incompletely, understood than the pathway back to a resilient system. Especially in the case of the Kissimmee river, the AM approach allowed managers to invent such a pathway by integrating stakeholder education and feedback with pilot research projects in the floodplain with computer modeling simulations of different policy implementations. This paper describes an initiative to use modeling within an AM framework to facilitate a regional discussion on how to manage the TRB while inventing a pathway back to a more resilient socio-ecosystem, linking natural and social processes. The search for new approaches arises out of frustration with failure of decades of research to generate concrete means to stem the rising trends of flooding and socio-economic decline. The TRB initiative begins from the practical perspective that ecological rejuvenation of ecological structure and function in the floodplain must also open opportunities for local employment and income. Concrete steps are already evident in uniquely parallel pilot studies of ecology and traditional forms of agriculture and fisheries in a re-flooded floodplain, but the challenge is to integrate such field research with on-going efforts to formulate policy, develop commerce and enterprise, and improve practices and methods at scales ranging from local to provincial to national to continental. Herein we describe these challenges and our efforts to model them as a prelude to launching a basin-wide AM effort to increase the TRB's resilience in the face of uncertainty.

1.1 Motivation

Parallel crises seem to reinforce one another in a downward spiral that increases the vulnerability of the TRB to disturbance from climate, globalization, and centralization of power in Hungary (Linerooth-Bayer and Vári 2003, Molnar 2003, Sendzimir et al. 2004). Efforts to control variability in river dynamics through more intensive and expensive forms of management continue to mount in cost as flooding increases in frequency and intensity (Horvath et al. 2001). Chronic and mounting crises suggest that intense management is misdirected due to inadequate understanding that is not keeping pace with changes from multiple sources of uncertainty at multiple scales (Sendzimir et al. 2004). The imperative to prevent injury, death and economic devastation hampers efforts to explore and learn. This raises the challenge to control even as we explore, to manage as we learn and to counterpose management actions and research in a cycle such that they reinforce one another in a progressive series that spirals upward to greater resilience. The challenge requires that different factors evolve and complement one another across the whole basin. Our ability to innovate and adapt to uncertainty (Adaptive Capacity *sensu* Walker et al. 2002, Yohe and Tol 2002) has to increase by riding a wave of trust and confidence that comes as our interventions lower vulnerability and increase resilience to uncertainty. In brief, the evolutionary challenge is summed by the question - How can we increase adaptive capacity as we manage to lower vulnerability such that our management approaches become more adaptive? It may mean short-term excursions into lowered resilience to cross to another, less vulnerable and more resilient, stability domain.

1.2 Study Area – Hungarian Reach of the Tisza River Basin

1.2.1 Historical challenges

Starting in the Ukrainian Carpathian mountains, the Tisza river cuts through Romania and across the great Hungarian plain (*Alföld*), eventually issuing into the Danube river in the Serbian Republic (Figure 1). The combination of a large mountain catchment issuing over a short and steep outfall onto a very flat floodplain drives some of the most sudden (24 hours) and extreme water level fluctuations (12 meters) in Europe (Kovács 2003, Halcrow Group 1999). Such extreme floods occur on average every 10-12 years in the Tisza River Basin (Wu 2000), but the last century has seen rising trends in all facets of flooding: flood crest or peak height, flood volume, and flooding frequency. Floods have increased in peak height by an average of 0.35 to 0.73 cm per year in the past fifty years (Horváth et al. 2001). Since the average minimal flow has declined, the difference between flood and drought extremes is increasing. The interval between extreme floods has declined sharply from once every 18 years (1877 – 1933) to once every 3 to 4 years

(1934 – 1964) to almost every other year over the last decade.

The roots of these increasing flood statistics may lie in massive river basin engineering that began with the original Vasarhelyi plan in 1870. In the early phases of the Industrial Revolution, rising urban populations that concentrated around factories created an exploding market for bread in European cities. The Austrian and Hungarian aristocracy seized this opportunity by modifying the Tisza river basin morphometry to fit socio-political demands for bread production, wheat export, habitation, and flood protection. The river was deepened to hasten water flow, shortened by 400 km to facilitate export, and bracketed with dykes to prevent flooding of wheat fields and habitations. By 1890 Hungary became the first wheat-exporting nation in Europe. Practically in step with mounting flood statistics, regional development has also climbed since the mid-nineteenth century, and the clash between these two rising trends has created ever larger losses. The infrastructure of towns and row crop farms burgeoned and spread into the flood danger zone, the TRB floodplain, reassured by the apparent security of a dike and canal flood defence system. The security promised by hydro engineering might hold for a decade or two, but ever-larger floods breached these defences, devastating homes, roads and crop fields. Damage to built capital and commerce from one major flood event could reach as high as approximately 25 percent of the GDP or riverine basin or 7-9 percent of national GDP (Halcrow Group 1999). These sudden catastrophic losses stand out against a backdrop of regional decline in all forms of capital that contribute to biocomplexity: natural capital (biodiversity and aesthetics lost, rising flood statistics), economic (previous industry gone, region no longer prosperous but empoverished, apathy about farming), and socio-political (cities, schools, businesses disappearing, political apathy as power concentrates in Budapest) (Sendzimir et al. 2004).

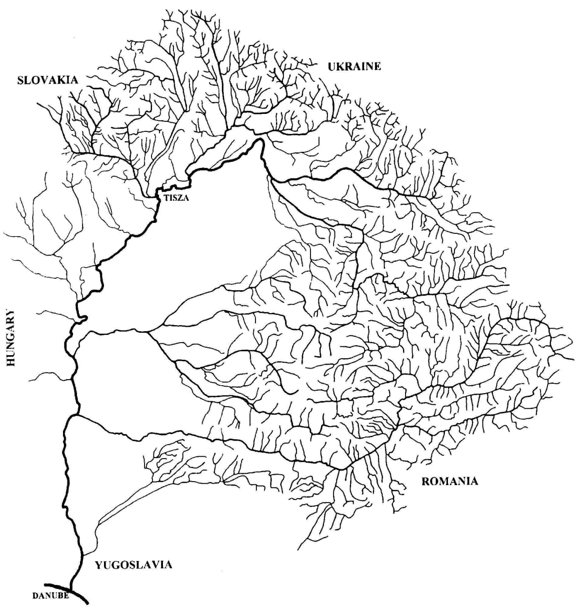

Figure 1. The Tisza river basin with tributaries in catchments in the Carpathian mountain range across portions of five different national territories (Romania, Ukraine, Slovakia, Federation of Serbia and Montenegro, and Hungary.

1.2.2 Present opportunities

Chronic flooding and toxic spill (Kosztolányi 2001) crises have also driven decades of research (Molnar 2003), but with little concrete effect on improving any of the facets of biocomplexity that affect vulnerability or reslience. Understanding has increased, but in sporadic spurts that have not been integrated and have not spread understanding or motivated action across disciplines or social sectors. Recently, however, WWF Hungary has sponsored a unique research initiative (Siposs and Kiss 2002) that combines analysis of both ecological functions and traditional agricultural methods in a floodplain with re-established hydrological connections. Understanding of how ecological and agricultural processes could reinforce each other could take advantage of new opportunities to trade wheat production to EU for credits under agri-environmental schemes. This means that credit gained from abandoning wheat production could be used to finance the research, engineering and organization to restore the resilience of the TRB and all forms of capital that compose biocomplexity. This opportunity raises the issue of how to spread understanding and trust in these pilot projects that might motivate wider discussion and experimentation that affects the basin as a whole. We contend that the AM framework that integrated pilot studies with public discussion in the Kissimmee river basin of Florida can serve as a model that we can adapt here to local conditions.

1.3 Objectives and Hypotheses

1.3.1 Objectives

The objectives of this initiative are as follows: Develop a better understanding of how key ecological variables, processes and relationships are affected by different flooding regimes on the Tisza river floodplain; Explore how the components of biocomplexity (ecological, economic and socio-political factors) interact to affect the resilience and vulnerability of a re-naturalized river floodplain with greater hydrological connectivity and more frequent flooding; establish a functional framework, such as Adaptive Management (AM), that integrates research and policy and local practice in a structured learning cycle; Test various hypotheses about how a natural flooding regime affects ecological processes and agricultural productivity in pilot projects prioritized and run by participants within an AM structured learning cycle; Use conceptual and formal modeling as a means to 1. build trust among collaborators that their separate experiences are incorporated in a mutually compelling vision of the key biocomplexity factors and their interactions that affect the resilience of the TRB; 2. explore the strengths and sensitivities of interactions in order to prioritize field research as well as the establishment of economic infrastructure (marketing and sales).

1.3.2 Hypotheses

Confining inquiry within bounds set by a preliminary set of hypotheses would stifle the potential of any AM process to incorporate heretofore-unknown experience and knowledge or to derive novel interpretations. Anticipating that questions, hypotheses and predictions will be derived and/or shaped by the AM participatory process (group assessment to bound the problem and derive a suite of hypotheses that are plausible alternative views of the key driving factors of biocomplexity), we pose one overall hypothesis as starting point for the AM assessment phase:

Hypothesis: *Re-establishment of hydrological connections across the Tisza river floodplain will promote nutrient cycling and productivity in a cascade of effects that will build all component factors of biocomplexity and boost agriculture, biodiversity and fisheries and lower the region's vulnerability to extremes of weather and economic variability.*

2. METHODS

Two methodological approaches will be applied to address the need to assess the state of biocomplexity in the TRB and to set priorities for integrating research with policy formulation. First, an *Adaptive Participatory Research Framework* will be established to coordinate collaboration between researchers and stakeholders. Second, within the Framework *system dynamics modelling* will be employed to secure a broad understanding among all participants of the key variables and interactions affecting biocomplexity.

2.1 Adaptive Participatory Research Framework

Along the TRB increased variability from climate and economic transition only adds to the uncertainty of a century of biocomplexity erosion. Coping with uncertainty requires the sustained capacity to learn and to flexibly manage. For thirty years a decision making process has been evolving to address the challenge of learning while managing. This process, Adaptive Environmental Assessment and Management (AEAM), also known as

Adaptive Management (AM), offers a framework to integrate research, policy and local practice that has been developed over three decades of experimental applications to understand and manage crises of collapsed fisheries, agriculture, forestry and rangeland grazing (Holling 1978, Walters 1986, Gunderson et al 1995, Gunderson and Holling 2002). AM increases adaptive capacity by shifting linear decision making processes (crisis → analysis → policy) to a cyclic learning process that iteratively integrates how we modify conceptualisation, policy formulation, implementation and monitoring in order to track and manage change in the world (Figure 2).

The TRB initiative attempts to apply innovations to AM developed in the Oder river basin (Sendzimir et al. 2003) for communities with scarce resources of time and money. The innovations aim to lower transaction costs of determining the composition of the stakeholder group participating in the AM exercise as well as the methods and ideas best suited to the question at hand. First, the AM process is conducted on a mini-scale by using only a handful of stakeholders (from two to six people from NGOs and government) with experience broad enough to reasonably convey the diversity of opinion in the community. The methods and concepts found useful to this preliminary group can then be applied at the larger scale of the entire community. Furthermore, the confidence and trust built within this group can then be extended to engage a wider segment of the TRB stakeholders than might have been involved if the AM framework was naively attempted at the larger scale to begin with. The second innovation to sustain and intensify stakeholder involvement throughout the learning cycle is to engage them in formulating and measuring indicators of progress towards restoration goals for biocomplexity. The "red thread" that binds stakeholders in the entire process emerges from their actions in participating in field experiments and monitoring the very indices that they themselves proposed as well as from the progression of ideas and model development within the AM dialogue.

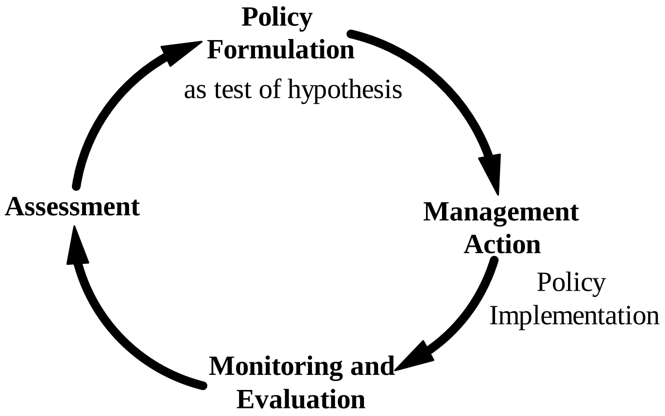

Figure 2. Adaptive management process as a structured learning cycle that iteratively links four phases: assessment, formulation, implementation, and monitoring.

2.2 Modelling

The AM learning cycle usually starts with an *Assessment* phase where-in stakeholders explore a range of assumptions and ideas in order to formulate a suite of equally plausible hypotheses that provide separate predictions of why the problem in question occurs (Sendzimir et al. 1999). Modelling can serve as a useful exercise for AM participant stakeholders to bound the problem and examine the key variables and interactions they consider crucial to the dynamics of resilience and vulnerability in the system. Conceptual models facilitate discussion and comparison of different interpretations of the system's structure (which variables are involved and how are they linked) including identification of reinforcing and balancing feedback loops and delays that affect system dynamics (Sterman 2000). Formal models involve mathematical expression of relationships linking key variables and allow participants to explore how the relative strengths of different interactions affect system dynamics, particularly with regard to questions of vulnerability and resilience to change. We discuss current progress in application of Conceptual Modelling that is intended eventually to set the stage for rigorous applications of formal models

2.2.1 Conceptual Modelling – Causal Loop Diagrams

Following the AM approach used in the Oder river valley (Sendzimir et al. 2003) NGO stakeholders and systems science researchers will meet in an initial scoping session to winnow a list of key variables down to a practical range (< 25) and then use causal loop diagramming (Sterman 2000) as a discussion guide in linking variables and slowly developing a graphic image of the system structure. As the web of relations takes shape, certain sections become more understandable as identification of reinforcing and balancing feedback loops reveals the system macro-structure. The group's desire to focus on specific parts of the model often generates sub-model diagrams that clarify some of the causal details underlying the more aggregate variables and relations in the general model, The TRB initiative is in the initial stages of mobilizing the resources to generate a large scale AM research collaboration that builds on the research initiative started by WWF in the Nagykörü region. Thus far conceptual modelling has helped the organizers to synthesize an overview vision (Figure 3) of the key relationships that affect resilience and vulnerability of agro-ecosystems in the TRB floodplain. Preliminary modelling exercises like these broaden the modellers intuition in preparation for their facilitating discussion in group modelling exercises for actors and stakeholders in the TRB. The model reveals the reinforcing feedback loops that trap policy in flood defence which strangles the hydrological connectivity that made the region one of the richest and most productive in Hungary before 1870.

3. CONCLUSIONS AND RECOMMENDATIONS

Causal loop diagramming has proven a useful tool to synthesize an initial overview of the factors and relations driving the erosion of biocomplexity in the TRB and will be improved in a group participatory process that refines the conceptual models and uses them to build formal models for exploring the relative strengths with which different interactions affect system dynamics.

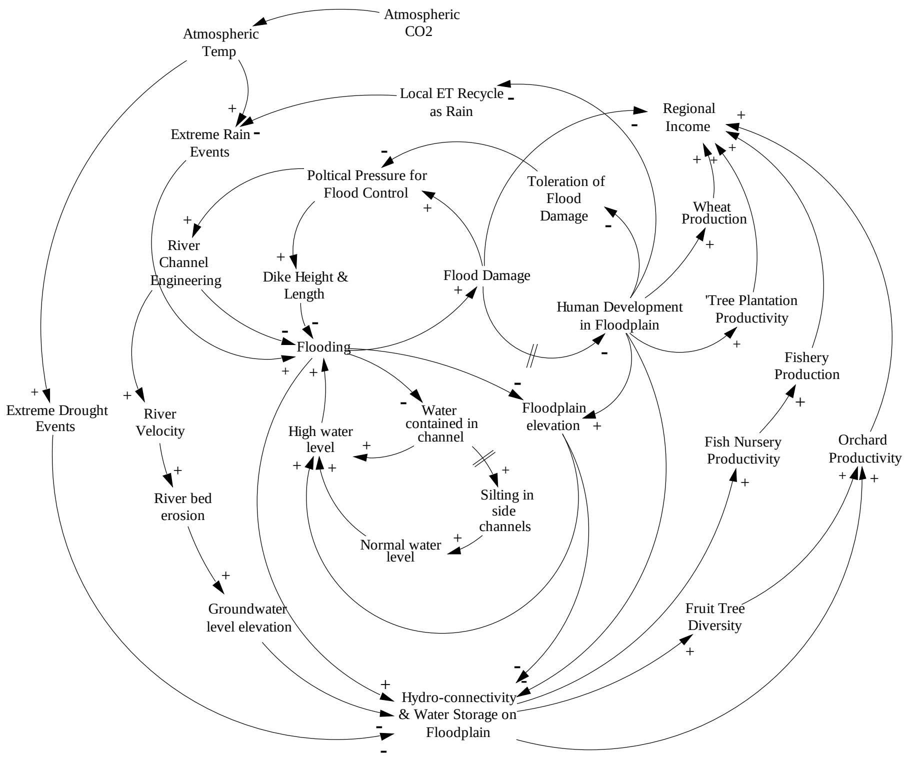

Figure 3. Conceptual model of key variables and causal loops that interact to affect Tisza river floodplain resilience to climate related hydro-dynamic variability.

4. ACKNOWLEDGMENTS

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