



Integrated assessment and modelling: Overview and synthesis of salient dimensions



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ABSTRACT

Integrated assessment and its inherent platform, integrated modelling, present an opportunity to synthesize diverse knowledge, data, methods and perspectives into an overarching framework to address complex environmental problems. However to be successful for assessment or decision making purposes, all salient dimensions of integrated modelling must be addressed with respect to its purpose and context. The key dimensions include: issues of concern; management options and governance arrangements; stakeholders; natural systems; human systems; spatial scales; temporal scales; disciplines; methods, models, tools and data; and sources and types of uncertainty. This paper aims to shed light on these ten dimensions, and how integration of the dimensions fits in the four main phases in the integrated assessment process: scoping, problem framing and formulation, assessing options, and communicating findings. We provide examples of participatory processes and modelling tools that can be used to achieve integration.

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Learning objectives

- Have a basic understanding of what needs to be integrated in integrated assessment and modelling, how and why
- Identify key developments and publications in integrated assessment and modelling
- Give examples of how integration dimensions are relevant to phases of integrated assessment and modelling.

Assumed background knowledge

- Awareness of basic concepts and terminology related to integrated assessment and environmental modelling
- Awareness of the complexity and uncertainty involved in analysing environmental problems

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1. Introduction

The impacts and causes of environmental problems transcend the boundaries of sectors, disciplines, system components and other divides. This has driven the need for integrated assessment (IA), a process that combines multiple and diverse components across their social, organizational and conceptual boundaries to provide a comprehensive analysis of the problem. Integrated modelling (IM) facilitates this by providing a single platform to explore the linkages and feedbacks between different system components, including the social, economic and ecological implications of different natural or anthropogenic factors. IM is generally considered the key tool for performing the IA process as it has the capacity to help deliver a systematic and transparent approach to integration. Together, integrated assessment and modelling (IAM) can help decision-makers develop policies to managing environmental resources and assets in a way that delivers acceptable environmental and socioeconomic outcomes. More broadly, effective use of IAM supports social learning by promoting a science-informed dialogue about the future.

The meta-discipline of IA first emerged in the context of global change problems to overcome limitations of traditional disciplinary methodologies, which were ineffective in handling the complex feedbacks and interactions of socio-ecological systems (Funtowicz and Ravetz, 1993; Rotmans, 1998). On looking into the historical evolution of IAM, one can distinguish three phases. Although White (1969) has long recognized the need for integration to consider the “multiple purposes” and “multiple means” of water management, it was not until the 1990s when IAM was explicitly recognized (i.e. *the inception phase*). Mitchell (1990) talked about integrating three aspects of water systems: surface water and groundwater, and quantity and quality; water and land interactions; and interrelationships with social and economic development. During the inception phase, the concept of IAM was defined and its practices became more established, with much of this work emanating from research in climate change, energy and economics (Dowlatabadi, 1995; Risbey et al., 1996; Rotmans and van Asselt, 1996; Rotmans, 1998; Toth and Hizsnyik, 1998; Weyant et al., 1996). Reflecting on this period, Hoekstra (1998) commented that: “the [integration] concept is still crystallizing, both in theory and practice”. In the 2000s, many of the foundations in the IAM were cemented (i.e. *the foundational phase*). These included: drawing frameworks, features and principles of the approach (e.g. Hare and Pahl-Wostl, 2002; Parker et al., 2002; Jakeman and Letcher, 2003); crafting the methodology (e.g. Dewulf et al., 2005; Castelletti and Soncini-Sessa, 2006; Jakeman et al., 2006; Newham et al., 2007), and showcasing its utility through case studies (e.g. Croke et al., 2007; Liu et al., 2008). The field is now in a *maturity phase*. The accumulated learning and experience as well as the advancements in related modelling and computing fields have allowed for addressing more sophisticated topics, such as good modelling practices (e.g. Van Delden et al., 2011), role of software development and computing platforms (e.g. Larocque et al., 2014), and uncertainty management (Haasnoot et al., 2014).

Whereas there is a wide consensus on the need for integration (e.g. Medema et al., 2008), there is less agreement on what integration really means (Hering and Ingold, 2012), and how it can be effectively incorporated into modelling processes. Integration is defined as “the making up or composition of a whole by adding together or combining the separate parts or elements” (Oxford English Dictionary, 2014). In this paper, we aim to shed light on what constitutes “integration” in IM, and how it is incorporated into the various activities of IA in order to improve the way we communicate about *what* and *how* to integrate. In this paper, IAM is considered as the integration of components across and within ten interrelated dimensions (Fig. 1). IAM should be a problem-driven

process and the first three dimensions correspond to key drivers for integration, namely the need to account for multiple i) issues of concern, ii) governance settings, and iii) stakeholders. This in turn requires the integration of multiple, iv) natural and v) human systems, and vi) spatial and vii) temporal scales. The remaining three dimensions represent the methodological aspects related to integrating viii) disciplines, ix) methods, models, other tools and data, and x) sources and types of uncertainty. There is overlap between some of these ten dimensions, for example it is acknowledged that stakeholders and governance settings are a part of the human setting. However each of the ten dimensions is distinguished as a salient dimension of IAM. The IAM process and its outputs can be rendered inadequate with a lack of careful consideration and appropriate treatment of any one dimension.

The idea of integration as a multi-dimensional concept is not new (see Table 1 for examples). In the context of integrated assessment, Parker et al. (2002), Jakeman and Letcher (2003) and Kelly et al. (2013) consider integration across five broad categories – issues, stakeholders, disciplines, processes and models, and scales. In the context of integrated research in environmental science and policy, van Kerkhoff (2005) identified integration across 12 thematic categories; six of these categories involve integration within the research sector (e.g. disciplines, research issues, research and teaching, research methods etc.), one category represented worldviews, and the final five categories related to integration between research and non-research organisations.

Janssen (2009) considered integration as the communication process of combining different elements (including tools, disciplines, scales etc.) and identified five types of integration – methodological, social, semantic, technical and institutional. Strasser et al. (2014) distinguished three dimensions of integration from a theoretical perspective, related to the integration of different linguistic expressions and communicative practices (*communicative*), interests and activities (*social*), and knowledge bases including theoretical concepts and methods (*cognitive*). The integration dimensions by Janssen (2009) and Strasser et al. (2014) were characterised in the context of agricultural systems and climate change research, respectively, but are applicable to all interdisciplinary fields.

Jønh-Clausen and Fugl (2001) discussed the concept of integrated water resources management as the integration of two categories – the ‘natural system’ and the ‘human system’. According to their categorisation, integration in the natural system included links between: i) land and water, ii) surface water and groundwater management, iii) water quantity and quality, iv) upstream and downstream zones, and v) freshwater and coastal zone management. The associated integration in the human system involves: i) holistic management across all levels of institutions, ii) considering water use, development and risk in all economic development planning processes for all sectors, iii) linking water resources management and poverty alleviation, iv) linking water resources management to national security and trade policies, and v) stakeholder engagement in the planning and decision process.

The ten dimensions identified in this paper are intended to capture both the integration of different components from the real world system (as in Jønh-Clausen and Fugl, 2001) and the methodological aspects related to incorporating different types of information, scales, perspectives, practices, theories, models and tools. While uncertainty has not previously been considered a dimension, its influence warrants explicit treatment. The notion of what is not known is quite distinct from what is known within each of the other dimensions, and has often been marginalised or even overlooked. There are several challenges entailed in integrating across these ten dimensions; in the next section we discuss these challenges as well as some solutions proposed by various methodological and technological advances. This is followed by a discussion on how the ten

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