Reports from the Field

Assessing the art and science of participatory environmental modeling

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Abstract: Since the early work of Tansley (1935) and others we have embraced the concept that an ecosystem is a synergy of its parts and the relationship between those parts. Many science-centric approaches have been developed to address ecosystem management while at the same time taking into account the needs of the public. Participatory environmental modeling that uses system dynamics is an effective process for facilitating the integration of ecosystem science and social concerns. Using the art of facilitation and the science of model building the methodology creates a common language that integrates various types of information into simulation models. This paper describes a diversity of case studies, modeling and facilitation technique, and the inventiveness of practitioners who adjust their efforts to the needs of the stakeholders and the environmental problems they are facing. Participatory modelers who use system dynamics create customized platforms through which stakeholders can simultaneously explore their system, stressors to that system, potential tipping points, whether it is fragile or resilient, and any variety of potential policies that address the environment, social concerns, and long-term sustainability.

Introduction

As the natural world has become dominated by human influences, environmental problems have become increasingly complex. In the United States, laws such as the National Environmental Policy Act (NEPA), the Clean Air Act (CAA), The Clean Water Act (CWA) and the Endangered Species Act (ESA) endeavor to protect the environment while at the same time consider the economic and social needs of the nation's human population. Yet the diversity of local situations often leaves both agency personnel and the public frustrated with laws and regulations that do not effectively address long term sustainability or the specificities of locale. In addition, since the early work of Tansley (1935) and others we have embraced the concept that an ecosystem is a synergy of its parts and the relationship between those parts. In an effort to embrace the ecosystem concept and improve or sustain environmental and social quality a number of problem-solving processes have been developed and implemented with varying degrees of success. These include the NEPA assessment process, adaptive management, shared vision planning and state and local planning processes. One critical element that has emerged from these science-centric approaches is that public involvement in the problem-solving process is essential. This invites a variety of information, knowledge, opinions and worldviews into the decision-making process. Creating a nexus of science and local knowledge through which problems and solutions may be discussed is essential for finding consensus-based solutions to environmental problems.

Participatory environmental modeling that uses system dynamics (SD) is an effective process for facilitating the integration of natural resource science and social concerns. Using the art of facilitation and the science of model building the methodology creates a common language that integrates various types of information into simulation models. These models assist stakeholders with problem definition and the evaluation of potential management or policy alternatives. The process of building a model helps stakeholders clarify their own mental models and gain a better understanding of important scientific relationships. The process of evaluating simulation results allows participants to explore "what if" scenarios that depict potential futures. The combination of problem definition, mental model clarification and futures exploration helps participants better understand the scope of a system, potential tipping points and how the system behaves over time.

This paper recognizes that processes designed for community-based interventions will vary according to the idiosyncrasies of the problem being modeled. The availability of quantitative data, types of participation, the timing and length of the intervention, and other variables create challenges for both process design and the comparison of processes. The goal of the analysis that follows is to learn about the variety of techniques and a broad range of interventions through an examination of case studies. The diversity of these case studies, and the inventiveness of the practitioners to adjust their efforts to the needs of the stakeholders and the environmental problems they are facing illustrates the flexibility of participatory modeling. Participatory modelers who use system dynamics create customized platforms through which stakeholders can simultaneously explore their system, stressors to that system, potential tipping points, whether it is fragile or resilient, and any variety of potential policies that address the environment, social concerns, and long-term sustainability.

System dynamics and participatory environmental modeling

When faced with complex, multi-stakeholder environmental issues, system dynamics has the greatest potential when used in a participatory fashion by scientists and managers working together with others who also have a stake in land management decisions. System dynamics modeling software (e.g. VENSIM, STELLA or POWERSIM) provides modelers and process participants transparent, user friendly, icon based simulation programs. Videira et al. (2006, p. 9) describe the unique features that make system dynamics methodology and software "specially suited for participatory exercise". These include: structured deliberation, shared language, openness and collaborative policy design, flexibility and team learning, and knowledge integration. Furthermore, dynamic patterns such as growth, decay and oscillations are the fundamentals of system behavior thus the methodology is useful for exploring system resilience, tipping points, sustainability and for understanding the issues that create limits to growth (Meadows et al. 1972, Ford 1999).

Participatory modeling for environmental problems is a process that has developed out of a combined need for public participation, systems thinking and simulation modeling. It is covered under a number of monikers:

- participatory modeling (Videira 2003, Langsdale 2006)
- Mediated Modeling (van den Belt et al. 1998)
- cooperative modeling (Cockerill et al. 2006)
- Computer Assisted Dispute Resolution or CADRe (USACE 2007)

Modelers in the case studies outlined in this paper have drawn on simulation and group modeling techniques including but not limited to: Forrester (1961,1969); Meadows et al. (1972); Richardson and Pugh (1981); Roberts et al. (1983) Vennix (1994); Ford (1999); and Sterman (2000, 2002). Important cited works include but were not limited to: Morecroft and Sterman (1994); Richardson and Anderson (1995); Vennix (1996, 1999); Anderson and Richardson (1997); Hines (2001); Rouwette et al. (2002); Stave (2002); Rouwette (2003) and van den Belt (2004).

Methodology for comparison of case studies

The number of stocks contained in a model was selected as a proxy for problem complexity and was compared to the need of the process, the time spent, and number of groups involved. This led to questions that inspired an assessment of the following characteristics: 1) Stakeholder involvement in the model building process varies on the "hands on" continuum. 2) Interventions may take place anywhere on the "problem definition to solution producing" continuum. 3) The type of data required varies on the "qualitative to quantitative" continuum. Model and process characteristics often drive one another, creating a need for concurrent evaluation of these characteristics. This paper describes the case studies, participatory model building methodology and the purpose of the models. The impact of the model purpose on the process in general brings to light two patterns of iterative model building. These patterns are also impacted by problem complexity, the need for and availability of data, and the individual techniques of the modelers.

Case Studies

Nine case studies have been chosen to compare models and group processes to better understand both their homogeneity and diversity. Three of the case studies are specifically concerned with wildlife management, six with water issues. The dominance of water models is indicative of natural resource conflicts. Water resources have long been a source of conflict and are forefront in planning efforts that reach beyond local jurisdictions. Modern communities with finite resources are trying to understand the implications of various types of water use on growth. In addition, the iconic nature of water stocks and flows works well with many types of modeling software. There are fewer examples of species management models. The statistical modeling conventions that are used by biologists, and the localized specificity of species management have perhaps created the perception that icon based modeling software is not useful. However, Beall and Zeoli (2008), and Siemer and Otto (Siemer and Otto 2005, Siemer et al. 2007) have used traditional life history model conventions in an SD platform then customized the effects of habitat changes to suit the particular attributes of the species and ecosystem.

Table 1 lists the case studies, the general environmental issue of concern and the purpose of the model. Models for management of sage grouse in central Washington (Beall and Zeoli 2008), and bear management in New York (Siemer and Otto 2005, Siemer et al. 2007) illustrate how human choices affect wildlife, and in turn how the abundance of wildlife may affect humans. The Gloucester fishery model addressed options to a fishing community that has been greatly affected by the decline of ground-fish stocks. The community was looking for a sustainable substitute such as establishing a surimi factory for pelagic fish (Otto and Struben 2004). Watershed management models of the Okanagan basin in British Columbia (Langsdale et al. 2006, Langsdale et al. 2007, Langsdale 2007) and the Rio Grande basin in New Mexico (Tidwell et al. 2004) illustrate the use of SD models for long-term water supply management. The Upper Fox River Basin (van den Belt 2004) project modeled a watershed with respect to agricultural and urban land use, water quality, natural capital and economics. The model for river basin management in the Baixo Guadiana in Portugal (Videira et al. 2006) includes planning for water quality and quantity, agricultural development, nature conservation and tourism. The Ria Formosa Natural Park, also in Portugal (van den Belt 2000, Videira et al. 2003, van den Belt 2004, Videira 2005), modeled land use and estuary management with an emphasis on the development of tourism. The Ria Formosa 2000 and 2003 projects illustrate a modeling process that has progressed over time from an initial scoping model to a management tool.

Case study	Issue	Purpose of model
Sage grouse in Washington (Beall and Zeoli 2008)	Endangered species	Management tool to assess policy alternatives
Problem Bears in New York (Siemer and Otto 2005, Siemer et al. 2007)	Human-bear interactions	Group learning tool that developed into an educational support tool
Gloucester Fishery (Otto and Struben 2004)	Sustainable fishery	Group learning; futures exploration
Middle Rio Grande (Tidwell et al. 2004)	Current water supply management	Management tool
Okanagan Basin (Langsdale et al. 2006, 2007, Langsdale 2007)	Future water supply management	Group learning; futures exploration
Upper Fox River (van den Belt 2004)	Watershed management	Scoping big picture
Baixo Guadiana River Basin (Videira et al. 2006)	Watershed management	Group learning; problem scoping
Ria Formosa 2000 (van den Belt 2000, 2004)	Estuary management	Scoping big picture
Ria Formosa Natural Park 2003 (Videira et al. 2003, Videira 2005)	Estuary management	Management tool

Table 1. Nine case studies and the general environmental issue of concern and model purpose.

Participatory modeling techniques

Practitioners use a variety of techniques to engage stakeholders. The choice of technique is determined in part by training or personal preference of the modeler, in part by timing, and in part by the needs of the stakeholder group. In addition, the initial makeup of the group will impact how facilitation must begin.

Stakeholder groups with a history of working together

Sage grouse in Washington

The sage grouse in Washington study (Beall and Zeoli 2008) was designed in collaboration with stakeholders. The goal of the modeling process was to produce a management tool. The participants who had a long history of working together, large amounts of quality data, and a need to combine that data into simulation model essentially drove the Foster Creek Conservation District (FCCD) modeling process. Beall and Zeoli introduced the group to systems modeling by using an existing model of a salmon population (Ford 1999) as an illustration. As residents of the Northwest, stakeholders were familiar with salmon life history so it was easy for them to apply the concepts to their own concerns. We believe that the stakeholders were comfortable with systems thinking because these ranchers, farmers and land managers had been working with their landscape for many years. They are accustomed to integrating a variety of parameters and time frames into their decisions. At the first meeting, the modelers stated they knew little about sage grouse or farming and ranching in shrub steppe ecosystems. Having no preconceived ideas was an asset; it helped build trust. Several hours were spent discussing the concerns and needs of the stakeholders. The modelers returned in two weeks for a presentation that included a simple simulation model of the system. It was based upon stakeholder comments at the first meeting and a great deal of research on life history modeling. The simulation created the reference mode described by the group who then provided a data set that would customize the model to their system. Over the course of the next two months, modelers met two more times with the group and had frequent email and phone discussions with key participants. Total length of the project was three months. The timeline was established in consideration of FCCD's US Fish and Wildlife Service grants. The modelers had initially planned to spend more time with group on causal loop exercises and building simple models in front of the participants. It became apparent early on that this was not necessary. The group had a clear hypothesis of the cause of their problem. They also had a vision of potential solutions. Spending extra time and effort explaining systems methodology to the group could have been an aggravation to people who had limited time and who intuitively understood systems concepts.

Fisheries in Gloucester, Massachusetts and Problem Bears in New York

The Gloucester fishery group, similar to the sage grouse group realized they had a problem that would require integrating various types of data. One could say they were also 'looking for system dynamics'. The Gloucester and the NY bears projects followed similar protocol; furthermore the NY bear process stakeholders were shown the Gloucester model as an example of system dynamics. As with the sage grouse group in the West and salmon issues, many easterners are familiar with the collapse of the Northeastern bottom fishery. Both the Gloucester and NY bears projects were conducted over periods of 18 months with groups that had at least, in part a history of working together. The Gloucester and bear projects each had four one half day workshops with the full groups and a series of meetings with subgroups. The modelers acted as facilitators; they were not there to solve a problem but to help with problem solving. Their approach "emphasizes the importance of identifying key variables, which usually involves in-depth discussion with the client, a reference mode to express a "hope" and "fear" scenario, and in-depth analysis of the different loops in the system" (Siemer and Otto 2005, p. 1). Problem definition was elicited through group discussion that identifies a list of variables, reference modes for those variables, and a problem statement. The dynamic hypothesis, in the form of causal loops is built into a models one loop at a time. Each loop is simulated and analyzed before another is added. The Gloucester models was designed for group learning about an anticipated future that had not yet happened while NY bears had a definitive problem for which stakeholders were trying to evaluate management options.

The three wildlife models began with well-defined stakeholder groups whose participants were self selected by choice or by design (in the case of agency personnel). The stakeholders interest in system dynamics may be more than a coincidence since natural resource managers and perhaps other stakeholders often have experience with adaptive management theory. Adaptive systems thinking and the need for modeling could easily lead one to system dynamics.

Rio Grande River in New Mexico

The next case study, in the Middle Rio Grande River (Tidwell et al. 2004) also had a defined set of stakeholders. The group was part of a community-based water planning effort that wanted to use a system dynamics platform to integrate social concerns into a technical yet transparent management tool. Group members were voluntary to the modeling team but once committed had a stake in participation. The model had the potential to influence decisions of the larger planning group.

The Rio Grande (Tidwell et al. 2004) case study was designed and facilitated to follow five steps that were integrated into the overarching community-based water planning process. The problem and scope of analysis were defined and a system description was developed. Causal loop diagrams were then converted into a system dynamics context with appropriate data. The simulation model is reviewed and then the general public uses the model for education and water planning

The modelers showed examples of other reservoir models to familiarize the group with system dynamics. They also used an example of a savings account model. Though they often built simple structures with the participants there was limited interactive building. Modelers and designated representatives from different stakeholder groups met bi-monthly for a year to develop the bulk of the model. For the last six months of the project the "Cooperative Modeling Team" met monthly "to review and update the model and to monitor the use of the model in the planning process" (Tidwell et al. 2004, p. 360).

Okanagan River in British Columbia

The Okanagan project, similar to Gloucester was designed for group learning about an anticipated future that had not yet happened. The process was comprised of a group of people familiar with one another through their work or through previous stakeholder engagement activities. Their participation in the project was voluntary (Langsdale 2007). The process was based on criteria used in a participatory air shed model project in Utah (Langsdale 2007). The first workshop began with visioning to explain systems thinking concepts to the participants. The participants played the "ice cream game" (Durfee-Thompson et al. 2005), which is an offshoot of the beer game, a popular SD training tool developed at the MIT Sloan School of Management. The second workshop included systems mapping, an introduction to STELLA, and causal loop exercises of the Okanagan system. Langsdale began building the model in the office and returned to workshop three for "structure construction and refining" with the first iteration of a simulation model. Between workshops three and four, mini workshops were conducted with small interest-based groups to gather essential quantitative data. Workshop five presented a simulation model and time was used for model calibration. Workshop six presented the calibrated model to the group for exploration.

Stakeholder groups with little history of working together

The Upper Fox River, Ria Formosa 2000 and 2003, and Baixo Guadiana

These processes began with the organization of stakeholder groups. Although some of the stakeholders were familiar with one another, or part of a group of people with similar concerns, the practitioner for the purpose of facilitating the group through a new problem-solving methodology brought the modeling group together. This is in contrast to the preceding five case studies whose stakeholder groups had either 1) a history of working together or 2) a defined problem or 3) both a history and a defined problem. This contrast in the dynamics of the group requires an initial added facilitation of interpersonal relationships and problem definition. Van den Belt developed a "mediated modeling" process to address these concerns. The Upper Fox River, Ria Formosa 2000 and 2003 and Baixo Guadiana all followed this technique. Van den Belt divides the process into three steps. (van den Belt 2004).

Step one, identifies stakeholders, sets the participant group, conducts introductory interviews and prepares a preliminary model. Step two covers a series of workshops in which participants discuss problem identification and build qualitative models of their problem using the mapping layers of modeling software. Van den Belt uses this time to elicit information about non-linear behavior, time lags and feedbacks. She states "qualitative modeling is always a prerequisite for quantitative models, whether performed on a flip chart or on a computer. A quantitative model is a prerequisite for simulation of "what if" scenarios" (van den Belt 2004, p. 88). Once the qualitative model is complete participants begin to fill in the parameter equations with quantitative data and then, with behind the scenes work from the modeler, a simulation model is developed. Step three, "typically at the last workshop" (Videira 2005, p. 112) gives the participants the opportunity to run the model themselves and tutors them so that they may demonstrate the model to others.

Each of the four case studies above followed an individually customized timeline. The Upper Fox River and Ria Formosa 2000 that were both four month projects led by van den Belt, are described in depth in *Mediated Modeling.* Ria Formosa 2003 (Videira 2005) had four days of workshops spread over eighteen months. The Baixo Guadiana had three days of workshops spread over nine months. The Upper Fox River, Baixo Guadiana and the Ria Formosa 2000 were designed to "scope out the big picture". The Ria Formosa 2003 took the initial model and built upon the process to produce a management model.

Modeling Technique and Process Characteristics

Emphasis on model formulation vs. simulation

Figure 1 illustrates the eight steps of model formation as described by Ford (1999). Though this is depicted as linear, experienced modelers obtain the best results by iterating through the steps in a trial and error process as models are built and tested.

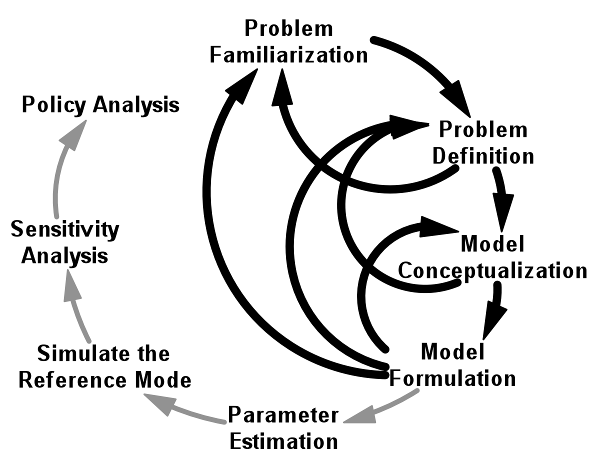
Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8
Problem familiar-ization	Problem definition	Model conceptual-ization	Model formulation	Parameter estimation	Simulate the reference mode	Sensitivity analysis	Policy analysis
Model formation				Necessary for simulation			

Figure 1. The eight steps of model formation (Ford 1999).

The case studies indicate two patterns of iteration. The first based on model formulation, the second on simulation evaluation. These patterns may happen in sequence but may also be determined by the preferred technique of the modeler.

Groups of people who come together in response to environmental concerns are problem driven. The collaborative definition of "the problem" is the first hurdle any group must overcome (Step 1 and 2). Qualitative models or system thinking exercises are useful aids for this process. With an emphasis on facilitation, skilled modelers may use the mapping layer of system dynamics software to identify variables of concern and the relationships between variables thus combining individual mental models into a group vision. Learning is driven by iterations of model conceptualization and formulation (Step 3 and 4). Figure 2 illustrates these steps linked together to highlight that this systems thinking exercise is an iterative process.

The group then begins to estimate parameters that help them describe a reference mode (step 5). Parameters are then integrated into a simulation model that produces a graphical representation of their reference mode (step 6). The model is then ready for participants to explore the sensitivity of specific parameters (step 7) and policy alternatives (step 8). Simulation models help the group better understand the dynamics of the problem they have defined with their qualitative model. Figure 2 illustrates these steps as part of an iterative process that produces simulation at the end.



Simulate at the end

Figure 2. Simulate at the end Emphasis of the process is highlighted in black.

The second pattern of iteration emphasizes the evaluation of simulations to facilitate group learning. Modelers elicit a reference mode of the problem through interviews then integrate scientific and social data provided by the participants into a simulation model (figure 3). Modelers return frequently to the group for discussion and verification of simulation results. A technical yet transparent model is created through a series of iterations that build the model one loop or one reference mode at a time. The participatory development of such a model results in a vetted simulation tool through which the group can explore policy alternatives.

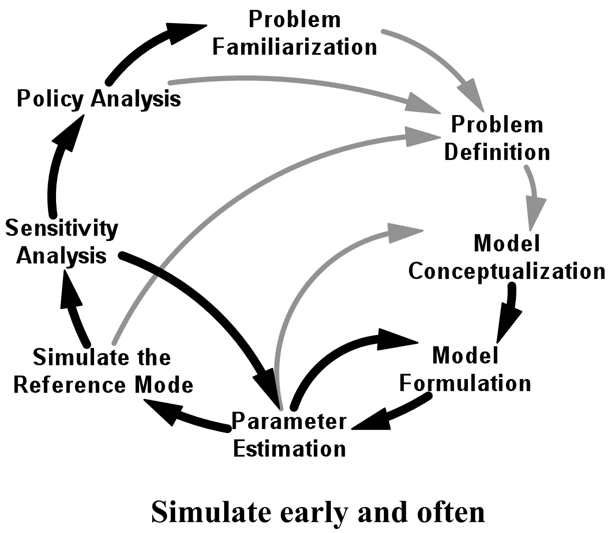


Figure 3. Simulate early and often. Emphasis of the process is highlighted in black.

Simulate early and often: Those following the methodology outlined by Forrester (1961, 1969), Meadows et al. (1972), Ford (1999) and others will begin with interviews of participants to elicit a reference mode of their problem. This reference mode is a graphical representation of an important variable and how that variable changes over time. This graphical representation will then drive the model building process. Figure 3 "simulate early and often" illustrates the emphasis that the modelers place on the eight steps of model formation. Practitioners in the sage grouse, Gloucester fishery and NY bears used this procedure, all have training in classic system dynamics that was developed by Forrester and initially taught at the MIT Sloan School of Business.

The Middle Rio Grande and Okanagan modelers came from hydrologic backgrounds. Hydrological studies often require simulation results that rely upon historic water levels or flows to establish historical benchmarks. Benchmarks differ from reference modes that indicate general trends. They are usually graphical or spreadsheet data of historic stream flow. They typically depict seasonal variations that are of strategic concern. This information is placed in simulation models to establish the flow and volume characteristics upon which other issues may be layered. In processes concerned with the availability of water, a simulation model is typically needed early to help participants decide upon parameters that will aid understanding of potential changes in reservoir levels or stream flows.

Simulate at the end: The Upper Fox River, Baixo Guadiana, Ria Formosa 2000 and 2003 began by using the mapping level of STELLA to build a systems map of the problem. This systems thinking exercise helps participants identify system boundaries and important parameters. When the group begins to quantify parameters, van den Belt lets the situation decide whether to first tackle the "spaghetti" (causal relationships) or the "meatballs" (stocks) (van den Belt 2004, p. 84). When the group does begin to talk about stocks the reference modes are elicited. Thus simulations are added at the end of the process (figure 2). This technique is useful for problems that take several workshops to define however it may leave little time for analysis of the simulation results.

Patterns of iteration and the benefits of simulation

Two patterns of iteration emphasis have emerged even though practitioners in the case studies used a variety of techniques. One pattern emphasizes system thinking exercises, model conceptualization and formation as the basis for group learning about problem definition. A model map of the entire problem is produced before simulation exercises are developed and performed. The second pattern emphasizes iterative simulation modeling which builds the model one "loop at a time" or "one reference mode at a time". This helps participants learn about policies or pieces of their problem though simulation results. This approach allows the modeler to build, test and evaluate the assumptions of small sections of the model. In addition it promotes the investigation of feedback mechanisms early in the process. Feedbacks can over-ride many other issues. It is beneficial to discover these problems early rather than later when they create big surprises.

Problem Complexity

Natural resource problems are sometimes describes as "wicked" (Rittel and Webber, 1973). Stakeholders have multi-dimensional interests overlaid with often competing values. Distilling these complexities down to a set of negotiable concerns is a common goal of facilitators in natural resource conflicts (Susskind and Field 1996, Carpenter and Kennedy 2001). These concerns need to be concise, such as a reference mode, before facilitated processes can begin moving towards finding solutions. The number of stocks that are in the model could be indicative of the number of concerns, and was therefore chosen as a proxy for problem complexity. Though it is arguable that the total number of parameters may also indicate complexity, many parameters help define stocks which are more indicative of the central problems.

If such is the case one would expect to see two reasons for a large number of stocks. The first of these is that the group is in the early stages of problem definition. The second is that a large number of representative groups are at the table bringing with them a diversity of concerns. If one combines these over the hypothetical lifetime of a long-term process, one could expect to see the number of stocks begin high as the group initially expresses all of their interests. The number of stocks would then decline as the group distills their interests to a workable (or model-able) set of issues. As the group finds cohesiveness and trust in each other and the process, one would expect to see them tackling new issues of concern thus the number of stocks would increase. Other factors that affect the number of stocks are fairly intuitive. A larger number of involved groups will tend to bring a larger number of issues to the table. In addition, the longer a group of people work on a model and clarify more concerns, the more concerns they want included. And, the modeler has more time to include these concerns in the model. Figure 4 illustrates general trends that support the effect that time and the number of involved groups has on the complexity of the problem that is modeled. More time, more groups, more stocks.

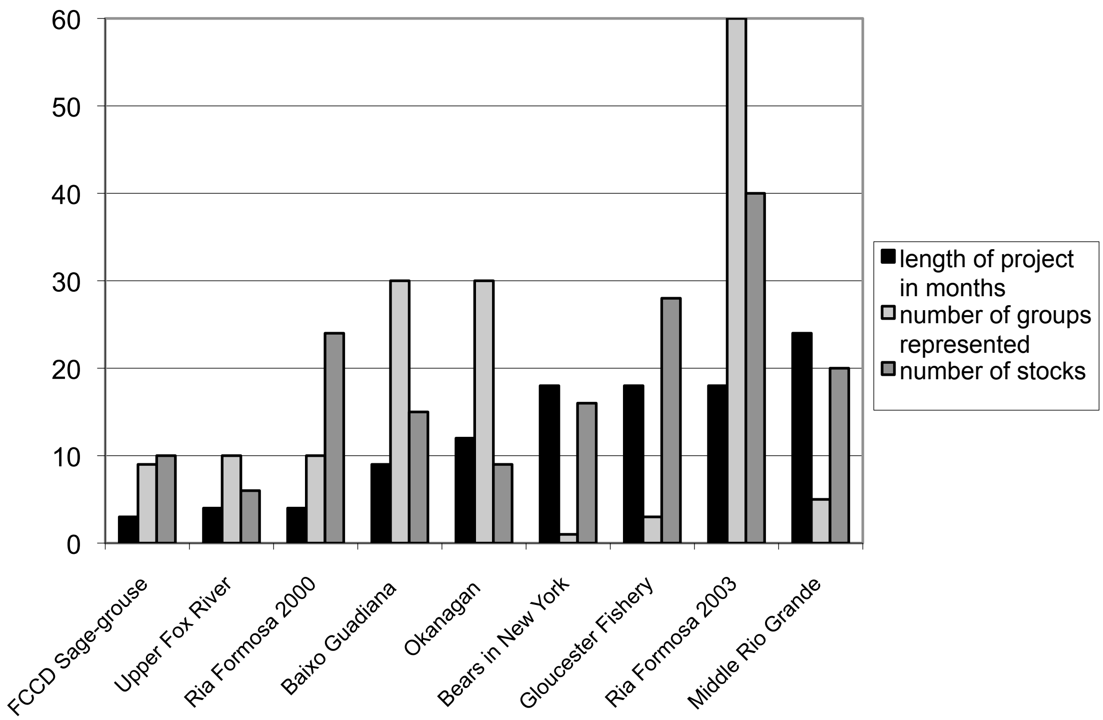


Figure 4. Sorted by project length, with number of groups represented and number of stocks added to the right of project length.

Though there are few examples of long-term studies with the same core group the Ria Formosa studies do show this trend. Initially a small number of groups came together to build a scoping model to help them clarify their problem. Then as the process developed over time into a management model, more groups were included and with them more complex issues. The number of stocks was initially 24 then progressed to 40 while the number of groups represented grew from 10 to 60.

The Continuums

To help further explain the divergence in technique used in the models three continuums will be discussed: 1) the "hands on continuum"; 2) the "problem definition to solution producing continuum"; and 3) the "quantitative to qualitative continuum". The "quantitative to qualitative continuum" in this context refers to the type of data being used in the models, not the models themselves. Although if a qualitative model or system map is being developed rather than an operating simulation model, large amounts of quantitative data will not be of assistance to the model.

The hands on continuum

Models built by experts with input from participants	⟺	Software used in workshops to assist with problem mapping

The problem definition to solution producing continuum

Well defined problem; simulation helps evaluate alternatives	⟺	Poorly defined problem; model development assists with problem definition

The quantitative to qualitative data continuum

Empirical data essential to policy concerns	⟺	Qualitative data indicative of social concerns or of poorly understood variables

Figure 5. Three continuums describing process and model characteristics.

Figure 5 illustrates the three continuums together to help elucidate another trend across the case studies. It is helpful to understand in advance that models that fall to one side of a single continuum will tend to fall on the same side of the other two continuums. The continuums will be discussed separately then a compilation of the continuums and modeling technique will follow.

The "hands on" continuum

This continuum portrays models built by experts with input from participants at one extreme. The opposite extreme portrays modelers using software to map a problem with the participants during a workshop. Practitioners on both sides of the continuum will educate participants about the basics of model icons. Modelers building structures in front of or with participants tend to teach participants more about the basics of model building.

Teaching stakeholders the basics of model building may accomplish two factors important to the process. First, it helps establish trust in the model and software and an appreciation of model transparency. Established groups who have trust in one another may have less need for hands on modeling. Second, it helps stakeholders to understand systems thinking. Those who are accustomed to viewing the world in a linear manner may benefit from this exercise.

The Washington sage grouse, Gloucester fisheries, NY bears, Okanagan basin and Middle Rio Grande performed the bulk of the modeling in the office whereas practitioners in the Upper Fox River, Ria Formosa 2000, 2003 and Baixo Guadiana spend more time involved in actual model building with the participants (though modelers operate the computers). These practitioners built the models from the general to the specific during stakeholder meetings. They began by identifying sectors that are important to the group to establish boundaries of the discussion to follow. Smaller groups then worked on individual sectors and spend time identifying parameters and the relationships of those parameters to one another. Practitioners take time between this step and the last workshop to fill in data and fine tune the equations so that a simulation model can be operating at the final workshop. The divergence of technique between hands on and hands off (or modeling in the office) is driven in part by the preferences of the modeler-facilitator but it is also driven by the purpose of the model and by the degree of problem definition.

The "problem definition to solution producing" continuum

The problem identification to solution producing continuum captures complexity issues and illustrates that modeling may be effective at different points in the problem-solving process. On the right side of the continuum is the Ria Formosa 2000 project that helped participants put boundaries on their problem through discussions that produced sectors and simple stock and flow structures. In the center of the continuum is the Okanagan study that helped concerned stakeholders wrap their minds around a problem they had all considered but had not yet begun to clarify. They worked together as a group to begin to put together all of the issues that may be part of the problem (Langsdale et al. 2006, Langsdale et al. 2007, Langsdale 2007). On the left side of the continuum is the Washington sage grouse model that will be helping stakeholders identify solutions that will be implemented on the ground (Beall and Zeoli 2008).

The "quantitative to qualitative" continuum

Quantitative to qualitative in this context is referring to the type of data that is integrated into a model. This is in contrast to previous use of quantitative and qualitative that referred to the model and whether it was a quantitative simulation tool or a qualitative map of the problem.

This continuum of data may be expressed in many ways: quantitative to qualitative, hard to soft, scientific to social; the divisions may be fuzzy (Table 3). The importance of the concept is in the value of the model to communicate information vital to the process.

Physical laws	Controlled experiments	Uncontrolled experiments	Statistical information	Case studies	Expert judgment	Stakeholder knowledge	Personal intuition

Table 3. The information spectrum (Ford 2009).

Conflict between community members can often erupt due to differences in how people value information. Scientists may be accused of using "black box mumbo-jumbo" or local knowledge referred to as anecdotal stories. Scientific parameters, social parameters and policy choices that may affect both scientific and social concerns may be equally expressed (or representatively expressed according the needs of the group) in a model.

Inclusiveness, education and respect can lead to less conflict and more creative problem solving (Carpenter and Kennedy 2001, van den Belt 2004). It should also be noted that it is currently not possible to scientifically quantify many environmental parameters. Concepts such as attractiveness can help capture intangibles such as the health of an ecosystem. The complexity of the problem, the number of group represented, and point on the problem definition continuum, will all have an effect on data concerns.

Different problems require different types of data. When dealing with economics, species demographics, habitat, or water flows modelers typically use quantified and often peer reviewed data. When including many human elements, stakeholders request parameters that are qualifications of such things as "tolerance" or "concern" for the New York bears, or "attractiveness" in the Ria Formosa Natural Park. The demand for quality data whether it is quantified or qualified tends to follow what one would expect of a non-modeled facilitation. Early in the process stakeholders often talk about their values with respect to potential solutions. These values may be difficult to quantify. As the process progresses the need for specific types of hard data become increasingly important as stakeholders begin to clarify their mental models and begin to focus on viable potential solutions.

The Ria Formosa 2000 model is an example of a simulation model built with a great deal of qualitative data. The following statement is found on the opening page of the model.

> "This is a "scoping model" meaning that a group of stakeholders interactively scoped out the linkages between ecology and economics. Many of the values incorporated are "estimates", "guesstimates" or assumptions to further the discussion in terms of "what if"…. More realistic or complete data and information can be incorporated as the discussion progresses" (van den Belt 2004).

This illustrates how generalities about parameters are useful when placed in a simulation model. When and if more definitive data is needed, it can be added to replace "best guesses".

One of the benefits of using system dynamic platforms for simulation is that "best guesses" based on experiential or anecdotal knowledge can be incorporated when no other data is available. Some argue that this may promote "garbage in garbage out" however the flip side of that argument is that mental models are often based on the same sort of knowledge. At least when placed in a simulation model this information is available to others in a clear and concise manner. Ford (1999) reminds us that a best guess can be very useful. If we exclude an uncertain parameter we are essentially stating that the value of the parameter is zero. Another issue of qualified data includes those parameters for which there is no real value other than a relative value that is understood by the participants. The Ria Formosa models both had parameters that captured "attractiveness" that were constructs of the participants and their values.

Two of the wildlife case studies illustrate a span of data types. The sage grouse model is primarily concerned with the recovery of an endangered species. It was entirely dependent on quantified, peer reviewed and expert biological data for species viability. As a comparison, the NY bears model is less concerned with species viability. In fact the bears are flourishing which causes concern about human-bear interactions. The model contains both quantified data on life history and habitat but also parameters such as "concern" or "tolerance". In addition, Siemer and Otto stated that "[w]hile exercising the model and providing insights to the team is a means to an end, modeling and its iterative process is a learning opportunity for the team as well as the modelers" (Siemer and Otto 2005, p. 11). The model has progressed into an education tool for the general public that may be utilized by agency professionals in problem bear areas (Siemer et al. 2007).

In general, the trend across the nine case studies is that management type models required more quantified data that was substantiated with standard scientific protocol. All of the practitioners noted that at some point in the process there was or would be a need for high quality technical data. They also value system dynamics software because it provides a platform to incorporate parameters based on the values of the participants when technical data is unavailable or unable to capture important concepts.

Compiled Analysis

Figure 6 integrates the continuums, patterns of model formulation, and the nine case studies. The placement of the case studies is not meant to be a specific comparison between the case studies but rather meant to illustrate general trends that reflect their internal issues. Emphasis on any specific continuum could potentially move a case study to either side of another. Models that fall to one side of a single continuum tend to fall on the same side of the other continuums.

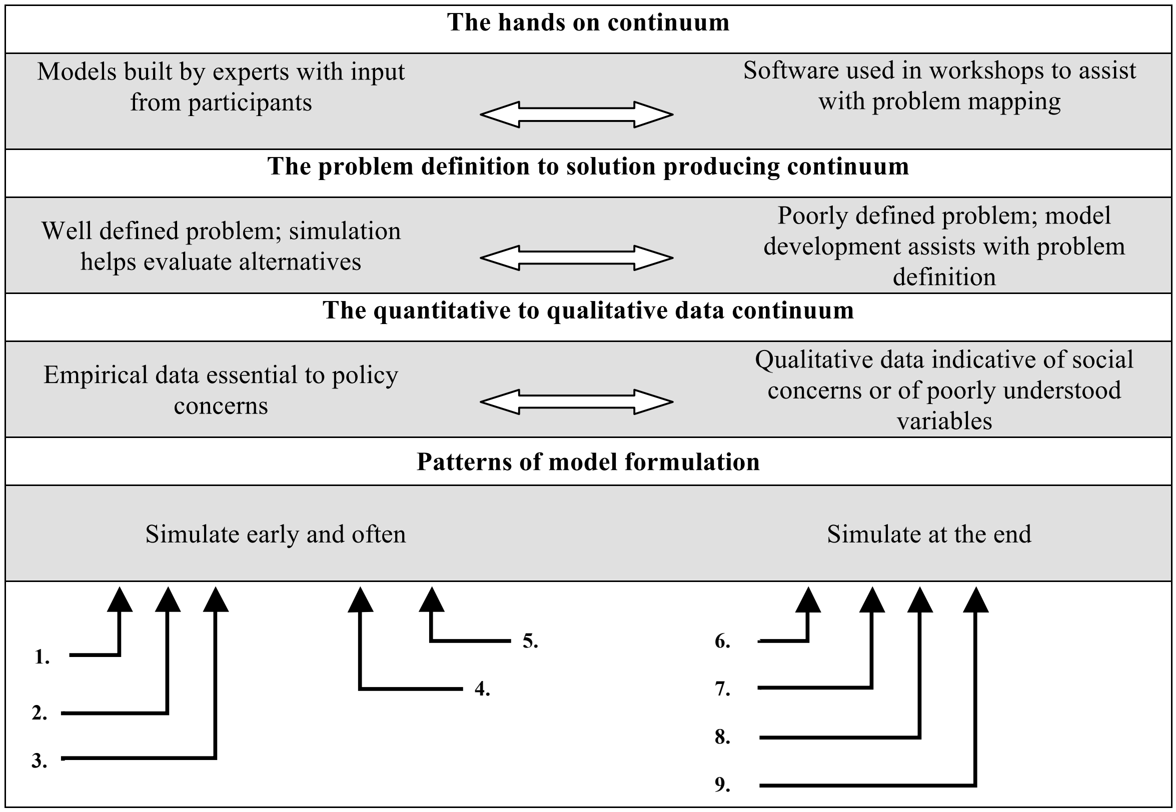


Figure 6. The continuums, patterns of model formation and the case studies. 1. Sage grouse in WA; 2. Problem Bears in NY; 3. Gloucester Fishery; 4. Middle Rio Grande; 5. Okanagan Basin; 6. Ria Formosa 2003; 7. Baixo Guadiana River Basin; 8. Upper Fox River; 9.Ria Formosa 2000.

On one end of the continuums is the Washington sage grouse model that was developed as a management tool for a group who had consensus on a well-defined problem. They had readily available, quantitative data that had been obtained through peer reviewed or peer reviewable processes. They needed a model to integrate their data into a simulation tool that could be used to explore policy alternatives. When comparing the time length of all of the modeling processes, this process had the shortest time frame. On the other end of the continuums we find the Ria Formosa 2000, Upper Fox and Baixo Guadiana that began as qualitative models that were designed to help stakeholders better define the scope and depth of their problem. The groups were then able to create simulation models of the qualitative problem map that the group developed as part of their problem definition process. These models were able to capture important social information that stakeholders were able to satisfactorily qualify.

The Ria Formosa 2003 built on the 2000 process. The stakeholder group expanded and developed a management tool in a process that still required the modeler to facilitate problem definition and clarification. Time restrictions did not allow these models to develop through a series of iterations driven by simulation results.

The Okanagan model used a combination of model development though group mapping and development though simulation. A large amount of quantitative data was available from the stakeholder group from earlier participatory and scientific efforts. Stakeholders appreciated the model for its ability to integrate these various data types. Model building was somewhat complicated by the large numbers of parameters that stakeholders requested to be included. However, process facilitation was fairly easy at this stage of the participatory effort. The degree of conflict in future exploration is different than in a situation where conflict over resources is already contentious. This case study exemplifies stakeholders who realize that system thinking is an important skill when planning for the future.

The Rio Grande model was developed as a management tool in a process that required the modelers to facilitate some degree of problem definition and clarification. It is a highly quantitative model requiring data from other water flow models. The quality of this data was essential to the model that was developed as part of a regional planning process. Iterations of simulation and analysis were used during model development.

The Gloucester model was developed for a small group of stakeholders with a well-defined problem who needed a model to explore a potential future. Stakeholders were trying to understand their potential alternatives so that the decisions of today would be made with the future in mind. Over the seven month modeling period, practitioners incorporated high quality quantitative and qualitative data one loop at a time into the model though iterations of simulation exploration.

The NY bears model also illustrates a model built using a classic SD technique that develops models though a series of iterations of simulation result analysis. Though the model is described as a learning tool it has developed into a model that is part of a public education program and will be used by wildlife managers to explain how humans impact human-bear interactions.

Conclusion

These case studies cover a broad spectrum of modeling technique. Four began with systems thinking exercises that developed models using the mapping layer of software to link together issues and concerns. Five developed models through iterations of simulation analysis. Problem definition technique varies from the use of causal diagrams to solicitation of reference modes. Process products range from a better understanding of "how we can learn to clarify problems" to management tools which simulate potential policy choices.

The success or long-range usefulness of these techniques is more difficult to tease apart. Case studies that used surveys indicate success in that individuals learned to think in a more holistic fashion and that participants appreciated learning about their system from a different perspective. The use of models for decision support should also be considered an indication of success; whether the actual model assisted with a decision or if it helped individuals understand the system better and thus made different decisions as a result is a matter for further study. Comparing an SD process to other methods of facilitation is not practical because of the inability to replicate the process with a control that uses another method of facilitation. Comparing case studies to one another has its challenges as well but this should not be a deterrent to using system dynamics in participatory processes but rather an encouragement for more case study assessments. Finally, the diversity of case studies indicates that a broad range of problems can be addressed by varying system dynamics modeling technique. There is no one technique that will always work with every group. Stakeholder groups vary in size, in need, in conflict, and in problem according to their place-based idiosyncrasies. Adaptability and a large repertoire of skills will benefit participatory modeling practitioners and the groups with whom they are working.

The complexity of environmental problems and the desire to find win-win sustainable solutions is driving a paradigm of problem solving that really began with the ecosystem concept brought forward by Tansley in the 1930's. When we began to see the natural world as a "system", we recognized that we had to develop an understanding of connections as well as the parts and recognize that systems have inherent behavior. System dynamics is a science that is uniquely suited to help us shift our focus from single pieces of a system to the connections between those pieces and to help "us to see the world as a set of unfolding behavior patterns" (Meadows 1972, p. 4). Modelers using the science of system dynamics and the art of facilitation in a participatory process can create a nexus of science and social concerns. With this understanding we are better equipped to contemplate the implications of our behavior, environmental stressors and the manifestations of tipping points. This in turn will help us understand how a system could be both fragile and resilient and what it means to be sustainable.

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