INTEGRATING ADAPTIVE LEARNING INTO ADAPTIVE WATER RESOURCES MANAGEMENT

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Abstract

Adaptive water resources management recognizes the centrality of learning to its effective implementation. However, the literature on learning in Adaptive Management (AM) is disjointed and lacks rigorous treatment. The purpose of this paper is to clarify how learning associated with AM is distinctive and explain the importance of successfully integrating it into policy design. Because adaptive learning holds a unique position within the adaptive management and assessment process, it should serve as the basis for a systematic redesign of water policy processes. The concept of adaptive learning as put forth by Parsons and Clark (1995) is built upon in this paper, as well as a reworked version of Holling's (1978) Adaptive Environmental Assessment and Management process, which highlights the role of adaptive learning. For the purpose of this paper, adaptive learning is defined as "an ongoing process of inquiry that incorporates new knowledge with the aim to continually improve management policies". In order for adaptive learning to live with and profit from nature's dynamism, it is argued that it must be problem-centered, decision relevant, reflective, and inherently transformative. When this kind of learning becomes a fully integrated component of AM, water resource institutions have a greater likelihood of maturing into what Schön (1973) described "learning systems". The specific objectives of this paper are to: 1) Redefine what adaptive learning is, 2) explain how this particular type of learning is distinctive and 3) outline the role of adaptive learning in policy formation. Regarding policy design, the paramount issue is determining how to respond to the speed, scale, and complexity of the planetary challenges. This paper draws on a number of related areas of research to present propositions for increasing the adaptive capacity of water organizations. These research topics include: demonstrating how adaptive learning should be integrated into policy design; establishing new standards of practice that are based on adaptive learning rather than achieving 'optimal' end-game solutions; using the breakthrough views of Niels Röling and his extension of the Santiago Theory of Cognition in order to transform learning into effective action; framing management problems in non-reductionist ways so that nature may serve as an ally and pilot; using shadow networks to inspire innovation, encourage institutional learning, and improve governance rules; and creating a new social reality that is more future-responsive to problems and more hospitable to new ways of thinking about water management.

Keywords: Adaptive management, Experimentation learning, Policy design, Public participation, Water resources management

1. Introduction

Human-technology-environment systems can be viewed as complex adaptive systems in which unpredictable co-evolution makes uncertainty irreducible. In order to confront this uncertainty and engage in shared risk taking, it is essential that water managers demonstrate an unprecedented commitment to learning how to learn (Pahl-Wostl, 2009). It may seem obvious that learning must be taken seriously, yet the majority of science practitioners engaged in policy and design analysis do not give "learning" the recognition or attention it deserves. Although some of the major authors on Adaptive Management (AM) have recognized the centrality of learning to its effective implementation (e.g. Holling, 1978; Holling, 1980; Walters, 1986; Hilborn, 1987; Hilborn, 1992; Parsons and Clark, 1995; Michael, 1995; Gunderson, 1999; Lee, 1999; Röling and Jiggins, 2000; Pahl-Wostl, 2007; Armitage 2008), the literature on learning is disjointed, *ad hoc*, and lacking systematic and rigorous treatment. Nonetheless, learning is crucial if we are to design responses equal to the globally unprecedented and menacing challenges that face us, which means adaptive learning must be placed on par with conventional considerations of assessment and management in water resources policy domains.

Although a science-based profession, water resources management relies predominately on assumption rather than fact. While reviewing a wide range of case studies put forth by policy and science experts, Gunderson, Holling and Light (1995) discovered that pervasive management pathology existed in regards to repeated partial solutions, and that over time this pathology exacerbated issues rather than improved them. As Hilborn (1992) laments: "Can we learn about learning?" The most important step is to put learning on the agenda, "to make it a subject of discussion" (Hilborn, 1992). From its very inception, founding members of this line of inquiry stated: "There is no clear boundary between adaptive management as (a) an ongoing learning process and (b) the more time-honored concepts of experimental design (Walters and Hilborn, 1978).

1.1 Learning for Sustainability

Unprecedented growth of human populations and demand for natural resources, combined with increasing uncertainty due to changes in climate, have created major challenges leading to the erosion of natural resources, as well as the decline of ecosystems services, biodiversity and sustainability of the essential ecological processes and life support systems in human-dominated ecosystems (Vitousek *et al.*, 1997; Phillips *et al.*, 1998; Lawton *et al.*, 2001; Schimel *et al.*, 2001; Forest *et al.*, 2002). To avert these threats, both natural and social sciences have helped to acquire and apply knowledge about ecosystem conservation and restoration, and by strengthening the policy and practice of sustainable development (Kates *et al.*, 2001). Sustainability science recognizes that the well-being of human society is closely related to the well-being of natural ecosystems, and should draw on the collective intellectual resources of both formal sciences as well as local knowledge systems (Pandey, 2001). Scholars in this community generally agree that learning is a critical hinge for sustainability (Parson and Clark, 1995).

Despite the great importance of successful learning to our ability to achieve sustainability, learning processes are still poorly understood (Kates *et al.*, 2001; Clark, 2007). Henry (2009) points out how learning processes generally differentiate along two dimensions: (a) the mechanism of learning (social versus individual learning); and (b) the properties of the information being learned (empirical versus normative knowledge), and defines learning as a "process by which actors assimilate information and update their cognitions and behavior accordingly". When it comes to choosing the mechanism of learning, the question is raised whether we should study learning at the level of societies (as in the Social Learning Group, 2001), organizations (Levitt and March, 1988), coalitions of policy advocates (Sabatier and Jenkins-Smith, 1999), or individuals. In that light, the difference between individual and social learning is perhaps one of the most fundamental dimensions along which perspectives on learning are differentiated in the literature (Henry 2009).

One of the most recent definitions of social learning is that by Reed *et al*. (2010): "a change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks". In other words, *social learning* - also referred to as "learning with each other" - is the process by which agents adopt cognitions and behaviors from their social environment. Water resources management, in that light, should be looked at as the outcome of interactions and relations between multitudes of highly diverse social actors (see also Woodhill, 2004; Ison *et al*., 2007). *Individual learning*, on the other hand, captures situations where agents are primarily concerned with learning through experimentation of experience and interpreting payoffs from their environment. In other words, new knowledge and understanding is developed through experience and inquiry. Henry (2009) states that one of the fundamental differences between social and individual learning is that "individual learning is about knowledge production, whereas social learning is about copying or diffusing knowledge through imitation or persuasion". This ignores, however, the ideas of knowledge co-construction in social learning. Bouwen and Taillieu (2004) describe, for example, how "sharing problem perspectives and working with different kinds of knowledge and competencies" helps multiple actors or stakeholder parties co-construct a social learning process in an emerging community of practice.

AM (Walters and Hilborn, 1978, 1978, 1986) – as a management concept aiming to achieve sustainability - is primarily concerned with the reform of institutional arrangements (including responsible authorities) while changing the way in which management actions are developed and implemented to focus on learning as a key way of combating uncertainty and promoting adaptive capacity. Although AM focuses primarily on responsible authorities and the improvement of their management processes, achieving meaningful stakeholder involvement that goes beyond water managers, decision-makers, and scientists and include other interest groups and even the general public is considered essential to AM (e.g. Lee, 1999; Pahl-Wostl, 2007; Medema *et al*., 2008). AM is often referred to as "learning by doing", which is intuitively appealing but deceptively simple and missing the essential goal of needing to experiment with complex systems to *learn from them*. In the process of AM, management actions are taken not only to manage, but also explicitly to learn about the processes governing the system (Shea *et al*., 1998).

Most policy makers and water managers assume that appropriate learning skills can and will be employed (Baskerville, 1979), and when faced with solving complex problems, the underlying assumption is that humans have learning deficiencies (Dörner, 1996) but not learning disabilities (Dörner, 1986). Although "learning how to learn" is a crucial component of water resources management, the majority of water managers and their institutions have largely ignored this in practice. When we consider learning in the context of sustainability, it becomes crucial to "take into account a wide range of learned behaviors and cognitions (some with and some without clear reference points for "truth") that have major impacts on sustainability" (Henry, 2009). Learning is, regardless of underlying theories and assumptions, essentially about change - more specifically "the act or process by which behavioral change, knowledge, skills and attitudes are acquired" (Knowles *et al*., 2005) – leading to changes on an individual level in the social, cognitive or emotional competencies of actors, with possible wider implications for management practices or institutional change (Muro and Jeffrey, 2008).

Learning for sustainability, as proffered in this paper is not for its own sake but to induce transformational change (Elgin and Bushnell, 1977) regarding the way we think and act (Heifetz, 1995) when faced with increasingly complex and uncertain social-ecological systems (Holland, 1998). According to change management literature, change can be categorized in several ways (e.g. Watzlawick, 1978; Hinings and Greenwood, 1988; Ackerman, 1997). AM really is about change of a transformational order, which requires a shift in underlying assumptions made by organizations and their members. This kind of change is radical in nature. In practice however, AM is often implemented in an incremental way: through a step-by-step movement towards a system ideal (Medema *et al*., 2008). In short, the problem solving techniques and approaches being used by water managers, engineers, and policy makers have not been proportional to the challenges being faced. Conventional responses continue to be linear although the issues they are seeking to address are in fact multidimensional. It will be crucial to develop a much greater understanding of how to develop the ability of 'learning how to learn' to appropriately respond to uncertainty and change.

Therefore, the goal of water resources management should be to increase the adaptive capacity to learn from, and better cope with, uncertain developments.

1.2 Challenges to learning

There are many names for learning that involve relationships with others. Many of these offerings are conventions or derivatives of primary research conducted by Kluckhohn (1951), Dunn (1971), Michael (1973), Argyris and Schön (1974), Röling and Jiggins (2001), and Scharmer (2007). Although a comparative analysis of the various ideas that have been put forth, such as situated learning, collaborative learning, social learning, and institutional and organizational learning would be a worthy endeavor; this paper on adaptive learning builds on Parsons and Clark (1995) who acknowledge that an agent's social network is a critical element of behavioral and cognitive change, but emphasize that agents heavily rely on accumulated individual experiences and direct observation. These authors recognize that models of learning simultaneously account for the role of social networks and experience since human behavior is both individually determined and socially embedded (Granovetter, 1985). It is important to note that models of learning by individuals may be aggregated to higher levels of analysis, but the converse is not necessarily true since studies of societal learning may hide much of the richness of learning by individuals (Henry, 2009). Adaptive learning, therefore, starts from the perspective of individual learning to then diffuse and aggregate that knowledge to higher levels, whereas social learning does not necessarily focus or include much detail about learning on an individual level.

Complex problem solving in water and land-related resources involves multiple and diverse constituencies (National Research Council, 2002) and adaptive learning asks us to take effective action in the domain of existence - the enigma we call the human dilemma. Fitting or appropriate responses are distinctive in that the response fills an "ecological niche" so to speak. An ecological niche in this sense is represented by how an organism shapes, and is shaped, by all requisite relations that influence or threaten it. It is another way of looking at the "curse" of dimensionality. In this context, the challenge of finding fitting and appropriate responses to specific issues is increasingly complicated by the fact that issues are never isolated, and causes are always multiple. The ever-growing stressors at work today (i.e., population growth, increasing demand for freshwater and energy, decreasing food security, threats to biodiversity) are creating negative synergies that are without precedent and inherently unmanageable given existing ideas, tools, infrastructure, and capacity. In other words, the magnitude, scale, and nature of challenges facing today's water managers are different from those of the past, and standards of practice and old ways of learning must evolve in order to meet the irreducible level of uncertainty and complexity within social-ecological systems.

In addition to the challenge to *understanding complexity*, Henry (2009, p. 133-34) points out other recognized and interrelated challenges to learning:

1. *Attenuating normative belief and value conflict*: competing values and normative beliefs frequently play a prominent role in driving debates over environmental policy (Sabatier and Jenkins-Smith, 1993, 1999; Lackey, 2006), indicating a need for decision-making processes to foster learning across competing groups of stakeholders. To ensure more "enlightened" policy choices for sustainability and to avoid the emergence of clear ideological losers, learning processes need to bring actors together for consensus on shared problems to be addressed and the set of acceptable strategies to be employed;
2. *Linking knowledge with action*: often the agents who are directly meeting the challenge of complexity and uncertainty (agents of knowledge) are not the same as the ones responsible for making appropriate policy decisions (agents of action). Empirical evidence suggests, for example, that information must be perceived as salient, timely, and legitimate (Cash *et al*., 2003; Mitchell *et al*., 2006) for it to be effectively transmitted between these communities. Kerkhoff and Lebell (2006) provide a detailed review of the issue of linking knowledge with action;
3. *Producing new values for sustainability*: the values needed to support a sustainable transition within contemporary society need to be learned (Dietz *et al*., 2005; Leiserowitz *et al*., 2006), which

is a process similar to knowledge creation without a clear reference point for the true value. In other words, we need to find and produce values and normative beliefs that are compatible with sustainability.

In light of the above, the overall goal of water resources management should be to increase the adaptive capacity to learn from, and better cope with, uncertain developments and complexity. Fundamental changes are needed in order to help humanity and nature face the threats placed before them (Union of Concerned Scientists, 1992), which is why water resources managers must strike a fundamentally new position with regard to policy formation. To that end, the specific objectives of this paper are to: 1) Redefine what adaptive learning is, 2) explain how this particular type of learning is distinctive and 3) outline the role of adaptive learning in policy formation. Regarding policy design, the paramount issue is determining how to respond to the speed, scale, and complexity of the planetary challenges we face.

2. Redefining Adaptive Learning

2.1 What is adaptive learning?

As Parsons and Clark (1995) began to unpack the literature regarding the nature of learning, much of the speculation and confusion they encountered seemed to be bound up in the "fundamentally messy, contingent, and ambiguous intermingling of knowledge, power, interests, and chance in the workings of the world". In humans, adaptations (learned behavior) take the form of origin, culture, and relationships to self or others; much of what is not being learned resides in our inability to understand the nature of the challenges we face. Therefore, they set about creating a formative guide for the development of postulates unique to learning in support of AM. A brief review of their postulates is presented in Table 1 below:

Initial Questions	**Follow on Questions**
Who (or what) learns? – Adaptive learning is relational both at the individual and social levels. The goals of adaptive learning are to employ ourselves and our cultures as agents of transformational change. *What kinds of things are learned?* – Adaptive behavior should be viewed as a series of learned responses rather than reactions to internal and external threats to survival. Adaptations are based on an intimate understanding of relational reality, as well as to threats and influences embedded in relational reality. To be effective, responses must induce internal and/or external changes. *What counts as learning?* – Learning is not just knowledge from past experience. Under increasing conditions of radical uncertainty and change, the future often diverges from the past and information from past experience begins to lose value. What counts as learning is effective action – action that brings responses into balance with challenges both existing and anticipated. *Why bother asking?* – Transformational change based on effective adaptive behaviors at systematic levels is required, especially as environmental mitigation displaces ecological structure and function. Partial solutions only make matters worse.	*What specific things did they learn?* *How did they learn them?* *Under what conditions and why?* *Did it make a difference?* *How could the effectiveness of learning have been increased?*

Table 1. Postulates unique to learning in support of AM (Parsons and Clark, 1995)

AM is often referred to as a scientific process, which suggests that the practice of creating knowledge for sustainability is an academic endeavor. Management of natural resources, however, has to take into consideration the plurality of knowledge systems. There is a more fundamental reason for the integration of knowledge systems: application of scientific research and local knowledge contributes both to the equity, opportunity, security and empowerment of local communities, as well as to the sustainability of the natural resources (Pandey, 2001). Local knowledge helps, for example, in scenario analysis, data collection, management planning, designing of adaptive strategies to learn and get feedback, and institutional support to put policies into practice (Getz *et al.*, 1999). Science, on the other hand, may provide new technologies (or help in improving the existing ones), tools for networking, storing, visualizing, and analyzing information, as well as projecting long-term trends so that efficient solutions to complex problems can be obtained (Pandey, 2002).

Making new knowledge available and useful to society in facing uncertainty, therefore, is a question of wider social processes that must include non-academic groups at all levels. In other words, inclusive language is important and instead of using the term "scientific", we propose to simply use the term "inquiry". Additionally, AM is not just about planning, but about designing; when one is not sure how to frame a problem or issue correctly, one is really in a design mode going through different frames and reframing of those issues. For this reason, we propose to define adaptive learning as "an ongoing process of inquiry that incorporates new knowledge with the aim of continually improving management policies".

2.2 Deep craft

Adaptive learning is foremost an exercise in self-mastery, reflection, and commitment - described here as "deep craft". This section aims at explaining how this particular type of learning is distinctive and purports that in order to successfully incorporate "learning by doing" (which is essential for strategy and leadership in water resources management) greater attention must be paid to the deep sources from which behavior and profound change originate. The capacity for deep social change comes from the capacity to pay much closer attention to the phenomena we live through – in other words, our experiences. Michael (1973) dubbed this as a "directed self-transformation" through which we take responsibility for self and others for today and tomorrow in pursuit of higher-order societal goals. Deep craft is as much an art form as a science (Gell-Mann, 2001) and does not employ reductionism. In other words, deep intuition and expertise must be involved in the area in which one is working. Explanations must pass through stringent filters and rely only on those assumptions, conditions, or parameters, which are absolutely necessary and appropriate. This is also referred to as the law of parsimony.

One person who successfully mastered and implemented "learning by doing" was Rod Sando of the Minnesota Department of Natural Resources (DNR).[1] A fire ecologist by training, Rod served as commissioner of the DNR for eight years during Governor Arnie Carlson's administration in the 1990s. When Sando took office, he supported the transformation of the DNR by identifying the key change masters in the organization and set about empowering them. Sando offered these masters the opportunity to implement radical changes in each of their respective domains, whether it was implementing sustainable forestry, restoring the Upper Mississippi River, improving community-tribe relations, or making an historic decision on wolf management. Furthermore, Sando allowed fisheries to adopt the policy of ecosystem management on the grounds that it was less expensive and more effective to enhance native populations of fish in a lake than to keep stocking non-natives. He also instituted watershed coordinator positions in crucial and fractious areas such as Leech Lake. During his eight-year tenure, he never changed the organizational chart because he never saw reorganization as a

[1] It should be noted that all the case study examples in this paper have been provided by Steve Light, the second author of this paper, based on the knowledge and experiences he developed while working in these different watersheds.

solution. Instead of force, he used reason, learning by doing, and persuasion through dialogue – and not only with his managers, but also with constituents and legislators. Rod Sando left MN-DNR a transformed organization.

Allan and Curtis (2005) emphasize a number of social and cultural issues that constrain our ability to learn from our actions. These constraints include short planning cycles, inflexible and inappropriate institutional structures and some cultural preferences for action and competition over reflection and collaboration. Sando recognized that genuine AM requires a new and different form of management that accommodates new ways of learning, new ways of sharing information, and new ways of incorporating learning into planning and design. His example indicates clearly the importance of sound leadership, will and commitment that is required to support the radical departure in thinking and practice (Shindler *et al*., 2002). It also indicates that managers may indeed be able to support and nurture adaptive learning by creating smaller pockets within organizations or projects that support and nurture adaptive learning (Allan and Curtis, 2005).

2.3 Problem-centered and decision-relevant

Hilborn (1992) observed that, "Wisdom comes from not making the same mistakes over and over again." But failure to learn from experience is precisely the persistent and pervasive management pathology highlighted in the cases reviewed by Gunderson, Holling and Light (1995). Managers show evidence of learning deficiencies due to the nature of their decisions (i.e. "ballistic" or "once and done" (Dörner, 1986, 1996); or "defensive routines" (Argyris, 1999; Hilborn, Pikitch, and Francis 1993). Thus, a relevant question to ask is, "Why are existing policies so often based on false assumptions and defensive reactions by management"? Rice *et al*. (2008) point out there is recalcitrance toward learning in the face of uncertainty, which is pervasive even in those organizations whose futures depend on technological innovation. In contrast to this, Rice *et al*. (2008) echo the sentiment of Hilborn and Mangel (1997) in *Ecological Detective* that: "Rather than feign a certainty that doesn't exist, managers need a systematic, disciplined framework for turning uncertainty into useful learning that keeps the project tacking on a successful course".

Part of the answer may also lie in the fact that facing uncertainties inherent in complex problem solving puts the competency and self-esteem of decision makers and managers at risk (Michael, 1973; Dörner, 1986, 1999; Argyris, 1999). Argyris (1999) discusses the dilemma that Total Quality Management (TQM) now faces. TQM has been effective at fine-tuning manufacturing operations, however, this management approach tends to expose flaws, gaps in thinking, or false assumptions upon which existing policies are based. Exposure of weaknesses is often viewed as threats to competence, which in turn triggers defensive routines in management ranks.

Therefore, adaptive learning should be consistently geared toward action and led by decision makers who are able and willing to manage risks despite being surrounded by differing descriptions of "how the world works" (Hilborn and Mangel, 1997). The goal of AM is *to learn to live with and profit from the dynamic nature of human-technology-environment systems*. Under a policy regime intended to be adaptive, policy should have two overall pursuits: (a) to obtain a yield from beneficial and sustainable use of the resource, and (b) to obtain information that informs and enhances the quality and appropriateness of subsequent decisions. Adaptive learning is meant to be decision relevant: assuming there is no single "answer" to complex problems in water resources management. Causes are always multiple (Holling, 1998), and learning is accelerated by testing multiple and competing hypotheses simultaneously (Chamberlain, 1894; Pratt, 1964). The principles of the method of inquiry (hypotheses testing, monitoring, evaluation and response) need to be harnessed as a disciplined way to learn about the consequences of human interventions with nature.

2.4 Learning how to learn

Adaptive learning does not necessarily lead to the “continuous improvement of policies and field practices” (Nyberg and Rozelle, 1999), unless it involves deliberate and conscious reflection and concerted and appropriate action. Quite often, new decisions are based on what was learned from previous actions, but complex problems are moving targets, which leave us few guarantees when trying to manage unpredictable socio-ecological systems. Therefore, adaptive learning requires reflection, and a willingness to repeatedly put aside past methods and techniques (i.e. those in need of repair or replacement) in order to teach ourselves new ones (Pratt, 1964; Baskerville, 1979). When faced with the radical uncertainty (Prigogine, 2004; Homer-Dixon, 2006; Kaufmann, 2008) that is inherent within complex adaptive systems (Holland, 1998), decision makers and policy analysts are in the midst of uncharted waters.

For this reason, it is not only imperative to monitor the trajectory of complex systems, but to monitor the way in which we process information in order to avoid the “vicious circle of incompetence” or “methodism” involving the strategies for hypothesis formation, monitoring, options analysis, field testing and policy design (Mintzberg, 1978; Dörner, 1996). Hence, there is *a ‘meta’* difficulty; namely thinking about when and how to do what. In short, the challenge is how to organize for the allocation of one’s cognitive resources for developing and enacting new ideas, tools and capacity/infrastructure. There are certain executive routines within organizations that serve as catalysts for innovation, or what may also be referred to as the capacity of “learning how to learn.” These routines provide steersmanship for policy and help identify what changes should be made and how those changes would be best implemented in order to make the organization more future-responsive and competent. Figure 1 illustrates the concept of steering capacity for institutional learning and innovation. Steersmanship helps make course corrections by consolidating the feedback from existing competencies with the anticipations of future organizational needs.

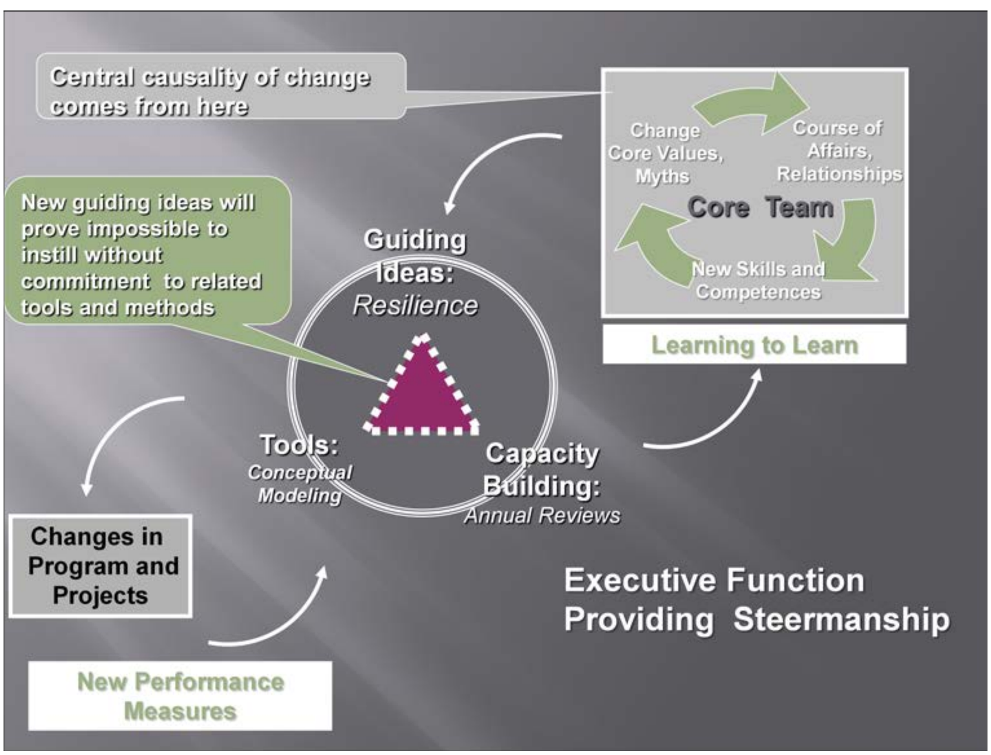

Fig. 1. Steering capacity for institutional learning and innovation

2.5 Transformation of social reality within the domain of existence

Views and perceptions regarding the legitimacy and urgency of certain problems, as well as the credibility of selected and implemented solutions, are determined to a great extent by the social reality of scientific and social communities in those contexts. Social reality is defined by the constellations of attainments – concepts, value orientations, norms, techniques, and practices embedded within a given culture. Kenneth Boulding, one of the architects of systems thinking, captured the dilemma that faces social reality today: "Growth creates form, but form limits growth" (Boulding, 1953).

The world is presently in an extraordinarily difficult period of adjustment, and making long-term projections about the future is beyond social control (Holling 1982; Ravetz, 1986; Homer-Dixon, 2002). The complexity of this adjustment renders the possibilities of the future to be radically uncertain. The learning tasks are enormous and intimidating, as learning must confront threatening and confusing situations (Prigogine and Stengers, 1984; Michael, 1973, 1995; Capra, 1998; Kauffmann, 2008). However, as Schon (1973) states: "We must…become adept at learning. We must become able not only to transform our institutions, in response to changing situations and requirements; we must invent and develop institutions which are 'learning systems', that is to say capable of bringing about their own continuing transformation".

The creation of "contexts for learning" or "learning systems" requires a genuine commitment to bring together people and groups who have very different worldviews and knowledge systems (Evely *et al*., 2008*)*. The power dynamics implicit in bringing these different knowledge holders together influence the subsequent learning outcomes (Wildemeersch 2007). A much deeper understanding of the context, power dynamics, and values that influence the ability of people and organizations to manage natural resources effectively is necessary (Keen et al. 2005).

2.6 Role of Learning in the Adaptive Process

As highlighted, in the process of AM, management actions are taken not only to manage, but also explicitly to learn about the processes governing the system (Shea *et al.* 1998). Various models of the AM process have been proposed, ranging from simple to fairly elaborate (e.g. Johnson, 1999; Parma *et al*., 1998; Walters, 1997; and Healey *et al*., 2004). Bormann *et al.* (1999), for example, describe AM as a process that involves "learning to manage by managing to learn" including: (i) development of management experiments; (ii) gathering information for and increasing understanding of uncertainties; and (iii) development of continuous monitoring procedures and space for adjustments. Many early scholars on AM already emphasized the importance of stakeholder involvement throughout the process for improving the quality and perception of decisions made at each step (e.g. Dovers and Mobbs, 1997; Shindler and Cheek, 1999).

AM is not just a 'fancy' name for muddling along or creating institutions that respond to every social or political whim, it is about learning from implementation. Although AM has often been perceived as a science based and inductive approach to learning, there is increasing recognition for the social and civic dimensions that are important elements of AM also (Allan, 2007). AM is based on 'an inductive approach of deriving insights from new information' where 'dynamic hypotheses guide reasoning and structured argumentation' (Pahl-Wostl, 2007). At the same time, combining adaptive and collaborative approaches to managing and solving interdependent water resources problems meets the challenges that external influences and stressors require. It is based on the proposition that responsive, durable and authentic solutions require mending and weaving of strategic relationships (economic, ecological and social) in ways that can be mutually beneficial and reinforcing.

Generally there are several phases recognized as part of a cyclical Adaptive Process – policy design and implementation, monitoring and evaluation, as well as learning, and all these phases revolve around a set of hypotheses upon which policy and management is based. These phases are not separate from one another, nor are they pursued only in a step-wise sequence. Although there is a specific logic applied to each phase, it is crucial that learning becomes an integral part of the entire AM cycle as it is meant to challenge our understanding based on feedback from policy implementation and serve as the basis of system monitoring and analysis. Evaluation is central to the AM cycle requiring adequate planning and resources (Allan *et al*., 2007) and moving beyond summative assessment (i.e. determining if project goals and milestones have been achieved in time) to formative assessment (i.e. understanding such things as client needs, the implications and side effects of implementation and program logic) (Cook and Shadish, 1986). It should be noted, that genuine AM is only possible if targets and goals are conceived of as approximations, otherwise there is no capacity to learn and modify practice.

Allan and Curtis (2005) emphasize that genuine AM processes embrace the 'messiness' of social activities by including people from a variety of backgrounds and discipline groups, and with different ways of approaching and understanding the world. This approach encourages collective responsibility for understanding and managing natural resources (Roling and Jiggins, 2001). There are, of course, increased 'transaction' costs with multi-disciplinary and collaborative approaches, and again this needs to be recognised when planning adaptive management projects by allowing sufficient time, funds and other resources (Allan and Curtis, 2005).

3. Proposed Best Practices for Adaptive Learning

The individual and collective changes facing water managers and scientists differ so greatly in terms of nature, magnitude, and scale that past practices will likely be of little assistance (Lubchenko, 1998). As subsequent paragraphs will set forth, we must learn to think and act in new ways to meet the "eco-challenges" of the 21st century (Röling and Jiggins, 2000; Allan and Curtis, 2005).

3.1 Deep craft

Deep Craft is 'not taught, it is caught', which is why sound leadership (as indicated in Section 2.2) plays such a crucial role in facilitating this aspect of learning; deep craft is a profoundly personal journey without many guideposts. In graduate school, future science practitioners are taught a set of tools that form the basis of practice. And as professionals we are often asked to fill a disciplinary niche that employs the "tools of our trade." Performance evaluations are typically based upon the level of skill demonstrated within one's specific discipline, but this only encourages one to continue getting better at "what has always been done" and respond to non-categorical goals with "that's not my job" (Senge et al., 2004). According to Clausewitz (1832), this form of "methodism" is a recipe for disaster in war, or in any other complex solving scenario (Beyerchen, 1997). The standard of deep craft demands that we break out of this mold of thinking.

Learning about ourselves and our relationship with others requires a willingness to put aside the "my-side-only bias" of our ideals and ideologies. Humans have a preoccupation with "boundaries" that block our openness and appreciation of not knowing if we are "right" (Rosch, 2002). We have well-developed defense strategies (Dörner, 1986; Argyris, 2002) that stand guard against any reframing of our perspectives and reference points (Schön and Rein, 1994), and it is these strategies that allow us to accept ignorance, error, and lack of competence in the face of radical uncertainty (Arthur and Caltyedt, 2000). However, the way in which complex problems are framed, and the process by which solutions are derived, are both irreducible factors by which the standard for quality decisions are judged (Ludwig, Mangel and Haddad, 2001; Drucker, 2001). Individually and collectively, there is no alternative to learning how to assume responsibility for the whole because: no one authority or set of authorities can take control; no easy answers exist (and partial solutions only make matters worse in the long run); no expertise can give us "the answer"; no established procedures can show us the way (Heifetz, 1995).

3.2 Problem-centered and decision-relevant

As practitioners, being problem-centered and decision-relevant draws our attention to the need for an increased capacity to incorporate adaptive learning into our decision making; it is an integral part of the systemic redesign of policy processes (Ludwig, Mangel and Haddad, 2001) at multiple levels of social-political reality (see also the concept of panarchy (Jantsch, 1970; Gunderson, Holling and Light 1995). Advocates of adaptive management (Holling, 1978; Holling, 1980; Walters, 1986; Hilborn, 1987; Hilborn, 1992; Parsons and Clark, 1995; Michael, 1995; Röling and Jiggins, 2001; Light, 2001; Pahl-Wostl, 2007) have viewed learning as an integral part of resource assessment and management. In addition, valuable research by Niels Röling and associates has greatly expanded our understanding of these core concepts related to adaptive learning (e.g. Röling and Wagemakers, 1998; Röling and Jiggins, 2000; Leeuwis, and Pyburn, 2002).

During the first half of the new decade, Röling and his colleagues have, in our estimation, made a significant breakthrough in extending the Santiago Theory of Cognition as it applies to learning for adaptive management. Fundamentally, the Santiago Theory contends that knowledge alone is not sufficient for learning; it is only through effective action that instances of learning move to completion. Röling's work (and that of his students) has gone even further to explore key functions of effective action in addition to the "ingredients" of emotion, knowledge, action and feedback. These key functions are internal coherence internal to the organism, correspondence with external influences, and an ethos designed to meet the eco-challenges of the 21st century.

Taking the "high ground" on crucially important problems will require rummaging through the rubble of ruined methods of inquiry, trial and error, and intuition in order to discern new ways of working together (Schön, 1983). When the toughest part of problem solving is figuring out how to frame and define the puzzle, planning falters and a design approach becomes essential. Design begins with the end in mind; both the final conditions (endgame) and the initial conditions must be considered simultaneously. This is the new standard of problem solving. Our long tradition of 'linear' engineering planning must end if the new standard is to be achieved. Mintzberg (1978) stumbled on this phenomenon (Fig. 2) when his graduate students analyzed three-dozen cases in complex decision-making. The more complex the problem, the more solutions tended to go through multiple cycles of design. In other words, comprehension of complex problems and the design of solutions happen simultaneously through successive iterations of hypothesis testing. This illustrates the ways in which planning and design frameworks can diverge. "Planning" tends to follow a set of steps that starts with a problem and ends with a preferred alternative, whereas "design" treats problem and solution formation simultaneously through iterations of hypothetical designs and comprehension.

Application of key aspects of the scientific method, such as the testing of multiple hypotheses (Chamberlain, 1864 Pratt, 1974; Hilborn and Walters, 1992), provides us with ways to design decision processes in water resources management that are more robust. For example, because the Kissimmee River Restoration Program (KRRP) involved multiple pilot projects to test hypotheses (regarding how the system would respond to different kinds of intervention), the design team has honed in on a promising approach that may help restore the Kissimmee River in the long term. Box 1 provides a sketch of the techniques used in the restoration process. To the best of our knowledge, no river restoration at this scale had ever been attempted nor achieved such success. There are a number of additional references available for those readers looking for a more in-depth analysis (Toth et al., 1993; Shen et al. 1994; Cummins and Dahm, 1995; Shen, 1996; Toth et al., 1998). Perhaps the most instructive of the KRRP reports is that of Loftin et al. (1990), as Loftin was the project manager who shepherded the unique combination of hydrology, ecology and engineering in the Kissimmee River mentioned above.

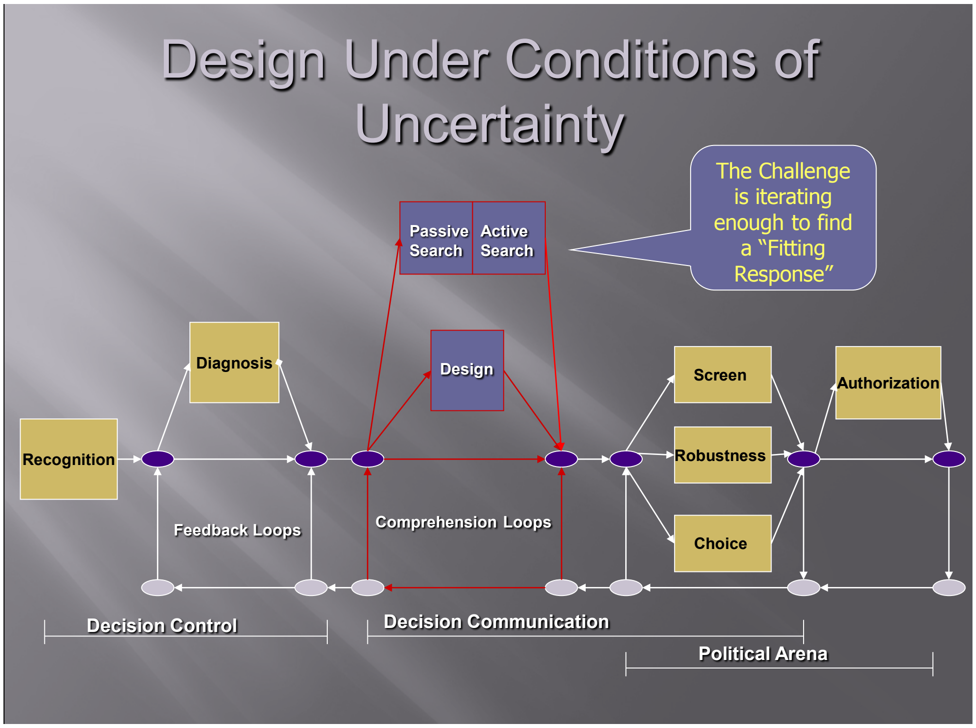

Fig. 2. The conceptual design of unstructured decision-making based on an empirical study of numerous cases

New policy design approaches are necessary to combat reductionism. These approaches must demand more than one description of how the world works. Multiple views must be considered and confronted with data in the process of taking action (Hilborn and Mangel, 1997). In water resources management, the framing of management problems in this way provides greater leverage over complex problems that would not be present otherwise. Also, this approach is one of our best antidotes for influences of bias, political agendas, and power that are so often unavoidable. In Northwest Colorado, the structure and allocation priorities for the Bureau of Land Management (BLM) Range Management Plan (RMP) (2006-2007) were highly contested, pitting the wilderness advocates, grazers, developers, and recreational users against each other as well as against those from the oil and gas industry. A collaboration of stakeholders was formed to facilitate development of a community-based alternative plan. Although political forces derailed the community-based alternative, the methods learned from the collaboration were instrumental in helping BLM develop recommendations for integrating collaborative adaptive management into RMP guidelines.

The scientific method helps us avoid the trap of relying on a "best guess" or subscribing to the belief that "that is the way we have always done it." Thinking explicitly about multiple ways (array of qualitatively diverse scenarios) in which the world works (hypotheses) not only broadens the perspectives of managers, scientists, policy makers and citizens, but also signals the powerful presence of uncertainty in decision making.

At Governor Bob Graham's behest, as a cornerstone of his "Save Our Everglades" program, a demonstration project was conducted from 1984 to 1989 in the Kissimmee River flood control channel. The objective was to test more thoroughly the feasibility of river regime restoration. Impoundments with gated culverts were constructed on adjacent grazing lands.

Three sheet-pile weirs with navigation notches were driven into the main channel to back water into remnant oxbows. The plant, fish and avian responses were encouraging; hence a new impoundment was constructed to help assess capacity to reset historic floodplain dynamics. Models were developed to help establish pre-drainage floodplain-main channel relationships.

The numerical modeling, demonstration projects and field studies were augmented by the construction of a physical model of the Kissimmee River at UC Berkeley. There, rating curves that tested alternative regimes – timing, frequency, volume, duration – could be refined. The physical model tested three principal restoration schemes – plugs, partial back-fill and complete backfill.

Box 1 Kissimmee River Restoration Program

3.3 Learning how to learn (Reflection)

As the 2000 Water Resources Development Act (WRDA) bill that authorized the Comprehensive Everglades Restoration Program (CERP) was being shepherded through committee, staff came to understand the adaptive management provisions in terms of "learning as we go." This attempt at encapsulating AM falls short of "a fundamentally new scientific approach to management" (Walters, 1986), and fails to consider that there needs to be a "guidance system" in place to help channel learning in the most effective directions.

To overcome such situations, Schön (1973) argued for increased development of informal institutional structures, ways of knowing, and ethics for the process of societal change itself. He referred to these flywheels of innovation as "shadow networks" that would exist on the periphery of formal institutional structure, responsible for preparing organizations for transformational change in ideas, tools and capacity, especially in response to crisis. The absence of "shadow networks" of leading scientists perpetuates the pathologies of the past (Gunderson, Holling and Light, 1995).

When faced with the challenge of dismantling structures internal to the Water Conservation Areas south of Lake Okeechobee, the scientists involved in CERP ignored the lessons learned from the Kissimmee River Restoration Program regarding restoring natural flow. The typical view was that the issues were fundamentally different; yet a major issue in the 'Decompartmentalization of the Water

Conservation Areas' was what to do with existing canals – partial backfill, complete backfill, or plugs. These are the same issues the Kissimmee River Restoration Program faced, for which a physical model was developed at the University of California, Berkeley to help answer this question. Without such a rudder for institutional learning, it is little wonder that we continue to see scientists, managers, and practitioners "reinventing the wheel" over and over again.

Institutions are governed by rules, and the most effective rules are those that adapt to changing conditions in order to enhance responsiveness. There are three crucial subject areas (levers for change) in which a meta-learning mechanism is needed in order to integrate adaptive learning into resource management and assessment processes. These three subject areas are: (1) ideas in currency and guiding principles; (2) tools and methods; and (3) capacity and infrastructure. In the 1990's, the MDNR demonstrated how to use these levers for change by redefining work behaviors instead of resorting to reorganization. More specifically, MDNR and Sando implemented the following:

- *For ideas and guiding principles*: Ecosystem management became a guiding principle and specific experiments were undertaken (re: watershed management, and elimination of fish stocking of preferred species in favor of indigenous ones);
- *For tools and methods*: Sustainable harvest practices were instituted to reverse the simplification of the northern conifer and hardwood forest into aspen and birch for pulp and paper, and cutting regimes for forest stands were improved;
- *For capacity building and infrastructure*: Instead of forcing fish and wildlife scientists into "public relations," the result of listening sessions led to the recruitment of professionals from all agency divisions to assume a more public face and work as agents of change.

3.4 Transformation of social reality in the domain of existence

Social reality is a configuration of ideas, value-orientations, and technologies that are based on how scientific and social communities define legitimate problems and credible solutions. "What works" (for whom, when, and how) is defined through the formation of social reality (Kaufmann, 2008). However, the current framing of "what works" has critically misjudged the state of affairs in the domain of our existence (i.e. watershed problems, species extinction, over population, climate change). It is during times of increased complexity, uncertainty, and rapid change that society needs to discover new modes and bold strokes that bring fresh simplicity to how society is configured (Arthur, 1994). This should be the standard for taking effective action in the domain of our existence. In order to engage in effective action in the domain of our existence, we must resist treating nature as an enemy, victim, or chattel and instead view nature as an ally, partner, and "pilot." Effective action requires reframing the way we think, act, and feel in order for social-ecological systems to survive long-term.

One such socio-ecological system is water. In every major culture water is a sign of the sacred, and it may be the most powerful symbol around which to organize social transformation. What better medium to challenge the power of dominion with the power of relationship - to learn how to live together with nature as ally? Water governance needs to be reframed as a series of reflective organizations capable of self-transformation that radically re-think and redesign policy as they co-evolve with social and natural systems (Carpenter and Folke, 2006). The adaptive moves of one actor, process, or function will inevitably influence and change other co-evolutionary partners, processes and functions (Kauffman, 1995; Gunderson, Holling and Light, 1995). Therefore, our responsibility is to find ways to expand the bounds of rationality in order to embrace a broader range of external and internal influences acting upon our decision environments. This responsibility must take precedence in forging a new-shared worldwide framework of values. We must re-examine our full humanity and how we can manage to persevere in the face of uncertainty. This requires the bridging of what Snow termed the "Two Cultures" – science and humanities (Snow, 1960). This means bringing the diversity of the affective - intuition, feeling, sensing and thinking - to bear on our reasoning, which is quite bowed toward what we consider objective, dispassionate 'acts'. To quote Vaclav Havel: "We must try harder to understand than explain" (Havel, 1991).

In our efforts to *understand* more and *explain* less we must learn to become more future responsive. Adaptive policy design necessitates the unremitting revisiting of what science and society consider legitimate problems and credible solutions. Adaptive learning is "learning by doing," but society will struggle to mobilize responses equal to the challenges faced until people learn to live as much in the imagination and conceptualization of the future as in the reminiscence of the past. To illustrate this, the Florida Everglades provide a good example: prior to major drainage activities in South Florida that began in the late 1800s, the Everglades consisted of approximately 4 million acres of subtropical wetlands and slow sheet-flow covering most of South Florida. In the early and mid-1900s, construction changes in the Kissimmee basin removed significant regional storage of around 3 million acre-feet upstream of Lake Okeechobee (North of the Everglades). South of the lake, construction of the east coast protective levee system in the Everglades reduced the overall natural area by one-half and constrained water flow south from the lake. This has left water managers today with an immense challenge of moving large volumes of water within a much smaller, managed system.

An attempt was made to develop a Natural System Model (NSM) to try to simulate the hydrologic response of a pre-drained Everglades, although this does not allow simulating the pre-drained hydrology since there is simply no data available to perform such a simulation. In other words, this model has been developed but does in this case not provide a suitable tool to dealing with the complexities and challenges inherent to the management of water resources in the Florida Everglades. The water deliveries in the Florida Everglades have been altered to the point that using a NSM (although useful in projecting water requirements for the future) is no longer appropriate: it is not only idealistic to aim for such a model, but also unrealistic. As long as there is no flow regime coupled with ecological restoration responses, the Everglades natural system will remain on "life support".

4. Pitfalls, limits and friction

A "to do" list for adaptive learning would have been convenient, unthreatening, and easy to ignore. For example, Hilborn (1992) provides such a list in the form of simple steps that can be taken to maintain institutional memory: short experience reports; old-timer's seminars; agency historians; annual historical reviews; memoirs of retiring staff; and new staff training.

Reviewing the ways in which feedback is given to various audiences (Harwell, et al., 1999; National Research Council, 2002) is instructive, however, these reviews often fall short of the breadth, and sweep required for adaptive learning. Witness the friction and denial involving action by the global community on climate change. While global responses to earthquakes and tsunamis have improved dramatically in the past dozen years, our capacity to move beyond "fire fighting" to self regulation (Walters and Maguire, 1996) and precaution (Hilborn et al., 2001) is embryonic at best. Because of institutional and political power struggles, as well as an overall unwillingness to employ science to address radical uncertainties that defy stochasticism, efforts at ecological recovery and restoration are faltering or halting (as exemplified by personal observations in the Everglades Restoration, Missouri River Recovery, and Coastal Louisiana). In the Everglades, "getting the water right" has meant (to date) increasing water supply capacity efforts, and not solving the riddle of the Everglades flow regime. In the Missouri Basin, single species habitat construction is halting efforts at testing hypotheses regarding nature's capacity to build better "bird hotels." Along Louisiana's coast the legacy of funding small individual projects by six federal agencies has perpetuated piecemeal solutions, which actually make matters worse. Science-initiated tests, such as diversions into Myrtle Grove basin from the main channel, are few in number and remain the exception to the rule.

Creating a new social reality (cultural transformation) that would reverse our refusal to learn as a species (Niebuhr, 1932) is necessary. Many institutions become self-serving and their main goal is to perpetuate themselves and to discourage the formation of new entities that might be considered "threats" to their dominance. A new social reality may be starting to emerge in the Netherlands with its completely new approach to water management: the country is essentially reversing (180 degrees) its 500-year-old tradition of controlling water and allowing the guiding principle to "let the rivers roam".

5. Conclusion

The magnitude, scale, and nature of the challenges facing today's water managers are different from those of the past. Thus, standards of practice and ways of learning must change in order to meet these new realities. Present-day actions and conventional planning processes do not adequately address the irreducible level of uncertainty and complexity within social-ecological systems; in short, the problem solving techniques and approaches being used by managers, engineers, and policy makers are not appropriate to the challenges being faced. Conventional responses continue to be linear although the problems they are seeking to address are in fact multidimensional. Learning how to learn helps bridge this gap.

Although learning how to learn is a crucial component of water resources management, the majority of water managers and their institutions have largely ignored it. This conclusion is based on an apparent ignorance or denial of what it will take to adequately respond to the problems bourgeoning just beyond the myopic "project scope." On the surface, this tendency speaks to the complexity and uncertainty inherent in water resources management, but upon further introspection, it perhaps reveals a professional and intellectual disregard for "learning by doing". Empirical and theoretical research show that most water managers tend to base their actions and decisions on convenient assumption rather than well-reasoned facts, but learning how to learn as a way of evolving can reverse this trend and facilitate more efficient and responsive management of water resources.

Therefore, we have argued in this paper that learning must become a more integral component in the adaptive process of assessment, design, and management of water resources, and a greater topic of discussion if water managers are to address the many evolving challenges in water resources management. Adaptive learning recognizes that complex problems are moving targets and that there is often not 'one' way to solve them. For this reason, adaptive learning must be rooted in action and simultaneous hypothesis testing. It requires that water practitioners be willing to put aside past methods, if necessary, in order to embrace and learn new ones.

In order for adaptive learning to live with and profit from nature's dynamism, we have argued that it must be deeply personal, problem-centered, decision relevant, reflective, and inherently transformative. When learning is a fully integrated component of AM, water resource institutions have a greater likelihood of maturing into what Schön (1973) described as "learning systems". As part of this, it is necessary to create a new social reality in which institutions are neither self-serving nor hostile to new entities, but rather encouraging and receptive to new approaches to water resources management. A greater understanding of how and why agents learn, including a detailed map of the parameters that influence this process, is a prerequisite for thinking about the types of institutions that are needed to promote learning (Henry, 2009).

In our current social reality, learning is not easily extracted from the web of power, interests, and knowledge in which it exists in most contexts. In that regard, learning is as much an attitude as it is a science and an art. Uncertain environments and unpredictable challenges need not be feeding grounds for obstacles, risks, and discourse, but rather sources of innovation and platforms upon which to construct systematic and disciplined frameworks for learning. Water managers, practitioners, and scientists who put aside past methods that no longer work (and teach themselves new ones) will be better equipped to combat the wide array of challenges they face in managing increasingly complex water resources systems. Remaining committed to learning will be imperative in order to withstand the relentless risks and unpredictability that challenge professionals in the field of water resources management. How to organize the skills and commitments of a diverse human community to strive for sustainability is a challenge we are only starting to address. The unifying idea of sustainability is the dream of humans living in harmony with nature: while striving for sustainability, humans are seeking to govern themselves so as to preserve the web of life upon which all depend. To paraphrase Walters (1997), the need now is not so much better ammunition for rational debate but creative thinking about how to make AM (including adaptive learning) an irresistible opportunity, rather than a threat to various established interests.

Acknowledgements
This research was partially funded by the Cyprus Institute in Nicosia, Cyprus, and a Social Sciences and Humanities Research Council of Canada (SSHRC) grant held by Jan Adamowski.

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