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Procedural knowledge for integrated modelling: Towards the Modelling Playground☆

Thorsten R. Arnold[a,b,*]

[a] Drinking Water Source Protection, Saugeen, Grey Sauble, Northern Bruce Peninsula Source Protection Region, Owen Sound, Ontario, Canada
[b] University of Hohenheim, Stuttgart, Germany

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A B S T R A C T

Integration aims to bridge disciplines and bring together knowledge that is fragmented across these disciplines. However, practical integration in Natural Resource Management (NRM) remains out-paced by the increasing pressures on natural resources. Research must become more effective at producing tools appropriate for NRM praxis (IAASTD 2009).

Quantitative integrated modelling (IM) offers NRM the precision of mathematical formalism for rigorously evaluating hypotheses, testing concepts and comparing management options. To support IM, software tools have made great leaps in recent years. On the other hand, the knowledge of how to apply this "cyber infrastructure" remains mostly tacit and no adequate guidelines are available to support project managers in choosing cyber infrastructure that is appropriate for a specific project.

The objective of this paper is to define a framework and a benchmark against which the efficiency of integrated modelling for natural resource management (IM-NRM) processes can be evaluated. First, the IM challenge is characterized by defining complexity, knowledge requirements and, using concepts from organizational theory, three strategies of knowledge acquisition. These include individual learning, collaboration within staff and cooperation with third parties. Next, the three strategies are used to categorize the organizational challenge of IM-NRM with five metaphors. Cyber infrastructure plays a pivotal and distinct role in each metaphor by sharing knowledge across project members. One of these metaphors, the "Modelling Playground," is defined as an optimal combination of the three strategies.

Finally, this perspective is used to describe two NRM projects, one from academia and one from a governmental program. Both case studies have undergone significant changes in organizational structure and in knowledge acquisition strategies. The initial choice of cyber infrastructure proved insufficient for these changes and resulted in significant adjustment costs.

In conclusion, it is suggested that guidelines for cyber infrastructure used in NRM, which take into consideration the aspired goals, the constraining organizational context and incentive structures, are crucial to improve the effectiveness of NRM. It is also suggested that lesson learning be based on the framework of organizational theory, as well as an action-based approach, to create a test Modelling Playground as a learning hub.

So oft in theologic wars, The disputants, I ween, Rail on in utter ignorance, Of what each other mean, And prate about an Elephant, Not one of them has seen.

John Godfrey Saxe.
"Six Blind Men and the Elephant"

Let a man say he is free, and he will instantly feel constrained; but let him acknowledge limitations, and he will feel free.

Johann Wolfgang von Goethe.
"Die Wahlverwandtsxchaften II, 5"

1. Introduction

Natural systems, such as the water cycle, are entwined with human land use decisions and agricultural practices. The management of these systems therefore requires a holistic understanding of how they function as individual parts but especially in their

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* R.R. 3, Concession 3, Allenford, ON, N0H 1A0 Canada. Tel.: +1 519 935 3005.
E-mail address: thorsten.r.arnold@gmail.com.

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interactions as a basis to formulate and implement policies collaboratively.

The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) reviewed how research on agriculture and natural resource (NR) management impacts real-world management practices. Its results were presented by leading academics, policy makers, and representatives from the United Nations, non-governmental organizations, and government. The IAASTD's conclusions are sobering. They found that the effectiveness of research and the pace of sustainability innovation fall behind today's rate of the deterioration of resources. Despite some successes, the managers of NR systems have failed to address NR problems in their full complexity and instead continue to cause unwanted outcomes. At the praxis level of NR management, the IAASTD summary for policy makers highlights that "capabilities for working together at multiple scales are not well developed" (IAASTD, 2008, p. 10). When referring to the role of Knowledge, Science and Technology (KST) in agriculture and NR management, the IAASTD warns that "business as usual is no longer an option" (p. 3) and challenges KST to rethink its role in achieving sustainability and development goals (p. 3).

According to this high-profile panel, the challenge of creating and implementing sustainable Natural Resource Management (NRM) requires a focus on system orientation, collaboration and partnership. The IAASTD recommends systems-oriented, holistic approaches that address the difficulties associated with the complexity of NR use in different ecologies, locations and cultures. At the same time, KST should support active participation of various stakeholders across multiple scales. Methodologically, environmental modelling is at the frontier of KST in response to the challenge of sustainable NRM.

Integrated modelling (IM) is defined as "a network of activities involving interdisciplinary teams collaborating closely with specialists in modelling methods and tools" (IIASA website). Similarly, Mittelstraß (2003) defined transdisciplinarity as a style of work *within* the realm of academia, based on collaboration and communication across departments and disciplines. Although IM is ultimately expressed in data and computer code, its essence is an organizational approach and a process of knowledge exchange. Methods for IM must thus foster a collaborative style of work and reduce barriers to the free flow of knowledge. Some examples include computerized simulation models that describe interactions and feedbacks, data management platforms that elucidate system behaviour from multiple perspectives, metadata that makes knowledge accessible and assumptions transparent, ontologies that bridge linguistic gaps between disciplines, and facilitation methods that improve the flow of communication and clarify tacit knowledge. And even the design of buildings as research settings, such that they nurture regular meetings in formal and informal settings.

On a practical level, integrated models are used to bridge knowledge across disciplines as most NRM projects are collaborative in nature and involve diverse stakeholders and perspectives. The scientific community has witnessed increased attention to integrated environmental modelling and assessment (Pahl-Wostl, 2007), which resulted in an explosion of supporting models, software tools and gadgets.

While environmental scientists have embraced the approach of IM-NRM, its adoption by practitioners remains limited. Many academic software tools are hardly reusable outside of their development community (Donatelli and Rizzoli, 2008) and authors lament that scientists continue to reinvent the wheel (e.g. Argent, 2004; van Ewert et al., 2006). Examples for successful collaborations between local Resource Managers (RM) and academic consortia exist, but their reproduction would require the replication of research funding, which local RM can seldom accomplish. Few local RM can even access cutting-edge scientific knowledge as it is mainly communicated in academic journals that are inaccessible outside of academic organizations. As a consequence, a gap remains between the expectation for IM methods within academia and the slow adaptation of the methods within NRM praxis.

This paper aims to describe this gap by understanding the role of knowledge in IM and to contribute to the bridging of it. Objectives, needs and constraints of a RM who would make use of IM methods are first defined. Next, the capabilities of software tools that support IM are reviewed and existing lessons and guidelines on how to perform IM are categorized and summarized.

In a step forward, the challenge of applying IM effectively is analyzed structurally by defining the nature of complexity in NRM. Knowledge management is identified as a fundamental challenge of dealing with complex systems. This introduces the problem of accessing and maintaining the relevant types of knowledge over an adequate time horizon. This challenge of knowledge management is then divided into three dimensions: collaboration within an organization, cooperation with external partners and the accumulation of new knowledge by individuals through learning. All of these options entail costs.

Five approaches are presented metaphorically, which lay out how modelling-based NRM processes can address knowledge management. One of these, the Modelling Playground, is effective both in its outcomes and cost-efficiency. All other strategies fail to resolve the IM challenge, either because their results lack depth, they cannot resolve interactions, they remain limited in scope or because costs exceed available resources. Ultimately these other strategies are unsuitable for application in NRM praxis.

Finally, the concepts are applied in two NRM case studies that offer insight into knowledge management. By implementing strategies of the Modelling Playground, both projects evolved structurally and improved knowledge management.

2. The challenge for the natural resource manager

2.1. The perspective of the resource manager (RM)

Ideally, NRM is based on a holistic understanding of the resource system and its interactions with human society. A wide range of stakeholders are consulted to define problems, identify management options and assess impact from multiple perspectives. A decision process should then make use of this knowledge and favour options which are socially equitable, environmentally sustainable, economically efficient, and robust under variable conditions.

In praxis, RMs must achieve NRM goals in a timely manner within an existing organizational context that is defined by hierarchies. They also, at least partially, must build on existing staff, their knowledge and problem solving approaches. The RM for a large part must furthermore accept the financial resources that are available, the timelines imposed by funders, as well as the legal, cultural, and political context.

Within these constraints, RMs may employ new staff with additional knowledge, expand partnerships, choose management styles, and define project procedures. RMs can create value by increasing the market value of environmental services. Many governments have recognized that market failure leads to an under-valuation of these common goods and therefore provide additional funding to the RM in compensation for this market failure. Third parties can contribute resources through financial donations or in-kind contributions from volunteers. Collaborations with externally funded scientists are valuable as well. Finally, the RM may support longer-term strategies regarding organizational change, for example a shift from an engineering approach toward