PARTICIPATORY ENVIRONMENTAL MODELING AND SYSTEM DYNAMICS: INTEGRATING NATURAL RESOURCE SCIENCE AND SOCIAL CONCERNS

By

ALLYSON MARIE BEALL

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School of Earth and Environmental Sciences

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of ALLYSON MARIE BEALL find it satisfactory and recommend that it be accepted.

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Chair

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ACKNOWLEDGMENT

The journey through graduate school has been life changing. Yet one does not travel alone down such as path, and my journey has been made much richer by the company with whom it was shared. A wise person once said that it takes a village to raise a child. I would say that it takes a village to support any worthwhile endeavor. My village is large and filled with amazing people.

Graduate journeys help one grow intellectually. This would not happen without the mentoring of exceptional people. My committee, Andy Ford, Bill Budd, Emmett Fiske and Barbara Cosens have been instrumental in not only my academic pursuits but also in my growth as a person. They have been patient and nurturing. They have been challenging and demanding. They have taught me an appreciation of subtleties; those nuances that are often found near the edges of thresholds.

In the spring of 2004, Andy Ford introduced me to system dynamics. I had always enjoyed math and was intuitively drawn to the transparent and straightforward logic that system dynamics offered. I was surprised and very grateful when he offered to sponsor my Ph.D.. An energy expert was encouraging the use of participatory modeling as a tool for facilitation in natural resource conflicts. He suggested that I look to the news for a project of current importance. The sage grouse listing was front and center in natural resource circles and looked like a prime target. This was the beginning. Later that year my colleague Len Zeoli found a meeting for sage grouse working groups and had the

foresight to petition our department chair Bill Budd to support a trip to the conference. It was at this meeting that we made connections with the Foster Creek group. The experience that ensued created a foundation on which to integrate intellectual endeavors which I have found to be practical, worthwhile and satisfying.

The sage grouse model provided the opportunity to co-write a paper with Len Zeoli that was accepted for presentation at the 2006 International System Dynamics Conference in Nijmegen, Netherlands. I am appreciative of those who reviewed our paper and of the conference organizers who invited me to present at the opening plenary. I am amazed to this day that this was my first experience at a professional conference and most grateful to Andy Ford for funding my trip to Europe. I am also appreciative of the openness, respect and camaraderie I received from the system dynamics society. This experience instilled confidence that has been a wonderful source of motivation.

Even through all of this, it wasn't until the summer of 2007, that I began to genuinely realize what system dynamics *is*. With Andy Ford's patient coaxing through Reports from the Field 2007, I began to sift out what I had taken for granted. It was a curious epiphany. I had been taught something so well that I didn't even realize that I knew what I knew. Learning is often arduous or even painful, mistakes typically hurt. Yet the best educators are able to create a positive learning environment that encourages curiosity, exploration, and challenge. The best educators teach intuition. Unlike facts, intuition is never forgotten. Its value is in the grounding that it provides for future experiences. Andy closes his final class lecture with analogies that allude to something greater than the obvious. Someone gave him an incredible gift. I am grateful to him for passing it on to me.

Bill Budd originally admitted me to the program for my Masters. His faith in my determination for graduate study, and the teaching assistantship he provided for my Ph.D. made this journey possible. My teaching assistantship has been a source of great joy and a valuable learning experience. Bill Budd also shared his amazing variety of perspectives with me and asked me to look at the world through new and challenging lenses. These experiences have helped me look well beyond the obvious and have been significant to the depth of this dissertation.

Emmett Fiske provided lessons in facilitation that are still inspiring. Not only did I learn the subtleties of process but realized the value of my past experiences. He helped me re-frame and look forward with a new and positive outlook. I don't know if I can ever fully explain how valuable this is to me. Those who show us to the pathways that we follow, hand us a light and words of encouragement, are the foundations of our accomplishments.

Barbara Cosens inspired an appreciation of law. She illuminated this world view with incredible clarity. Her combined understanding of science and facilitation helped me develop the basis for the bridge I strive to build between disciplines. I believe that the next 20 years will see a shift towards more collaborative governance of natural resources. The legal insights I have learned have given me the confidence to be part of that shift.

And I think, if I ever have the energy to embark on another degree, it will be a Juris Doctorate.

None of this would have been possible without Len Zeoli, my Ph.D. colleague and project partner. His hard work and dedication to clear and concise science on the sage grouse project was instrumental to its success. It is still inspiring. He is also a demanding yet patient editor; he has made me a better writer. I cherish the many wonderful conversations that we have had. They brought insight and clarity while inspiring introspection and curiosity. I look forward to many more and I am thankful that he shared my journey. He is a true friend and a fine scholar.

Stacy Langsdale asked me to be a part of the Okanagan project in the fall of 2004. I feel privileged to have been invited to join her Ph.D. project and to be involved in such an interesting endeavor. I gained valuable insights about participatory modeling by looking at the process through the lens of a hydrologist. In addition the experience was instrumental for inspiring me to look across more case studies. She was also responsible for my invitation to join the CADRe community… finally a room full of like minded people!

In addition to Stacy Langsdale, I would also like to thank my other co-authors on the Reports from Field 2006 and 2007 posters: Todd BenDor, Rosemary Jackson, Peter Otto, William Siemer, Jeroen Struben, Vincent Tidwell, Marjan van den Belt and Nuno

Videira. Their data and discussions have been of great value, and it has been a privilege to learn about their techniques.

I renewed my love of teaching on this journey. Rick Gill has been an inspiration. I feel fortunate for all of the semesters of environmental science 101 that I worked as a teaching assistant for him. Every semester has taught me something new. Sometimes new facts, other times new concepts, but always something more about teaching. Learning from a master educator is truly a privilege.

The funding that I received through the Robert Lane Fellowship provided the opportunity to spend the summer before the Nijmegen conference immersed in writing. This stress free time was valuable to more than my dissertation. It gave me the freedom to be totally self absorbed and to be able to think about what I wanted to think about. This was a turning point. I found that I wanted to stay in academics.

Words cannot express my thanks to Elaine O'Fallon who not kept me straight through all of the administrative issues, but who was always there when I needed an encouraging word or a smile. There were many times that hearing "you're going to make it!" jump-started a new flurry of work.

To my graduate colleagues and friends who are now far more than friends. My heartfelt thanks go to Asmeret Bier, Lorrie Bradley, Brendon Kelly, Rachel Emswiler, Kim Hamblin-Hart, Courtney Bennett, Hayley Andrus, Lauren Bissey, Marla Chassels, Audrey Willard and Dan Crowther for listening to my frustrations, cajoling me with humor and showering me with support.

Beyond my circle of academic mentors and colleagues is a village of supportive friends and family.

Jim King, Christie Zeoli, Janna Jahn, and Antone Holmquist have patiently supported me through a life change of grand proportions. I hope that the results are as worthy as your friendship.

My family inspired this life change. I am, and will be eternally grateful to you all. To my brother John, your high standards, patience and kindness are appreciated more than I could ever express. Colette and Li your kind words of support and encouragement have been a source of great strength. Charlotte, Otto and Erin, you bring me joy and give me hope. To the rest of my Northwest family, thank you for making this home.

To my mother Lola, I know that where ever you are that you have watched over me every step of the way. I just wish you were here to share this with us. To my father John, you have always encouraged me to follow my dreams and listen to my heart. Your wisdom is beyond measure.

Thank you all,

I am grateful to have shared this journey with a village of such extraordinary people.

Allyson Marie Beall
November 14, 2007

PARTICIPATORY ENVIRONMENTAL MODELING AND SYSTEM DYNAMICS:

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Abstract

by Allyson Marie Beall, Ph.D.
Washington State University
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Chair: Andrew Ford

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 using system dynamics can create such a nexus. This process uses the tenets of scientific theory, hypothesis testing and clear statements of assumptions. Models may be used to integrate professional science, street science and experiential knowledge with timeframes that reflect the needs of agency and private resource management. In so doing, models serve as repositories for collective knowledge that have a shared language.

Literature and experience support this thesis. The first chapter of this dissertation provides a review of the literature and supplies the reader with the reasoning behind the use of this methodology. It is followed by an in-depth case study involving sage grouse which are currently being petitioned for endangered status under the Endangered Species

Act. The experience of this case study further supports the thesis and provides a foundation for the exploration of other modeling processes. An analysis comparing ten participatory modeling case studies illustrates the effectiveness of a broad range of applications and techniques.

The design of system dynamics software makes it easy to use. Designing an effective model is not easy. After assessing the case studies a variety of techniques have surfaced that modelers use to manage different types of problems. The final chapter argues that simulation models can be built with scientifically defensible standards. In so doing, participatory models can serve as effective facilitation tools for the problems and conflicts that come with the management of natural resources.

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CO-AUTHORSHIP STATEMENT

The Foster Creek Conservation District Sage grouse project, which is described in depth in chapters two and three of this dissertation, was a collaborative effort that included Len Zeoli, a fellow Ph.D. student at Washington State University, and members of Foster Creek Conservation District. Len is a co-author of the manuscript for chapter two which has been submitted for publication with Ecological Economics. Chapter three is a revised version of the official report which was presented to Foster Creek Conservation District at the conclusion of the project. I was the primary author on the first section of the report which describes the systems model. Len is primary author on the second section which describes the Population Viability Analysis which Len conducted. We both strongly support the combined use of system dynamics modeling and PVA for endangered species modeling. I have included the PVA section in this dissertation, even though I consider myself a second author, because of the significance it holds to the project.

Chapter four, Reports from the Field, is an assessment that grew out of co-authored conference posters for which I was the lead author. The purpose of the posters was to gather information about different aspects of participatory models. These posters provided the opportunity for discussion at the conferences with my co-authors. They were highly supportive of my using the data for a cross case study analysis. Chapter four of this dissertation is the result of data collected for the posters and personal communication with the lead modelers. I am the sole author of the analysis contained therein.

This dissertation is dedicated to Mom and Dad,

and to my family and friends.

It does take a village…

PROLOGUE

The dissertation to follow is a collection of manuscripts that began with the concept that system dynamics modeling is a useful method of problem solving for complex environmental issues. Chapter one is an introduction to system dynamics and participatory environmental problem solving. Chapter two describes the case study that Len Zeoli and I conducted with the Foster Creek Conservation District during the summer of 2005. Our experience with the Foster Creek group was very positive and has reinforced our thesis that this type of modeling can be helpful for groups struggling with endangered species management. Chapter three is the report that was delivered to Foster Creek in conjunction with their models at the conclusion of the project. Chapter two and three are in manuscript form and some text is repeated.

In the fall of 2004, Stacy Langsdale, who at the time was a Ph.D. student at University of British Columbia invited me to join her group modeling project. Stacy's dissertation titled "Participatory Model Building for Exploring Water Management and Climate Change Futures in the Okanagan Basin, British Columbia, Canada" was funded by Natural Resources Canada through the Climate Change Impacts and Adaptation Program. Our first workshop was held on February 1, 2005. The facilitated portion of the project culminated in workshop five on February 10, 2006. Though I acted only in an advisory capacity with the actual model building I attended all of the workshops as a model adept facilitator. Being one step removed from the lead provided me with a different perspective of the process than I had had with the Foster Creek group. This was a valuable experience. It gave me the luxury of learning about the technique of another practitioner while she was in action and at the same time view the reactions of the participants.

After the completion of the Foster Creek sage grouse modeling project described in chapters two and three and the experience gained co-facilitating the group modeling effort in the Okanagan Basin questions arose concerning modeling processes. The sage grouse and the Okanagan projects used very different albeit equally effective group model building techniques. Why and how these two processes were so different became of great interest. The opportunity to lead a co-authored conference poster with a group of participatory modelers provided the basis for the cross case study analysis in chapter four. Reports from the Field 2006 was presented at the International Systems Dynamics Society Conference in Nijmegen, Netherlands and Reports from the Field 2007 at the society conference in Boston. The poster gave me the opportunity to gather data about different modeling processes. With the encouragement of my co-authors I have looked across the case studies to find what they shared and how they differed. There is need for such an analysis in this young field. I hope that Reports from the Field encourages other practitioners to follow with additional analysis. We have come to participatory modeling through different avenues of interest and training and share a desire to learn from one another.

Chapter four describes the cross case study analysis of ten participatory modeling projects. The Foster Creek sage grouse and two additional projects are concerned with species management. The Okanagan watershed project and six others are concerned primarily with watershed issues. I chose to have a broad scope for three reasons. First, I already had experience with an endangered species and watershed modeling. Secondly, multitudes of environmental issues have concerns with both water and species management. Though none of the case studies explicitly dealt with both water flow concerns and the life history of an individual species, the methodology can be combined to do so. Thirdly, the published or soon to be published accounts of these case studies did not provide all of the information that I needed. Modelers from the other nine case studies have been most accommodating in responding to requests for information. This analysis would not have been possible without direct contact with them.

Chapter five is an overview of the lessons learned and recommendations to others who use or would like to use participatory modeling as a part of their efforts to find solutions to environmental problems.

CHAPTER ONE

PARTICIPATORY ENVIRONMENTAL PROBLEM SOLVING AND SYSTEM DYNAMICS

1 Participatory Environmental Problem Solving and System Dynamics

1.1 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 the specificities of locale. Others may argue that laws and regulations are so ambiguous that they are not effective tools to protect the environment. In an effort to 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 world views 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.

> System dynamics can provide that dynamic framework to give meaning to detailed facts, sources of information, and human responses. Such a dynamic provides a common foundation beneath mathematics, physical science, social studies, biology, history and even literature. (Forrester 1991 p. 27)

Participatory environmental modeling that uses system dynamics is effective for facilitating the integration of natural resource science and social concerns. This methodology uses a common language to integrate 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.

This thesis is supported by the literature and experience. Chapter one provides a review of this literature and supplies the reader with the reasoning behind the use of this methodology. Chapters two and three describe a case study involving sage grouse management. This experience further supports the thesis and provides a foundation for the exploration of other modeling processes. Chapter four looks across participatory modeling processes to illustrate the effectiveness of a broad range of applications and techniques. Chapter five describes lessons learned and recommendations to others who use or would like to use participatory modeling as a part of their effort to find solutions to environmental problems.

Chapter one will begin with an overview of participatory modeling and the role of system dynamics. It will continue with a discussion of the benefits of participatory modeling with respect to facilitation and scientific understanding. Using a systems approach creates the opportunity to integrate different types of information such as professional science and local knowledge. This chapter will conclude with a discussion of participatory modeling efforts undertaken by natural resource agencies. Legal concerns will also be addressed. This issue is important because agency stakeholders in participatory processes have to work within the boundaries of laws and regulations. Furthermore, if a model is to be used to assist with a decision that may potentially be challenged in a court of law then it must adhere to "best practice" scientific protocol.

1.2 ***Participatory modeling***

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) and Computer Assisted Dispute Resolution or CADRe (USACE 2007).

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.

Group system dynamics modeling for participatory environmental problem solving has been used on a variety of environmental problems such as air quality, water quality and quantity, and biological conservation management. Van den Belt (2004) describes five case studies, their models and the lessons learned from the processes. Stave (2002, p. 139) used group system dynamics modeling to help the citizens of Las Vegas explore remedies to air quality problems. Tidwell et al. (2004, p.357) used system dynamics modeling to assist citizens with watershed planning in the Middle Rio Grande River valley. Langsdale modeled the effect of climate change on future water supplies in the Okanagan Basin, British Columbia (Langsdale et al. 2006 and 2007; Langsdale 2007). Wildlife models have been developed for bear management (Faust et al., 2004, p. 163; Siemer and Otto 2005; Siemer et al. 2007) and fishery management (Otto and Struben 2004, p. 287). Videira et al. (2004; Videira, 2005, p. 27) modeled "tourism, eco-tourism, aquaculture, fishing, wildlife protection and nature conservation, effluent discharge and navigation of fishing and recreation boats." Spatial-dynamics were used by BenDor and Metcalf (2006, p. 27) in a decision support tool for ash borer eradication. Nine of these case studies and the Washington sage grouse study highlighted in chapter two and three will be discussed in-depth in chapter four. Chapter four contrasts participatory modeling processes with the intention of illustrating the flexibility of process and the effectiveness of a broad range of interventions. Comparisons include that of process protocol and modeling technique, the number of stocks, the need of the process, number of groups involved and the time spent on the project.

1.2.1 The role of system dynamics

System dynamics was developed in the early 1960's by Jay Forrester (1961) as a methodology that could be used to gain understanding about the dynamics of any system. Meadows (1972, p. 4) maintains that system dynamics training helps "us to see the world as a set of unfolding behavior patterns." For natural resource concerns a system could include an endangered species, such as a bird or rabbit. It would also include its habitat and historic, current and future land use changes which have affected, or will affect, that habitat and species. It could also include the impacts of those land use changes on the human occupants. System dynamics teaches us to shift our focus from single pieces of a system to the connections between those pieces. This methodology facilitates understanding of system behavior with the assistance of dynamic simulation models.

System dynamics has been used to study industrial, urban (Forrester 1961, 1969), and business dynamics (Sterman, 2000). Meadows et al. (1972) and Sterman (2002) encourage the use of system dynamics to grapple with the daunting problems of global sustainability. The system dynamics paradigm "recognizes all systems as having the same fundamental structure of levels and rates (accumulations and flows) structured into feedback loops that cause all changes through time" (Forrester 1994, p. 251). While static models advance understanding of systems at rest by providing snapshots of a particular moment, dynamic models provide insight as to how a system changes. Growth, decay and oscillations are the fundamental dynamic patterns of systems. The methodology is useful for understanding the issues that create limits to growth (Meadows et al. 1972, Ford 1999). For example, a natural population will grow exponentially until it reaches a limit or what biologists refer to as carrying capacity. When modeled, this dynamic behavior is graphically represented by an s-shaped curve.

It is useful to distinguish between system dynamics and systems thinking. System thinking literately means thinking about systems. Checkland (1981) introduced *Systems Thinking, Systems Practice* to the field of soft operational research and in 1999 returned with *Soft System Methodology: A 30-year Retrospective*. System thinking has been brought to a wider audience by Senge (1990) who integrated it into organizational learning in the best-selling book *The Fifth Discipline*. Senge points out that there are archetypes of behavior that are typically found in organizations.

System thinking exercises help establish parameters that are important to a particular system of study and the relationships between those parameters. Causal effects can be identified through the exploration of causal loop diagrams; however, one is still left to use mental models to grasp the importance and magnitude of time lags and feedbacks. Forrester (1994, p. 252), remarks that "systems thinking can serve a constructive role as a door opener to system dynamics and to serious work toward understanding systems." He further cautions that "diagrams that connect variables without distinguishing levels (integrations or stocks) from rates (flows or activity)… do not provide the discipline to thinking imposed by level and rate diagrams in system dynamics… and [thus] will fail to identify the system elements that produce dynamic behavior" (Forrester 1994, p. 252). The 1994 *System Dynamics Review*, volume 10, numbers 2-3 provides a comprehensive overview of both systems approaches.

Systems thinking exercises can be useful in natural resource issues for assisting stakeholders with qualitative problem definition. However as Forrester cautions, this can only take stakeholders so far. Once they have agreed upon parameters and system boundaries they will benefit from simulation models which will help them evaluate and refine the qualitative vision of the problem. An understanding of inter-relationships, feedback and time lags will be established as the simulation model develops. This understanding will be of benefit to stakeholders as they use the model to assess policy alternatives.

1.2.2 The role of group model building

A large body of literature maintains that the use of system dynamics for group computer modeling is useful for group learning and consensus building. Group model building was initially designed for business and organizational applications. Table 1.1 lists literature from practitioners who were instrumental in the development of this methodology. Rouwette et al. (2002) looked across case studies and group modeling techniques. They found a wide variety of elements and scripts that were used to elicit information, explore and evaluate policy options. In addition, there was variation in the duration of the intervention, the number of participants and the involvement of the client in the model building phases. Insights from their assessment include two important concepts. First, "[l]earning about the problem seems to be a robust outcome of group model building." And secondly, "commitment and consensus are found to increase after participation in modeling" (Rouwette et al. 2002, pp. 31-32).

Author(s)	**Title**
Vennix 1994	Building consensus in strategic decision-making: insights from the process of group model-building
Richardson and Anderson 1995	Teamwork in Group Model Building
Anderson and Richardson 1997	Scripts for group model building
Vennix 1996	Group Model Building: Facilitating Team Learning Using System Dynamics
Anderson and Richardson 1997	Scripts for Group Model Building
Vennix 1999	Group model-building: tackling messy problems
Rouwette et al. 2002	Group Model Building Effectiveness: A review of assessment studies
Rouwette 2003	Group model building as mutual persuasion

Table 1.1 Group model building literature with business applications.

Environmentally oriented modelers built on the group model building techniques of the business modelers. Table 1.2 lists literature that discusses the use of group model building interventions for environmental problems. Stave (2002, p. 143) notes that "[a]t a minimum system dynamics offers a consistent and rigorous problem-solving framework for identifying the scope of the problem, eliciting participant views about problem causes and system connections and identifying policy levers." A common theme across this literature is that the benefits of using system dynamics include structured deliberation, group learning and conveying the effects of feedbacks and time lags. Practitioners comment that the process of model building helps groups establish a shared vision of the problem. Chapter four discusses additional literature and case studies. It describes the techniques used by modelers to facilitate group learning and consensus building through the integration of science and local knowledge.

Author(s)	**Title**
Stave 2002	Using system dynamics to improve public participation in environmental decisions
van den Belt 2004	Mediated Modeling: A system dynamic approach to environmental consensus building
Tidwell et al. 2004	System dynamics modeling for community based water planning: Applications to the Middle Rio Grande
Videira 2005	Stakeholder participation in environmental decision-making: The role of participatory modeling
Langsdale 2007	Participatory model building for exploring water management and climate change futures in the Okanagan Basin, British Columbia, Canada

Table 1.2 Group model building literature with environmental applications.

1.3 A systems approach to environmental problem solving: integrating science and local knowledge

> The twentieth century has amply demonstrated that neither science nor democracy can enhance human [or environmental] welfare in the absence of the other. (Deitz 2004, p. xiii)

The complexities of environmental issues now require the public to be involved in decision making. Questions such as ‘how does an agency facilitate dialogue with groups of people with potentially polar visions of the world’, and ‘how should decisions be structured to respect a plethora of social values’ are being addressed. In many cases those who must deal with the public are scientists who have been trained to be scientists, not policy makers. Or conversely, policy makers are being asked to make decisions based on science when they have little or no scientific training.

Historically, science has been segregated from social issues. Certainly science exists to serve the needs of humankind but the need to be free from biased outcomes has always been a basic tenet. This need has been served well by professional science research institutions such as universities which encourage scientific exploration for the sake of exploration and knowledge. Classic reductionist science that dissects problems into their parts thrives in such an environment. Research timeframes are dictated by researchers and their funding entities. Ecosystem science has developed in the last several decades and recognizes that reduction is needed for specific issues but primarily focuses on relationships. The relationships integrate parts into a complex whole creating a synergistic system that must be studied from the systems perspective.

Systems are "sets of interconnected material and immaterial elements that change over time" (Meadows et al. 1972, p. 4). Natural resource sciences typically refer to systems as eco*systems* which are communities of different species interacting with each other and the surrounding abiotic environment. On a grand scale there is one ecosystem, that of the planet, however ecologists will put boundaries around unique areas of flora and fauna to limit the parameters of their study. Ecosystem research includes issues of scale and time therefore large and long term studies such as LTER[1] are needed. These studies help us understand how ecosystems function in accordance to the individual characteristics of their parts and the dynamics relationships between those parts over time. In addition, ecosystem ecology recognizes that humans are integral parts of all ecosystems. Therefore the study and management of biological systems should consider the impact of humans and social factors an implicit part of natural systems.

Agencies in the US charged with scientific management of our natural resources are typically required to manage those resources in the context of multiple use.[2] The US Forest Service must balance timber harvest with wildlife protection. The US Army Corp of Engineers, the Bureau of Reclamation and NOAA must balance salmon populations and hydropower. Professional science is required for data collection yet it is done in an

[1] LTER: The Long Term Ecological Research (LTER) Network, funded by the National Science Foundation is a collaborative effort involving more than 1800 scientists and students investigating ecological processes over long temporal and broad spatial scales. http://www.lternet.edu/
[2] Multiple Use Sustained Yield Act. 16 U.S.C §§528 to 531

agency setting that by necessity must modify scientific protocol. For example, agency scientists do not have the luxury of extended years of research and are asked to answer policy-based questions within specific time frames. Management decisions have to be made. In recognition of time constraints these decisions should be based on the best science that is available at the time. These policy-science questions inevitably require the use of judgment. This creates the potential for value-biased decisions, politically-biased decisions, conflict and citizen law suits.

One could postulate that many of the problems that natural resource agencies are dealing with are further compounded by the potentially conflicting world views of science and policy. Science presents a world view of how things should be studied, of how data should be collected and validated, and how to deal with uncertainty. It is a world view that has a long and established protocol with results expressed via statistical quantifications. For good reason there is resistance to muddying the already murky waters with a bunch of amateurs and their "unscientifically" related social problems. Policy makers on the other hand are more accustomed to the "squishiness" of social science and have dealt with the issues of qualification through the doctrines of law and such tenets as the reasonable man standard.

Another issue is that in general, the public has limited knowledge of the specifics of scientific study. Some scientists may contend that their work is "too complicated" for the general public to grasp. Whether or not one thinks that scientific issues are beyond the average person does not alleviate the fact that, when decisions are made, the public will be involved. A better understanding of the underlying science is integral to informed decisions.

Local knowledge is also important to natural resource management. The utilization of such knowledge in problem-solving processes can help improve inclusiveness and process transparency. These types of knowledge are typically not offered in a format that will withstand scientific peer review. However they differ, both scientific and local knowledge are valid and useful. Conversely, both types of knowledge may contain inconsistencies brought about by lack of information, misinformation, or inadequate understanding of system complexity and dynamics. Costanza et al. (1997, p. 72) reinforce the importance of local input with the statement that "to the extent that social and ecological systems differ from place to place, local experiential knowledge will be essential to implementing specific solutions."

Local knowledge presents itself in many forms. The terms street science and experiential knowledge have been chosen to segregate and qualify different facets of knowledge that is typically consolidated into what we call local knowledge. This segregation is important because it points to the fact that this kind of knowledge is highly valued and extensively used.

Street science is a kind of local knowledge that is accumulated in a community (Corburn 1998). Corburn coined the term when working with impoverished communities suffering from health problems caused by environmental hazards. He maintains that the “contextual intelligence” of local knowledge is essentially fused with professional knowledge when science and policy are working together to solve problems. Scientific expertise is co-produced when local knowledge is co-opted into the process. Community bird counts could be used as an example for natural resource concerns.

Experiential knowledge has been chosen because it qualifies local knowledge in another important manner. Experiential or instinctual knowledge is what one acquires by living. It includes practical skills and wisdom that are learned over time from practice that teaches one to have a feel for, and the instincts to adjust to, a variety of changing conditions. In situations involving natural resources this could include how a particular species responds to a harsh spring, or the effects of irrigation on soil, or the effects of different weather conditions on stream flow. Experiential knowledge is used on a daily basis by successful farmers and ranchers who often have time series knowledge about a place which has been passed down through generations. Experiential knowledge is also used in resource management by scientists who have years of experience working on a particular landscape. Though there are difficulties addressing this experience in a scientific manner, few would argue against the benefits of such knowledge. Participatory modelers can frame local knowledge into the scientific format of a model which essentially creates a body of street science. The use of “street science does not devalue science, but rather re-values forms of knowledge that professional science has excluded and democratizes the inquiry and decision-making process” (Corburn 2005 p. 3).

Collaborative processes rely upon shared information for the purposes of problem identification, education, increased trust and buy-in from local stakeholders (Cormick et al.1996, Weber 1999, Beierle and Konisky 2000, Brick 2001, Weber 2003, Beall 2004). Participatory system dynamics modeling is a process that can integrate science with social concerns and policy. In doing so, it opens the lines of communication between potentially different world views. It recognizes that environmental systems contain physical, biological and social elements and that the relationship between those elements is critical to the system. This process uses the tenets of scientific theory, hypothesis testing and clear statements of assumptions. Models may be used to integrate professional science, street science and experiential knowledge with timeframes that reflect the needs of agency and private resource management. 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 (Figure 1.1).

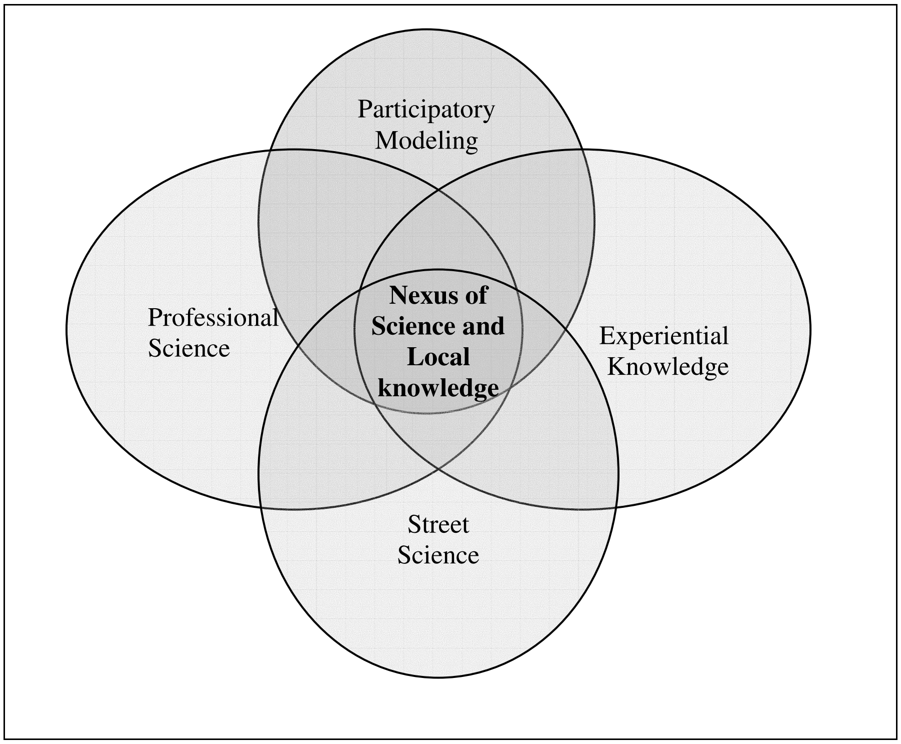

Figure 1.1 Participatory modeling may be used to create a nexus of science and local knowledge.

1.3.1 Participatory modeling benefits facilitated problem solving

Figure 1.2 is taken from Forrester (1994) and describes the system dynamics process and the progression from problem to solution. This figure emphasizes the importance of iteration. Forrester calls this an “active recycling back to previous steps” (Forrester 1994, p. 246).

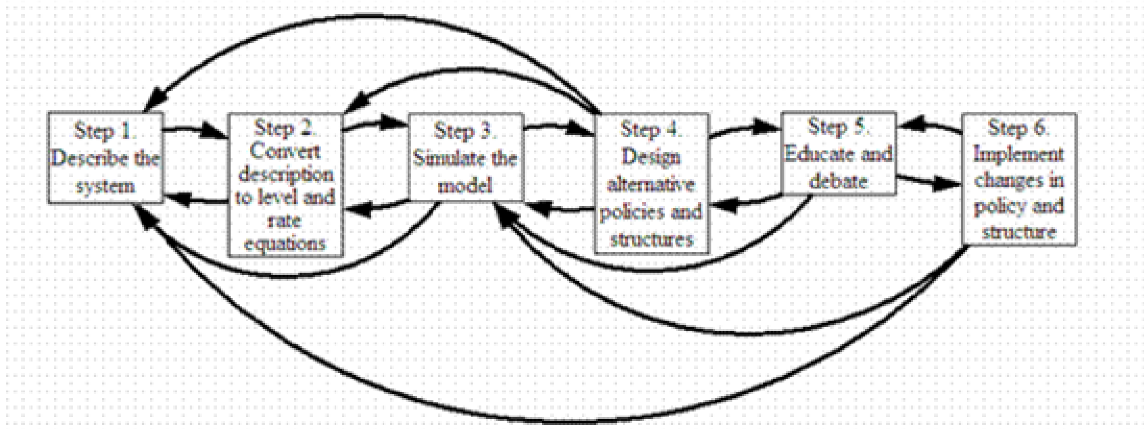

Figure 1.2 The steps of system dynamics from system description to solution.

Building of the actual simulation model can be depicted as following a linear process but within that process multiple iterations often take place. Ford (1999) uses the following steps: find a reference mode, identify key variables, inter-connections and feedbacks, perform a sensitivity analysis then test the impacts of policy (Figure 1.3).[3] A reference mode is a graphical representation of a variable that is important to the problem and how that variable changes over time. Ford (1999) further emphasizes the importance of iteration.

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

Figure 1.3 The steps of model building.

[3] Appendix 1 lists model language and definitions.

System dynamics as a problem-solving methodology is similar to that used by traditional facilitators in environmental conflicts. Natural resource problems are sometimes describes as "wicked"[4] or "messy"[5]; 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). Implementing solutions comes after much work is done building relationships, trust and communication (Cormick et al. 1996, Susskind and Field 1996, Carpenter and Kennedy 2001). One could go so far as saying that this process often starts with participants communicating their perception of the problem with their mental models of solutions. Facilitators point out that this is often the root of conflict and that persuading participants back to a collaborative effort that identifies the problem is the first step to finding consensus (Cormick et al. 1996, Susskind and Field 1996, Carpenter and Kennedy 2001). Figure 1.4 is designed like the diagram of the system dynamics process to illustrate the similarities of the two. And again, returning to previous steps is often a part of the process.

[4] The term "wicked" in the context of the environment was originally coined by Horst Rittel and Melvin Webber (1973) who was dealing with planning problems that were messy, circular and aggressive.

[5] Sterman (2000), Vennix (1996) and cite that messy problems are ideally suited for group system dynamic interventions

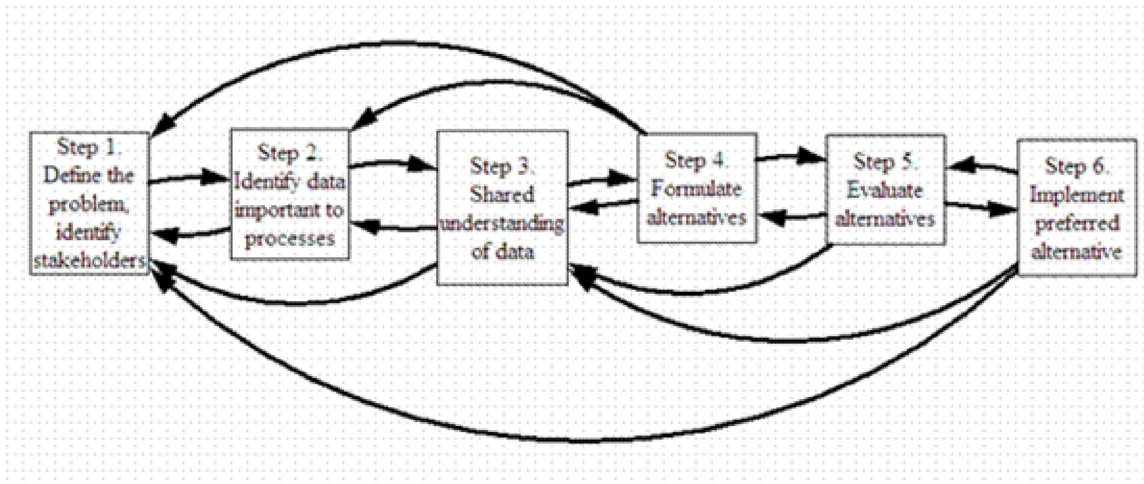

Figure 1.4 The steps of a facilitated process.

In step one defining the problem often encompasses identifying stakeholders. Understanding who should be involved helps with boundary definition. This is similar to describing the system (figure 1.2, step 1). Step two identifies data that is important for determining facts about a problem. For example a sage grouse group may need to know how sage grouse utilize land and the size of their range. A shared understanding of this data is necessary to establish "what we do know" before stakeholders can decide upon management alternatives. Often processes begin with statements such as 'farmer and ranchers are poor land manager who don't care about sage grouse, if the birds are listed federal management will be better'. The perception of the conflict is couched in a solution. By distilling the complexity down to negotiable concerns such as how farmers and ranchers actually use their land and the timing of specific biological needs of sage grouse, stakeholder can move forward to the development of alternatives. Although these steps are segregated in figure 1.4, the arrows are illustrative that facilitated processes will often return to previous steps.

During participatory modeling exercises there are two processes taking place simultaneously; model building and facilitated group problem solving. Model building creates a simulation of the problem and offers insights on potential solutions through policy simulations but may be only a part of the larger group process. Using Forrester's steps in figure 1.2, the development of a simulation model would provide stakeholders the insight to a preferred policy alternative and then they would implement that alternative. In the steps of facilitation figure 1.3 this would place the group at step six. Often participatory modeling processes are only used for learning and to assist stakeholders with problem definition. The group is still at steps one through three of facilitation. Models are also built in advance of an anticipated problem or conflict when a current change in policy is not yet needed. This could be considered pre-step one for facilitated processes. Chapter four provides examples and descriptions of case studies and their position on this problem definition to alternative implementation or solution producing continuum.

Groups who are in the early stages of problem definition will benefit from the model building process in several ways. In order to build their concerns into a model, the parameters of the problem must be clarified which inspires participants to evaluate and clearly communicate their own mental models. Participants may view the model or the model building process as a game which will help them focus on detail (the particulars of the problem) rather than outcome (the alternative that *must be* implemented). Parameter definition focuses attention on specific details on which there may be little disagreement helping to establish common ground between stakeholders. Also there can be an easing of tensions because if things "don't quite work like they should" there is only a model at stake.

Participants may also begin to realize that their piece of the puzzle only works with information from a potential adversary. Model building helps participants learn to prioritize and to compromise because model builders can only put in so many variables at a time. With each iteration of the model, participants have essentially practiced the roadmap that facilitators use to help groups find consensus. Consensus-based facilitated processes encourage group learning and "[t]hrough discussion, a new and better understanding of the problem may arise" (Susskind and Field 1996, p. 231).

Participatory modeling groups that are in the initial stages of problem definition have used both systems thinking and simulation modeling for assistance. Chapter four discusses case studies to compare these techniques. However, as in traditionally facilitated processes there comes a point when reliable, quantified, and scientifically oriented data becomes a priority.

1.3.1.a Using participatory modeling to convey the experiential knowledge of professional scientists and resource managers

At a national meeting of working groups for endangered species management, a high level agency representative remarked, in response to the idea of a species management model that included biology and social concerns, "you can't do it, we don't have enough data, we just don't know enough." The not too welcome reply was "you are managing in spite of your lack of knowledge right now." The biologist was visibly disturbed by the comment which was not made with the intent of criticism. On another unrelated occasion a different biologist stated that he was very uncomfortable with local working groups assisting with management because "we don't know enough about this species, now we will have [amateurs] involved." All of this is said with great respect for the knowledge of these biologists and the belief that decisions are being made with the best intentions. But the point should be ventured that these decisions are being made with mental models of incomplete information combined with an intuition for the problem that has developed through years of working in a specific environment. This is being human but it is also, contradictory to the tenets of scientific management.

These comments are not made as a criticism of these biologists who are among the best in their field. It is made as an example of the discomfort of the classic scientific mind to manage a system with limited information. No doubt scientists recognize that ecosystems are shared by humans, and in reality it is the human activity that needs to be managed not the activity of individual species. However that inclusion requires the consideration of social values which are often considered outside the realm of science.

The paradigm shift from the "balance of nature" manner of thinking to ecosystem science which acknowledges that change and humans are an inherent part of nature is an indication of the recognition of the limits of classical scientific thinking. Ecosystems are synergistic entities with no real boundaries except those imposed by humans. The need of the mind to constrain those ecosystems is an effort to take a snapshot and try to capture the essence of that snapshot. But arguably the moment the snapshot is taken, all of the intrinsic parts have changed.

For example, in endangered species management what does a percent chance of extinction mean? Will that percent chance be the same tomorrow? Can we even consider the concept valid in the face of the great uncertainties that climate change will have on ecosystems and individual species? What data like this ultimately tells us is whether or not we should be worried enough about something right now to warrant spending the money for conservation management and recovery. Does 45% warrant worry? Does 75%? We can only make value judgments such as this when we view the data in the context of the system of concern with understanding of all of the assumptions that were a part of the percentage calculation. This is where scientists often choose to step aside lest they become involved in moral judgments or social concerns and it is precisely where they need to stay involved.

Resource management is more complicated than it was historically when the public was not included in decisions. The culture of agencies has been greatly impacted by environmental laws such as the ESA, CWA, CAA and the APA which allow for citizen suits[6] against agencies. Historic command and control management may have allowed scientists to devise plans that included their experience with less oversight; hopefully a culture that is now driven by law suits does not discourage the benefits of the experiential knowledge of agency scientists. Participatory modeling can help scientists explain

[6] ESA 16 U.S.C. § 1540; CWA 33 U.S.C. § 1365; CAA 42 U.S.C. §7604; APA 5 U.S.C §552a (g).

scientific data and experiential knowledge to non-scientists such as policy people and the public.

*1.4 **Participatory modeling approaches in natural resource agencies***

Natural resource agencies recognize the need for modeling. Managers must be able to assess the ecosystem of concern with respect to its boundary, time frames, endogenous and exogenous impacts, and the feedbacks and time lags inherent in natural systems. Additionally, they must juggle a myriad of different personal, social and economic values in a system that is continually changing.

To accommodate the need for dynamic understanding of ecosystems and public participation, natural resource management agencies have been encouraged to look holistically at the problems they oversee through the lens of adaptive management. Agencies are incorporating the theoretical concepts of adaptive management into operational processes. The US Department of the Interior recently adopted the following operational definition.

> Adaptive management is a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of

> natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders (DOI 2007).

Adaptive management theory focuses on the understanding that knowledge is provisional. It tells us that we should learn by monitoring the results of scientifically designed management plans and then adjust accordingly (Grumbine 1994). It builds on key premises which include: 1) significant connections need to be determined; 2) structural features are more important to measure than numbers; 3) changes in one variable can have unexpected impacts; 4) monitoring of one variable can seem to indicate no change when drastic change is imminent (Nagle and Ruhl 2002, p. 337, Hollings 1978).

Folke (2006) emphasizes that the understanding of resilience is also required. This perspective takes into account uncertainty, surprise and more importantly acknowledges that variability is a fundamental quality of ecosystems. This means that decision makers should learn to view ecosystems as dynamic entities with intricate feedbacks that are inherent to both the system and to its dynamics. In addition, stakeholder participation, social and economic goals must be considered along with environmental goals. This requires the inclusion of potentially non-scientific data and a plethora of world views.

Current adaptive management theory incorporates variability, uncertainty, and the relationship of impacts with respect to potential temporal and spatial disconnects. This manner of thinking is captured by the field of system dynamics. Hollings (1978), Costanza and Ruth (1998) and others point out that modeling is a requisite component of adaptive management. In *Adaptive Environmental Assessment and Management*, Hollings (1978) encouraged its use with the caveats that we are always careful of process. "Abstraction and simplification are necessary, and in this process important, but often inconspicuous, components may be overlooked" (Hollings 1978, p. ix). They further emphasize the importance of understanding dynamics, and whether elements are sensitive or robust (Hollings 1978, p. xi). Costanza and Ruth, supporting the use of dynamic models for environmental problem solving, note that models "help us close spatial and temporal gaps between decision, actions and results" (1998, p. 185).

The US Geological Survey (USGS) the science agency for the Department of the Interior (DOI) and Massachusetts Institute of Technology (MIT) have formed the MIT-USGS Science Impact Collaborative (MUSIC). This effort endeavors to develop tools to assist with adaptive management (MUSIC 2007). Another inter-agency effort, Framing Research in Support of Adaptive Management of Resources (FRAME) project at Mesa Verde National Park, Colorado is an example of a collaborative modeling effort. FRAME couples models which simulate water, energy and biogeochemical processes into a geographic information system (GIS) interface. The USGS Modular Modeling System (MMS) allows managers to use open-source software in a collaborative and inclusive manner to evaluate management alternatives (Turner et al. 2007).

> By coupling the principles of collaboration with integrated modeling approaches we are developing a collaborative modeling framework to facilitate adaptive, multi-objective resource management that is applicable across a wide range of ecosystems. Recent trends in natural resource management – toward integrated science approaches, co-management in the face of uncertainty, and public engagement in land-use decision-making are trends that developed in response to a greater appreciation of the inherent complexity, feedback mechanisms, and uncertainty in natural systems, plus increased public scrutiny of decisions on public land (Turner et al. 2007, p. 40).

The US Army Corps of Engineers has used a variation of group model building called Computer Assisted Dispute Resolution (CADRe) to assist with watershed processes in what they refer to as Shared Vision Planning or SVP. SVP was developed by the Corps in the early 1960's (USACE 2007) however the term Shared Vision Planning originated in the business community (Palmer, personal communication 2007) and has roots in systems thinking. Senge (1990) encourages organizations to find a shared vision using system thinking to enhance group learning and improve decision making.

Water lends itself well to a variety of modeling techniques because of its inherent stock (reservoirs or lakes) and flow (rivers and streams) characteristics. However more important to SVP modeling is the long history of conflict over the use of water resources.

> Shared vision planning is an approach to managing this conflict in a way that can increase the chances for reaching constructive agreements. Shared vision planning relies on deliberative, inclusive decision making processes as the forum in which to debate how water resources will be used among competing ends. What is unique about shared vision planning, however, is how analytical technical expertise and analysis is integrated into a collaborative planning process. Through a structured planning process, an analytical computer model of the water resource system, called a shared vision model, is constructed with the participation of stakeholders. The shared vision model is designed to be used by stakeholders themselves to develop a mutually satisfactory water supply plan. (USACE 2007, Kurt Stephenson)

Facilitators for the Army Corps use system dynamic software such as STELLA to help collaborative groups integrate the outputs of hydrological models such as RIVERWARE or MODFLOW into models that can quickly simulate[7] management scenarios which the group has developed. SVP has been used to assist with the Corp with projects such as US

[7] MODFLOW and RIVERWARE are used to construct complex hydrological models of large watersheds. The disadvantage of using these models in management setting is 1) due to their complexity hydrological modeling expertise is necessary to understand the model itself. And 2) Simulations can take hours to run. System dynamics models can typically run simulations in seconds.

Drought Preparedness Study (USACE 2007), Joint Commission project on Lake Ontario and the St Lawrence River (USACE 2007), and for watershed planning in the everglades and the Delaware River (Sheer 2007).

USGS and other DOI agencies and the Army Corps use of participatory modeling supports the thesis that this is a useful problem-solving methodology. They also recognize the need for management models that integrate the outputs of complex research models into a format that allows mangers to explore policy alternatives. This process may be used to integrate the tenets of adaptive management theory, science, local knowledge and policy. In doing so it has the potential to open lines of communication between diverse world views and to help people understand the dynamic systems in which they live. A clear vision of a problem, and an understanding of cause and effect and time lags, will help people make more informed environmental decisions.

1.5 System dynamic models in the legal arena

In theory, public participation in agency decisions should improve decisions and reduce the number of controversial decisions that end up in court. Agencies could then be more proactive in plan development and scientific enquiry rather then spending time and money being reactive to law suits. If models are used in participatory processes they should maintain the same standards as other scientific endeavors so as not to compound the issues that are creating suits to begin with. It is questionable at this juncture whether a participatory model would ever be introduced in court but if it is used to compile experiential knowledge or street science, side by side to professional science, legal scrutiny should be expected. Modelers should strive to establish the same criterion of quality that creates other scientifically defensible models.

Participatory models are built for two general purposes. The first is to aid discussion and group learning. In such cases, qualitative data and "best guess" parameters may be sufficient. The second is to assist with problem comprehension and alternative analysis in management decisions. If these management decisions have the potential to be challenged in court then the model must held to the standards of best available science. In cases that involve scientific practice the US Supreme Court looks to Daubert Standards[8] to guide their judgment of science and to weigh expert testimony. Stephens et al. (2005 p. 95) have experience as expert witnesses in court cases involving dueling experts. They assert that "best-practice system dynamics work adheres to the scientific method and should prove admissible". Though their experience is limited to business disputes they are looking to scientific protocol as a defense because system dynamics is science based. Legal challenges to models may increase with their use. Modelers should anticipate this in advance and adhere to best-practice scientific protocol. Chapter five discusses recommendations for scientific defensibility. These include clear statements of hypotheses, transparency, documentation and replicability. Issues surrounding the use of different kinds of data and uncertainty will also be discussed.

[8] U.S. Supreme Court Cases: *Daubert v. Merrill Dow Chemicals, Inc.* 509 US 579 (1993); *General Electric Co. v. Joiner,*, 522 U.S. 136 (1997); *Kumho Tire Co. v. Carmichael*, 526 U.S. 137 (1999).

1.6 Concluding remarks

Participatory modeling can be time consuming and the quality of work will be dependant on the quality of available data, the techniques of modelers and facilitators and the willingness of the group to work together to find solutions. In addition, an important stakeholder may not be at the table, or at the last minute elect to advance their own best alternative to a negotiated agreement (BATNA) through legislative or legal avenues. Beyond the complexities of stakeholder groups, environmental problems are regulated by a variety of local, state and federal laws that may slow the process of alternative implementation. Even under conditions when no implementation takes place, participatory modeling stakeholders may still benefit. Participatory modeling can add value to a group process in a variety of ways. It can improve comprehension of the problem, and assist with group dynamics and group learning. It can be used to integrate professional science and different forms of local knowledge including street science and experiential knowledge.

Creating a nexus of science and local knowledge is essential for finding consensus-based solutions to environmental problems. Participatory models are effective for creating such a nexus. This thesis is supported by combined bodies of literature from the fields of system dynamics, group model building, facilitation, and adaptive management. The use of similar techniques by federal agencies within the Department of Interior and the Army Corp of Engineers provide further support.

It is also supported by the experience acquired building and assessing participatory models. Chapter two and three describe a modeling project for sage grouse management carried out with the Foster Creek Conservation District in Douglas County, Washington. The model was created as a part of their Multi Species Habitat Conservation Plan. Chapter four compares the Foster Creek project and nine others to illustrate the effectiveness of a broad range of interventions and the flexibility of participatory modeling techniques. Chapter five is an overview of lessons learned and recommendations to others who use or would like to use participatory modeling as a part of their efforts to find solutions to environmental problems.

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CHAPTER TWO

CASE STUDY:
SIMULATING SAGE GROUSE AND LAND USE
IN
CENTRAL WASHINGTON

2 Case Study: Simulating Sage grouse and Land Use in Central Washington

Allyson Beall and Len Zeoli

A version of the following chapter has been submitted for publication with the Journal of Ecological Economics and is presented here in manuscript form.

2.1 Introduction

The following case study describes a participatory modeling process which has successfully integrated ecological and economic considerations while at the same time melding federal, state and local values.

2.1.1 The Sage grouse

The Greater sage grouse (*Centrocercus urophasianus*) is a unique western North American gallinaceous species that lives in the sagebrush (*Artemisia*) habitats of the western United States and adjacent Canada (Fig. 2.1). Sage grouse are known as a sage brush obligate species because they depend on sagebrush for food, shelter and nesting. The sagebrush areas of Douglas County, Washington (Fig. 2.2) and other North American locales have been greatly changed by agricultural conversion, fire, invasion of exotic annuals, fragmentation, urbanization and inappropriate livestock management (Schroeder et al., 1999. 2000; Connelly et al., 2004) to the extent that sagebrush is now found in patches of varying size and condition (Quigley and Arbelbide, 1997). In

Douglas County alone, about 75% of the natural ecosystem has been converted to agricultural land (Douglas County Draft MSHCP 2005). The Douglas Country sage grouse population has an estimated 650 birds over approximately 300,000 hectares (Schroeder, personal communication, 2005). Estimates in the early 1960's indicated a population of 3000 birds (Connelly et al., 2004; Schroeder et al., 1999). Stories handed down from the original homesteaders, who began arriving in the late 1800's, tell of flocks of sage grouse that would darken the sky (Davis, personal communication, 2005).

Anthropogenic change and fragmentation of habitat have been the major driving forces in the decline of sage grouse populations. (Connelly et al., 2004; Stinson et al., 2004). Concern about this decline across the western United States has caused the sage grouse to be considered for inclusion in the US federal threatened and endangered species list by the US Fish and Wildlife Service (FWS). Listing will likely result in changes in the management of the remaining lands that harbor populations of sage grouse and consequently affect the activities and livelihoods of those dependent on sage grouse lands (Wambolt et al., 2002). Due to the controversy over this potential listing, and in lieu of listing at this time, federal land management agencies have agreed to participate with local working groups to develop long-range management plans that address sage grouse population declines and habitat needs (BLM, 2004; FWS, 2005; Western Governors, 2005).

Figure 2.1 Greater sage grouse (*Centrocercus urophasianus).* Photo by Kevin Pullen.

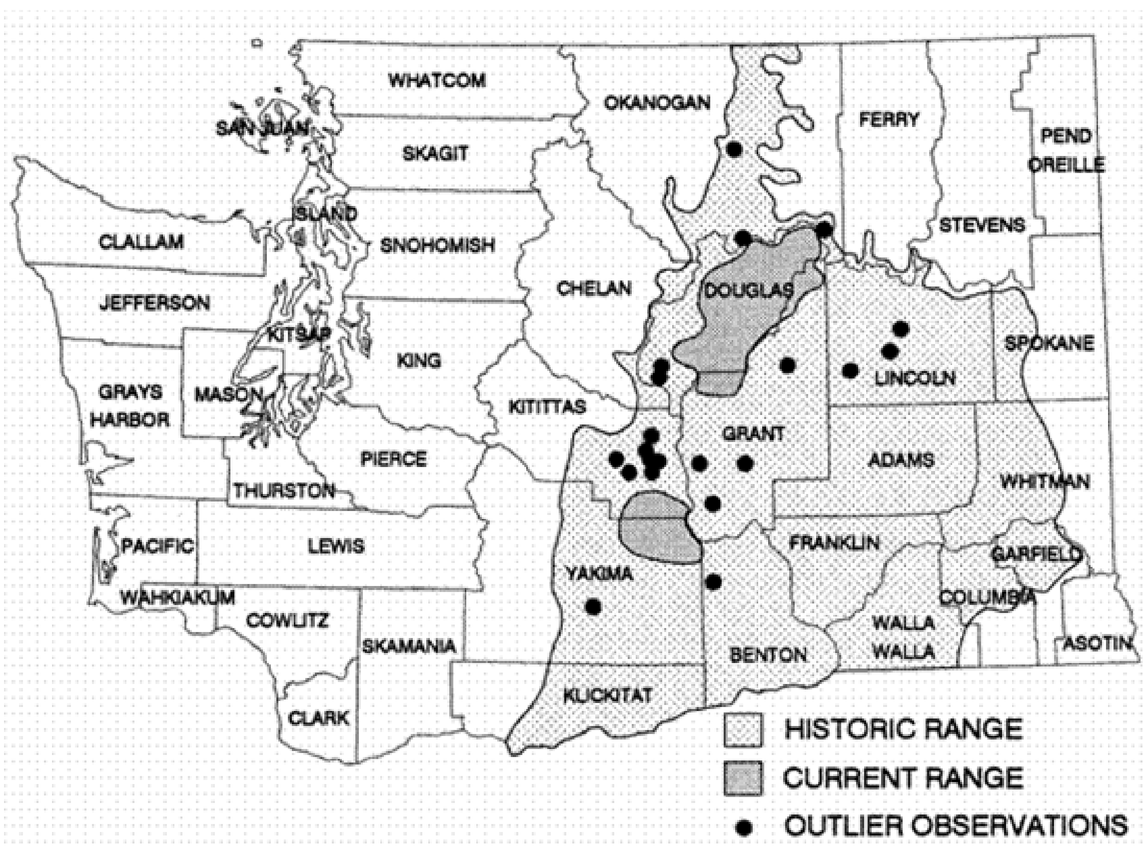

Figure 2.2 Current and historic range of the Greater sage grouse in Washington State (Schroeder 2000).

2.1.2 The Foster Creek Conservation District

Aside from the potential of federal listing, the sage grouse is listed as threatened in the State of Washington (Washington Department of Fish and Wildlife, 2005).[9] To help address the sage grouse and other species of concern, the Foster Creek Conservation District (FCCD), Douglas County, Washington has developed a Multiple Species Habitat Conservation Plan (MSHCP). The development of this plan has been inspired by the fact that a large percentage of the land in the County is privately owned and both federal and state listings have the potential to influence management of such lands.[10] "It is the expressed desire of the private agricultural land owners in Douglas County to reverse the declining population trends of [federally listed] species as well as other key fish and wildlife species within the County" (Douglas County Draft MSHCP, 2005). FCCD saw the potential for system dynamics to synthesize sage grouse biology with land use patterns to form a system-wide perspective of local impacts on the sage grouse population. The Integrated Sage grouse and Human Systems Model was designed to facilitate and support land use management decisions affecting the Greater sage grouse and to assist FCCD with adaptive management. "We know that we don't know everything, [and] FWS is comfortable allowing us to use adaptive management to fill in

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[9] WAC 232-12-297 Endangered, threatened and sensitive wildlife species classification.
RCW 77.12.020 (1) The director shall investigate the habits and distribution of the various species of wildlife native to or adaptable to the habitats of the state. The commission shall determine whether a species should be managed by the department and, if so, classify it under this section.

[10] (A) ESA section 9 upheld in Babbitt v Sweet Home Chapter of Communities for a Greater Oregon, 515 U.S. 687 (1995).
(B) WAC 232-12-297 11.1.3 An implementation plan for reaching population objectives which will promote cooperative management and be sensitive to landowner needs and property rights. The plan will specify resources needed from and impacts to the department, other agencies (including federal, state, and local), tribes, landowners, and other interest groups. The plan shall consider various approaches to meeting recovery objectives including, but not limited to regulation, mitigation, acquisition, incentive, and compensation mechanisms.
(C) Also see Langpap, L. 2006.

the blanks" (Dudek, personal communication, 2006). Additionally, because sage grouse are sage brush obligates, improving sage grouse habitat should also assist with the conservation of several other shrub steppe species of concern in Douglas County (Rich and Altman, 2001).

Development of the model was guided by a belief that sound ecological management happens only with respectful coordination and communication between land management agencies and land owners. Part of this coordination includes data sharing. Agency biologists are bound to scientific protocol, such as Population Viability Analysis (PVA), and peer review that produces reports that may be difficult to understand or hard to access by the general public. Land owners use historical information handed down through generations, personal observations, and instinct developed by their intimate knowledge of the land. Local knowledge is typically not offered in a format that will withstand scientific peer review. However they differ, both scientific and local knowledge are valid and useful. Conversely, both types of knowledge may contain inconsistencies brought about by lack of information, misinformation, or inadequate understanding of system complexity and dynamics. Furthermore, landowners may feel that issues concerning their livelihoods should be more prominently included in the process. Costanza et al. (1997, p. 72) reinforce the importance of local input with the statement that "to the extent that social and ecological systems differ from place to place, local experiential knowledge will be essential to implementing specific solutions". Melding local and scientific information into a system dynamics model offers a unique venue for data verification, shared learning, and improvements in communication and trust (Costanza, 1998, p. 183, Stave, 2002 p.139, van den Belt, 2004).

System dynamics was developed in the early 1960's by Forrester (1961). This methodology facilitates comprehension of system behavior and synergy with the assistance of dynamic simulation models. While static models advance understanding of systems at rest by providing snapshots of a particular moment, dynamic models provide insight as to how a system changes over time (Ford 1999). Growth, decay and oscillations are the fundamental dynamic patterns of systems and the methodology is useful for understanding the issues that create limits to growth (Meadows et al. 1972, Ford 1999). For example, a natural population will grow exponentially until it reaches a limit or what biologists refer to as carrying capacity. When modeled, this dynamic behavior is graphically represented by an s-shaped curve.

2.1.3 The role of system dynamics

System dynamics has been used to study industrial, urban (Forrester 1961, 1969), and business dynamics (Sterman, 2000). Vennix (1996) and others have used system dynamics in group model building exercises to promote team learning. Meadows et al. (1972) and Sterman (2002) encouraged the use of system dynamics to grapple with the daunting problems of global sustainability.

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. Using group system dynamics modeling for participatory environmental problem solving is a relatively new process which has been used on a variety of environmental problems such as air quality, water quality and quantity, and biological conservation management. Van den Belt (2004) describes five case studies, their models and the lessons learned from the processes. Stave (2002, p. 139) used group system dynamics modeling to help the citizens of Las Vegas explore remedies to air quality problems. Tidwell et al. (2004, p. 357) used system dynamics modeling to assist citizens with watershed planning in the Middle Rio Grande River valley. Wildlife models have been developed for bear management (Faust et al., 2004, p. 163; Siemer and Otto, 2005) and fishery management (Otto and Struben, 2004, p. 287). Videira et al. (2004; Videira, 2005; p. 27) modeled "tourism, eco-tourism, aquaculture, fishing, wildlife protection and nature conservation, effluent discharge and navigation of fishing and recreation boats". Spatial-dynamics were used by BenDor and Metcalf (2006, p. 27) in a decision support tool for ash borer eradication.

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.

2.2 *The Group Modeling Process*

The Integrated Sage grouse and Human Systems Model was developed in collaboration with land owners, agency representatives[11] which included scientific experts, and representation from The Nature Conservancy. FCCD needed a management model that integrated their current knowledge and could help them prioritize conservation efforts. The FCCD process depicts an effective collaboration that has a current problem well defined, plausible solutions well defined, and plans which acknowledge a future with many unknowns.

The modeling process was conducted, and the model completed in 12 weeks, which is considerably shorter than many other participatory modeling processes (Stave, 2002, p. 139; Tidwell et al., 2004; Otto and Struben, 2004; Videira et al., 2006). Project length was set by budgetary constraints, yet in spite of the short timeframe, success was made possible by a combination of factors.

First, the modelers were able to build on earlier wildlife simulation models. Akcakaya (1998), Lacey et al. (2007) and others have developed life history modeling software, known as population viability analysis (PVA) that is used to assess probability of persistence for populations of threatened and endangered species. There are a few examples of modelers using system dynamics for threatened or endangered species planning. Faust, Jackson and Ford (2004) used system dynamics software to model a

[11] Washington Department of Fish and Wildlife (WDFW), US Fish and Wildlife Service (FWS), Bureau of Land Management (BLM), Natural Resources Conservation Service (NRCS), Washington Department of Natural Resources (WDNR), Douglas County Farm Service Agency, and an “at large” range expert.

threatened grizzly bear population in Yellowstone with the intent of testing the usefulness of the methodology and software for life history modeling. The work by Pederson and Grant (2004, p. 187) *Sage grouse Populations in Southeastern Idaho, USA* used system dynamics to study sage grouse affected by sheep grazing and fire management policy on public lands. These models exemplify effective learning tools that illustrate the use of wildlife demographics in a system dynamics model.

The second and perhaps more significant factor which enabled the success of the project was the FCCD group itself. Many other participatory modeling processes are used for, and spend substantial time defining their problem. For these processes, qualitative models which articulate the collaborative vision of the problem can be the most valuable product of the process and essential for group learning (van den Belt, 2004; Videira, 2006). FCCD group members have a 25 year history of working together successfully addressing a litany of problems. Board members who represent nine stakeholder groups have an established working relationship and have achieved considerable consensus with respect to problem definition and potential solutions. In addition to their local insights, the science team has amassed a great deal of data and statistical estimates developed through peer reviewable processes. They needed to integrate their wealth of knowledge into an operating simulation model that could be used to evaluate policy alternatives and to explain those alternatives to others.

At the first meeting, modelers met with 12 group members who were either on the science team or members of the board. A salmon population model developed by Ford

(1999) was used to illustrate system dynamics. As residents of the Northwest, participants were familiar with salmon life history. The modelers felt that it would provide an example of an anthropogenically influenced biological system that was similar enough to allow them to grasp how this could work for sage grouse, but different enough that the participants would not feel that the modelers had preconceived ideas or assumptions. Having no preconceived ideas was an asset; it helped build confidence that the model would reflect the needs of the stakeholders. Other modelers who have used preliminary models of the actual issue have found that participants may be distracted by the results and not focus on system structure (Pederson and Grant, 2004, p. 187), or found the initial model did not accurately portray their concerns (van den Belt, 2004). The stock and flow illustration of salmon life history gave stakeholders an opportunity to scrutinize the structure of a system dynamics model and question model assumptions. This inspired them to think how a similar structure could apply to sage grouse. The modelers had initially planned to spend more time with the group on causal loop exercises and building simple models. It became clear early on that this was not necessary, and in hind sight may have been an aggravation to people with limited time for meetings and who seemed to intuitively understand systems thinking. The stakeholders are ranchers, farmers and land managers who have been working with their landscape for many years. They are accustomed to integrating a variety of parameters and time frames into their decisions. Systems thinking is part of their management strategy.

After introducing system dynamics, several hours were spent discussing the concerns and needs of the stakeholders. The modelers returned after two weeks for a presentation which included a simple model of the system based upon collective stakeholder comments at the first meeting and a great deal of research on life history modeling. The initial model was accepted because it outlined a platform that would accommodate concepts and data developed by the stakeholders. Over the course of the next two months, modelers met two more times with the group in conjunction with regular FCCD board meetings that were typically attended by 9-11 people and covered topics well beyond sage grouse. The insights learned during these meetings illuminated the larger picture of endangered species management on private land and were of great assistance to the modeling team who were free to ask questions of the board members. There were also frequent email and phone discussions with key participants.

FCCD is primarily concerned with two policy issues, each with potential costs. First, for the MSHCP to be successful land owners need to sign on to it and use prescribed best management practices (BMPs). If landowners use BMPs the habitat should improve and sage grouse numbers should increase. The district manager noted that the management changes required for inclusion in the MSHCP may be costly to individual farms or ranches. However, he felt that the burden of managing land under federal regulation that would result from listing without the MSHCP in place, would be far more costly to private property owners (Dudek, personal communication, 2006). The second concern is land in the Conservation Reserve Program (CRP)[12], a designation which is controlled by

[12] "The Conservation Reserve Program (CRP) is a voluntary program for agricultural landowners. Through CRP, [a farmer] can receive annual rental payments and cost-share assistance to establish long-term, resource conserving covers on eligible farmland. The Commodity Credit Corporation (CCC) makes annual rental payments based on the agriculture rental value of the land, and it provides cost-share assistance for up to 50 percent of the participant's costs in establishing approved conservation practices. Participants enroll in CRP contracts for 10 to 15 years." (Farm Service Agency, 2006)

the Farm Service Agency. There is concern that a significant portion of quality sage grouse breeding habitat presently designated as CRP will loose its status. Loss of CRP designation discontinues payments that keep these lands in wildlife habitat and could result in significant habitat destruction if farmers break out the land and plant crops. Through the addition of this economic issue in the model, the concerns of landowners have been placed on equal footing with science and made more explicit to agency representatives and scientists.

2.3 The Model Structure

The model was designed with VENSIM software which was chosen for two reasons. First, the drop-down menus provide convenient access to model pages that contain both model structure and user interfaces. Secondly, FCCD had requested that the modelers build a population viability analysis (PVA)[13] of their sage grouse population and the modelers wanted to use the VENSIM statistical screening capabilities for comparing results with the PVA.

The user interfaces and the stock and flow structures are spread across 26 views, all of which are available to the user. Interfaces include graphs that illustrate the effect of land use change upon the sage grouse population and potential economic impacts of land use changes on farmers and ranchers. The model contains 273 parameters of which 10 are stocks. One may argue that this number of parameters reduces transparency; however, the 26 views are designed to segregate issues which reduces the tendency for users to be

[13] see Akcakaya, H.R. and W. Root. 1998.

overwhelmed by a large and cumbersome model map. The sources of the model constants and reasoning behind the quantitative links between them have been thoroughly documented in the comment window of each variable. A monthly time step allows the model to capture the effects of breeding and winter area habitat suitability. The FCCD planning horizon is 50 years and therefore a typical simulation runs for 50 years.

Spatial aspects of the system have been incorporated through the aggregation of land use categories and habitat suitability indices which include consideration for sage grouse density and their use of different areas during breeding and winter seasons (Schroeder personal communication, 2005). Although system dynamics models can be designed to include a higher degree of spatial detail with the use of SME[14] (Costanza and Vionov, 2004; BenDor and Metcalf, 2006, p. 27) in this case, a cell by cell analysis would not create any additional practical information. The sage grouse are already confined to well-defined habitat fragments and seasonal movement between breeding and winter ranges is accounted for in the suitability indices.

2.3.1 Economics and Local Knowledge

Simulation outputs of economic issues are in the form of graphical representations of district wide net wheat production and CRP income so that it may be compared to costs of management changes for inclusion in the MSHCP. Due the high variability of wheat production costs and price per bushel, participants requested that sliders[15] be added for

[14] SME: Spatial Modeling Environment
[15] Sliders are model interface components that allow users to choose the values of variables that are otherwise constants.

users to adjust these parameters for changing conditions. In addition, the cost that landowners may incur for inclusion in the MSHCP varies between land types, so again sliders were added. CRP payments per acre are fairly uniform and were included at an area wide per acre average with option to experiment with this value.

2.3.2 Sage grouse Demographics, Habitat and Land Use

Important life stages and demographic rates of the Greater sage grouse were provided by FCCD science team member and WDFW biologist Schroeder, and supported with current literature (Schroeder, 1997; Schroeder et al.; 1999, Stinson et al., 2004). Life stages appear in the model (Fig. 2.3) as stocks for eggs in nests, chicks, adult female birds, and adult male birds. Demographic rates appear as the flows between the stocks and include variables such as "successful hatches".

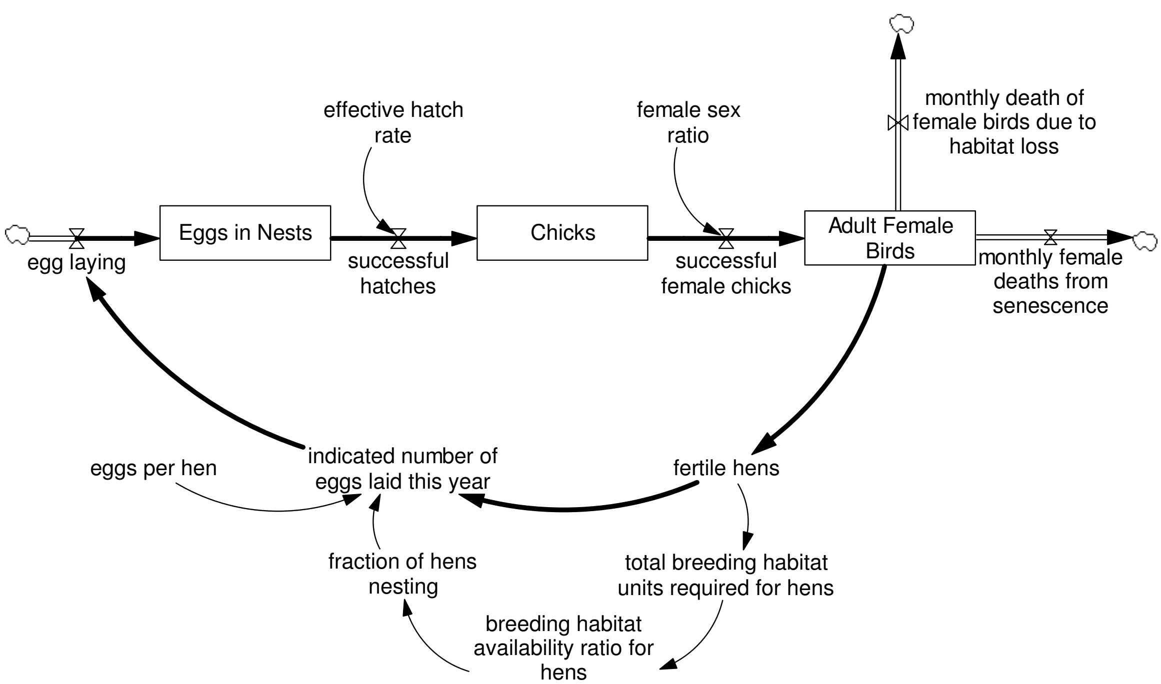

Figure 2.3 Female Bird Life History and Reproduction.

The basis for FCCD's conservation efforts is the thinking that habitat improvement will increase sage grouse numbers. Model simulations substantiate that the Douglas County sage grouse population has a positive rate of growth and therefore the size of the population is constrained by habitat. If the population was limited by genetic and reproductive issues, habitat improvement alone would not be sufficient for improving numbers. Given this positive rate of growth, more habitat units, whether acquired by expanding habitat through restoration, or by improving existing habitat, should support more birds and gives direction and support for efforts to improve habitat. Figure 2.4 (with the hypothetical initial population of 100 birds) illustrates the dynamics of the model with a classic s-shaped curve indicative of a population with a positive growth rate which has reached carrying capacity. The yearly saw tooth shape is a result of the birth pulse and high chick mortality. The model includes a "smooth function"[16] (Fig. 2.5) at the request of FCCD for ease of graph viewing and because the yearly pulse is not a management issue.

[16] The smooth function is designed by VENSIM to take time averages of a variable. The smoothed graphs for the sage grouse represent an average over a two year period.

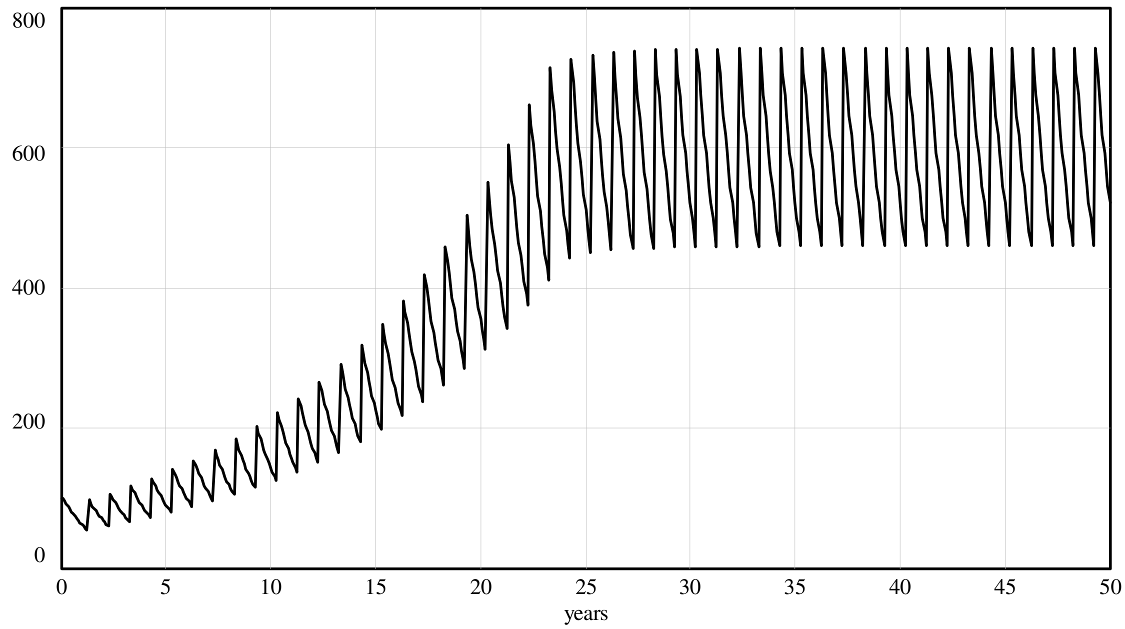

Figure 2.4 S-shaped curve illustrating a population with a positive growth rate reaching carrying capacity. The yearly sawtooth shape is the result of the spring birth pulse.

Biologists have indicated that the current Douglas County population of approximately 650 birds is most likely at carrying capacity (Connelly et al., 2004). Schroeder (personal communication, 2005), suggests that breeding and winter habitat may both be equally limiting at this time. Therefore, population limits have been set in the model by dividing the current estimated population into the total breeding and winter habitat units. This establishes a density dependence between the birds and both types of habitat units that puts the current population at carrying capacity. Other feedbacks include the number of nests in available breeding habitat (Fig. 2.4), and the effect of habitat on both chick and adult mortality.

This population of sage grouse is migratory and uses different parts of its range for winter and for breeding; therefore, each of the land use categories has an assigned suitability index for both winter and breeding use. There are 11 aggregated land categories which include cropland, Conservation Reserve Program (CRP) and shrub steppe designations that are further delineated by their proximity to one another, steepness of slope, and degree of fragmentation.[17] With consideration for breeding or winter suitability, this effectively splits land designation into 22 categories. For example, the highly fragmented shrub steppe has a suitability of 0.65 (out of 1) for breeding habitat and 0.05 for winter habitat, while gentle and continuous shrub steppe has a breeding suitability of 0.1 and a winter suitability of 0.6. Due to the potential for debate over the suitability indices, user interfaces have sliders to manipulate them.

At equilibrium, as illustrated by the baseline simulation in Figure 2.6, the model produces a population of approximately 600 birds rather than the estimated 650. FCCD was comfortable with this discrepancy because a small change in even one of the suitability indices could result in 650 birds.

FCCD is very concerned about chick survival because their scientific research indicates that it is the most critical time in sage grouse life history. Simulation results (Fig 2.6) support this concern. Additional examination using VENSIM sensitivity analysis confirmed that chick survival is by far the most sensitive parameter in the model. These results support that field monitoring and conservation efforts should be especially cognizant of breeding habitat.

[17] Land designations: cropland in crop landscape, cropland in shrub steppe (ss) landscape, CRP in crop landscape, CRP in shrub steppe landscape, shrub steppe gentle and continuous, shrub steppe steep and continuous, shrub steppe gentle and moderate, shrub steppe steep and moderate, shrub steppe fragmented, palustrine wetland and barren.

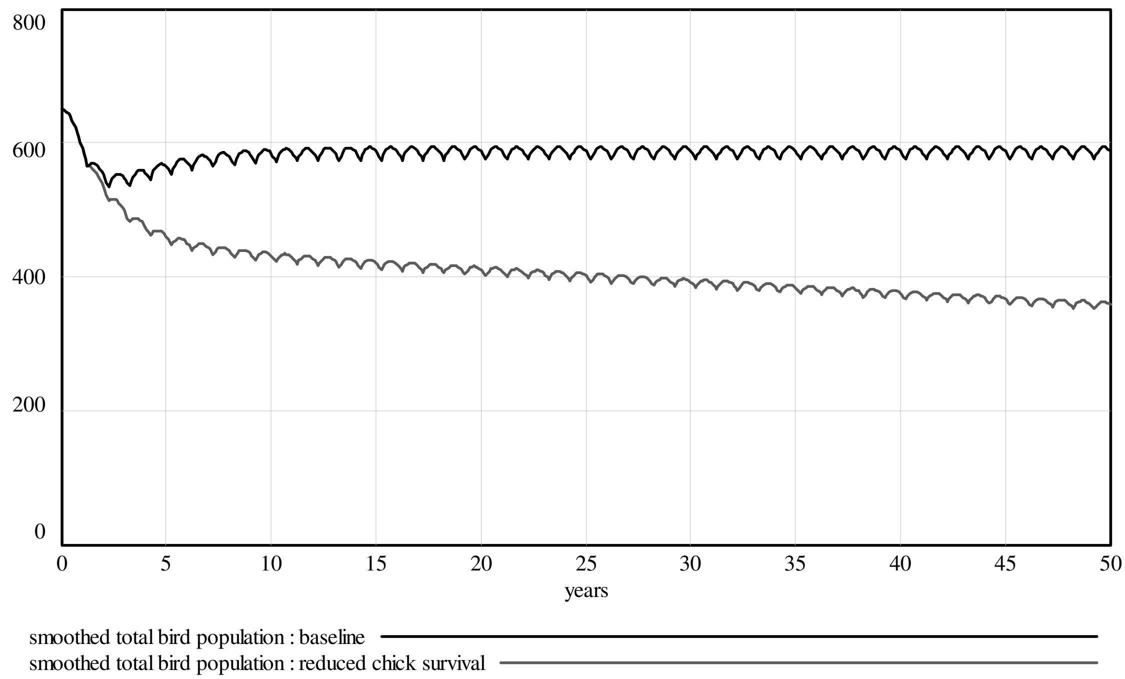

Figure 2.5 Response of the Douglas County Greater sage grouse population to a downward change in the annual chick survival rate from the baseline (black) model value of 0.167 to a critical value of 0.128 (gray). The critical or threshold value was found by experimentally decreasing the survival rate until the population trajectory began to go down.

2.3.3 Environmental Variation

Biologists, managers and people who make their living from the land know that productivity of the land and therefore its carrying capacity change from year to year. This is in large part due to variations in local weather patterns. Sage grouse populations tend to fluctuate in approximately 10 year cycles (Connelly et al., 2004); however, the drivers of these cycles in Douglas County are not well understood (Schroeder personal communication 2005). The FCCD group originally requested that this type of variability be included to add more realism to the model. Due to the lack of data on natural cycles, variability was determined by a loose correlation with historic rainfall. The resulting output did show a cyclic behavior in the sage grouse population, but not at the expected interval. There was the option of adding other variables that could help explain natural cycles, such as observed changes in predator populations. It also is well known that major reductions in the sage grouse population occurred when large blocks of shrub steppe land were plowed under for wheat. Yet there is little or no likelihood that significant tracts of land will be removed from wheat production and restored to shrub steppe. In the end, the group decided that recreating the past or speculating on the causes of cyclic behavior would not affect their current choices of management strategies and was therefore not a value added part of the model at this time.

*2.4 **Illustrative Results***

Users of the model may explore hundreds of potential scenarios. Individual interfaces emphasize different concerns so as not to overwhelm the user with too many choices at once. Once a user becomes familiar with the different interfaces he or she may navigate between them to address any combination of concerns. Sliders were included for important constants in the model. It was delivered with the VENSIM software in two formats: a synthetic simulation format and a gaming option. Synthetic simulation gives the opportunity to instantly simulate changes in demographic rates (Fig. 2.6), or other constants such as habitat suitability indices or changes in wheat price or production costs. The gaming option let users run the model in predetermined time steps, such as 5 years, and ask “what if” questions that have time dimensions.

For example a landowner who has been approached to sign on to the MSHCP could potentially ask about the following scenario: "What if 50% of us sign on to the MSHCP at costs to each of us of $0.50 per acre per year for 5 years. What does that add up to for total investment in the sage grouse? And then, what if many years down the road we have three consecutive cold wet springs during the hatch and we loose every one of the chicks for three years, could we loose the entire population?" The habitat conservation view of the model has sliders for the 50% and $0.50 cost per acre. Graphical outputs show that the total investment would be $1.75 million per year or $8.75 million over 5 years. For a rancher with cattle on 20,000 acres this equates to $1000.00 per year for each of the 5 years.

Figure 2.6 illustrates the scenario over time. In year 10, landowners sign onto the MSHCP and change their management practices to accommodate sage grouse conservation. In the next 8 years the population grows until it reaches its new equilibrium or carrying capacity. Years 25, 26, and 27 then have chick survival rates of zero and the population declines rapidly. Years 28 and 29, with chick survival returning to normal still show a declining population; however it levels off and begins to climb until it again reaches carrying capacity in about 15 years.

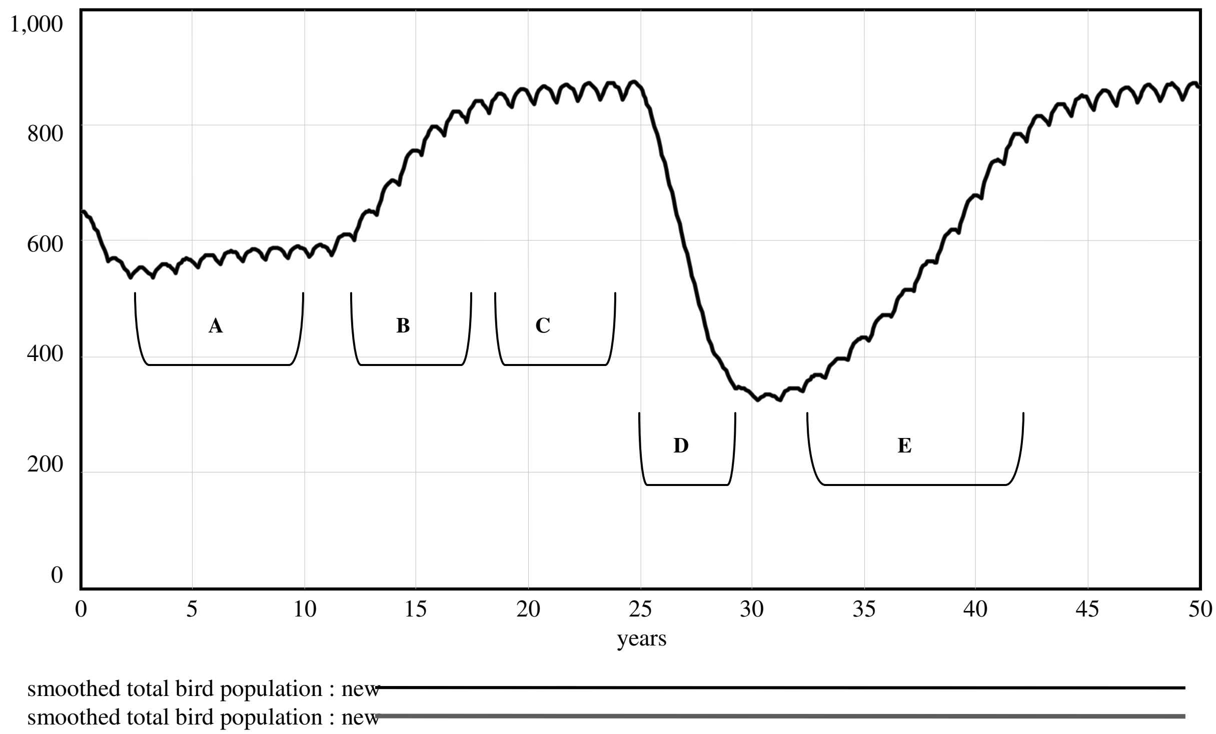

Figure 2.6 A potential "what if" scenario. A: system in equilibrium. B: 50% sign on to MSHCP. C: new equilibrium. D: three years with no chicks surviving, population continues to drop for two more years. E: population recovers.

2.5 Concluding Discussion

This case study highlights the integration of science, local knowledge and social concerns into a participatory process that uses system dynamics. The resulting model is a forum for the exploration of the impacts of land management decisions upon the sage grouse population and the landowners of Douglas County, Washington.

The Integrated Sage grouse and Human Systems Model was developed as the result of a group of people reacting to political and financial uncertainty, and out of a love of their land and home. They understand that the economic climate has pressed them to break out shrub steppe land that was once important sage grouse habitat, and that much of that land is not highly productive for crops. And though respectful of the laws of the nation and state, they feel that local land use decisions should be made with local knowledge and local participation.

The FCCD plans to integrate the model into their MSHCP adaptive management program and use the model as an educational tool to explain program benefits to area landowners. During the modeling process FCCD realized that they were not satisfied with their habitat suitability indices. They are presently working with landsat data which will be used to create new land categories with suitability indices that more realistically capture the potential for habitat improvement. By including new parameters such as soil depth they feel that they may better target land for restoration projects. Landsat data will then be added to the model and updated as necessary so that simulations reflect current conditions. Additionally, the land use template of the model has the potential to be adapted and applied to other species of concern in Douglas County with the addition of new life history views for individual species. The dedication of Foster Creek to their MSHCP adaptive management and monitoring program will also provide the unique opportunity for current model simulations to be evaluated and cross checked in the future with real time data.

The significance of this project is that it shows that a collaborative group who has learned to solve problems through deliberation, openness, respect and dedication can integrate science and long term visioning. FCCD realizes that environmental problem solving is not a linear process but one of learning and iteration as illustrated by their inclusion of adaptive management protocol in their MSHCP. The modelers did not design the model to teach the group the functional basics of their system; the group taught the modelers about their problems. Though multiple iterations of the model during the building process and through exploration and scrutiny of simulation results, the model was developed to reflect years of accumulated knowledge. The model was designed so that the group could teach themselves and others, and to help farmers and ranchers make individual land use choices in the context of the area wide impacts that those choices may have. It provides FCCD a platform to share their talents for dynamic systems thinking.

Collaborative problem solving has great benefits but also comes with incredible challenges. We hope that by sharing this experience we can encourage other collaborative groups who are dealing with challenging group dynamics or poorly defined problems. Success comes out of long term commitment to hard interpersonal work, and an understanding of the structure and dynamic relationships that are inherent to the system of concern.

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CHAPTER THREE

FOSTER CREEK CONSERVATION DISTRICT INTEGRATED SAGE GROUSE AND HUMAN SYSTEMS MODEL

AND

DOUGLAS COUNTY GREATER SAGE GROUSE POPULATION VIABILITY ANALYSIS

3 Foster Creek Conservation District Integrated Sage grouse and Human Systems Model and The Douglas County Greater Sage grouse Population Viability Analysis

The following chapter is a version of the report presented to the Foster Creek Conservation District at the completion of the modeling project. It is presented in manuscript form.

The models contained herein are property of Foster Creek Conservation District and may not be used without their permission. Information included in this dissertation on the Integrated Sage grouse and Human Systems Model and the Douglas County Greater Sage grouse Population Viability Analysis is provided with the permission of the Foster Creek Conservation District.

The authors of this report, Allyson Beall and Len Zeoli would like to acknowledge the support of Foster Creek Conservation District. We are especially appreciative of Britt Dudek, District Manager and Mike Schroeder, Washington Department of Fish and Wildlife. Support for the Douglas County Multi-species Habitat Conservation Plan was provided by the US Fish and Wildlife Service.

Summary

The Greater sage grouse (*Centrocercus urophasianus*) is a unique western North American gallinaceous species that lives in the sagebrush (*Artemisia*) habitats of the western United States and adjacent Canada. Sage grouse are known as a sage brush obligate species because they depend on sagebrush for food, shelter and nesting. The sagebrush areas of Douglas County, Washington and other North America locales have been greatly changed by agricultural conversion, fire, invasion of exotic annuals, fragmentation, urbanization and inappropriate livestock management[18] to the extent that sagebrush habitat is now found in patches of varying size and condition[19]. In Douglas County alone, about 75% of the natural habitat has been converted to agricultural land. [20] Anthropogenic change and fragmentation of habitat have been the major driving forces in the decline of sage grouse populations which no longer exist across their former extensive historical range.[21] Concern across the US West about this decline has caused the sage grouse to be considered for inclusion in the US federal threatened and endangered species list. The State of Washington has listed the sage grouse as

[18] Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver 2004. Conservation Assessment of Greater Sage grouse and sagebrush habitats. Cheyenne, Wyoming, Western Association of Fish and Wildlife Agencies.
Schroeder, M. A., J. R. Young, and C. E. Braun 1999. Sage grouse. The Birds of North America. A. Poole and F. Gill, Cornell Laboratory of Ornithology.
[19] Quigley, T. M. and S. J. Arbelbide. 1997. An assessment of ecosystem components in the interior Columbia River Basin and portions of the Klamath and Great Basins. Portland, Oregon: U. S. Dept of Agriculture, Forest Service, Pacific Northwest Research Station, U.S. Dept of Interior, Bureau of Land Management. Report nr PNW-GTR-405.
[20] Draft Douglas County Multiple Species habitat Conservation Plan January 13, 2005.
[21] Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver 2004. Conservation Assessment of Greater Sage grouse and sagebrush habitats. Cheyenne, Wyoming, Western Association of Fish and Wildlife Agencies.
Stinson, D.W., D.W. Hays, and M.A Schroeder 2004.Washington State Recovery Plan for the Greater Sage grouse. Washington Department of Fish and Wildlife, Olympia, Washington.

threatened.[22] Listings will likely result in changes in the management of the remaining sagebrush lands that harbor populations of sage grouse and consequently affect activities and livelihoods of those dependent on sage grouse lands.[23]

To help address such issues, Foster Creek Conservation District (FCCD), Douglas County, Washington is presently developing a Multiple Species Habitat Conservation Plan to help not only the sage grouse but 19 other species of concern. "It is the expressed desire of the private agricultural land owners in Douglas County to reverse the declining population trends of FESA Species as well as other key fish and wildlife species within the County."[24] As part of this effort, an Integrated Sage grouse and Human Systems Model, and a Douglas County Sage grouse Population Viability Analysis (PVA), have been developed.

The Douglas County Sage grouse Population Viability Analysis and the Integrated Sage grouse and Human Systems Model development have been guided by a belief that sound ecological management happens only with respectful coordination and communication between land management agencies and land owners. Part of this coordination includes data sharing. The management agency-land owner relationship may be strained, perhaps, not so much by the data itself but by the data collection processes and types of data which either party considers important when making decisions. Agency biologists are bound to

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[22] July 1, 2005 http://wdfw.wa.gov/wlm/diversty/soc/threaten.htm

[23] Wambolt C.L., Aaron J. Harp, Bruce L. Welch, Nancy Shaw, John c. Connelly, Kerry P. Reese, Clait E. Braun, Donald A. Klebenow, E. Durant McAuthur, James G. Thompson, L. Allen Torell, and John A. Tanaka. 2002. Conservation of Greater Sage grouse on Public Lands in the Western U.S.: Implications of Recovery and Management Policies. Caldwell, Idaho: Policy Analysis Center for Western Public Lands. Report nr PACWPL Policy Paper SG-02-02.

[24] Draft Douglas County Multiple Species habitat Conservation Plan January 13, 2005

scientific protocol, such as PVA, and peer review that produces reports that may be difficult to understand or hard to access by the general public. Land owners use historical information handed down through generations, personal observations, and instinct developed by their intimate knowledge of the land. Local knowledge is typically not offered in a format that will withstand scientific peer review. However they differ, both scientific and local knowledge are valid and useful. Conversely, both types of knowledge may contain inconsistencies brought about by lack of information, misinformation, or an inadequate understanding of system complexity and dynamics. Furthermore, landowners may feel that issues concerning their livelihoods should be more prominently included in the process. Melding local and scientific information into a systems model offers a venue for data verification, shared learning, and improvements in communication and trust.[25] This in turn increases the likelihood that land use decisions will lead to improved stewardship.

System dynamics modeling is a powerful approach by which sage grouse working groups may better understand land management challenges posed by declining sage grouse populations. This method has the greatest potential when used in a collaborative fashion by scientists and managers working together with others who also have a stake in land management decisions. The intention of the Integrated Sage grouse and Human Systems Model is to further develop insights into the cropland and shrub steppe ecosystems of Douglas County to facilitate and support land use management decisions concerning the greater sage grouse. This model integrates greater sage grouse demographics, current

[25] Stave, K. 2002.Using system dynamics to improve public participation in environmental decisions. System Dynamics Review, Vol. 18 #2. van den Belt, M. 2004. *Mediated Modeling*. Island Press. Washington, D.C.; Covelo, California; London.

land use and suitability indices from the FCCD habitat matrix, and elementary Douglas County wheat and Conservation Reserve Program (CRP) economic data. The model has been built with VENSIM ® software. Please find the Model Report in Part 1.

Population Viability Analysis assesses risk of extinction and assists with identification of sensitive demographic parameters. The need for sage grouse PVA was identified at the National Conference for Sage grouse Local Working Groups in Reno, NV in February 2005. Two have been published thus far, one by Johnson and Braun (1999)[26] who completed a PVA for the sage grouse in North Park, Colorado. Another has been done by the Colorado Division of Wildlife for the Gunnison sage grouse (2005)[27]. PVA is not only useful in addressing species viability in any specific geographic area, but also adds to knowledge of sage grouse population dynamics and to the development and application of tools for decision making in the context of conservation biology. The Population Viability Analysis delivered to FCCD incorporates an extensive literature search and data provided by Mike Schroeder, WDFW biologist, into a model built with Vortex[28] software. Please find the complete PVA report in Part 2.

Though PVA is a standard used by biologists to identify sensitive parameters, model format, operation and analysis would hardly be considered "user friendly". However, placing PVA identified sensitive demographic parameters in a systems model provides

[26] Johnson K.H. and C.E. Braun. 1999. Viability and conservation of an exploited sage grouse population. Conservation Biology 13(1):77-84.
[27] Gunnison Sage grouse Rangewide Steering Committee. 2005. Gunnison sage grouse rangewide conservation plan. Denver, Colorado: Colorado Division of Wildlife.
[28] Vortex is a PVA simulation software. R.C. Lacy, M Borbat, and J.P. Plooak. 2005 VORTEX: A Stochastic simulation of the Extinction Process. Version 9.50. Brookfield, Illinois: Chicago Zoological Society.

landowners and land managers the opportunity to investigate demographics in a more accessible format. The systems model also offers the user the opportunity to investigate sage grouse habitat suitability indices, potential land use changes and area economics as a holistic system rather than as segregated parts.

These models have been designed as decision support tools and to help develop instincts for adaptive management of a complex environmental system.[29] They are not designed as definitive predictors of any specific point in time but rather should be used for combining and computing values that have been depicted by human minds as descriptors of their environment. Models are valuable because the human mind is not capable of computing the myriad of parameters and relationships found in complex systems. Traditionally, humans have assessed various types of data and often made management decisions based on "gut feelings" as to how the actual system will respond. With models, these "gut feelings" may be tested and analyzed. Adaptive management suggests that humanity take a holistic view of its surroundings and learn about the parts as they are related to the whole. These models offer a step towards that goal.

As we integrated PVA and land use information into the systems model we tried to anticipate the questions that would be asked of the model as well as the reactions of the FCCD working group. Experience tells us that as users explore a model they inevitably

[29] Ford, A. 1999, *Modeling the Environment: An Introduction to System Dynamics Modeling of Environmental Systems*, Island Press.

want to start making improvements. Potential improvements suggest that we have encouraged people to better understand a system that is important to them.

3.1 Foster Creek Conservation District Sage grouse and Human Systems Model

The Integrated Sage grouse and Human Systems Model incorporates Greater sage grouse demographics, current land use and suitability indices from the FCCD habitat matrix, and elementary Douglas County wheat and Conservation Reserve Program (CRP) economic data. It has been built with the intention that it will assist with development of insights into the cropland and shrub steppe ecosystems of Douglas County and the sage grouse that are a part of those ecosystems. It is designed to facilitate and support land use management decisions through the collaborative exploration of model parameters and simulated scenarios.

This system dynamics model uses stocks and flows to represent land and land transitions, and sage grouse life history. These stocks and flows form mathematical relationships to one another and to other variables that affect or are affected by said stocks and flows (for model language see appendix 1). As relationships are often complex, many variables are used to assist with model transparency. For example, there is a variable which describes acres to hectares conversion. Most mathematical relationships use simple algebra, although timing devices and switches may be more complicated. The user may view all of these variables and their relationships; there are no hidden equations.

Users may explore and create simulated futures in which land use change affects sage grouse populations. Systems models such as this are not designed to predict exact numbers, but rather to educate users about potential trends in the dynamic systems that are important to them. This chapter describes the Integrated Sage grouse and Human Systems Model with respect to the data that were used for inputs, the model views and interfaces, and specifications for software, format, time, special aspects and environmental variability. It then describes how the Model may be used to explore system parameters and offers several illustrations of simulated results. For a complete printout of model views see appendix 4.

3.1.1 Input Data

All land and suitability data have been derived from the FCCD habitat matrix (Appendix 2). Sage grouse viability and production data have been obtained from Mike Schroeder, WDFW and cited literature, and confirmed by Mike Schroeder. Sensitive parameters have been identified with the accompanying PVA. Model variables which use any of the above data include citations on the comment screen for that variable.

3.1.2 Sage grouse Demographics

Important life stages of the Greater sage grouse have been identified from current literature (Schroeder et al. 1999, Stinson et al. 2004) and with information provided by Mike Schroeder, WDFW biologist. These stages appear in the model (Figure 3.1) as stocks for eggs in nests, chicks, adult female birds, and adult male birds. The flows between the stocks such as "successful hatches" are regulated by rates as described in the literature (Schroeder 1997) and have been confirmed by recent discussions with Mike Schroeder. Male birds are separated from female birds because they have a different mortality rate and because they are not responsible for the productivity loop involving egg laying.

It is not known how density dependence limits sage grouse populations; however, it does occur. Biologists have indicated that the current population of approximately 650 birds is most likely at carrying capacity (Connelly et al. 2004). Schroeder (personal communication 2005), notes that breeding and winter habitat may both be equally limiting at this time. Therefore, population limits have been set in the model by dividing the current estimated population into the total breeding and winter habitat units as defined by the FCCD habitat matrix (Appendix 2) (found in the "current" setting of the model). This establishes a density dependant relationship between the birds and both breeding and winter habitat units. Another density dependant relationship is established through the major feedback loop highlighted with the darkened blue line on the "Female Life History" view of the model. This relationship limits the number of nests in available breeding habitat to a default amount based on the current conditions. In other words, to establish more nests, more habitat units are needed. Other feedback loops operate through mortality rates of both chicks and adults and appear on their associated life history views.

The calculations appearing on the view "Availability of Breeding and Winter Habitat" define the relationship between habitat units and bird population. As habitat units are added or subtracted, the population expands or shrinks to fill those units to capacity. The effect of shrinking habitat is an increase in mortality as outlined on the two views, "Habitat Effects on Chicks" and "Habitat Effects on Adults". The effect of adding habitat is to allow more space for nesting, which allows for increased productivity.

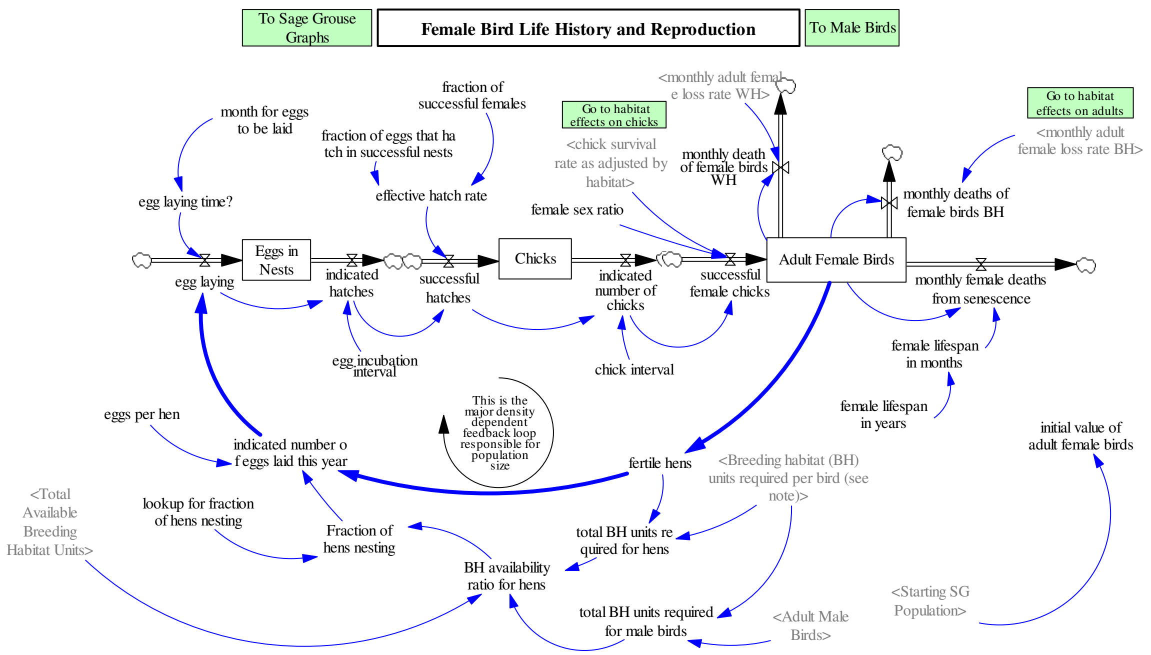

Figure 3.1 Female Bird Life History and Reproduction.

3.1.3 Land Use, Economics and Local Knowledge

Land use data and land areas have been taken directly from the FCCD habitat matrix (Appendix 2). The FCCD habitat matrix defines the sage grouse range within Douglas County as covering 292,030 hectares and includes 11 land categories. Each of the 11 land categories has been included in the model. Wheatland and CRP have been integrated into stock and flow variables to allow the user to change percentages of CRP contracts in the sage grouse area (Figure 3.2). Shrub Steppe designations are static. Suitability Indices indicated on the matrix have been included and multiplied with their appropriate land designations to create habitat units.

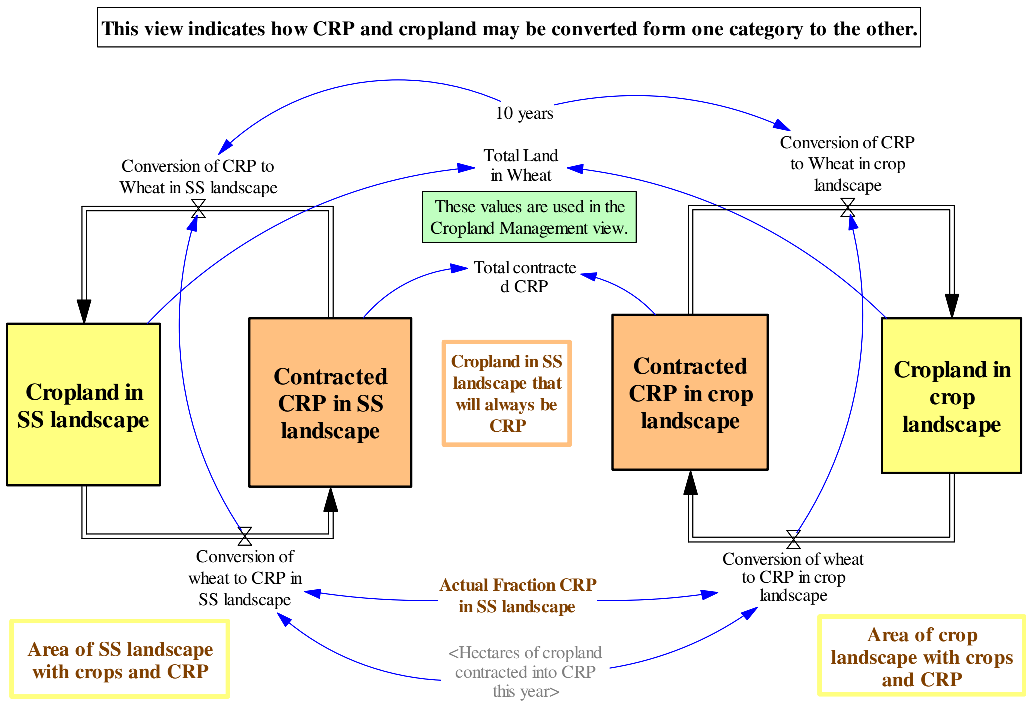

Figure 3.2 Cropland and CRP View of the systems model.

3.1.3.a Suitability Indices

The user has been offered three ways to manipulate suitability indices (Figure 3.3). The default position illustrates the "current" condition as indicated in the matrix. A second option allows the user to improve suitability indices through inclusion in the Habitat Conservation Plan (HCP). It should be noted that simply moving the model into HCP mode increases habitat units (even with "0"% HCP). Britt Dudek (per. com 2005) has noted that this is due to the "0"% HCP scenario being sometime in the future when the current land categories have had time to further develop their habitat quality. A third “manual” option is offered to allow the user to manipulate individual indexes to test their effect on the system.

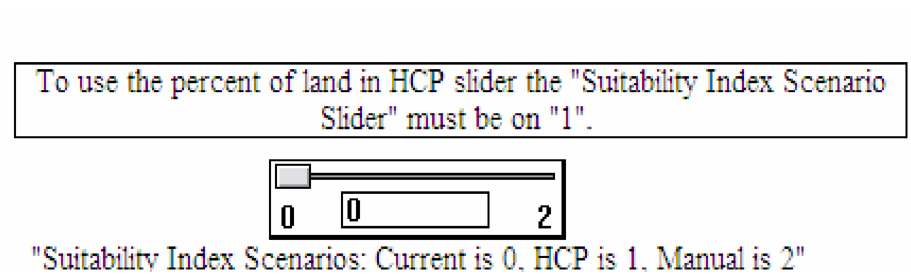

Figure 3.3 Suitability Index Scenario Sliders found on the Habitat Suitability Indices view, Habitat Conservation Plan view and Matrix Verification view moves land into HCP or allow the users to test individual suitability indices.

3.1.3.b Local Information and Economics

Gathering local information in Douglas County has been limited due to the time constraints of the model building period and the onset of summer harvest. Concerns addressed at the FCCD June 7, 2005 meeting and the June 16, 2005 Settlers and Sage grouse gathering have been included as much as possible with the consideration that these inclusions are generalized. To go beyond generalities requires verification of values and relationships by stakeholders.

The model offers a starting point for discussion and continued discovery of the potential impacts of land and sage grouse management upon land owners and sage grouse. For example, wheat growers and sage grouse are likely to be impacted by the 2007 Farm Bill. After a quick review of an earlier version of the model, Wade Troutman (per. com. 2005) suggested a “switch” that would remove CRP from the system (a potential outcome of a farm bill which removed conservation support). This was subsequently added and the model now simulates the impact of this potential loss of CRP upon sage grouse populations and area economics.

A simple economic model that contrasts area-wide net CRP income with wheat income and production costs has been included (Figure 3.4). Considerable time has been spent on a “cattle economics and potential land impacts of grazing” component of the model. At present this has not been integrated into the sage grouse model due to the lack of verification from ranchers. This is a complex system and there are many assumptions and parameters that require consensus as to both their impacts and usefulness to the sage grouse model. However, the model presently offers ranchers a platform to discover potential impacts to sage grouse through the improvement of shrub steppe suitability. Ranchers will no doubt begin to describe how the improvements should or will take place, and the benefits, costs and impacts to ranching operations. As this discovery develops, FCCD may find it useful to include these items in a future version of the model.

The “Habitat Conservation View” offers three sliders that allow the user to estimate cost of improvements per acre that landowners may incur for inclusion in the HCP. The costs are segregated for shrub steppe land, wheat land and CRP. Please note that the inclusion of land in HCP assumes an equal distribution across land types.

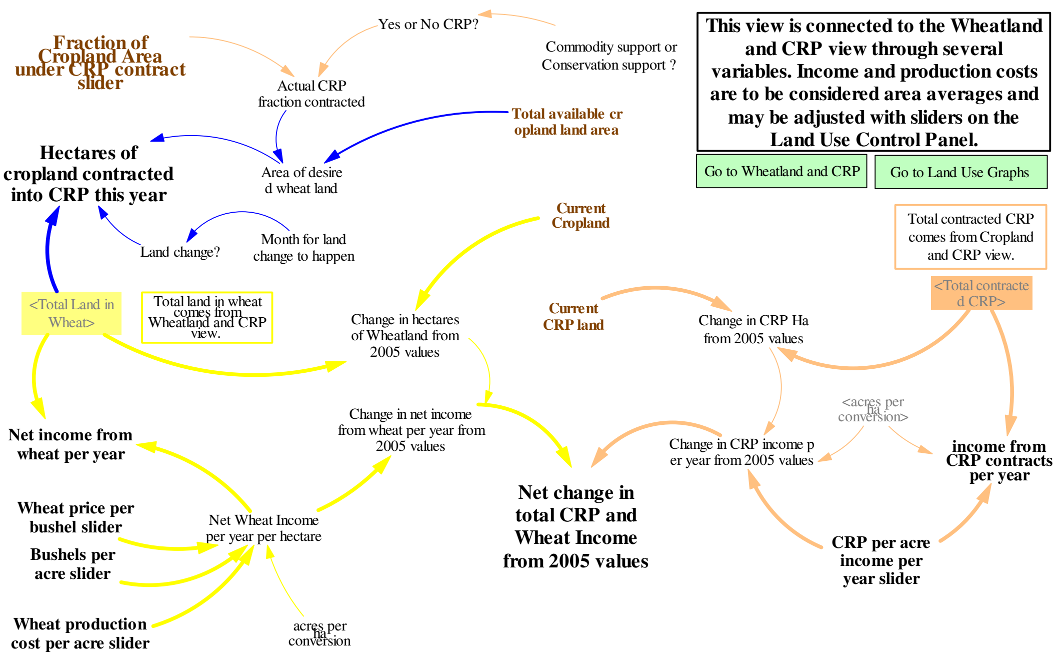

Figure 3.4 Cropland Management View.

3.1.4 Interactive Views

The model user is offered several user interface views with instructions and model outputs (all interfaces may be seen in appendix 4). Figure 3.5 shows the interface which explores sage grouse life history. Each of these interactive views are linked to several views of model structure that show variables, their relationship to one another (visually seen as connectors or arrows), and how they are linked algebraically. The sources of the model constants and reasoning behind the quantitative relationships have been documented in the comment window of each variable. Navigation buttons have been designed to aid with movement throughout the model.

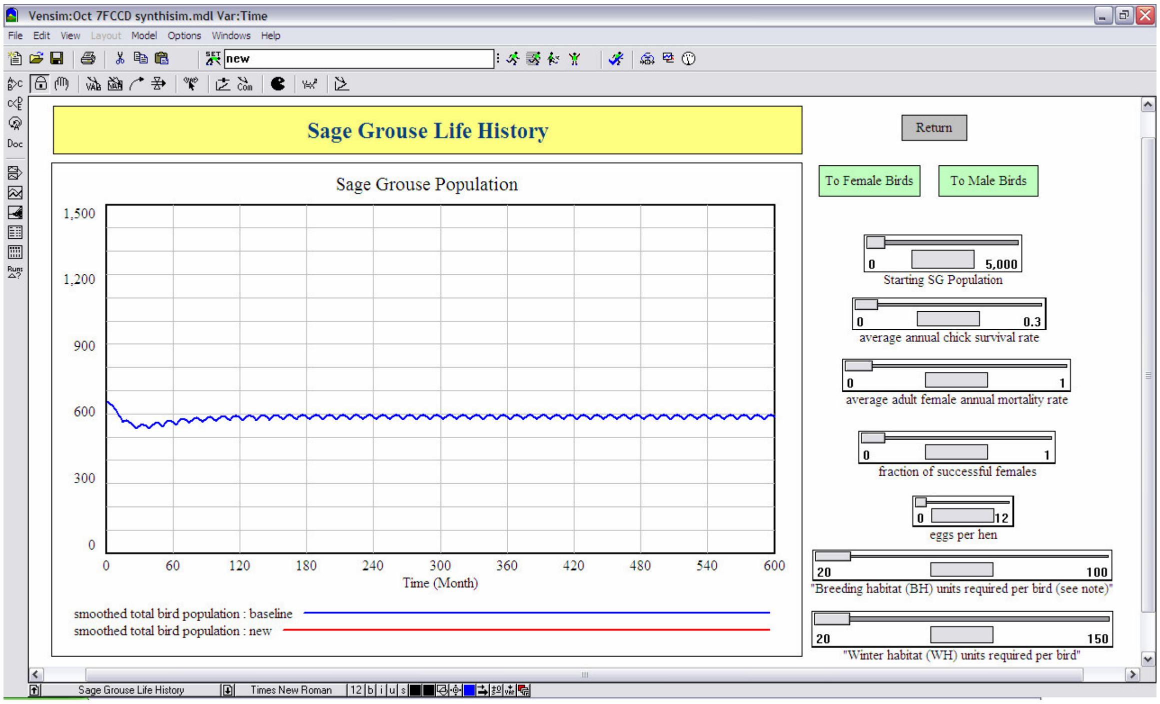

Figure 3.5 Sage grouse Life History Interface showing a graph of population size and sliders for adjusting sensitive demographic parameters.

3.1.5 Model Specifications

The Foster Creek Conservation District Sage grouse and Human Systems Model has been built with the following specifications.

3.1.5.a Model Software

VENSIM ® PLE plus, a product of Ventana Systems INC., 60 Jacob Gates Road, Harvard, MA 01451.

3.1.5.b Format

The model is offered in two different formats: synthetic simulation (synthi-sim) and gaming. The synthi-sim format allows the user to manipulate controls and watch graphical and tabular outputs instantaneously respond. The gaming format allows the user to run the model for a given time period, make changes to the system, and then continue to run the model to learn how a specific management decision changes system output.

3.1.5.c Time

The model runs for 50 years, the time period covered by the HCP.

Though not explicitly a function of time, suitability indices have a time element built into their assumptions. Suitability indices, as per the habitat matrix, are default settings for the “Current” and “Manual” settings on the “suitability index scenario slider”. Any changes to suitability while in the “Manual” scenario instantly change the habitat from present to a future state with no consideration for the time it takes for vegetation to grow. Therefore, how these indices change over time must be user defined outside of the model. When set in the “HCP scenario”, habitat units are increased over the “current” values due to the increase in suitability as noted in the FCCD matrix. This is based on an assumption that the HCP scenario will begin at a time in the future when the “current” landscape conditions will have matured (Britt Dudek per. com.). A potential improvement in the model would allow for suitability adjustments to happen over a discrete time period. This change would require substantial structural modification to all land stocks and flows with the rate of landscape maturation built into the flow variables.

CRP contracts have been set for a 10 year renewal pulse with the assumption that the outgoing CRP suitability is the same as the incoming CRP suitability. Again, the time issue discussed above would potentially improve this aspect of the model. Please note that during a one month renewal period, CRP is removed from the system, and the land "becomes wheatland". When the renewal month is over, the land returns to CRP with the pertinent values and percentages reflecting any changes made to CRP contracts in the previous 10 years.

3.1.5.d Spatial Aspects

The model does not have explicit spatial aspects; however, the sage grouse area in Douglas County has been delineated and the included landscape has been split into 11 land categories as defined by the FCCD matrix (appendix 2). The model assumes that changes to any of the land categories will be uniform across that given landscape with the exception of CRP distribution. The slider "actual fraction of CRP in SS landscape" allows the user to manipulate the distribution of CPR between crop and shrub steppe landscapes.

The model assumes that any changes to habitat units available for the sage grouse happen uniformly across their range with the relative importance of that change reflected in the suitability index. For example, breeding habitat suitability for CRP in shrub steppe landscape has a higher index (.4-.55) than CRP in crop landscape (.05-.12). A substantial transfer of CRP from shrub steppe landscape to crop landscape could significantly change available habitat units for nesting.

3.1.6 Environmental Variation

Environmental variation may be added to a simulation by turning the “habitat variability on?” switch to the “on” position. This switch is found on the Environmental Variation view. The randomness that occurs is the result of a randomness generator found on the Randomness Generator view. The variability was determined by a loose correlation with historic rainfall. Several sliders mute the effects of this variable but this should not be taken as “muting” actual environmental variability (for example decreasing chick survival). This graph is not shown with the smoothed function to better illustrate the effect (Figure 3.6). The red and green lines show the degree of variation imposed on breeding and winter habitats.

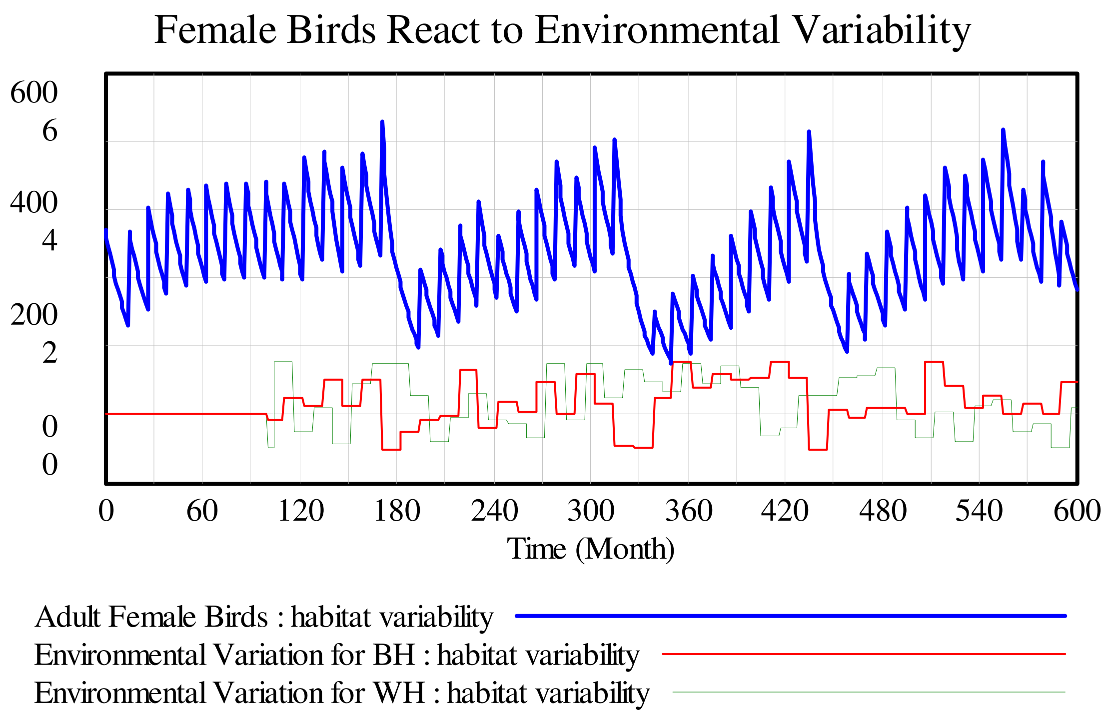

Figure 3.6 Environmental variability.

3.1.7 Using the Systems Model to Explore Land Use and its Dynamic Interaction with Sage grouse

Systems dynamic models combine chosen variables of complex systems to create simulations that help reveal important dynamic relationships. In this model, exogenous variables such as total hectares of land, initial bird population, and bird demographics are combined with endogenous variables such as habitat units and fraction of hens nesting to create illustrative graphs of potential population. Exogenous variables are any inputs that are placed in the model but have been determined externally. Endogenous variables are those that are created by model operation and will vary according to the dynamics of the entire system. For example, the fraction of hens nesting in any given year is an endogenous variable determined by the number of fertile hens, needed breeding habitat and available breeding habitat. This number will fluctuate with changes in land use and changes in bird population. It is the combination of exogenous and endogenous variables that allow the model to find its own equilibrium, growth or decline. It should be noted that the baseline, or current population finds equilibrium just below 600 birds rather that the expected 650. This equilibrium has been reached by the model as the result of combining parameters and is not "fixed" by model builders. Thus, by combining the estimates of suitability with the hectares of land into habitat units and integrating those units with bird demographics, the model has in effect found a population number quite close to the bird population calculated by Mike Schroeder. Small adjustments in one of many parameters will produce 650 birds. For example, Figure 3.7 illustrates that increasing the gentle and continuous shrub steppe breeding habitat suitability from 0.1 to 0.15 will produce a graph of 650 birds. Note the "ramp up" portion of the graph. The model is seeded with 650 adult birds, as seen on the far left of the graph. The birds then reproduce, live and die in their given habitats until the population "finds equilibrium".

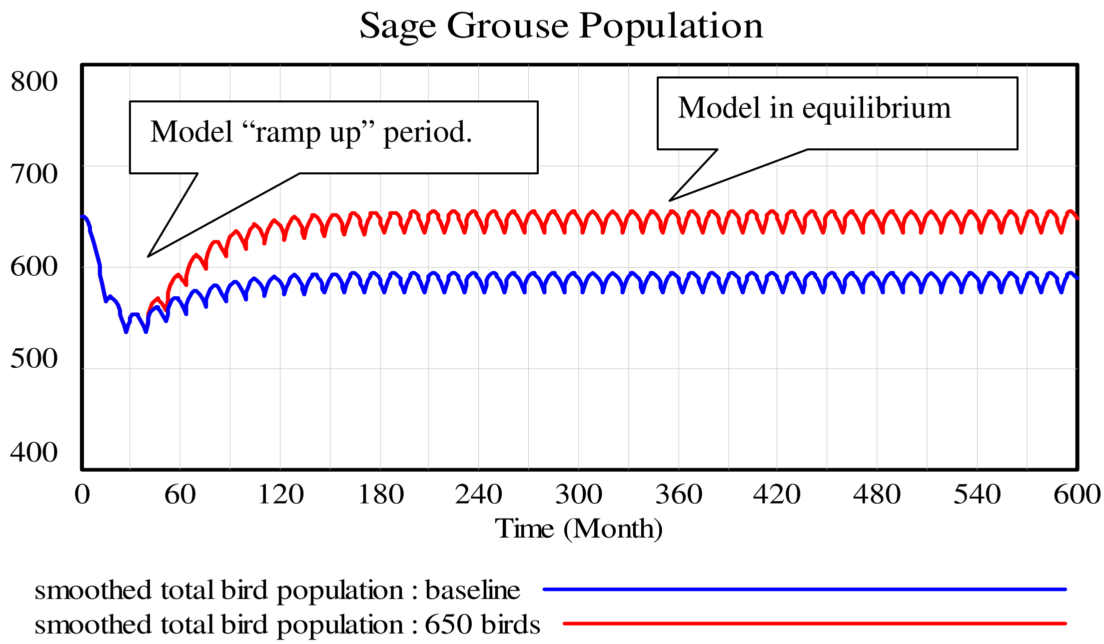

Figure 3.7 Baseline population is lower than the expected 650 birds. Simple adjustments to one of many parameters will raise the population to 650. In this scenario, the gentle and continuous shrub steppe breeding habitat suitability was raised from 0.1 to 0.15.

The population numbers have been smoothed for ease of illustration. Figure 3.8 depicts both the smoothed and "not smoothed" populations. The large annual fluctuation is the result of the yearly birth pulse. Smoothing occurs over 24 months and is a rolling average of population numbers.

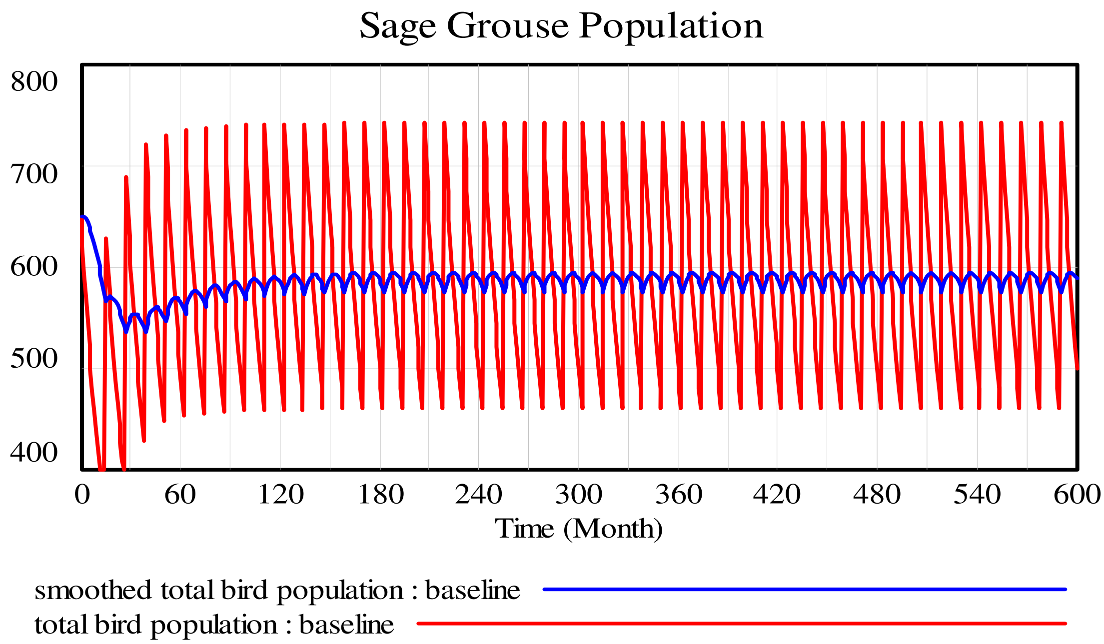

Figure 3.8 Population smoothing is shown by the blue line. The red, unsmoothed line, depicts the large annual birth pulse.

The following sections offer examples of model simulations to illustrate how changes in sage grouse demographics and land use parameters might affect the size of the sage grouse population.

3.1.7.a Using the Systems Model to Explore Sage grouse Demographics

Current demographic rates are favorable for the continued persistence and growth of the Douglas County population. Productivity is high and female mortality is low compared to other studies.[17] The model population responds positively to increases in habitat quantity or quality. However, demographic parameters are not givens, but rather they are estimates with an associated standard deviation and they may change over time with changing environmental or other conditions, such as an Allee effect (described in section

3.3.2). Sensitivity analysis in both the PVA and systems models has shown that the model is sensitive to certain demographic rates. Sensitive parameters are chick survival, female mortality, percent of successful females (*i.e.*, females that have more than 1 chick) and eggs/nest. The PVA analysis of these parameters is in section 3.3.3. The systems analysis of these parameters was conducted by discovering a critical or threshold value for each, defined as the value at which the sage grouse population began to decline. Each sensitive parameter was explored independently of the others. For example, the annual chick survival rate is 0.167. Chick survival is an adjustable slider on the Sage grouse Life History view set at the default position of 0.167. By decreasing chick survival in small increments, it was found that the trajectory of the grouse population began to decline at a value of 0.128 (see Figure 3.9). This is a very small downward change in the survival rate (approximately .04) and shows the sensitive nature of this parameter. The specified amount of change is well within the standard deviation assigned to that rate, and therefore should be considered as a possible annual rate for any year. Chick survival is the only parameter with a threshold value that falls within the standard deviation of its rate, although eggs/nest is very close. The model indicates that chick survival is the most critical parameter which coincides with the PVA analysis and with the literature cited above and expert opinion (Schroeder, per.com). The same type of analysis was done for the other 3 sensitive parameters. Results are in Table 3.1. When these rates are monitored or updated, future values can be compared to the critical values to evaluate the importance of changes.

There are also synergistic effects when more than one demographic rate changes at the same time. Small (and declining) populations are subject to an inverse density dependence known as the Allee effect which is any factor, or more likely, combination of factors that cause the growth rate of a population to decline as it gets smaller (see section 3.3.2). The systems model allows the user to change several demographic rates at the same time to simulate the decrease in productivity and survival normally associated with declining populations. For example, the 4 sensitive demographic rates were reduced concurrently by 10%. Results are in Figure 3.10 and show the population in serious decline. Although it is not possible to fully model the effects of inbreeding depression at this time, it can be tentatively explored in this format by changing the demographics rates most likely to be affected such as chick survival and successful females. Such explorations show the ease of using systems models for simulation and investigation, although the user should have a good rationale for the changes being simulated.

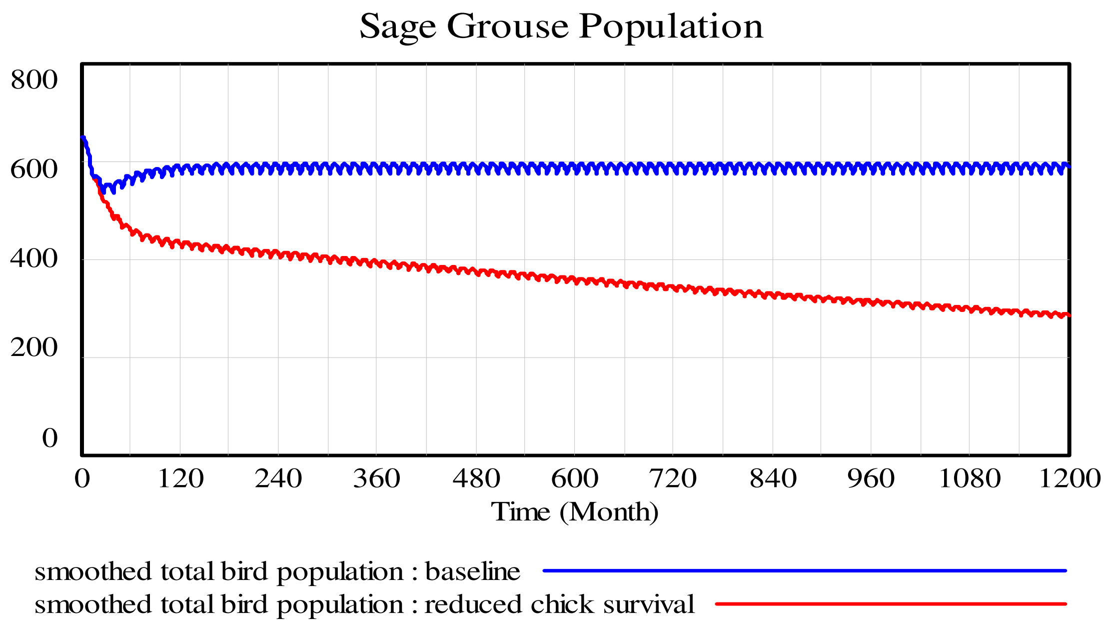

Figure 3.9 Response of the Douglas County Greater sage grouse population to a downward change in the annual chick survival rate from the model value of 0.167 to a critical value of 0.128. The critical or threshold value was found by experimentally decreasing the survival rate until the population trajectory began to go negative.

Parameter	Model Value	Threshold Value	Difference	Standard Deviation
Chick Survival	0.167	0.128	~0.04	0.10
Female Mortality	0.25	0.36	.09	0.068
Fraction of Successful Females	0.59	0.45	0.14	0.10
Eggs/nest	9.1	7.0	2.1	2

Table 3.1 Threshold values for sensitive parameters in the systems model of the Douglas County Greater sage grouse population.

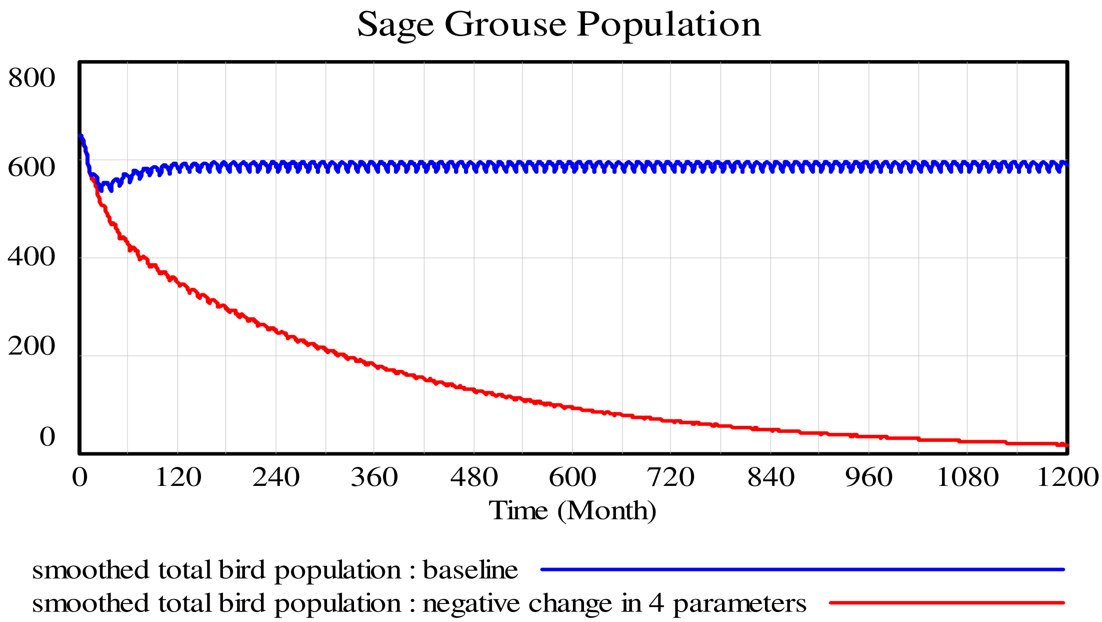

Figure 3.10 Synergistic response of the Douglas County Greater sage grouse population to a negative change of 10% in the four sensitive parameters, chick survival at 0.15, female mortality at 0.275, fraction of successful females at .53, and eggs/nest at 8.2.

3.1.7.b Exploring Land Use Changes

The system model allows users to investigate the effects of potential land use changes on the sage grouse population. Model users have been supplied with sliders for many parameters that can be used alone or in combination to investigate possible future scenarios. Population projections resulting from the inclusion of land in the HCP on the Habitat Conservation Program view, and changes in percent of contracted CRP may be estimated by changing sliders on the Land Use and Economics Conservation Reserve Program views. The Manual Suitability Index Control Panel also offers users the opportunity to explore the effects of suitability improvement in any of the breeding or winter habitat categories as illustrated in Figures 3.7 and 3.11.

Figure 3.11 offers an illustration of potential increases in sage grouse numbers with the inclusion of lands in the HCP. As discussed before, placing the model in HCP mode increases habitat units due to the assumption that the current conditions have matured into something more suitable at some time in the future when the HCP is initiated. Inclusion of 100% of the available land into the HCP will further improve suitability. The graph illustrates a new and higher equilibrium for the bird population.

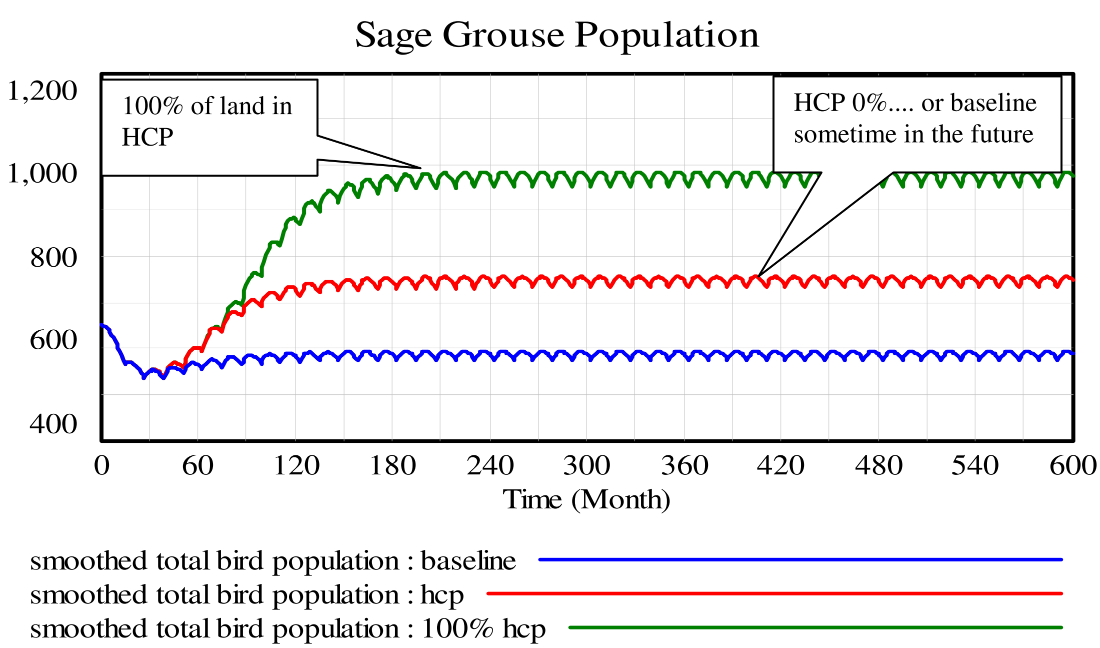

Figure 3.11 The effect of HCP inclusion on sage grouse population showing a potential population of up to 1000 birds.

Concerns over changes in CRP and the effect that losses of CRP will have on sage grouse populations have been voiced. Figure 3.12 illustrates several scenarios. The blue line is again the baseline or current condition. The green line illustrates an 8% loss range wide (includes CRP in cropland). The grey line illustrates an 8% loss just in shrub steppe landscape CRP. And, finally the red line is total loss of CRP. The boxes note the approximate change in population numbers between the scenarios.

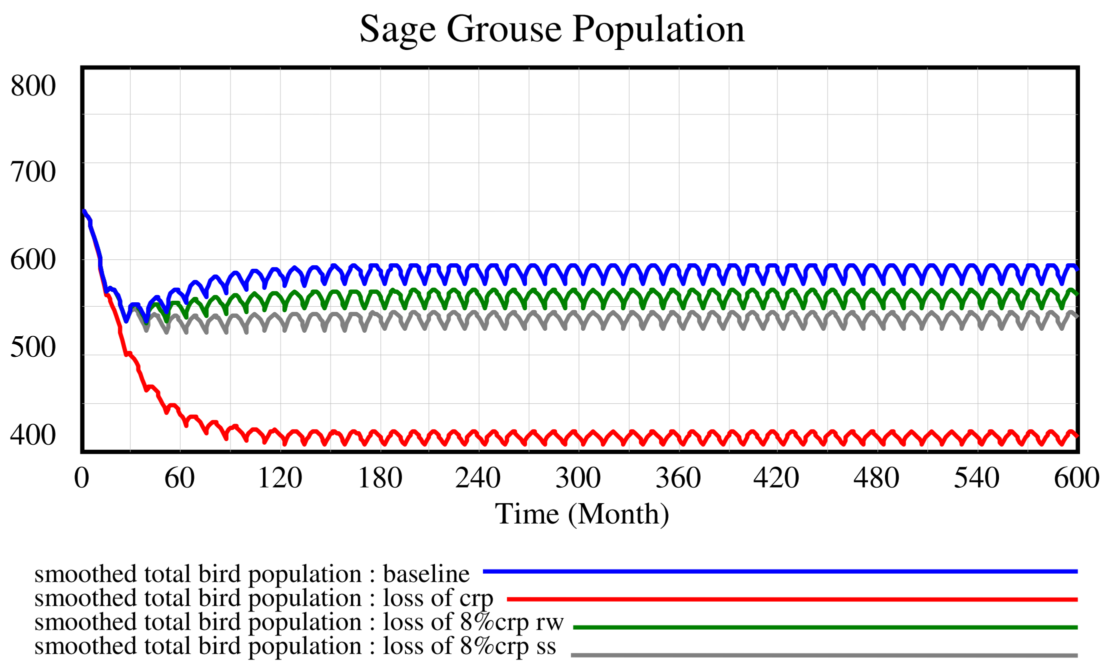

Figure 3.12 An illustration of the effect of CRP loss on sage grouse population.

Figure 3.13 illustrates that a loss of 100% of the CRP can be more than offset by inclusion of half the land in HCP.

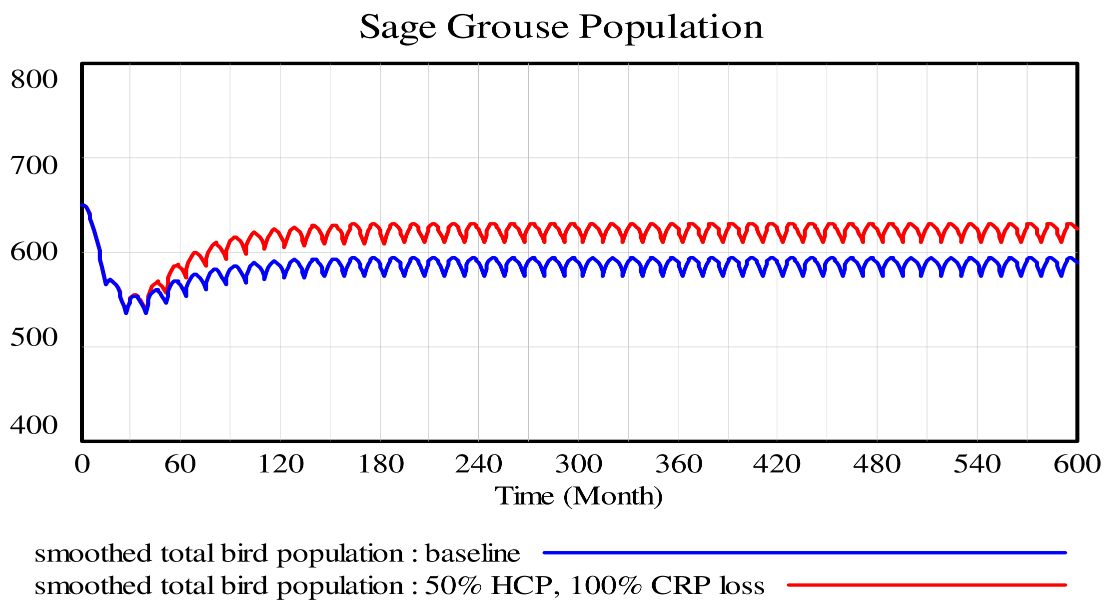

Figure 3.13 50% inclusion in HCP can offset a 100% loss in CRP on sage grouse population.

Model users have been supplied with sliders for many parameters that can be used alone or in combination to investigate possible future scenarios. The final example, shown in Figure 3.14, offers a screen capture that illustrates one possible combination of improvements in suitability that could produce 1300 birds. The vortex PVA indicates that a doubling of the current population size significantly reduces the probably of extinction from 54% to 20%. See section 3.2.

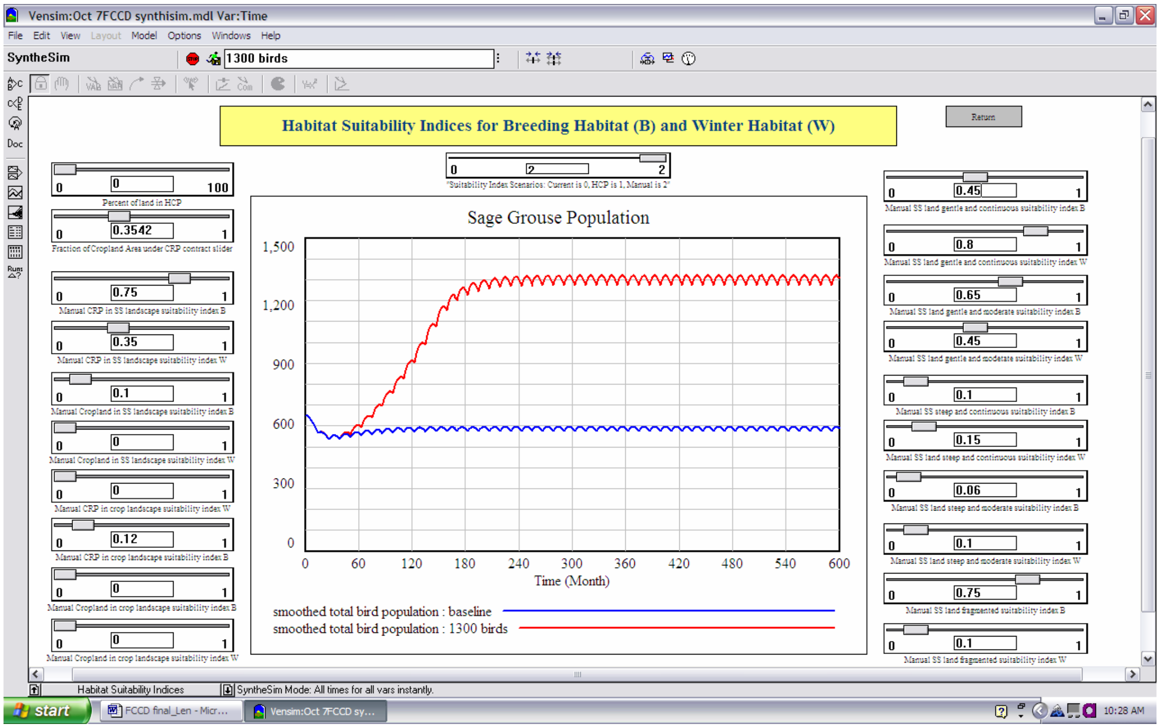

Figure 3.14 Changes in suitability to double the sage grouse population.

3.1.8 Conclusion

This model has been designed as a decision support tool and to help develop instincts for adaptive management of the complex sage brush steppe and cropland ecosystems that are home to the sage grouse of Douglas County. It will not predict any specific values or points in time but rather it indicates trends based on past and present data. It is designed, and should be used for combining and computing data into an illustrative representation of a complex system. Models are valuable because they simultaneously compute a myriad of parameters and relationships. Models offer a step up from decisions made on "gut feeling" by allowing those feelings to be tested and evaluated.

As we assimilated PVA and land use information into the systems model we tried to anticipate the questions that would be asked of the model as well as the reactions of the FCCD working group. Experience tells us that as users explore a model they inevitably want to start making improvements. Potential improvements suggest that we have encouraged people to better understand a system that is important to them. Adaptive management suggests that humanity take a holistic view of its surroundings, to learn about the parts as they are related to the whole; to understand the dynamic interactions of those parts as they work together as a system. Furthermore, when new information is gained, and better options discovered, better management should follow. Both the systems model just described and the PVA which follows in Part 2 are not static either. They may both be updated with new information. Therefore, by using the systems model and the PVA for discovery and evaluation of the shrub steppe and cropland ecosystems which the sage grouse inhabit, Foster Creek Conservation District may further their adaptive management objectives.

3.1.9 References for Foster Creek System Dynamics Model

Connelly, J. W., Knick, S. T., Schroeder, M. A., and Stiver, S. J. 2004. Conservation assessment of Greater Sage grouse and sagebrush habitats. Cheyenne, Wyoming: Western Association of Fish and Wildlife Agencies.

Dudek, B. 2005. District Manager, Foster Creek Conservation District. Waterville, WA.

FCCD matrix 07/01/05 (Schroeder and Heiner) provided by Britt Dudek, manager FCCD. Sage grouse data listed in Appendix 2.

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Stinson, D.W., Hays, D.W., and Schroeder, M.A. 2004.Washington State Recovery Plan for the Greater Sage grouse. Washington Department of Fish and Wildlife, Olympia, Washington.

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3.2 Preliminary Population Viability Analysis for the Greater Sage grouse in Douglas County, Washington

3.2.1 Introduction

The need for Sage grouse population viability analysis (PVA) was identified at the National Conference for Sage grouse Local Working Groups in Reno, NV in February 2005. Two have been published thus far, one by Johnson and Braun (1999) who completed a PVA for the sage grouse in North Park, Colorado. Another has been done by the Gunnison Sage grouse Rangewide Steering Committee (2005). PVA is not only useful in addressing species viability in any specific geographic area, but also adds to knowledge of sage grouse population dynamics and to the development and application of tools for decision making in the context of conservation biology. Sage grouse have been identified as an umbrella species (Rich and Altman 2004) for sagebrush habitat and an indicator of its condition (Wambolt et al. 2002). An umbrella species is one that requires extensive blocks of natural habitat to maintain a viable population (Meffe and Carroll 1997). Its continued existence has broad implications that involve the conservation of many other at-risk species both plant and animal; therefore, it would be wise to use tools to analyze the probability for the continued existence of umbrella species. One of the tools used to analyze the risk of extinction for a species is population viability analysis (PVA).

Population viability analysis (PVA) is a method for assessing the risk of extinction faced by a threatened or endangered species, or put another way, it's ability to persist into the future. Demographic parameters and life stage information are synthesized to construct analytical population models that use quantitative methods to assign probabilities of survival over some specified time period (Ralls et al. 2002). According to Morris and Doak (2002), "The uniting theme of PVA's is simply that they all are *quantitative* efforts to assess population health and the factors influencing it." Some of these factors are rates of survival (or mortality) for different age classes, rates of fecundity and reproductive success, and changes in the genetic structure of a population. Processes in nature are inherently random and unpredictable causing demographic rates to vary stochastically over time and between different habitats. A PVA takes into account demographic, environmental and genetic stochastics and how they affect chances of survival or extinction (Beissinger 2002). For instance, there will be natural fluctuation in the survival rate between years for the various age classes of a species due to both demographic and environmental variability. PVA can help determine the relative importance of age class survival to total survival through sensitivity analysis. It can help answer a question about whether male, female or juvenile survival is most important. A better understanding of these issues can focus research questions on underlying causes to determine if management can effectively improve a sensitive demographic rate. Management can then be directed to develop plans and focus resources on that part of the population dynamic that will have the greatest likelihood of success in stabilizing or causing increase in population numbers. As an example, Johnson and Braun (1999) used their model to predict population dynamics over the next century. They identified survival of adults and juveniles as the most important demographic parameters, and their model results allowed them to suggest directions for management of habitat as well as for analysis of the impact of hunting on overall mortality.

The simulation software used for the Douglas County sage grouse PVA is Vortex (Lacy et al. 2005). Estimates of multiple demographic parameters are entered into the model where they interact in simulations to produce an approximation of population trajectories over time. It is important to realize that results are not to be taken as predictions of the future, but as probable outcomes based on estimates of demographic rates that are often difficult to make (Beissinger 2002). Variability is entered into the model as the standard deviations of the parameter estimates. In order to capture the total stochasticity in the system, a large number of iterations is necessary. The Douglas County model is set to run for 1000 iterations. For each iteration, Vortex randomly chooses a value for each estimate from the range designated by the standard deviation. Results for all the iterations are averaged to produce outcome statistics. The probability of extinction (PE) is the fraction of the total number of iterations that generate extinction, usually expressed as a percentage. For a visual representation of the stochastic nature of the model simulations, see Figure 3.15, which displays the first few runs of the model.

In short, PVA is a tool for synthesizing demographic data and projecting it into the future to test probable outcomes. It captures essential patterns even though it may not be exact in all details (Lacy 2000). In addition, it is a way to test assumptions about the species under consideration, confirm intuition and support actions. It can help to identify research needs, and by comparison of different simulations, test how proposed management actions may alter model projections. PVA is most useful when it is periodically reviewed and updated as an evaluation tool in an adaptive management conservation program (Ralls et al. 2002).

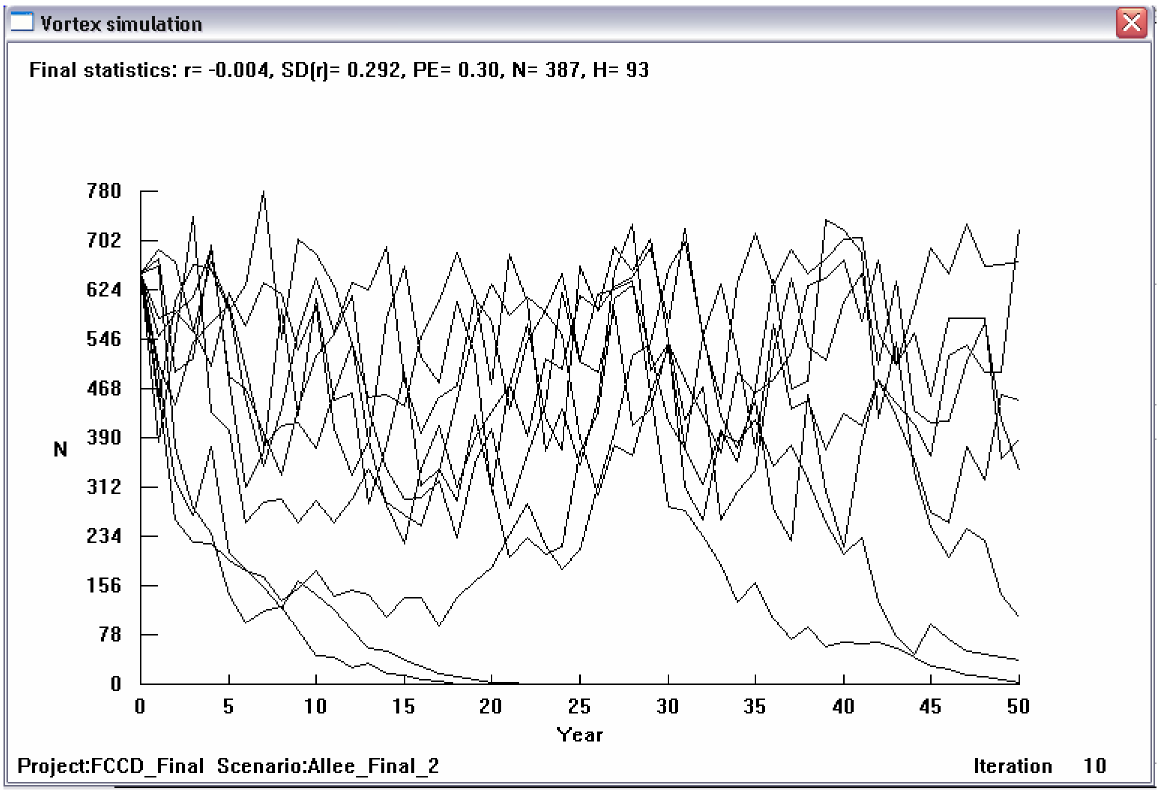

Figure 3.15 Vortex plot of the Simulation of the Douglas County Greater sage grouse population showing the inherent level of variability in the system. (Final statistics are only valid for the iterations shown).

3.2.2 Summary of Model Results

There is no doubt that the Douglas County greater sage grouse population is under threat. This fact is documented in the Washington Greater Sage grouse Recovery Plan (Stinson et al. 2004). A preliminary PVA for an assessment of this risk shows that values for the probability of extinction (PE) range from 0% - 100% in various simulation scenarios. Because acceptable levels of risk can only be determined in the political and social arenas, this PVA can be used to explore how sage grouse demographics are integrated to produce the expected probabilities, and to inform decision-makers of the important elements that maintain this population. Whether or not any assigned risk is acceptable, however, is a social and political decision. As a reference, the International Union for the Conservation of Nature (IUCN) categorizes a species as endangered if the probability of extinction exceeds 20% over 20 years and vulnerable if it exceeds 10% in 100 years (IUCN 2001).

The model is limited at this time by two important issues. The first is that there is no biologically acceptable critical population size that can be used as a definition of extinction. For this reason, the model follows other similar models and defines extinction as "0" animals; however, an Allee effect was included that accounts for at least part of this problem. A second factor that cannot be quantitatively included at this time is the effects of inbreeding depression and the loss of genetic diversity, although they are known to cause decreases in productivity, survival and fitness (Keller and Waller 2002). Simulations show that a decrease of 2 eggs/nest or a very small increase in chick mortality which could be taken as surrogates for inbreeding depression, result in a dramatic increase in the PE.

A model was developed with the best available demographic data as a point of departure for further investigation. This model indicates a PE of 0%. Results of this particular simulation suggest that the persistence of the Douglas County population of sage grouse is due to its favorable demographic rates and high productivity, as documented by Schroeder (1997). The mean number of eggs/ nest is the highest of several studies (Stinson et al. 2004). The percent of successful females is high and female mortality is low compared to rates used in other PVA models cited in this report. Model results based on only the demographic rates must be viewed as overly conservative and optimistic. Therefore, a density dependent function, described below, was added that resulted in a PE of 54%. This model is referred to as the Baseline Density Dependent (BDD) model and was the one used in further investigations.

Sensitivity analysis shows that chick mortality, female mortality, number of eggs/nest, maximum age of reproduction and carrying capacity are all important and sensitive model inputs. Biologists and managers seeking to improve conditions for sage grouse must decide if these sensitive parameters can be influenced by improvements to habitat or other actions, and if such actions are logistically and financially possible. The model could be used to test how much any given parameter needs to be changed to produce a desired reduction in the PE, followed by a survey of management options that have potential to change that demographic rate. This PVA can also be incorporated into an adaptive management program by updating model inputs as new or more accurate estimates become available.

3.3 Model Analysis

3.3.1 Simulation Time Frame

In order for the Vortex model to project a range of possible outcomes large enough to produce reliable output statistics, several years and many iterations are required to allow for the detection of possible delayed responses that may not appear until after the population has gone into irreversible decline (Miller and Lacy 2005). The Foster Creek Habitat Conservation Plan (HCP) is designed to be in effect for 50 years and sets the time frame of concern. It is adequate to project the variability in this system; however, because 50 years includes only 6 generations of birds which have a longevity of 9 years it is likely that there would be some still living after 50 years even if conditions were to seriously deteriorate (Reese per.com 2005).

The main output of concern in this analysis is the probability of extinction (PE) over simulation time, *i.e.*, 50 years. Keep in mind that the PE is a probable, not certain, outcome based on a given set of multiple inputs interacting over time. As any observer of both nature and human influence on the environment can readily see, very little remains constant over a 50 year time period. For this reason alone, according to one biologist, it is very difficult to have planning horizons greater than 25 years (Wielgus per.com. 2003). Thus the risk derived from these model simulations should be considered conservative, and it is advisable to have a PVA model updated as part of an adaptive management program.

3.3.2 Density Dependence

There is no scientific evidence of density dependence in breeding for greater sage grouse (Connelly et al. 2004). The current favorable demographic rates of the Douglas County sage grouse population do not suggest a problem, yet there is no question they are at risk and that the risk is associated with the small population size. The risk to small grouse populations has been seen in the greater prairie chicken where concurrent declines in population size, productivity, fitness and genetic diversity have been documented (Westermeier et al. 1998). In order to account for this risk, I have included a density dependent function in breeding. An Allee effect is incorporated into the model which begins to take effect if the population in any simulation declines to 200 birds.

Allee effects are an inverse density dependence that influences reproduction when a population falls below a critical density that is required for the stimulation of breeding. It can be very important in species that have a socially structured mating system (Ebenhard 2000). It is also inclusive of any combination of factors that cause the growth rate of a population to decline as it gets smaller. Several things can occur in small populations including an inability to find mates or not enough animals to stimulate a breeding response (Akcakaya et al. 1999). Also, if predation is constant, birds in a declining population are subjected to greater and greater risk. At some point, reduced fitness and inbreeding depression can also occur. Declines in breeding success can cause further declines in population size and coupled with demographic stochasticity, leading to what is termed the extinction vortex. In sage grouse, the social structure associated with the lek mating system might begin to break down in a declining population causing a lower percentage of females to be successful. Using 200 birds as this critical point is a suggestion from Mike Schroeder (personal communication 2005) who says that the breeding system would probably have begun to break down by then if not sooner (but consider the use of the Allee effect the sole responsibility of the modeler). The probability of extinction when the Allee effect is included is 54%, and this report considers 54% to be the extinction risk faced by the Douglas County sage grouse population.

3.3.3 Sensitivity Analysis

Sensitivity analysis is a method used to address two questions. First, parameters to which the model is especially responsive can be identified. Second, parameters that have higher levels of uncertainty can be investigated to see if a particular uncertain input has significant influence on the system. Uncertainty is defined as inaccuracy in estimates, where data are inadequate to produce more precise population trajectories. Sensitive and uncertain parameters for the Foster Creek population were identified from communications with Mike Schroeder, from running various model simulations to discover them, and from the literature (Gunnison Sage grouse Rangewide Steering Committee 2005, Connelly et al. 2004, Brook et al. 2002, Peterson et al. 1998).

Uncertain parameters are 1) the maximum age of reproduction (assume the same for male and female) because it varies widely in the above cited sources, 2) % of males in the breeding pool for the same reason, and 3) adult male mortality because the sample size is small, n=26.

Parameters thought to be sensitive are 1) % female mortality because it is lower in Douglas County than several other studies, 2) the standard deviation (SD) of female mortality which could indicate that measurement of this parameter is critical and 3) % chick mortality (includes both male and female). Parameters identified as sensitive in this model have been included in the Interactive Sage grouse and Land Use Model (VENSIM model) as user-adjustable sliders so that their effects on the sage grouse population can also be explored in that format.

Some parameters thought to be insensitive are 1) initial population size, 2) male mortality, 3) the percent of males in the breeding pool and 4) use of mean and SD for the number of eggs per nest as opposed to the specific distribution of the number of eggs per nest.

The value used in the model for each parameter of interest was taken as a middle value, and a minimum and maximum value were assigned to each one (see Table 3.2). A model scenario was run for each minimum and maximum value to compare the PE to that of the Baseline Density Dependent model. The magnitude of the effect of a parameter value on the PE was taken as the degree of sensitivity for that parameter. Tabular results are in Table 3.2, and a visual representation is in Figure 3.16.

Sensitive Parameters	Minimum	PE %	Parameter Estimate	BDD PE %	Maximum	PE %
Chick mortality %	73	0	**83.3**	**54**	93	100
Female mortality %	15	3	**25.0**	**54**	35	98
SD Female mortality %	3.8	45	**6.8**	**54**	9.8	68
Eggs/nest	7.1	99	**9.1**	**54**	11.1	52
Max age of reproduction	5	96	**9**	**54**	13	40
Carrying capacity	86	450	**650**	**54**	1300	20
Uncertain Parameters						
Male mortality %	33	52	**43.0**	**54**	53	55
% Males in the breeding pool	10	54	**49.6**	**54**	89	50

Table 3.2. Uncertain and sensitive parameters with assigned ranges used in Vortex simulations of the Douglas County Greater sage grouse population. The degree of sensitivity to the parameter can be seen in the change in the probability of extinction (PE) relative to the BDD model.

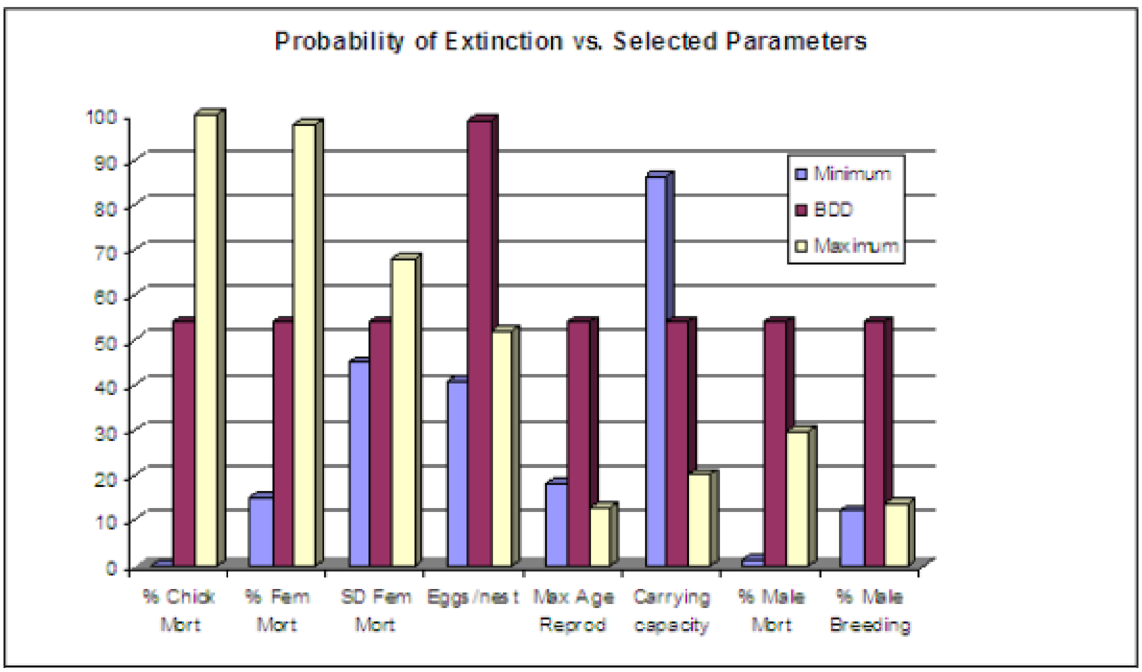

Figure 3.16 A visual representation of the sensitivity analysis for uncertain and sensitive parameters for Vortex simulations of the Douglas County greater sage grouse population. The degree of sensitivity to the parameter can be seen in the change in the probability of extinction (PE) relative to the BDD model.

3.3.3.a Chick Mortality

The most sensitive parameter was chick mortality. This was expected and corresponds to expert opinion (Schroeder per.com.) and the studies cited above. Model scenarios were simulated that raised the level of chick mortality by 1% for each successive run to find the critical point at which the PE becomes 100%. That point is 88.3% chick mortality, only 3% above the estimate used in the BDD model. This is well within the designated range of environmental and demographic stochasticity and is therefore a critical component for the survival of the Douglas County population.

3.3.3.b Female Mortality

The model is sensitive to increases and decreases in the annual female mortality rate. Thus it is an important factor in the maintenance of the population. Another way of saying this is that adult female survival to 9 years is important. The SD of female mortality is also sensitive to change. (The lower the standard deviation, the closer the model becomes to a deterministic non-stochastic model). This highlights the need for monitoring and for accuracy in estimates obtained in any monitoring program. Several simulations were run to test the sensitivity of the model to the SD's for both male and female mortality rates and showed the importance of these values in a stochastic model. The fact that the standard deviation of mortality is sensitive is indicative of three things. The first is the need for good data. Second, since SD stands for environmental variability, the natural "cycle" of good versus bad years has a strong influence on persistence. This of course is not under the control of management; however, the size of the population can more easily buffer this variability as it increases. Third, adult survival is not an insignificant issue.

3.3.3.c Eggs/nest

The number of eggs/nest is the highest of several studies (Stinson et al. 2004). A decrease of 2 eggs/ nest results in a PE of 99%. A decrease of just 1 egg/ nest results in a PE of 75%. An increase of 2 eggs/nest results in a negligible decrease in the PE. Eggs/nest appears to be at an optimum value, and any decrease is serious.

3.3.3.d Maximum Age of Reproduction

The Gunnison Sage grouse Rangewide Steering Committee (2005) stated 15 years as the maximum age of reproduction of Greater sage grouse. Their investigation of this as an uncertain parameter prompted the same for the Douglas County population. However, increasing the age reduced the PE only a small amount to 40%, probably because so few birds would attain that age due to their mortality rates, and a 15 year old bird would be rare. Reducing the age to 5 years causes a sizeable increase in the PE to 96%. It is likely, however, that the actual maximum breeding age is close to 9 years (Schroeder per. com.). Reducing this age by only 1 year raises the PE to 60% and by 2 years raises the PE to 75%. Again, the strength of this population is in its favorable demographics, and monitoring for change is very important.

3.3.3.e Carrying Capacity

An important model assumption is that carrying capacity is equal to the current population of 650 birds. With the favorable demographics of this population, its size should easily increase to accommodate any upward change in carrying capacity. Two model scenarios were run to explore this. When carrying capacity was raised to 1300, twice the current value, PE was reduced to 20%. When it was raised to 3200, the minimum viable population proposed in Stinson et al. (2004), PE decreased to 11%. Conversely, an reduction in carrying capacity to 450 caused the PE to rise to 86%. Population size is a critical component in the risk of extinction faced by this population, especially since it is isolated from other populations. The reduction in PE from increases in carrying capacity offers hope and encouragement that management to improve habitat and the signing of landowners into the HCP can be very effective. O'Grady et al. (2003) found that population size was the single best correlate of predicted extinction risk for 45 vertebrate taxa and stated that population size, along with trend, was the most important data to collect for threatened species.

3.3.3.f Male Mortality

The model is not sensitive to increases and decreases in male mortality.

3.3.3.g Percent of Males in the Breeding Pool

The % of males in the breeding pool is also an insensitive parameter. Other models (cited above) use much lower values, and it was thought prudent to investigate this estimate. How this estimate was determined is described in section 2.5.9. This parameter may have an effect on genetic diversity.

3.3.3.h Other Insensitive Parameters

Other simulations show that the model is not sensitive to 1) initial population size and 2) the use of mean and SD for the number of eggs per nest as opposed to the specific distribution of the number of eggs per nest.

3.3.3.i A Note on Sensitive Parameters

All sensitive parameters should be included in a monitoring program if possible, and estimates should be made as accurately as possible by proper sampling procedures. Should any of these estimates show unusual change in the direction that would increase the probability of extinction, it could be a warning of problems for the sage grouse population. Sensitive parameters point out vulnerabilities in the demographics of the species and suggest where conservation efforts might be directed. It does not necessarily follow, however, that management can influence these parameters. PVA is a risk assessment not an evaluation of management options or priorities. Demographic rates may be more subject to environmental variability than to human activity. For instance, adult mortality at current rates may be simply the biology of the species at work in its environment. On the other hand, some think that chick mortality, could be influenced by predator control. Should management decide to make such efforts, the program should be designed as an experiment, systematically applied and carefully monitored for results.

If it is estimated that management could improve chick mortality by 5%, a Vortex simulation could be run to estimate the probable change in the risk assessment. Another way of evaluating this strategy would be to decide that the risk of extinction should be below an agreed upon value, and then running simulations adjusting chick mortality downwards until that point is reached. This would indicate how much change is required to achieve the desired level of risk and generate discussion about its logistics and costs.

3.3.4 Assumptions and Limitations of PVA

3.3.4.a General Assumptions

The most basic assumption of this model is that the current values for input parameters extend over the entire simulation period. This may not be the case. It does, however, provide a projection of where the population is headed under current conditions and provides an opportunity to decide if it is acceptable. The premise of adaptive management is that as new information becomes available and as actions are evaluated to see if they produce intended consequences, adjustments should be made to change system trajectory. The PVA can and should be updated to help confirm the effectiveness of management and to support ongoing plans.

Another assumption is that, since carrying capacity is not explicitly known, the current population estimate of 650 indicates the carrying capacity of Douglas County.

The definition of extinction is "0" animals. This is a generous definition, but one used in the other models cited. No definition of extinction or critical population size for greater sage grouse has been agreed upon (Reese per. com. 2005). Therefore this model has chosen to follow other models of gallinaceous birds and set extinction value at "0" (Gunnison Sage grouse Rangewide Steering Committee 2005, Brook et al. 2002).

3.3.4.b Inbreeding Depression

The final area in which the current model is limited is the incorporation of inbreeding depression. Loss of genetic diversity has negative consequences for population viability It is usually underestimated in PVA analyses (Allendorf and Ryman 2002). Research in this area for sage grouse is in its infancy. Oyler-McCance et al. (2005) have shown that a definite decrease in genetic diversity has occurred in both populations of Washington sage grouse. They state that these populations have the same potential for expressing the effects of inbreeding, *i.e.*, lowered fertility and hatching success, as has been seen in the greater prairie chicken (Bouzat et al. 1998, Westermeier et al. 1998). They conclude that their findings need to be integrated with large-scale demographic and habitat data to assist conservation efforts. Such work is beyond the scope of this PVA. Since inbreeding depression is not specifically included, PE results for this analysis should be considered optimistic. The Allee effect does account for changes that could occur with inbreeding depression such as reduced breeding success, so that the concept is not ignored although it is not explicitly included. The model is very sensitive to rates that would likely become more pessimistic with inbreeding depression and can be taken as surrogates for it, including female and chick mortality rates, the number of eggs/nest and the maximum age of reproduction. It is important to understand that negative influences of inbreeding depression may not show up immediately, but tend to have a threshold effect (Frankham 1995).

3.3.5 Summary of Inputs for The Baseline Vortex Model of the Douglas County Greater Sage grouse Population.

This section explains the quantitative inputs for the Vortex PVA model of the Douglas County sage grouse population. Some inputs are straightforward. Others require explanation and are outlined below. Sources for this data include Schroeder (1997), Stinson et al. (2004), Connelly et al. (2004), and personal communications with Mike Schroeder (2005). The BDD model constructed with this data is a starting point for exploring the population dynamic. It does not include inbreeding or genetic issues, but has incorporated an inverse density dependence or Allee effect. Schroeder (per. com.) stated that the likelihood of a catastrophe is remote and therefore the model does not include one. A complete list of inputs for the model is provided in Table 3.

3.3.5.a Definition of Extinction

See section 3.3.4.a

3.3.5.b Environmental Variability (EV)

"Environmental variation is the annual variation in survival or reproduction caused by random variations in the environmental conditions. . . . sources of this environmental variation are outside the population; examples include weather, predator and prey densities and parasite loads" (Lacy et al 2005, p 32). This input answers the question, Is a good year for breeding also a good year for survival, or vice versa? The Douglas County population is migratory between two distinct habitats designated as breeding and wintering. Because they are geographically different and support different life stages, a good year in one habitat is independent of a good year in the other. Therefore the answer to the question is "no". The model uses this information to keep the variation in survival and reproduction in separate categories.

3.3.5.c Breeding System

Polygynous. The species has a lek system for breeding where males strut and females choose a mate. Not all males breed. Age of first reproduction for males is 2 years and for females is 1 year. Vortex randomly selects a group of adult females to breed with a particular male each year. Sex ratio at birth is assumed to be 1:1.

3.3.5.d Maximum Age of Reproduction

It is assumed that all birds, once they have reached breeding age, reproduce at the same rate until senescence, 9 years for this population.

3.3.5.e Percent of Adult Females Breeding

This is the probability that a female will produce offspring in a given year. There is 100% breeding effort, but not all attempts are successful. Input is the estimate of the percentage of females that are successful breeders and is the aggregate of both first nests and renests. Stinson et al. (2004) gave this as 61%. Schroeder has updated it to 59% (per. com. 1Aug2005). Yearly variation in breeding success due to environmental variability is the standard deviation of the estimate. The BDD model replaces this estimate with a function that initiates an Allee effect when any simulation population reaches 200 birds.

3.3.5.f Maximum Litter Size

Maximum number of eggs per nest is from Schroeder (1997).

3.3.5.g Distribution of Number of Offspring

Schroeder (1997) provided 5 years of data for the number of eggs/nest. The model uses the mean and standard deviation for this data, and assumes a normal distribution. Using the mean is necessary in order to perform sensitivity analysis by varying the mean number of eggs/nest The exact distribution can also be specified. Environmental variability is the standard deviation. Although the standard deviation for the mean number of eggs/nest is 1.31 from the data set, Schroeder states that it is probably higher and suggested using 2, which was done.

3.3.5.h Mortality Rates

Rates are from Stinson et al. (2004). Expert opinion refers to (Schroeder, per. com. 7June05). Mortality is both age and sex specific. For chicks of both sexes, mortality is the same and is derived from a combined estimate of chick survival at 0.334 for the first 50 days of life, and then estimated by expert opinion to be 0.5 until chicks reach their first year and are considered adults. 1- (0.334*0.5)=.833 or 83.3% mortality. SD of 10% is also expert opinion. The female mortality rate is from the above source and the SD is produced from data received from Schroeder (1August2005) as follows: mean survival =72.5, n=82, 95% CI=64.1-80.9. I have assumed it is an estimated proportion and thus SD = sq root p(1-p)/n = 0.0493. Thus SD is 0.0493/.725=.068 or 6.8%. Adult males have a higher mortality than adult females, presumably because they are more conspicuous during the breeding season. Male mortality is from the literature and the SD is produced from data received from Schroeder (1August2005): mean survival =56.9, n=26, 95%CI=35.8-78.1. I have assumed it is an estimated proportion: SD = sq root p(1-p)/n = 0.0971. 0.0971/0.569=0.17 or 17%. This seems unreasonably high. There is no reason to think that the variation in male mortality should be any different than that for females (Wielgus personal communication 2005), even though the rates are different. Using 17% in the model made it the driving factor in many simulations, and so I used the value of 6.8.

3.3.5.i Mate Monopolization

Not all males breed in the lek system. The pool of available males comes from those 2 years and older. The ratio of males to females is 1:1.4 (Stinson et al., 2004, confirmed by Schroeder, per.com, 7June2005). The estimated current population is 650 birds, and of these, 271 would be male. From the stable age distribution provided by Vortex (see screen "Initial Population Size"), 144 are first year birds. (271-144)/271=46.9. 46.9% of the males are 2 years or older and available for breeding.

3.3.5.j Initial Population Size

The value is set at the current estimate of 650.

3.3.5.k Carrying capacity

The carrying capacity of Douglas County is not known (Schroeder, pers. com. 7June2005). However, the SG Conservation Assessment (Connelly et al. 2004) states there is a high likelihood that some form of density dependence is at work since the population has not rebounded from the large decline in the 1970's. The general decline in SG populations has coincided with a general decline in habitat quality and quantity, and the birds may be doing the best they can. Two types of habitat, brood rearing and winter, are important in Douglas County and either or both may provide the limiting habitat. They are not differentiated in the model. Environmental variability is arbitrarily set at 10% of 650. Vortex chooses a random value within this 10% range for each simulation year.

Number of iterations		1000
Number of years simulated		100
Definition of extinction		0
No inbreeding depression		
EV in mortality concordant among age-sex classes but independent from EV in reproduction		Yes
Catastrophes		0
Polygynous		Yes
First age of reproduction for females		1
First age of reproduction for males		2
Maximum breeding age (senescence)		9
Sex ratio at birth (% males)		50
Maximum litter size (# eggs/clutch)		12
Density dependent breeding		Yes
Adult females breeding (% successful)		59
EV in adult females breeding		10
Distribution of eggs/nest (% litter size)	1	0
	2	0
	3	0
	4	0
	5	0
	6	2
	7	9
	8	23.6
	9	23.6
	10	27.3
	11	12.7
	12	1.8
Mean of eggs/nest/year		9.1
SD of eggs/nest		2
% Mortality females age 0-1		83.3
% EV in female mortality		10
% Mortality females age 1-9		25
% EV in female mortality		6.8
% Mortality males age 0-1		83.3
% EV in male mortality		10
% Mortality males age 0-1		43
% EV in male mortality		6.8
% Mortality males age 2-9		43
% EV in male mortality		6.8
% Males in breeding pool		46.9
Initial population size		650
Carrying capacity		650
% EV in carrying capacity		10

Table 3.3 Model parameters used in the Vortex simulation of the Douglas County Greater sage grouse population.

3.3.6 Conclusions

The threat to the continued persistence of the Douglas County greater sage grouse population is documented in the Washington Greater Sage grouse Recovery Plan (Stinson et al. 2004). A computer generated PVA model for an assessment of this risk was developed with the best available demographic data as a point of departure for further investigation. It shows that values for the probability of extinction (PE) range from 0% - 100% in various simulation scenarios. The risk of 0% is based on the current demographic rates of this population projected over 50 years excluding density dependence or inbreeding depression, both known issues. This particular simulation shows the reproductive strength of these sage grouse as documented by Schroeder (1997). As long as these rates hold, there is strong hope of recovery. However, model results based on only the demographic rates must be viewed as overly conservative and optimistic. Therefore, density dependence in the form of an Allee effect was added that resulted in a PE of 54%. This model is referred to as the Baseline Density Dependent (BDD) model and was the one used in further analysis.

Because acceptable levels of risk can only be determined in the political and social arenas, this PVA can be used to explore how sage grouse demographics are integrated to produce the expected probabilities, and to inform decision-makers of the important elements that maintain this population. Whether or not any assigned risk is acceptable, however, is a social and political decision. As a reference, the International Union for the Conservation of Nature (IUCN) categorizes a species as endangered if the probability of extinction exceeds 20% over 20 years and vulnerable if it exceeds 10% in 100 years (IUCN 2001).

The model is limited at this time by two important issues. The first is that there is no biologically acceptable critical population size that can be used as a definition of extinction. For this reason, the model follows other similar models and defines extinction as "0" animals. A second factor that cannot be quantitatively included at this time is the effects of inbreeding depression and the loss of genetic diversity, although they are known to cause decreases in productivity, survival and fitness (Keller and Waller 2002). Simulations show that a decrease of 2 eggs/nest or a very small increase in chick mortality which could be taken as surrogates for inbreeding depression, result in a dramatic increase in the PE.

Sensitivity analysis of uncertain and sensitive parameters indicated that the model is insensitive to male mortality and the percent of males in the breeding pool are. Sensitive and important model input parameters are chick survival, female mortality, eggs/nest, maximum age of reproduction and carrying capacity. The fact that the standard deviation of female mortality is sensitive is indicative of two things, first the need for good data, and second, since SD stands for environmental variability, the natural "cycle" of good versus bad years for reproduction has a strong influence on persistence. This of course is not under the control of management; however, the size of the population can more easily buffer this variability if it increases. The fact that the standard deviation of mortality is sensitive is indicative of three things. The first is the need for good data. Second, since

SD stands for environmental variability, the natural "cycle" of good versus bad years has a strong influence on persistence. A larger population can more easily buffer this variability than can a small one. Third, adult survival is not an insignificant issue.

Population size is a critical component in the risk of extinction faced by this population, indicated by its sensitivity to carrying capacity. The favorable demographics of this population should allow it to increase to accommodate any upward change. Simulations show that if carrying capacity is raised to 1300, twice the current value, PE is reduced to 20%, and if it is raised to 3200, the minimum viable population proposed in Stinson et al. (2004), PE is reduced to 11%. Conversely, an reduction in carrying capacity to 450 caused the PE to rise to 86%. The reduction in PE from increases in carrying capacity offers hope and encouragement that management to improve habitat and the signing of landowners into the HCP can be very effective.

Biologists and managers seeking to improve conditions for sage grouse must decide if these sensitive parameters can be influenced by improvements to habitat or other actions, and if such actions are logistically and financially possible. The model can be used to test the potential of a proposed change in any sensitive parameter to reduce the PE. This PVA can also be incorporated into an adaptive management program by updating model inputs as new or more accurate estimates become available tracking adjustments to the risk assessment.

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CHAPTER FOUR

REPORTS FROM THE FIELD

4 Reports from the Field

4.1 Introduction

After the completion of the Washington sage grouse modeling project described in chapters two and three and the experience gained co-facilitating a group modeling effort in the Okanagan Basin, British Columbia questions arose concerning modeling processes. The sage grouse and the Okanagan projects used very different albeit equally effective group model building techniques. Why and how these two processes were so different became of great interest. The thesis that developed recognizes that processes vary according to the idiosyncrasies of the problem being modeled. Furthermore, they vary because of the individual techniques of the modeler-facilitators. The goal of the analysis that follows was to learn more about “common sense and flexibility” (van den Belt 2004, p. 59) from a diversity of case studies and the inventiveness of practitioners. Rather than propose a standardized process for participatory environmental modeling this chapter illustrates that practitioners benefit from a large repertoire of skills and the ability to adapt to the problem at hand.

Environmentally-oriented group modeling processes that are designed for community-based interventions are subject to many uncontrollable issues. Types of participation, the timing and length of the intervention, and other variables make both the design and comparison of the processes and models difficult. This should not be a deterrent to using system dynamics in this fashion, but practitioners should keep in mind that there are different ways to intervene and perceptions of trust in models will vary (Cockerill et al.

2006). The availability of quantitative data will also vary, and adjustments mid-process will inevitably have to be made. The diversity of these case studies, and the inventiveness of the practitioners to customize their efforts to the needs of the stakeholders and the environmental problems that they are facing, is a demonstration of process adaptability. Process standardization is impractical if for no other reason than every environmental problem has place-based idiosyncrasies**.**

Participatory system dynamics modeling for environmental problems is a relatively new methodology. This chapter adds to the limited body of literature that looks across environmental participatory modeling processes that use system dynamics (SD). The first analysis was presented in *Mediated Modeling* by Marjan van den Belt (2004). She evaluated five case studies with respect to stakeholder involvement, process timing, number of participants and degree of conflict. All of her case studies follow a step by step process that she refers to as mediated modeling and produced scoping models[30] as a result of the process. Nuno Videira (2005) compares lessons learned from two studies that used the mediated modeling process. Videira (2005, p. 218) notes that "participatory modeling seems to be well suited for application beyond scoping levels, which means that an increase in the model complexity and detail does not necessarily imply a reduction in direct stakeholder involvement". Langsdale (2007) was interested in integrated assessment and the use of participatory modeling for water resource management and climate change. She looks at the effectiveness of participatory modeling and changes in policy. Case studies from each of these practitioners will be included in the assessment to follow.

[30] Costanza and Ruth (1998) delineate models into three types: scoping, research and management.

This chapter compares case studies with the intention of illustrating the flexibility of process and the effectiveness of a broad range of interventions. The number of stocks 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 more questions which 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. This creates a need for concurrent evaluation of these characteristics. This chapter will begin with a description of the ten case studies, group model building methodology and the purpose of the model. The impact of the model purpose on process 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 in this chapter were selected because the models 1) were designed to assist community-based management scenarios; and 2) consider human concerns and the needs of ecosystems. Most have been published in current literature. Valuable aspects of the process and model were always not included in published versions of the cases studies therefore contact with the lead modelers was important. Appendix 5 and 6 lists process and model characteristics that were provided by the modelers.

Modelers in the ten case studies outlined in this paper have drawn on simulation modeling techniques described by a number of sources 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). Group model building (GMB) has built on simulation modeling and encourages the use of this technique for improving shared learning experiences. 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).

4.2 The Ten Case Studies

Ten 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, seven 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 which reach beyond local jurisdictions. Downstream users have historically had an interest in upstream management both ethically and legally. 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 (2006, 2007), and Siemer and Otto (Siemer and Otto 2005, Siemer et al. 2007) have used traditional life history model conventions in an SD platform[31] then customized the effects of habitat changes to suit the particular attributes of the species and ecosystem.

Case study	Issue
Sage grouse in Washington (Beall et al. 2006, Beall and Zeoli 2007)	**Endangered species**
Problem Bears in New York (Siemer and Otto 2005, Siemer et al. 2007)	**Human-bear interactions**
Gloucester Fishery (Otto and Struben 2004)	**Sustainable fishery**
Middle Rio Grande (Tidwell et al. 2004)	**Current water supply management**
Okanagan Basin (Langsdale et al. 2006, 2007, Langsdale 2007)	**Future water supply management**
Upper Fox River (van den Belt 2004)	**Watershed management**
Baixo Guadiana River Basin (Videira et al. 2006)	**Watershed management**
Ria Formosa 2000 (van den Belt 2000, 2004)	**Estuary management**
Ria Formosa Natural Park 2003 (Videira et al. 2003, Videria 2005)	**Estuary management**
Upper Mississippi River (BenDor 2007)	**Watershed management**

Table 4.1 Ten case studies and the general environmental issue of concern.

Table 4.1 lists the case studies and the general environmental issue of concern. Models for management of sage grouse in central Washington (Beall et al. 2006, Beall and Zeoli 2007), 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

[31] Faust et al. (2004) developed a model of grizzly bears in Yellowstone and spectacled bears in a zoo population for the explicit exploration of using an SD platform for life history modeling.

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) 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 which has progressed over time from an initial scoping model to a management tool. Finally the Upper Mississippi River modeling process brought stakeholders together to investigate the incorporation of participatory models at "an institutional level as an element of integrated ecosystem management" (BenDor 2007). BenDor used this opportunity to promote concepts similar to those employed by the Army Corps Shared Vision Planning strategy described in chapter one.

4.2.1 Group modeling methodology

Practitioners in the ten case studies 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.

The Washington sage grouse study (Beall et al. 2006, Beall and Zeoli 2007) was designed by the modelers in collaboration with the stakeholders. The Foster Creek Conservation District (FCCD) modeling process was essentially driven by 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. 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. The modelers speculate that the stakeholders were initially very 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[32] 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.

The Gloucester group, similar to the sage grouse group realized they had a problem that was beyond their mental model to solve. One could say they were also 'looking for system dynamics'. Modelers at MIT were asked for assistance. The NY bear group was 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 half day workshops

[32] Reference Mode – A reference mode is graphical representation of an important variable and how that variable changes over time. A reference mode is typically drawn in the initial stages of system dynamics modeling building to help describe the behavior of the system. For other model language see appendix 1.

with the full groups and a series of meetings with subgroups. The “standard method” (Hines 2001) was used in the both cases (Otto and Struben 2004, Siemer and Otto 2005). This methodology was originally designed for a consulting environment however the modelers in these case studies acted as facilitators; they were not there to solve a problem but to help with problem solving. The method “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 is elicited through group discussion which 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 (Hines 2001).

Though it is coincidental, 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). It may not be a coincidence that the stakeholders were interested in using system dynamics to help them with their problems. The natural resource managers and perhaps other stakeholders that were involved in these processes should have experience with adaptive management theory. The similarity to systems thinking and the need for modeling as described in chapter one, could easily lead one to system dynamics.

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 water model. 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.
- A system description was developed.
- Causal loop diagrams were converted into a system dynamics context with appropriate data.
- The simulation model was reviewed.
- The model is used by the general public for education and water planning.

To familiarize the group with system dynamics the modelers showed examples of reservoir models they had previously built. 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).

The Okanagan study was comprised of a group of people who were familiar with one another and had worked on previous stakeholder engagement activities however their participation in the project was voluntary (Langsdale 2007). The process was based on criteria used in a participatory air shed model project (Langsdale 2007, Forster personal communication 2007). The first workshop began with visioning to explain system 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 classic 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 workshop 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.

The next four case studies 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 modeling group was brought together by the practitioner for the purpose of facilitating the group through a new problem-solving methodology. 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 group dynamics requires an initial added facilitation of interpersonal relationships and problem definition. Marjan van den Belt developed a process she calls "mediated modeling" that helps 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 as outlined in chapter four of *Mediated Modeling* (van den Belt 2004).

- Step one, preparation, 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 that "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, both four month projects, were led by van den Belt who describes these processes 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 Mississippi River (BenDor 2007) also used the mediated modeling process; however it was different from the other nine case studies in many facets. The modeling workshops were held over two consecutive days. The short time frame only allowed the group to develop a qualitative models or system maps of their problem although the modelers had originally intended to produce simulation models. The diversity of stakeholder interests, long standing conflict over those interests, and the complexity of the problem compounded issues. In spite of these issues stakeholders indicated that the process was useful. This case study has been included in this analysis to illustrate that participatory modeling can add value to a group process even in the initial steps of an effort designed to tackle a messy problem. In addition, the purpose of the model was to introduce participatory modeling as a facilitation technique that could help this group and others get beyond entrenched inaction.

Table 4.2 lists the case studies and the general purpose of the modeling process. The 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. The Okanagan and the Gloucester models were designed for group learning about an anticipated future that had not yet happened. The Middle Rio Grande, NY bears and the Washington sage grouse had fairly definitive current problems for which stakeholders were trying to evaluate management options.

Case study	Purpose of model
Sage grouse in Washington (Beall et al. 2006, Beall and Zeoli 2007)	**Management tool to assess policy alternatives**
Problem Bears in New York (Siemer and Otto 2005, Siemer et al. 2007)	**Group learning tool that developed into an educational support tool**
Gloucester Fishery (Otto and Struben 2004)	**Group learning; futures exploration**
Middle Rio Grande (Tidwell et al. 2004)	**Management tool**
Okanagan Basin (Langsdale et al. 2006, 2007, Langsdale 2007)	**Group learning; futures exploration**
Upper Fox River (van den Belt 2004)	**Scoping big picture**
Baixo Guadiana River Basin (Videira et al. 2006)	**Group learning; problem scoping**
Ria Formosa 2000 (van den Belt 2000, 2004)	**Scoping big picture**
Ria Formosa Natural Park 2003 (Videira et al. 2003, Videria 2005)	**Management tool**
Upper Mississippi River (BenDor 2007)	**Scoping the use of SD for this issue; group learning**

Table 4.2 General purpose of the modeling process.

4.3 Modeling Technique and Process Characteristics

4.3.1 Emphasis on model formulation vs. simulation

Figure 4.1 illustrates the eight steps of model formation as described by Ford (1999). Though this is depicted linear, experienced modelers obtain the best results by iterating through the steps in a trial and error process as models are built and tested. [33]

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 4.1 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. The process which emphasizes model formulation will be discussed first.

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 and survive (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

[33] Ford (1999) gives advice on iteration: "A useful rule of thumb is to complete the initial iteration within the first 25 % of the time interval available for the project. [He has] seen a dramatic increase in the contributions from other members of the project teams once a "demonstration model" is available" (p. 178).

vision. Learning is driven by iterations of model conceptualization and formulation (Step 3 and 4). Figure 4.2.1 illustrates these steps linked together to highlight that this systems thinking exercise is an iterative process.

If time or need dictate further exploration, the group may begin to estimate parameters which help them describe a reference mode (step 5). Parameters are then integrated into a simulation model which 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 4.2.2 illustrates these steps as part of an iterative process that produces simulation at the end.

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 4.2.3). 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 which 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.

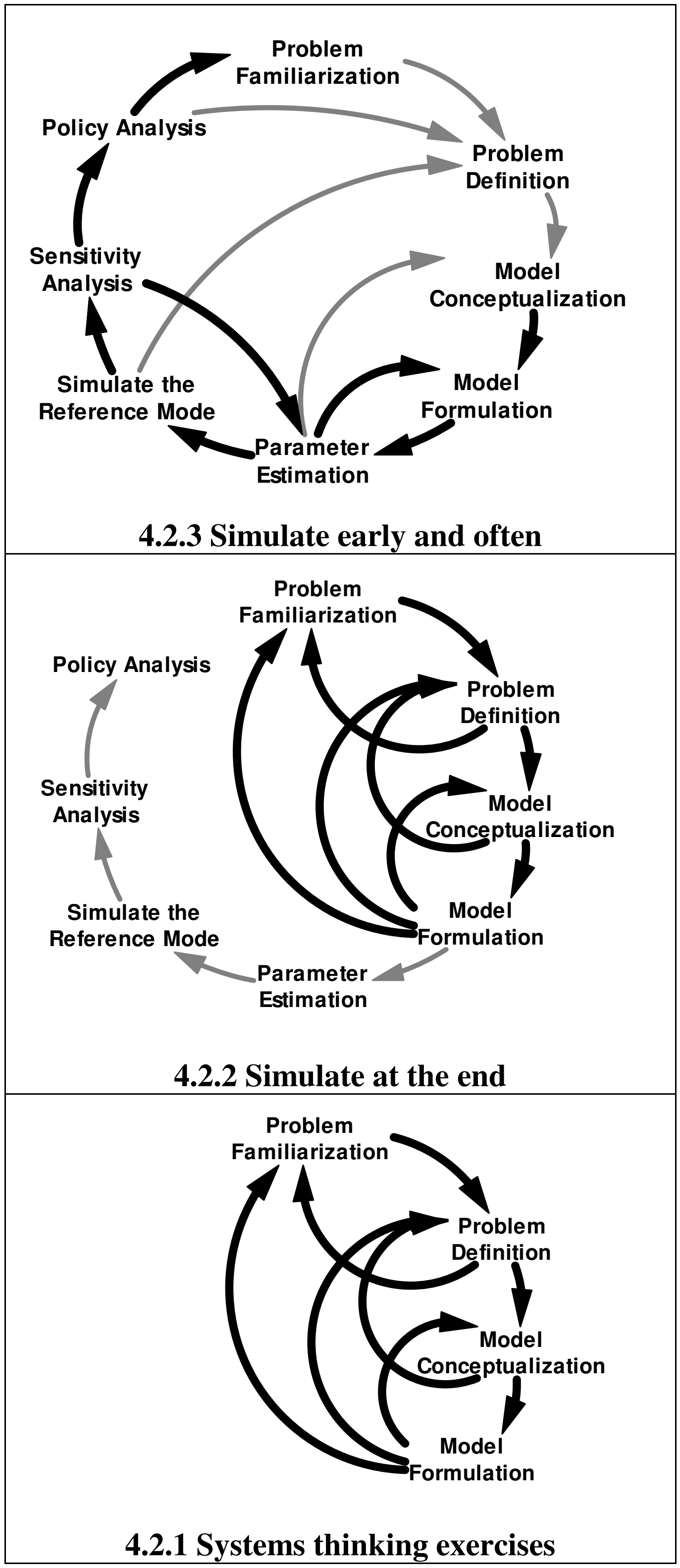

Figure 4.2 Three patterns of model formulation in participatory modeling processes. Emphasis of the process is highlighted in black.

The two patterns of iteration may result in three processes each with a different emphasis on simulation. The preferred technique of the modeler, the degree of problem definition and the timing of the process will affect the choice of technique through which groups are facilitated. Table 4.3 lists the case studies and the emphasis on simulation.

Simulate early and often	Simulate at the end	Systems thinking exercises no simulation
Sage grouse in WA Problem Bears in NY Gloucester Fishery Middle Rio Grande Okanagan Basin	Upper Fox River Baixo Guadiana River Basin Ria Formosa 2000 Ria Formosa 2003	Upper Mississippi River

Table 4.3 Ten case studies and the emphasis on simulation.

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 4.2.3 "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 (table 4.3). All have strong training in classic system dynamics which 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 which indicate general trends. They are usually graphical or spreadsheet data of historic stream flow. They typically depict seasonal variations which 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 then reference modes are elicited. Thus simulations are added at the end of the process (figure 4.2.2). This technique is useful for problems that take several workshops to define however it may leave little time for analysis of the simulation results.

Systems thinking exercises: The initial stages of simulation model formulation encompass what is often considered a systems thinking exercise. The systems thinking approach (figure 4.2.1) helps participants identify important parameters, relationships and system boundaries. It was used in the initial stages of the “simulate at the end” models.

The technique elicits information by encouraging participants to draw causal links connecting parameters of concern. The Upper Mississippi used the mapping interface of STELLA to build diagrams of causal relationships. Practitioners had initially planned for the group to get to the point that their models would simulate. The short timeframe of the project compounded by complex group dynamics led an abbreviation of the actual model building. Although the Upper Mississippi is the only example contained in this analysis there is extensive use of systems thinking techniques. Interested readers should look to the work of Senge (1990), Checkland (1999) and to the field of soft operational research.

4.3.2 Impact of model purpose on process

The stakeholders need has a bearing on the type of model produced. Participants in the Washington sage grouse, Middle Rio Grande and Ria Formosa 2003 needed management models. These models were required to run simulations that allowed participants to compare the impacts of policy alternatives. The NY bears model became an educational tool and relies upon simulation results to educate the public about problem bears. The Gloucester fishery and the Okanagan Basin models were needed so that participants could explore potential futures that were of concern to the participants. Although the modelers considered these cases learning tools, simulation was essential to learning.

The Upper Fox River, Ria Formosa 2000, and the Baixo Guadiana were developed as learning tools with an emphasis on model formulation but resulted in models that could run some simulations at the end. Some of data in these models was considered qualified data based on the "best guesses" of participants. Modelers (van den Belt - Ria Formosa

2000) and participants (Videria - Baixo Guadiana and Ria Formosa 2003) noted that future iterations of the models should include more solid data.

The Upper Mississippi River was designed with the emphasis on qualitative model formulation as a venue for group learning. The practitioners did make a concerted effort to produce simulation models with qualitative or "best guess" data however the short time frame and problem complexity required the facilitators to abbreviate model building in lieu of group discussion (BenDor 2007).

4.3.3 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 the lower portion of figure 4.2 and uses 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.

If the entire model is built qualitatively, all of the causal links in place in advance, and then the equations designed there is the possibility that a causation error may exist that could require significant changes in model structure. The modeler will have to return to the group with an explanation of structural change which is potentially counter intuitive and "not what we modeled last session". Creating simulation results in the office that match reference modes allows modelers to create structures through a series of iterations that test relationships, equations and assumptions. A simple, transparent structure that simulates the reference mode can then be presented to the group for improvement. The modeler will only have to explain their own assumptions, not why their assumptions work better in a model than the original assumptions of the group. Also reference modes are self descriptive and concise and are not subject to the changes in value that can happen to text based descriptions when they have been subjected to word-smithing.

4.4 Problem Complexity

Natural resource problems are sometimes describes as "wicked"[34] or "messy"[35]. 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

[34] The term "wicked" in the context of the environment was originally coined by Horst Rittel who was dealing with planning problems that were messy, circular and aggressive.
[35] Sterman (2000), Vennix (1996) note that messy problems are ideally suited for group system dynamic interventions.

facilitated processes can begin moving towards finding solutions. The number of stocks[36] that are in the model could be indicative of the number of concerns, and was therefore chosen as a proxy for problem (and process) 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.[37] 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.[38] 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 4.3 illustrates general trends that support the effect that time and the number of involved

[36] A systems model is built by choosing key variables, called stocks, which show the collection points in a system. The movements in and out of those stocks are flows. Other variables are added to assign rates to the flows or as descriptors of those variables. Taken together all are considered parameters (Ford 1999).
[37] A third reason for a large number of stocks is that there may be a need for many easy stocks that are interconnected in a straight forward manner. An example could be an age structure model.
[38] Some modelers start with very simple stock and flow structures then field participant suggestions as to the extra parameters or stocks that could be added. This is done to avoid model complexity from killing the process in the early stages.

groups has on the complexity of the problem that is modeled. More time, more groups, more stocks.

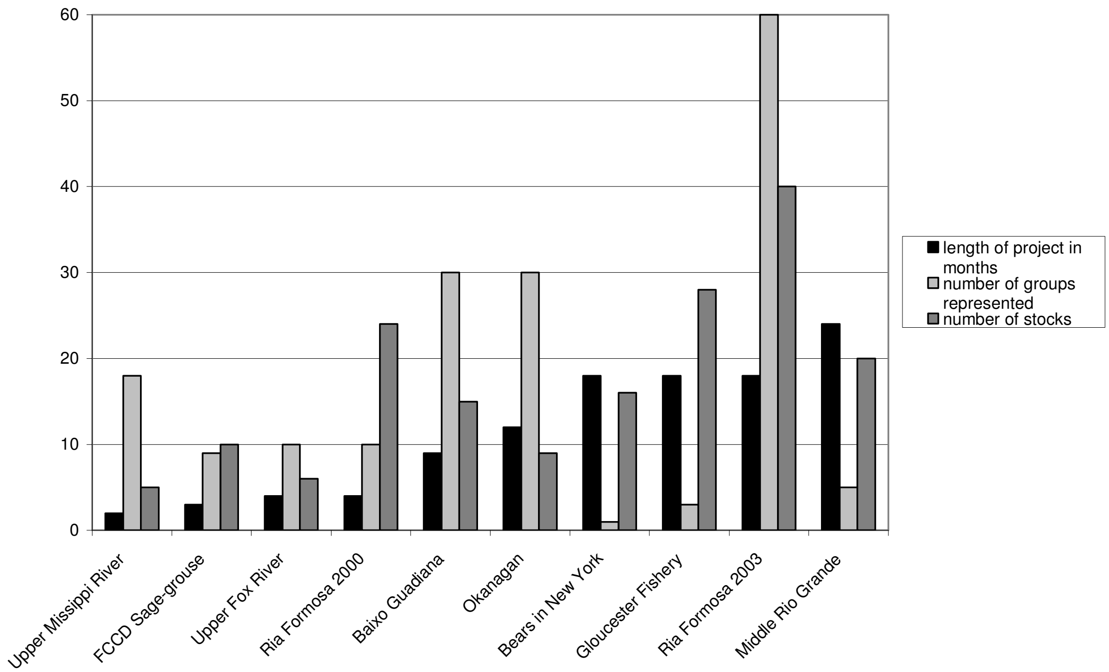

Figure 4.3 Sorted by project length, with number of groups represented and number of stocks added to the right of project length.

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.

4.5 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.

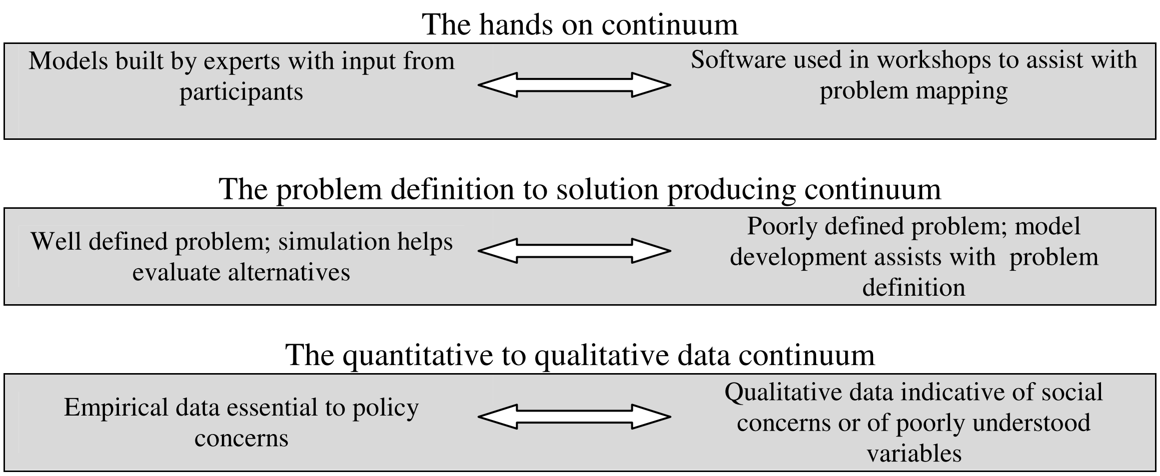

Figure 4.4 Three continuums describing process and model characteristics.

Figure 4.4 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 in figure 4.4 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.

4.5.1 The "hands on" continuum

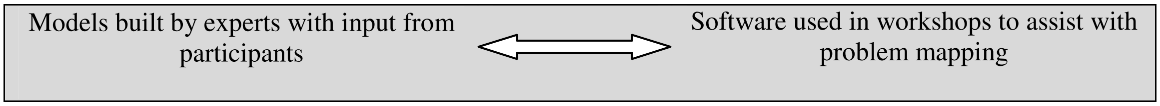

Figure 4.5 The hands on continuum.

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 systems thinking exercise.

Table 4.4 depicts data elicited from the modelers and the literature. Absent from the table are the Washington sage grouse, NY bears and Gloucester Fishery projects who showed their groups examples of SD models but did not build models in the presence of the group. This is another example of the divergence in techniques discussed in section 4.3.

Case study	Built simple stock and flow diagram *in front of* group	Built simple stock and flow diagram *with* group	Built *some* sectors of the model *with* group	Built *all* sectors of the model *with* group
Okanagan				
Middle Rio Grande				
Upper Mississippi River				
Upper Fox River				
Ria Formosa 2000				
Ria Formosa 2002				
Baixo Guadiana				

Table 4.4 Model building exercises (grey blocks) performed with groups. (Personal communication with modelers 2007; see Appendix 6).

The Okanagan project used system thinking exercises including the ice cream game (Durfee-Thompson et al. 2005) at the first workshop. The second workshop began with an introduction to STELLA that included building a simple bank account model and a simple "one bucket" model of the Okanagan basin in front of the participants. Beyond this, all of the model building was conducted in the office. The Rio Grande modeler also illustrated the building of a simple bank account model in conjunction with providing illustrations of previous SD water models. Portions of the participatory model were built with participants in small workshops attended by the model building team component of the stakeholders. This was practical for the modeler because the "cooperative modeling team" met bi-monthly for year and a great deal of detail was required.

The Okanagan and Middle Rio Grande performed the bulk of the modeling in the office whereas practitioners in the Upper Mississippi River, 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).

Practitioners in the Upper Fox River, Ria Formosa 2000, 2003 and Baixo Guadiana 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 work on individual sectors and spend time identifying parameters and the relationships of those parameters to one another. After the map of the entire model is built, parameter equations are added. 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 Upper Mississippi workshops were conducted in two consecutive days. This limited the number of issues or sectors that could be modeled. The time frame also ultimately prevented the modelers from helping the participants create a simulation model.

After corresponding with the lead modelers the line is not entirely definitive between techniques. Some problems were worked out in the office by the practitioners of the "hands on" groups and some structures were modeled at the direction of the participants in the "hands off" modeling processes.

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 (section 4.2.2) and by the degree of problem definition.

4.5.2 The "problem definition to solution producing" continuum.

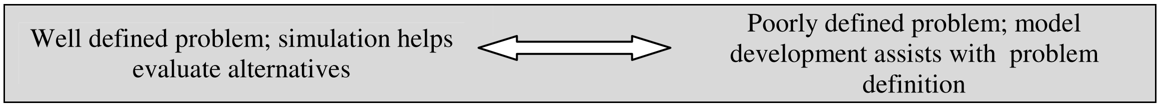

Figure 4.6 The problem definition to solution producing continuum.

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 Upper Mississippi project. It helped participants begin to 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. It helped a group of 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 central Washington sage grouse model which is helping stakeholders identify solutions that will be implemented on the ground (Beall et al. 2006, Beall and Zeoli 2007).

There is another continuum tangential to the problem definition to solution producing continuum. This continuum is the timing for model intervention. Each practitioner in the ten case studies has adapted the process to the timing of the intervention and to the needs of stakeholders. Modelers have typically become aware of a problem and offered their services but the point at which they joined the group process varies widely. Van den Belt discusses the potential effect of intervention timing in what are typically wicked problems (van den Belt 2004). Others have noted that interventions often occur when funding becomes available (Tidwell, personal communication 2007, Langsdale, personal communication 2007.). The availability of funding may also affect the type and length of a project.

There may be preferred times for intervention but environmental issues typically do not have clear start and stop points from which modelers may calculate where and when to intervene. The case studies indicate that interventions may be effective at any point on the continuum from problem definition to the production of solutions. Modeling is useful even if it does not take participants to a final goal of implementing their solutions in the field. Group learning as a product, especially in situations with the potential for intense conflict, may be in of itself of greater value than the future use of a model. Several of the case studies have assessed group or individual learning using qualitative measures even thought they recognize that it is difficult. Long term success of this methodology will perhaps be measurable in time when modelers are invited to continue the evolution of the original model or be asked to address another problem. The Ria Formosa group did return to participatory modeling after the completion of the initial project. There may be other instances outside the scope of the case studies included here, but at this point the youth of the field does not allow for a time series analysis of process effectiveness at this time.[39]

[39] The Foster Creek Conservation District's dedication to its Multi Species Habitat Conservation Plan and general interest in conservation oriented land management has inspired Beall and Zeoli to keep track of FCCD's progress over time. There is no funding available for a long term study at this time but personal interest of all those involved should insure that the case study will be revisited in the future.

4.5.3 The “quantitative to qualitative” continuum

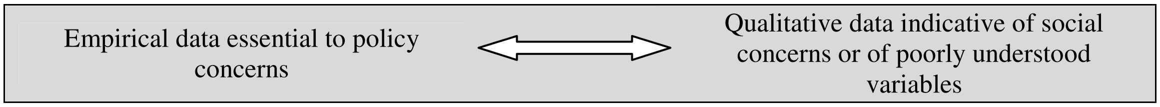

Figure 4.7 The quantitative to qualitative data continuum.

Quantitative to qualitative in this context is referring to the type of data which is integrated into a model. This is in contrast to previous use of quantitative and qualitative which 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 4.5). The importance of the concept is in the value of the model to communicate information vital to the process.

Physical laws	Controlled physical experiments	Uncontrolled physical experiments	Social system data	Social system cases	Expert judgment	Personal intuition

Table 4.5 The quantitative to qualitative continuum (Ford 1999).

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 which 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 leads 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.[40] 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 Upper Mississippi River model was an evaluation of the potential for an SD intervention into a highly contentious, broadly based, and long standing conflict. BenDor noted that "quantitative definitions were the hardest to understand for all stakeholders... 'development hurts the environment' was a common accusation, but understanding how this worked quantitatively was much more difficult" (BenDor personal communication 2007). The process, which is in the "pre-problem" definition phase, produced a model

[40] There is a group of researchers attempting to capture valuation on such considerations. For examples see Franz E.H. 2001. Ecology, Values and Policy. BioScience, Vol. 51 No. 6. and Daily et al. 2000. The Value of Nature and the Nature of Value. Science. Vol. 289 Issue 5478, p. 395.

that only used qualitative data yet was able to effectively communicate the value of constructing both conceptual and simulation models (BenDor 2007).

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. The accuracy of this data and the manner in which it was modeled was far and above the most important aspect of the process. The model was designed as a management tool in a realm where the standard for population models is population viability analysis or PVA. To help increase confidence in the SD model and to promote the use of SD models for population dynamics, the modelers built a PVA model in Vortex software. The outputs of both models were comparable (Beall et al. 2006, Beall and Zeoli 2007). 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 ten 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.

4.6 Compiled Analysis

Figure 4.8 integrates the continuums, patterns of model formulation, and the ten 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.

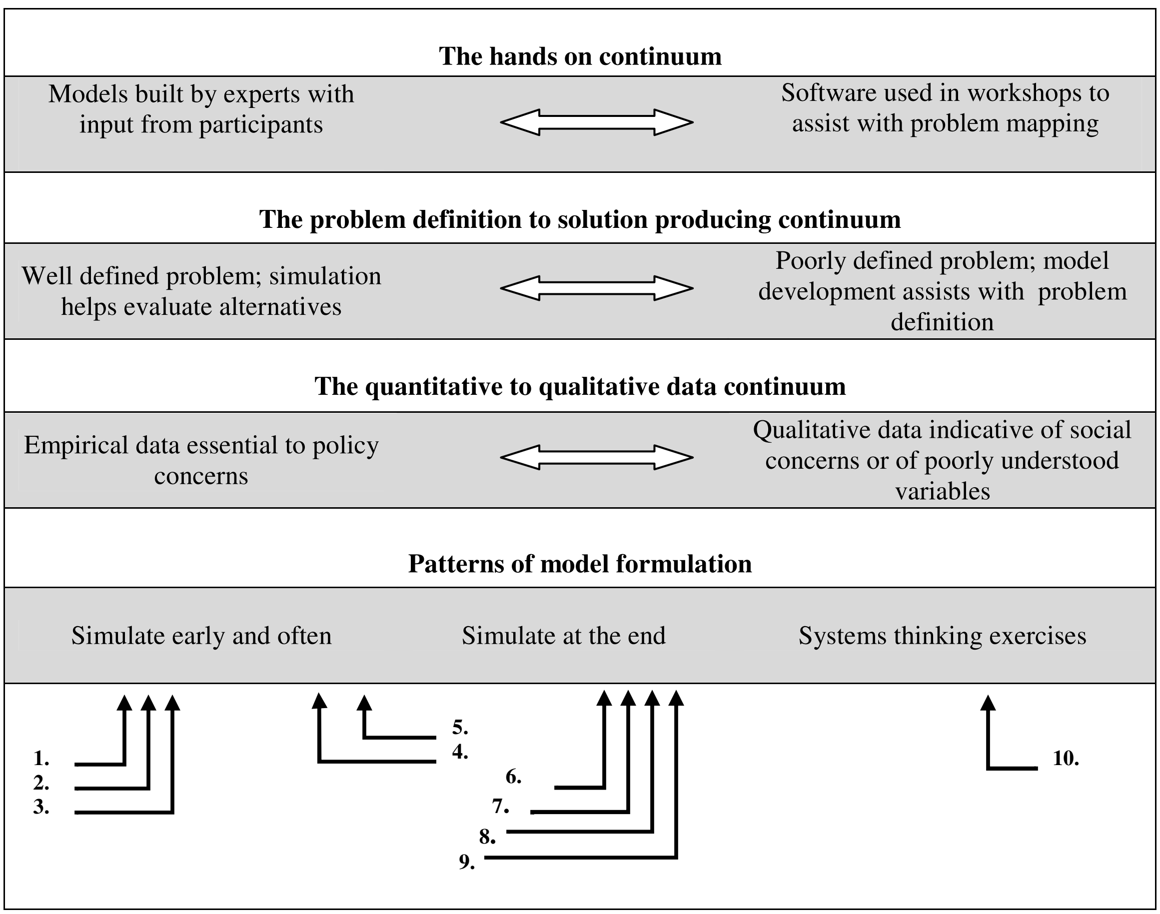

Figure 4.8 The continuums, patterns of model formation and the case studies. 1. Sage grouse in WA; 2. Problem Bears in NY; 3. Gloucester Fishery; 4. Middle Rio Grande; 5. Okanagan Basin; 6. Ria Formosa 2003; 7. Baixo Guadiana River Basin; 8. Upper Fox River; 9.Ria Formosa 2000; 10. Upper Mississippi River.

Two case studies form the ends of the continuums. The Washington sage grouse model 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. The Upper Mississippi model was a learning tool. It was a purely qualitative model, which used the mapping level of STELLA. It was designed to explore the feasibility of using a participatory modeling process to bring together a large group of stakeholders that are responsible for different aspects of ecosystem management. When comparing the time length of all of the modeling processes, these two had the shortest time frames. However, the sage grouse model spent the bulk of the three months building the model with four days spent with the group. Whereas the Upper Mississippi used the bulk of the three months setting up the stakeholder group with modeling workshops lasting two days (Appendix 5 lists timing details of individual projects).

The Ria Formosa 2000, Upper Fox and Baixo Guadiana 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 earlier Ria Formosa effort. 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 which 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.

4.7 Conclusion

The ten case studies cover a broad spectrum of modeling technique. Half of the case studies began with system thinking exercises which developed models using the mapping layer of software to link together issues and concerns. The second half of the case studies 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 that individuals learned to think in a more holistic fashion. Comparative measures are not possible because of the inability to replicate the process with a control that uses another method of facilitation. Comparing techniques is not possible for the same reason. This should not be a deterrent to using system dynamics in participatory processes but an encouragement for more assessments. The field is young and practitioners have much to learn from one another.

Facilitating a participatory modeling exercise is very much like teaching or coaching. Within each educator there is resides a personal methodology for teaching that has developed through training, personal experience, and individual creativity. The best constantly assess not only their own students but the teaching techniques of others to try to find the best combination of skills that will help people learn the task at hand. Participatory modelers should do the same. 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.

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CHAPTER FIVE

LESSONS LEARNED

5 Lessons Learned

> The twentieth century has amply demonstrated that neither science nor democracy can enhance human [or environmental] welfare in the absence of the other.
>
> Thomas Deitz 2004[41]

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.

> System dynamics can provide that dynamic framework to give meaning to detailed facts, sources of information, and human responses. Such a dynamic provides a common foundation beneath mathematics, physical science, social studies, biology, history and even literature.
>
> Forrester 1991[42]

Participatory environmental modeling that uses system dynamics is an effective methodology for creating a nexus between science and local knowledge.

> Computer models could be tools of democracy instead of autocracy, and the people who make them could be valuable, sharing, inspiring partners in social evolution…
>
> Dana Meadows 1985[43]

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[41] Thomas Deitz 2004. From the forward of *Mediated Modeling* (van den Belt 2004, p. xiii).
[42] Jay Forrester 1991. The Ranch to System Dynamics: An Autobiography. p. 27

5.1 Creating a nexus of science and local knowledge with participatory system dynamics modeling

Participatory environmental modeling using system dynamics can create a nexus of science and local knowledge (figure 5.1). This effective and transparent methodology integrates scientific information and policy alternatives into a model that can be used by scientists, managers and the public. "At a minimum system dynamics offers a consistent and rigorous problem-solving framework for identifying the scope of the problem, eliciting participant views about problem causes and system connections and identifying policy levers" (Stave 2002). This process uses the tenets of scientific theory, hypothesis testing and clear statements of assumptions. Models may be used to integrate professional science, street science and experiential knowledge with timeframes that reflect the needs of agency and private resource management.

[43] Dana Meadows 1985. *The Electronic Oracle* p. 15.

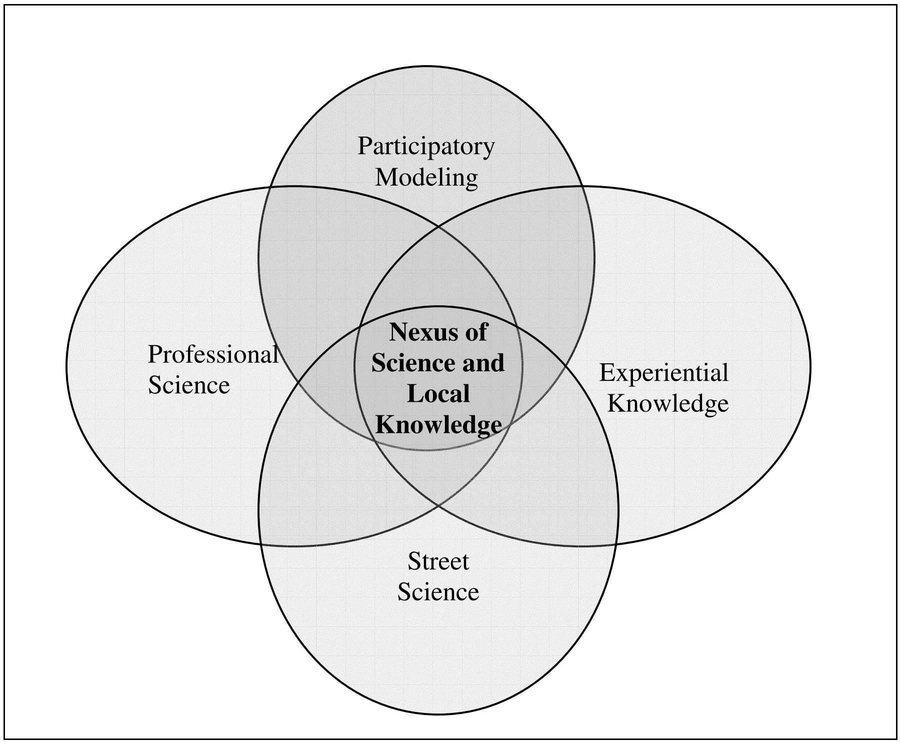

Figure 5.1 Participatory modeling creates a nexus of science and local knowledge.

System dynamics uses the tenets of the scientific method to help us understand change in causally closed systems. In such systems, behavior is endogenous to the structure.

> A causally closed system still is open in the sense that it can receive material, energy, random disturbances, and test inputs from outside the boundary. Requiring that the system boundary be drawn to include the causes of relevant dynamic behavior means that one must seek the generating causes in conceptualizing a model of the system. Until one understands the dynamic cause of present undesirable conditions, one is not prepared to explore moving from present conditions to more desirable conditions. (Forrester 1994, p. 254)

There are many models used in natural resource management which capture snapshots of time. Econometrics helps us with cost-benefit analysis. PVA[44] helps us understand the threat of extinction for small populations. Some of these models include stochasticity which simulates variation by changing one or more parameters at a time. Hydrologic models use historic flows and what is known about the structure of a watershed to help us understand how flows will be impacted by changes in consumption, land use or climate. General Circulation Models (GCM's) are helping us understand the feedback processes that affect climate. These research models simulate history to help us understand how the world works.

Research models are potentially limited by the availability of historic data. For example in natural systems species are subject to density dependence. Habitat quantity and quality may limit numbers for certain species while others are unable to breed if their numbers are too low. Scientists will agree that these phenomena exist but may have a difficult time compiling data that supports their intuition. In spite of this, experienced agency biologists will manage with these considerations in mind. Their decisions will be respected because we recognize the value of experience.

Relationships such as density dependence are important to understand because they help explain the underlying dynamics of a system and limits to growth. In the sage grouse life history described in chapters two and three, density dependence is created by the

[44] Population Viability Analysis (PVA discussed in Chapter 3.2) and see Akçakaya and Sjögren-Gulve 2000, for an overview of PVA other modeling methods used in conservation planning. Akçakaya, H. R. and Sjögren-Gulve, P. 2000. "Population viability analyses in conservation planning: an overview." *Ecological Bulletins* 48: 9-21.

parameters which link the birds to their habitat. Even in the absence of scientific evidence (see Chapter three sec. 3.3.2) once the assumption was made that the birds were at carrying capacity in their present habitat and suitability of that habitat quantified, density relationships could be simulated. There is potential for controversy over this modeling approach in traditional circles. Nevertheless there is little controversy that the sage grouse are at risk, that they are habitat limited, and that conservation through restoration and changes in land management which improves habitat should increase the numbers of sage grouse. There is a willingness to invest large amounts of time, effort and money on a well founded hypotheses such as the effects of habitat loss to the Foster Creek sage grouse. There are multitudes of similar efforts for sage grouse and other species across the country and world. And for most part these efforts are often based on limited scientific knowledge and a large amount of experiential knowledge.

If there are not obvious management alternatives, or if there are competing management alternatives how do decisions get made? What is it that resource managers need to effectively develop and choose between management alternatives? They need to understand the current state of affairs and how it was produced. They need to understand the implications of decisions in advance so that they may better understand the pros and cons of different alternatives. Then theoretically, the alternative with the most positive and lease negative attributes would be chosen.

System dynamics models are helpful in these situations. The point is not to have a model that precisely predicts but rather to have one that helps us better understand alternatives and the complexities that created them. This is difficult to tease out of the messy problems inherent to ecosystems that include human interests. Participatory modeling can be used to help managers and stakeholders investigate a variety of alternatives in an effort to find the "most positive". Sheer (2007) describes this process as an effort at satisfy-zing rather than optimizing[45] and emphasizes the importance of finding "non-inferior" alternatives which recognize the needs and values of all concerned.

Yet in the process of satisfy-zing natural resource managers still have to juggle different currencies (for example returning fish numbers or kilowatts of hydropower) and different public values concerning those currencies. To manage these issues, effective engagement and good information are critical. Good information comes in many forms such as professional science, street science and experiential knowledge. System dynamics models offer a way to better use such information. For example, rather than discounting entirely or demanding that data produced from experiential knowledge be quantified and statistically analyzed with traditional scientific methodology, it can be included in a system dynamics model. In so doing, models serve as repositories for collective knowledge that have a shared language. When built with scientifically defensible standards, participatory modeling can be used to integrate varying forms of knowledge into a nexus of participatory science.

[45] Multi attribute utility analysis or cost benefit analysis using proxies such as travel cost are examples of methods used for optimization.

5.2 *Recommendations for participatory modeling best practices*

Computer modeling helps us understand complexities that are beyond the capacity of our own minds. System dynamics adds to computer simulation by helping us capture feedback and time lags that are inherent to many complex problems. Computers are so effective at performing these tasks that Meadow and Robinson (1984) have referred to them as "electronic oracles". However, computer models are only as good as their designers**.** Many modelers and participatory participants may be inclined to include *everything* in a model. The ease of which software can be used aggravates this situation. Careful consideration of *the problem* and the use of output data generated by complex research models can help simplify the requirements of a system dynamics model. It also helps to remember why system dynamics was originally designed.

5.2.1 System dynamics is more than software

The design of system dynamics software makes it easy to use. A person can spend a short period of time becoming familiar with the icons and begin building models. This does not necessarily mean that they are designing system dynamics models. Another temptation most novice modelers have experienced is the addition of a plethora of parameters to insure that "everything is included". The need to "including everything" is also a potential problem of participatory processes. Understanding the basic tenets of system dynamics and continually returning to those basics will help modelers build better models.

Classic system dynamics was designed to help us understand the dynamics of feedback relationships and time lags. The methodology begins with a discussion of the problem to be modeled. Practitioners encourage us to develop a reference mode of a key variable. This reference mode is a graph (often hand drawn) that describes how an important parameter changes over time. The graph also captures units of time and the units of the important parameter. From this reference mode we can then begin the process of designing stock and flow structures that create simulations which are expressed graphically. If our simulated graph does not reflect the reference mode we use the opportunity to evaluate our model and learn from the insights. Through iterations of problem description, model development and evaluation, we learn. After we are satisfied with our simulation of the problem, we can develop policy options that offer solutions.

> System dynamic models are usually intended for use at the general-understanding or policy-design stages of decision making. Therefore they tend to be process-oriented, fairly small, aggregated, and simple. Most fall within the range of 20-200 endogenous variables. The individual model relationships are usually derived directly from mental models and thus are intuitive and easily understandable. The paradigm requires that every element and relationship in a model have a readily identifiable real-world counterpart; nothing should be added for mathematical convenience or historical fit. Thanks to the high standards initially set by Forrester, system dynamic models are usually well-documented and easy to reproduce. (Meadows 1985 p. 38)

The standard of modeling that Forrester developed emphasizes simplicity, intuitive relationships and clarity. This manner of explaining systems is in line with another scientific principle. *Occam's Razor*[46] helps guide scientific hypothesis building and testing. The premise is that when choosing a hypothesis the best explanation for an event or phenomena is the most simple and uses the fewest assumptions.

5.2.2 Iteration: simulate early and often

Conflicts may arise about how and when to use a resource. Therefore before these questions can be answered, data surrounding the resource should be compiled and consensus on the data should be reached. Building a simulation model of "what we do know" as early as possible in the process will assist with data compilation and analysis. In processes with poorly defined problems this could be done simultaneously with systems thinking exercises. Building a simulation model will accomplish two objectives. First, it will encourage the collection of data and the ensuing discussions as to its usefulness. This is a tenet of traditionally facilitated processes. Secondly, discussion will be facilitated by encouraging stakeholders to reveal their own reference modes of the problem. This will also help stakeholders reflect upon time horizons and concepts which require nonlinear thinking. The problem will be illuminated, and data and mental models elucidated as the model progresses through iterations.

When creating a quantitative simulation model, much of the work is typically done by the modeler "in the office" whether or not the process requires system thinking exercises.

[46] Also called Ockham's razor. The principal was first described in the 14th-century by English logician and Franciscan friar William of Ockham.

Moving a group from systems thinking exercises which use modeling software to the quantitative simulation model may come with problems.

> Groups that were most intimately involved in both the qualitative and the quantitative model building experienced a more difficult transition [to the quantitative model] than the groups that were less involved in the quantification of the actual model. The question remains to what extent and based on what characteristics of a group and mediated modeling process the participants should be involved in the quantification of the model. (van den Belt 2004, p. 255)

Van den Belt (2004, p. 240) also noted the difficulty of eliciting information about feedback and emphasizes that "[a]ddressing feedback loops and time lags should be a routine part of the process when the qualitative structure is being formed".

This brings forward the difficulties of building system dynamics simulation models. Often multiple iterations of seemingly simple concepts are required before a workable version of the model is created. This may cause frustration in group processes. It could be eliminated by modeling in the office, and simulating early and often. If modelers adhere to transparent practices this should not prove to be problematic to group ownership of the model. Returning to the classic SD method describe by Forrester will also help. Design models around stocks, flows and feedbacks, simulate early and iterate. Forrester (1994, p. 252), remarks that "systems thinking can serve a constructive role as a door opener to system dynamics and to serious work toward understanding systems". He further cautions that "diagrams that connect variables without distinguishing levels (integrations or stocks) from rates (flows or activity)… do not provide the discipline to thinking imposed by level and rate diagrams in system dynamics… and [thus] will fail to identify the system elements that produce dynamic behavior" (Forrester 1994, p.252). Or in other words, build simulation models.

Following these tenets in a group process is not always easy if there is a large group and a poorly defined problem. In addition, a group may want "everything" in the initial model. Modelers should use their skills as facilitators to help the group negotiate which stocks and flows will be initially included and encourage the group to build a simulation model of what they know as early as possible. Begin with a stock, flow and reference mode that the group can agree upon, simulate, then iterate. This concept is not in conflict with remaining neutral, unbiased, and respecting the needs of all individuals in the group. To the contrary, it encourages consensus, problem clarification and transparency. And if necessary, can be done at the same time systems thinking exercises of the bigger picture are taking place. Most importantly, it reminds us that models are conduits of both scientific and social information and are being used to *test hypotheses*.

5.2.3 Transparency: Modelers are translators; models are conduits

Models used to enhance scientific and social understanding are conduits of information. The modeler is a neutral facilitator who translates and integrates that information into a vision that reflects the interests of the group. This requires skills in social facilitation which enable participants to feel respected and valued. It also requires modelers to effectively, and without bias, translate scientific data and social concerns into model language. Ideally this should be done in such a manner that any stakeholder could follow the train of logic in the model. In reality the needs of a group may create certain occasions when complex relationships may only be captured with complex equations or graphics. In cases such as these the complexity should be thoroughly documented and a designated scientific stakeholder available for explanation. For example, systems models concerned with hydrology may have complex parameters which are used to create flow patterns. To create confidence in model outputs, comparisons can be made to traditional hydrologic models which have been created and validated with historic flows. If modelers are striving for simplicity and clarity as called for by system dynamics methodology then these situations should be uncommon rather than the norm.

Model transparency is also improved with concise parameter labels and well designed model maps and interfaces. Concise parameter labels will encourage the group to clarify their concerns and it will help them segregate physical laws and personal values. In addition, as a tenet of good model building, it will improve model quality and clarity. There are different schools of thought concerning model maps. For example, STELLA maps allow users to see the entire model as one big picture, yet to actually read parameters or navigation tools one must zoom in to a smaller scale. VENSIM uses drop down menus to segregate model pages which can help users view a list of pages whenever navigation is needed. With any modeling software, the design of user interfaces allows modelers to create places where stakeholders can view model relationships, graphics, instructions or any information of importance. The design of these interfaces is critical to the transparency of the model. A well designed interface will provide the information and the tools for effective model operation. It should also be an effective tool to encourage exploration of the model map, parameters and relationships of those parameters. This is especially important with larger models that may appear at first to be "black boxes".

5.2.4 Scientific defensibility

Science helps us understand the world around us through observation, hypothesis development, experimentation, and data analysis. It is an iterative process of unbiased hypothesis revision guided by principals of Occam's Razor. Moreover, as we find better ways of doing things we modify our methods; as we find better analytical tools we revise our methods of analysis. System dynamics was developed as a methodology to improve scientific analysis of complex relationships in synergistic structures. Simulation software and models are the tools.

Participatory modeling processes use these tools to integrate science and non-science. Nevertheless the process of building the model is still a scientific endeavor even though it takes place in a social context. Modelers are facilitating participatory model building with the premise that it helps reduce conflict but that is not insurance that conflict will not persist. Processes that use models to develop policy alternatives with the anticipation of implementation should be concerned about liabilities associated with their decision. In addition, any agency that is involved must adhere to legal and regulatory standards which include agency rules and protocol. Add in the conflict which usually surrounds natural resource management, models should be built with the scrutiny that would make them defensible in a court of law. This is not to emphasize what could be considered a sad state of affairs but rather to point out that model building is a scientific endeavor and should be held to the standards of scientific defensibility.

Replication: Replication is a basic tenet of experimental science. Concise labeling, clear interfaces, simple equations, and documentation of all parameters will assure that all relationships and assumptions can be easily replicated.

Peer reviewed data: Models may not go through a classic peer review that is typical of other scientific assessments however there is no reason they should not. When designing parameters that describe physical properties or professional science try to use peer reviewed data or the equivalent. Document its use and origin within the model as the structure containing the parameters is designed.

Non peer reviewed data, experiential knowledge and street science: Clearly labeled parameters will distinguish professional science and physical laws from other valuable data. When at all possible present this information in the same format as one would find peer reviewed data. If necessary create the opportunity for various types of knowledge to be independently tested within the model. If there is discussion between the validity of peer reviewed data versus local knowledge for the same or similar parameter, place the parameter in a slider so that the value may be tested. If it is not highly sensitive the discussion over its value may become a moot point.

Clear statement of policy alternatives: When designing policy options details of that option should be easily identified by model users. Ideally the parameters that are adjusted to create the policy alternative should have sliders, indicator lights or the equivalent on the graphical interface on which the results of the policy option are displayed.

Companion models: All models are simplifications of the real world. We use them to test our knowledge and assumptions. Most disciplines in natural resource management have a type of research model that is considered a convention. Scientists are familiar with the inputs, outputs and assumptions. Stakeholders may or may not have confidence in these models because the size and complexity could easily hide agendas. In highly contentious situations the use of more than one type of model can build confidence that neither model has fatal flaws. The sage grouse project described in chapter three is an illustration of the use of system dynamics and population viability analysis (PVA). These models use information in different manners however they were both able to produce comparable outputs. Hydrologic models such as RIVERWARE or MODFLOW can typically be tested against historic data for model verification; however these models are not practical for quickly testing management alternatives. Therefore outputs from hydrological models are used in system dynamics models that are better able to test policy. Running base case scenarios of both models and producing like results increases confidence in the systems model.

Uncertainty: Participatory models parameters contain a variety of data types as described in chapter 4 (sec 4.5.3). Table 5.1 describes the types of data on the quantitative to qualitative continuum. Each data type comes with its own uncertainties.

Physical laws	Controlled physical experiments	Uncontrolled physical experiments	Social system data	Social system cases	Expert judgment	Personal intuition

Table 5.1 The quantitative to qualitative continuum (Ford 1999).

If data from professional science sources comes with known uncertainties then this is easily documented. But what of those parameters that contain street science or experiential knowledge? Professional science may argue that the issue of uncertainty or those types of parameters invalidates the scientific defensibility of the model. The following argues to the contrary. Concise labeling of parameters will clarify the type of data it contains. Also these models are being used to test policy options and if changes in the parameter do not affect that the implications of that option then greater accuracy is not necessary (Ford 1999, p. 174). If such a parameter does show high sensitivity then this points to an issue that should be researched more thoroughly by the group. Another argument is that expert opinion used by experienced managers to make decisions is potentially uncertain but it is used nonetheless. Finally excluding an uncertain parameter essentially states that the value of the parameter is zero. If a guesstimate is better than zero, clearly label the parameter and put it on a slider so that its relative value may be explored (Ford 1999, p. 176).

To avoid uncertainty that is created by model structure, iterations and "extremes" testing will help eliminate modeling errors and create a robust model. Sensitivity analysis of individual parameters will help troubleshoot issues that may be a result of model structure.

The *Daubert* Standards: The US Supreme Court looks to Daubert Standards[47] to guide their judgment of science. Best practice model building should follow the tenets of best practice science. A clearly stated hypothesis, rigorous testing of that hypothesis, clearly stated assumptions and uncertainties, and replicability are required for scientific defensibility in any discipline. Another requirement of science is peer review. Group processes that build models should fulfill this requirement by proxy because transparency and review are inherent.

A well built model should follow all of the tenets of scientific defensibility.

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[47] U.S. Supreme Court Cases: *Daubert v. Merrill Dow Chemicals, Inc.* 509 US 579 (1993); *General Electric Co. v. Joiner*, 522 U.S. 136 (1997); *Kumho Tire Co. v. Carmichael*, 526 U.S. 137 (1999).

5.3 My final thoughts

I was introduced to system dynamics during the final semester of work on my masters. I found myself drawn to the transparent and straightforward logic. The product of my masters titled *A Sense of Place: Ecological Values, Ethics, and Collaborative Problem Solving in the American West* was essentially an essay on the benefits of place-based collaborative problem-solving and democratic principals. My class in system dynamics provided much needed relief from complexities of "messy problems". Sometime during that semester I made the connection that it could also be of assistance to others who were seeking to sort through messy problems. In fact system dynamics was designed for messy problems. The desire to combine such logic with my interest in facilitating natural resource problems led me to an obvious conclusion. Participatory system dynamics can create a nexus of science and local knowledge that will serve to bridge natural resource science and social concerns.

It is interesting to note that participatory environmental system dynamics modeling has "been discovered" by a diversity of seemingly unrelated people who appear to have had little exposure to one another. The commonality appears to be experience with system dynamics or systems thinking, interdisciplinary training, and an interest in consensus-based environmental problem solving.

> "Uniform ideas originating among entire peoples unknown to each other must have a common ground of truth." Giambattista Vico[48]

[48] Giambattista Vico (1984 g. XXV)

5.4 References

Deitz, T. 2004 (p. xiii). From the forward of van den Belt, M. 2004 *Mediated Modeling*.

Forrester, J. 1991. From the Ranch to System Dynamics: An Autobiography. Management Laureates: A collection of Autobiographical Essays, Vol. 1 Arthur G. Bedeian ed. JAI Press, 1992.

Forrester, J. 1994. System dynamics, systems thinking, and soft OR. *System Dynamics Review,* 10(2-3): 245-256.

Meadows, D. and Robinson, J.M. 1985. *The Electronic Oracle: Computer Models and Social Decisions*. John Wiley & Sons Ltd. New York.

Stave, K. 2002.Using system dynamics to improve public participation in environmental decisions. *System Dynamics Review*, Vol. 18, No 2:139-167.

van den Belt, M. 2004 *Mediated Modeling*. Island Press. Washington, D.C.; Covelo, California; London.

APPENDICES

Appendix 1- Model Language

Connector- arrows found in the model which link two or more variables.

Drop down menu- found on the lower left of the screen and provides an index of model views.

Flow- the rate the item in a particular stock moves to another stock or out of the system. For example a “deaths from senescence” flow is the rate at which adult birds die from old age and are removed from the system.

Navigation button- green square text boxes that when clicked send the user to the described location.

Reference Mode – A reference mode is graphical representation of an important variable and how that variable changes over time. A reference mode is typically drawn in the initial stages of system dynamics modeling building to help describe the behavior of the system.

Stock- a place or stage where something is stored for a period of time. For example, in the case of sage grouse the “eggs in nests” stock is a definable place or time where grouse numbers can be defined.

Variable-a stock, flow or other model input or output that are involved in mathematical equations used in the model. For example “acres to hectares” is a variable that holds said conversion for use in other equations.

View-a model page that may contain variables, stocks, flows, model outputs (graphs, tables etc.) or notes or any combination of the above. A list of views may be found in the lower left hand drop down menu.

Appendix 2 - FCCD Habitat Matrix for Sage grouse

Greater sage-grouse H.S.I. (breeding) for Douglas County, Washington

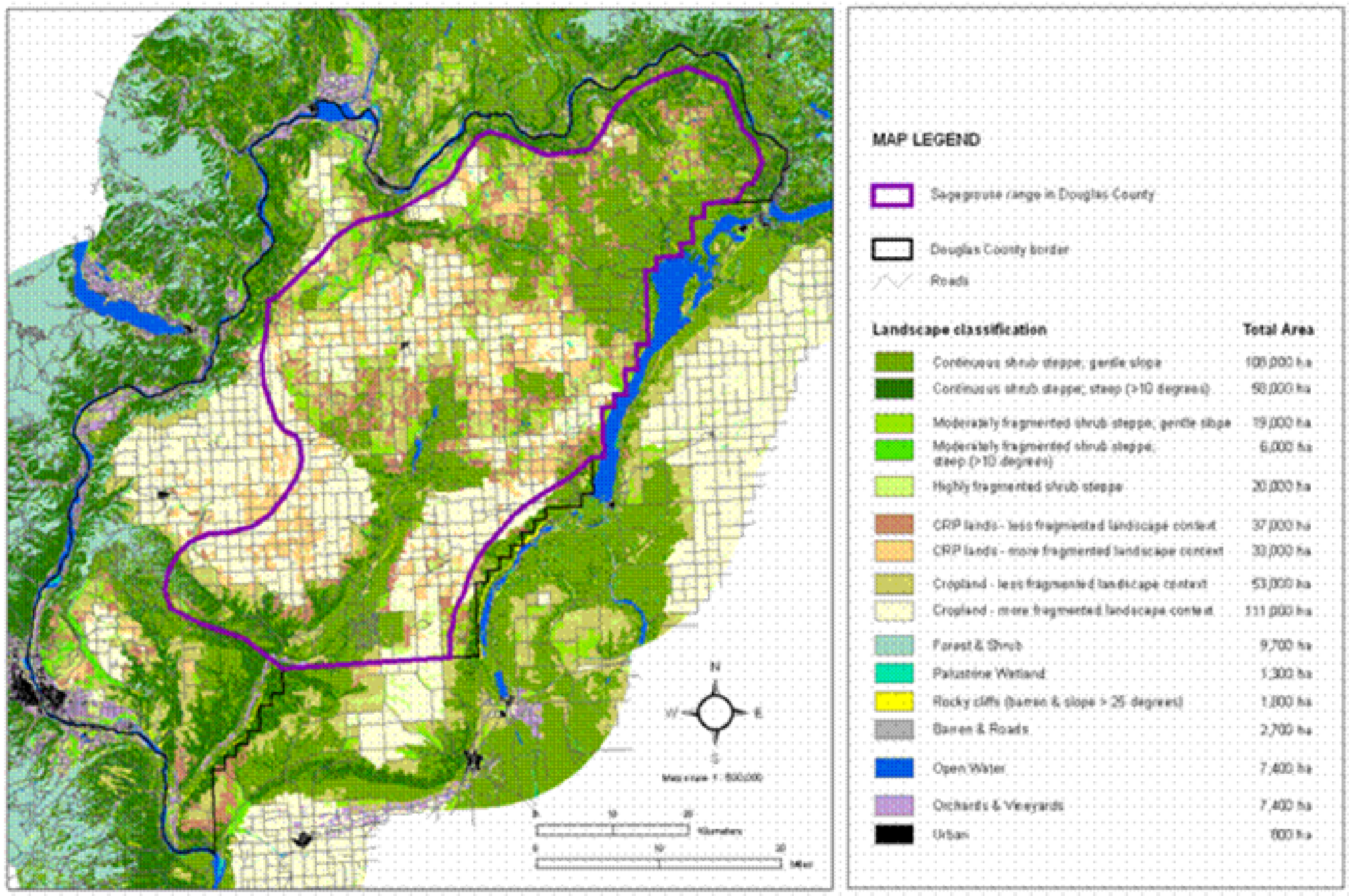
Habitat type	Total habitat in Douglas County	Habitat with elimination of CRP (assumes 10% CRP retention in shrubsteppe landscapes)	Habitat with reduction of CRP to 25% (assumes equal reduction in CRP by landscape type)			No HCP						100% HCP					
				Current		0% CRP		25% CRP		33% CRP		0% CRP		25% CRP		33% CRP	
				Suitability	Units	Suitability	Units	Suitability	Units	Suitability	Units	Suitability	Units	Suitability	Units	Suitability	Units
SS - gentle & continuous	76072	76072	76072	0.1	7607.2	0.15	11411	0.15	11411	0.15	11411	0.3	22822	0.3	22822	0.3	22822
SS - steep & continuous	16912	16912	16912	0.05	845.6	0.05	845.6	0.05	845.6	0.05	845.6	0.1	1691.2	0.1	1691.2	0.1	1691.2
SS - gentle & moderate	15548	15548	15548	0.4	6219.2	0.45	6996.6	0.45	6996.6	0.45	6996.6	0.55	8551.4	0.55	8551.4	0.55	8551.4
SS - steep & moderate	1818	1818	1818	0.05	90.9	0.05	90.9	0.05	90.9	0.05	90.9	0.06	109.08	0.06	109.08	0.06	109.08
SS - fragmented	14398	14398	14398	0.65	9358.7	0.75	10799	0.75	10799	0.75	10799	0.75	10799	0.75	10799	0.75	10799
CRP - SS landscape	26970	2697	23202	0.4	10788	0.5	1348.5	0.5	11601	0.5	13485	0.55	1483.4	0.55	12761	0.55	14834
CRP - crop landscape	30800	0	26496	0.05	1540	0.1	0	0.1	2649.6	0.1	3080	0.12	0	0.12	3179.5	0.12	3696
Cropland - SS landscape	72491	96764	76259	0.01	724.91	0.01	967.64	0.01	762.59	0.01	724.91	0.01	967.64	0.01	762.59	0.01	724.91
Cropland - crop landscape	32796	63596	37100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orchards	205	205	205	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cliffs	490	490	490	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Open Water	996	996	996	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urban	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Palustrine Wetland	1150	1150	1150	0.2	230	0.2	230	0.2	230	0.2	230	0.2	230	0.2	230	0.2	230
Barren	814	814	814	0.1	81.4	0.1	81.4	0.1	81.4	0.1	81.4	0.1	81.4	0.1	81.4	0.1	81.4
Forest/shrub	570	570	570	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	292030	292030	292030		37486		32770		45467		47744		46734		60986		63538

Greater sage-grouse H.S.I. (wintering) for Douglas County, Washington

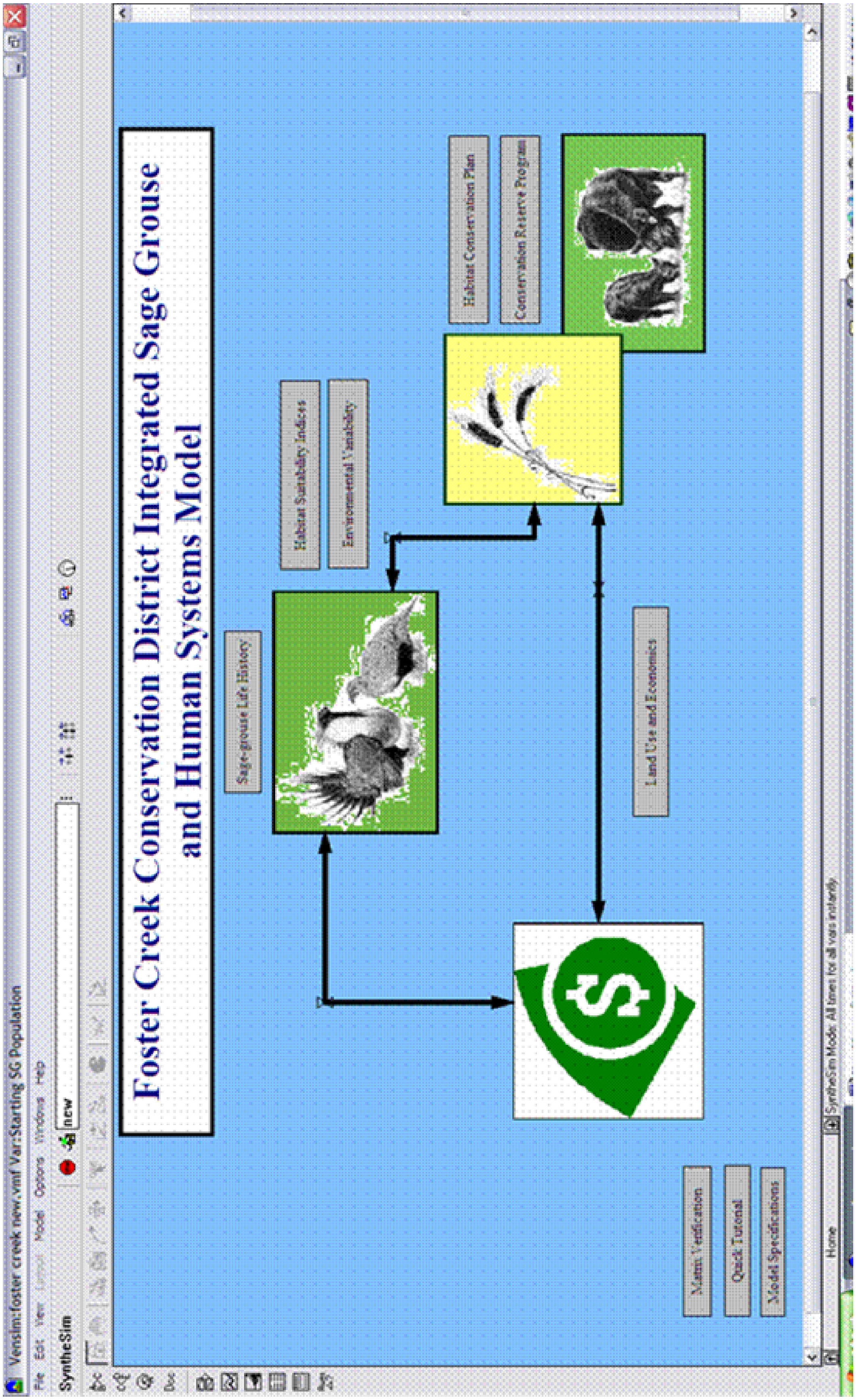
Habitat type	Total habitat in Douglas County	Habitat with elimination of CRP (assumes 10% CRP retention in shrubsteppe landscapes)	Habitat with reduction of CRP to 25% (assumes equal reduction in CRP by landscape type)			No HCP						100% HCP					
				Current		0% CRP		25% CRP		33% CRP		0% CRP		25% CRP		33% CRP	
				Suitability	Units	Suitability	Units	Suitability	Units	Suitability	Units	Suitability	Units	Suitability	Units	Suitability	Units
SS - gentle & continuous	76072	76072	76072	0.6	45643	0.65	49447	0.65	49447	0.65	49447	0.7	53250	0.7	53250	0.7	53250
SS - steep & continuous	16912	16912	16912	0.15	2536.8	0.15	2536.8	0.15	2536.8	0.15	2536.8	0.15	2536.8	0.15	2536.8	0.15	2536.8
SS - gentle & moderate	15548	15548	15548	0.3	4664.4	0.3	4664.4	0.3	4664.4	0.3	4664.4	0.35	5441.8	0.35	5441.8	0.35	5441.8
SS - steep & moderate	1818	1818	1818	0.1	181.8	0.1	181.8	0.1	181.8	0.1	181.8	0.1	181.8	0.1	181.8	0.1	181.8
SS - fragmented	14398	14398	14398	0.05	719.9	0.1	1439.8	0.1	1439.8	0.1	1439.8	0.1	1439.8	0.1	1439.8	0.1	1439.8
CRP - SS landscape	26970	2697	23202	0.05	1348.5	0.15	404.55	0.15	3480.3	0.15	4045.5	0.15	404.55	0.15	3480.3	0.15	4045.5
CRP - crop landscape	30800	0	26496	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cropland - SS landscape	72491	96764	76259	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cropland - crop landscape	32796	63596	37100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orchards	205	205	205	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cliffs	490	490	490	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Open Water	996	996	996	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Urban	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Palustrine Wetland	1150	1150	1150	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barren	814	814	814	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Forest/shrub	570	570	570	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	292030	292030	292030		55095		58674		61750		62315		63255		66331		66896

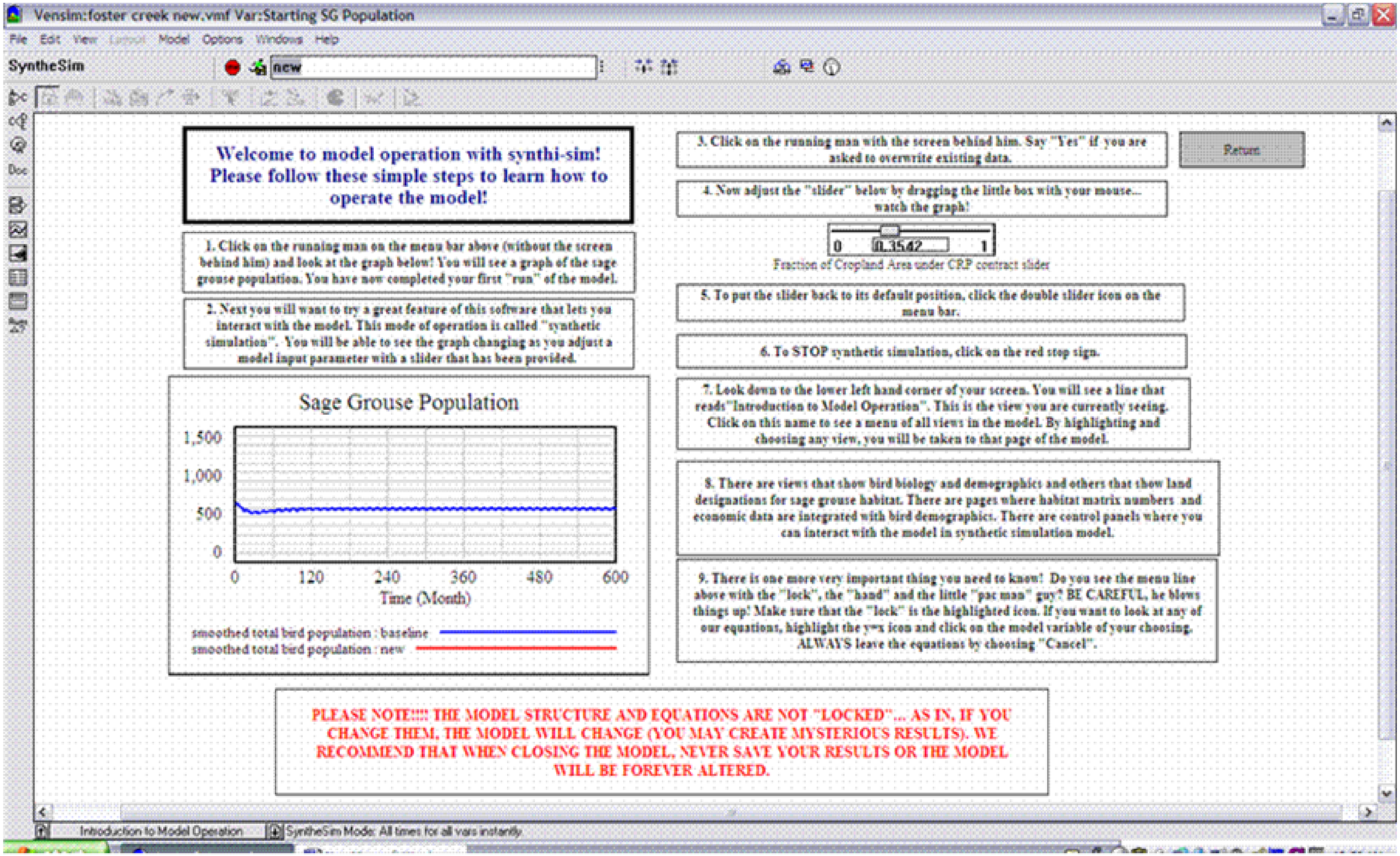
Appendix 3 - GIS map outlining sage grouse area in Douglas County

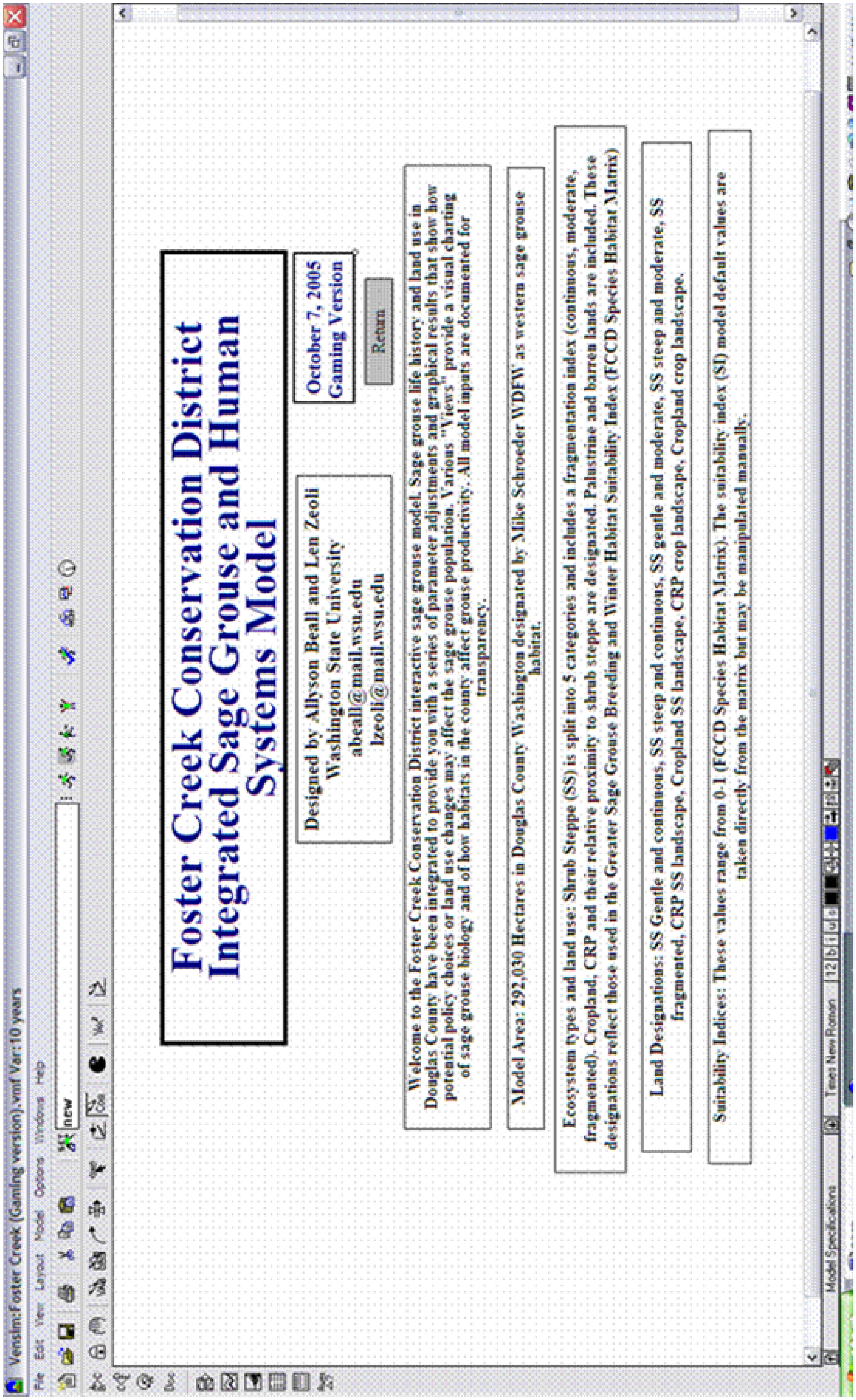
Provided by Mike Heiner, TNC

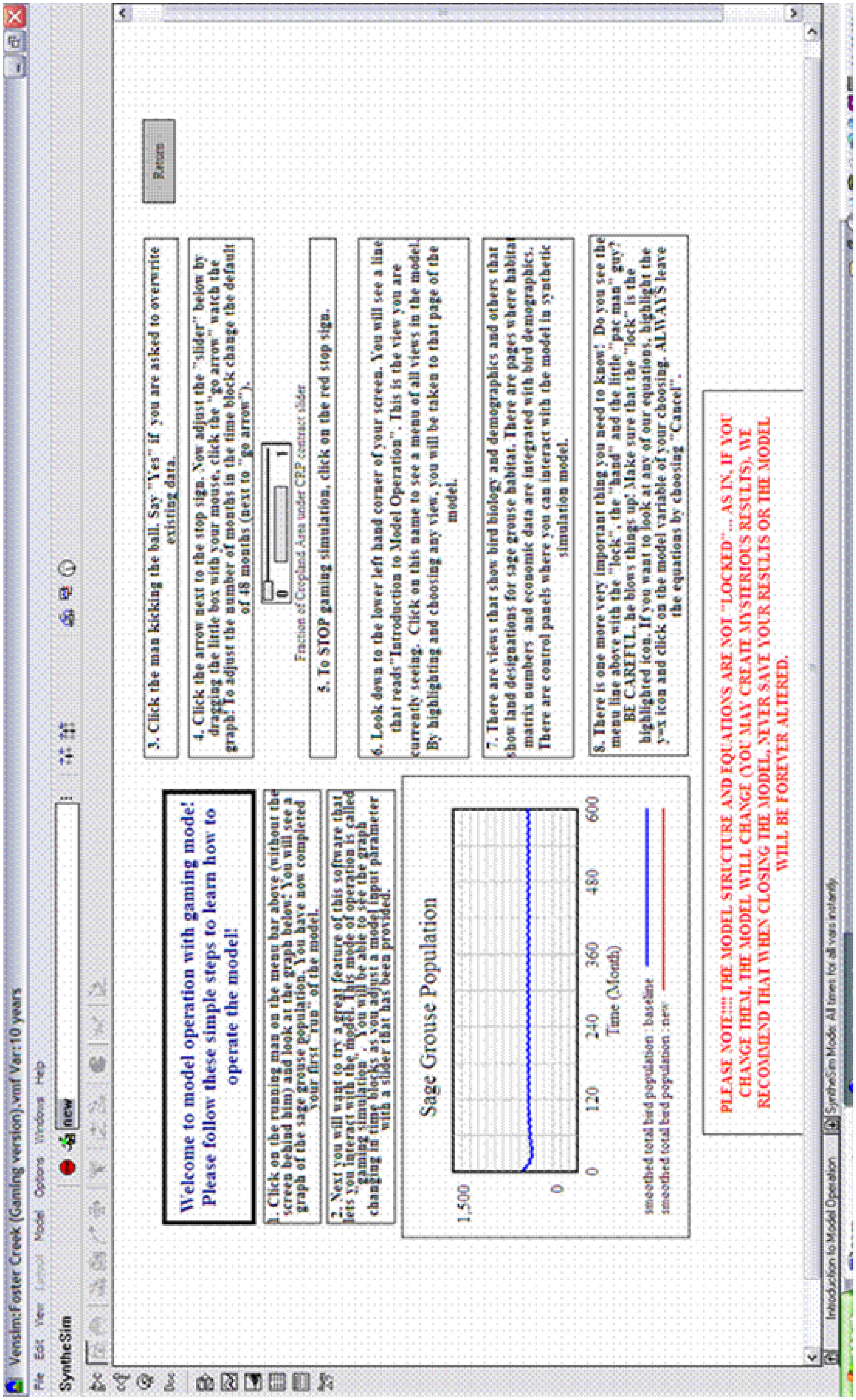


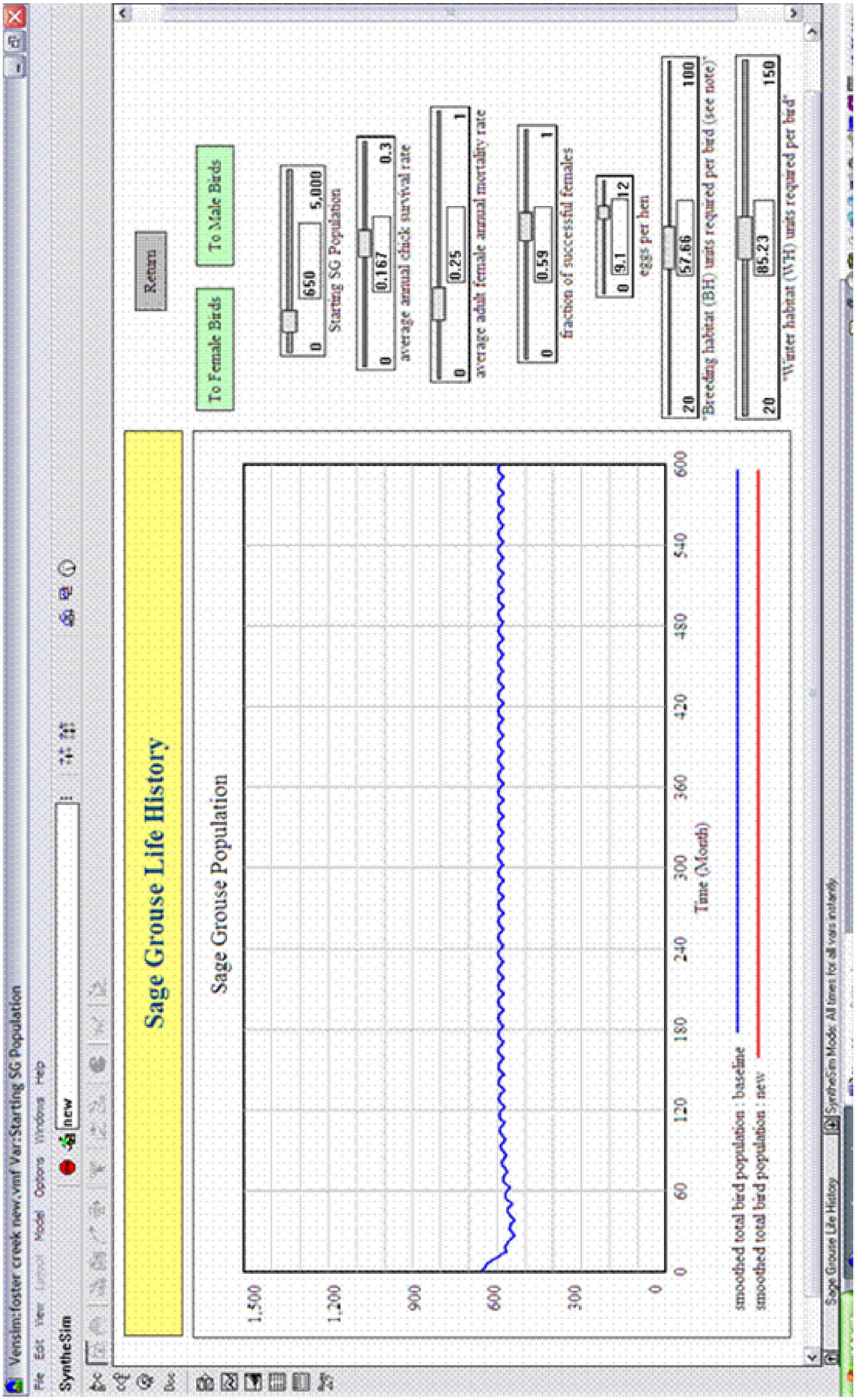
Appendix 4 - Model Printout

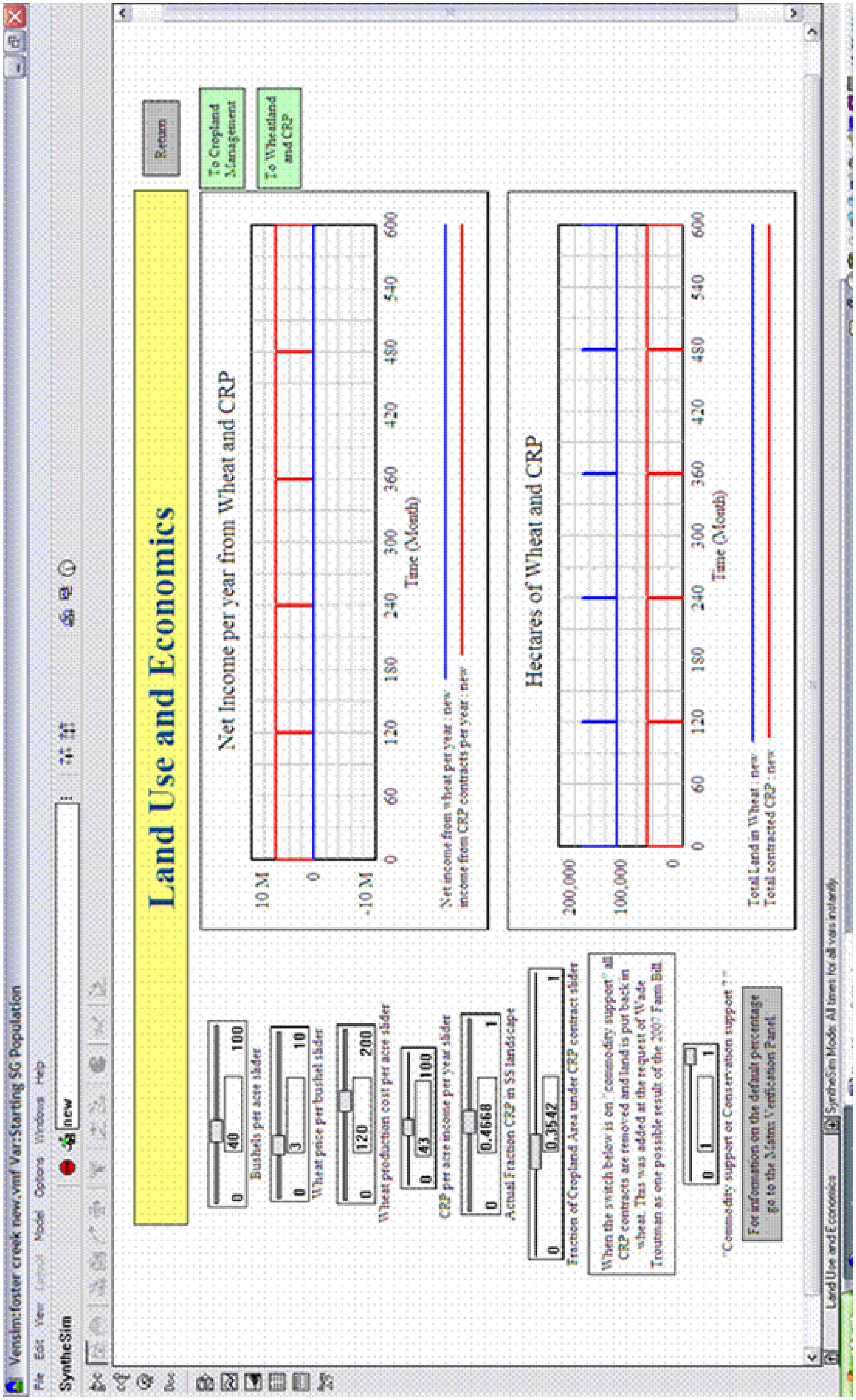

Vensim:foster creek new.vmf Var:Starting SG Population
SyntheSim
Foster Creek Conservation District Integrated Sage Grouse and Human Systems Model
Sage-grouse Life History
Habitat Suitability Indices
Environmental Variability
Habitat Conservation Plan
Conservation Reserve Program
Land Use and Economics
Matrix Verification
Quick Tutorial
Model Specifications

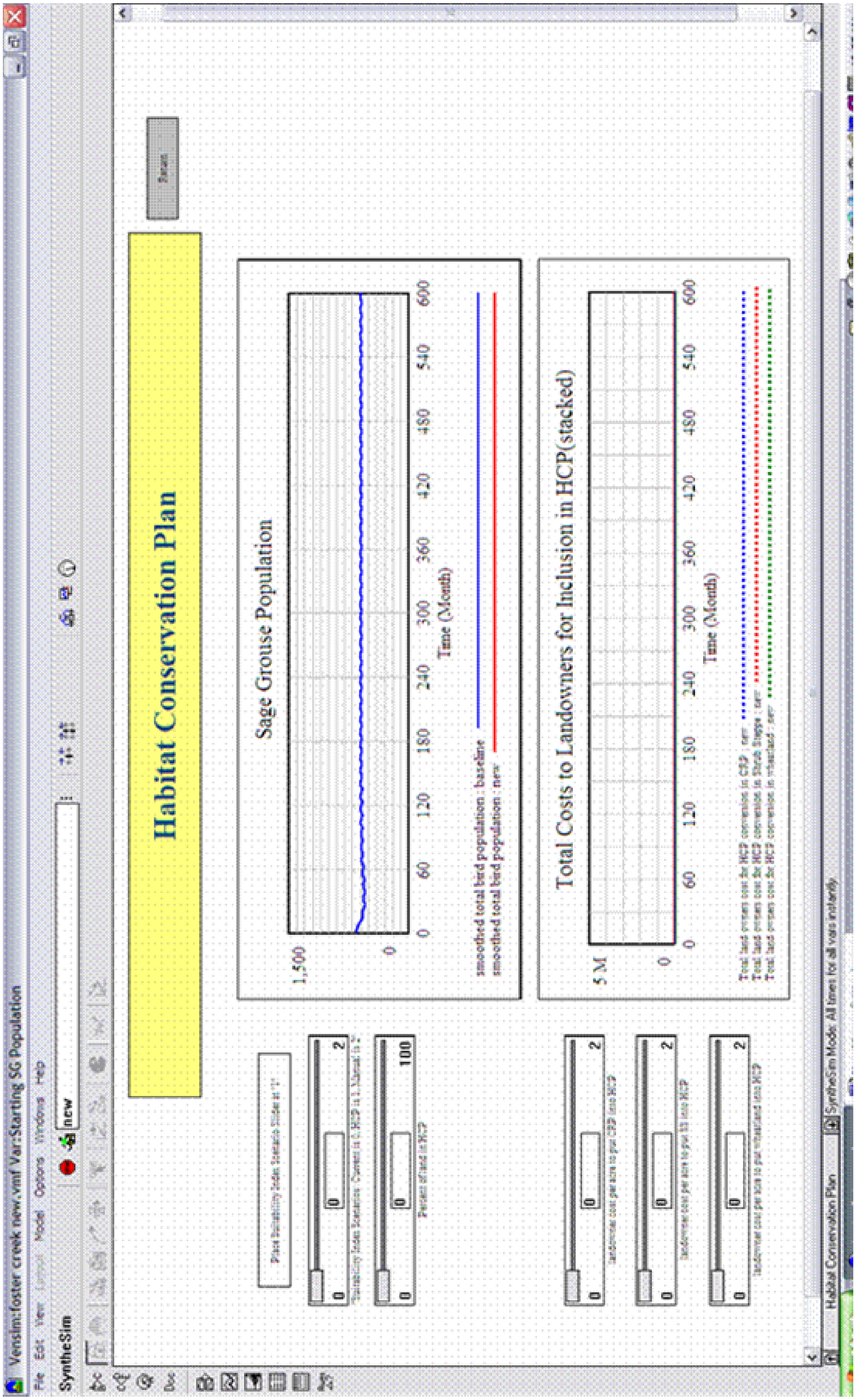

Vensim:foster creek new.vmf Var:Starting SG Population
File Edit View Layout Model Options Windows Help
SyntheSim
new
Welcome to model operation with synthi-sim! Please follow these simple steps to learn how to operate the model!
1. Click on the running man on the menu bar above (without the screen behind him) and look at the graph below! You will see a graph of the sage grouse population. You have now completed your first "run" of the model.
2. Next you will want to try a great feature of this software that lets you interact with the model. This mode of operation is called "synthetic simulation". You will be able to see the graph changing as you adjust a model input parameter with a slider that has been provided.
Sage Grouse Population
1,500
1,000
500
0
0 120 240 360 480 600
Time (Month)
smoothed total bird population : baseline
smoothed total bird population : new
3. Click on the running man with the screen behind him. Say "Yes" if you are asked to overwrite existing data.
Return
4. Now adjust the "slider" below by dragging the little box with your mouse... watch the graph!
0 0.3542 1
Fraction of Cropland Area under CRP contract slider
5. To put the slider back to its default position, click the double slider icon on the menu bar.
6. To STOP synthetic simulation, click on the red stop sign.
7. Look down to the lower left hand corner of your screen. You will see a line that reads "Introduction to Model Operation". This is the view you are currently seeing. Click on this name to see a menu of all views in the model. By highlighting and choosing any view, you will be taken to that page of the model.
8. There are views that show bird biology and demographics and others that show land designations for sage grouse habitat. There are pages where habitat matrix numbers and economic data are integrated with bird demographics. There are control panels where you can interact with the model in synthetic simulation model.
9. There is one more very important thing you need to know! Do you see the menu line above with the "lock", the "hand" and the little "pac man" guy? BE CAREFUL, he blows things up! Make sure that the "lock" is the highlighted icon. If you want to look at any of our equations, highlight the y=x icon and click on the model variable of your choosing. ALWAYS leave the equations by choosing "Cancel".
PLEASE NOTE!!!! THE MODEL STRUCTURE AND EQUATIONS ARE NOT "LOCKED"... AS IN, IF YOU CHANGE THEM, THE MODEL WILL CHANGE (YOU MAY CREATE MYSTERIOUS RESULTS). WE RECOMMEND THAT WHEN CLOSING THE MODEL, NEVER SAVE YOUR RESULTS OR THE MODEL WILL BE FOREVER ALTERED.
Introduction to Model Operation
SyntheSim Mode: All times for all vars instantly

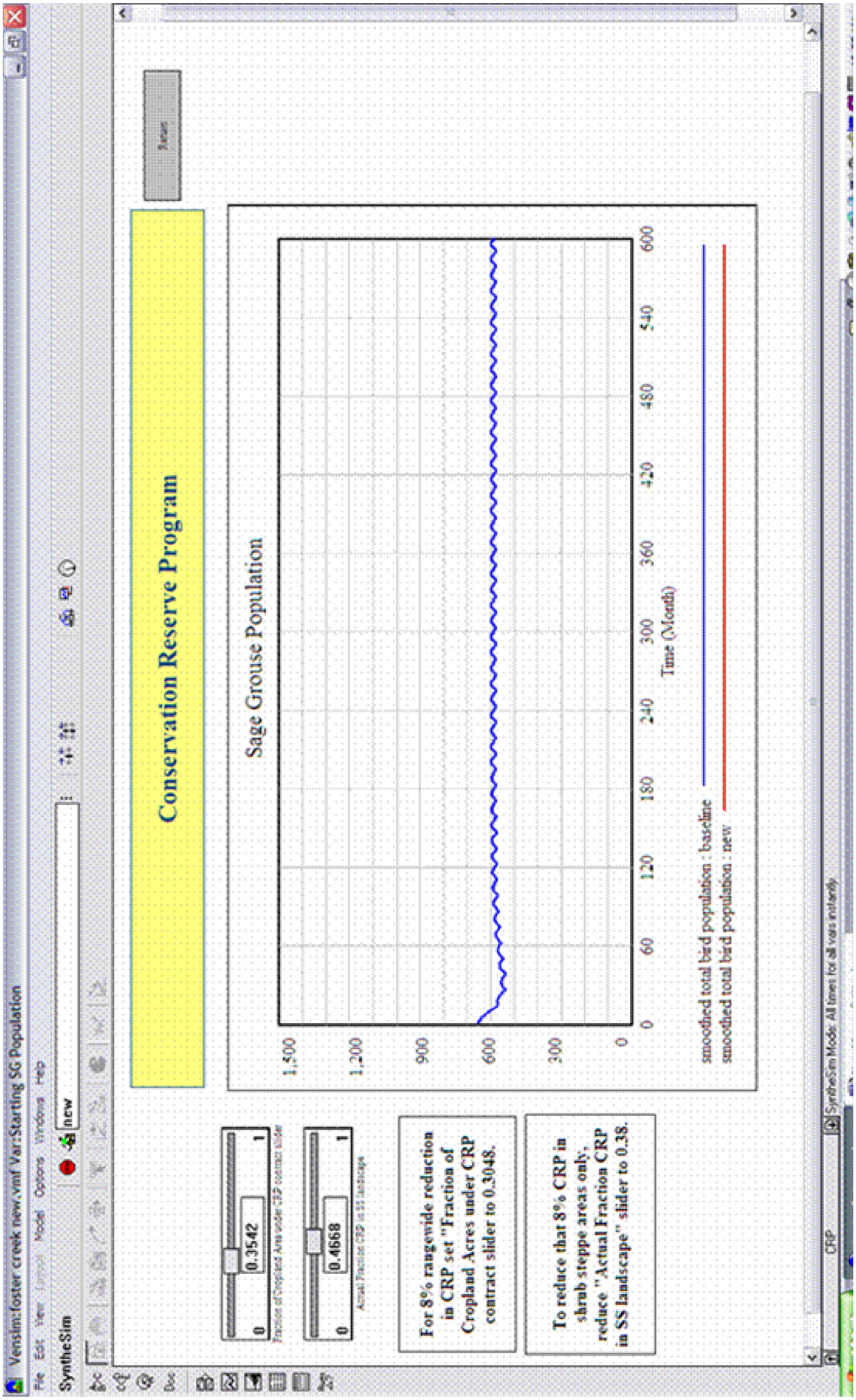

Vensim:Foster Creek (Gaming version).vmf Var:10 years
File Edit View Layout Model Options Windows Help
new
Foster Creek Conservation District Integrated Sage Grouse and Human Systems Model
Designed by Allyson Beall and Len Zeoli
Washington State University
abeall@mail.wsu.edu
lzeoli@mail.wsu.edu
October 7, 2005
Gaming Version
Return
Welcome to the Foster Creek Conservation District interactive sage grouse model. Sage grouse life history and land use in Douglas County have been integrated to provide you with a series of parameter adjustments and graphical results that show how potential policy choices or land use changes may affect the sage grouse population. Various "Views" provide a visual charting of sage grouse biology and of how habitats in the county affect grouse productivity. All model inputs are documented for transparency.
Model Area: 292,030 Hectares in Douglas County Washington designated by Mike Schroeder WDFW as western sage grouse habitat.
Ecosystem types and land use: Shrub Steppe (SS) is split into 5 categories and includes a fragmentation index (continuous, moderate, fragmented). Cropland, CRP and their relative proximity to shrub steppe are designated. Palustrine and barren lands are included. These designations reflect those used in the Greater Sage Grouse Breeding and Winter Habitat Suitability Index (FCCD Species Habitat Matrix)
Land Designations: SS Gentle and continuous, SS steep and continuous, SS gentle and moderate, SS steep and moderate, SS fragmented, CRP SS landscape, Cropland SS landscape, CRP crop landscape, Cropland crop landscape.
Suitability Indices: These values range from 0-1 (FCCD Species Habitat Matrix). The suitability index (SI) model default values are taken directly from the matrix but may be manipulated manually.
Model Specifications
Times New Roman
12

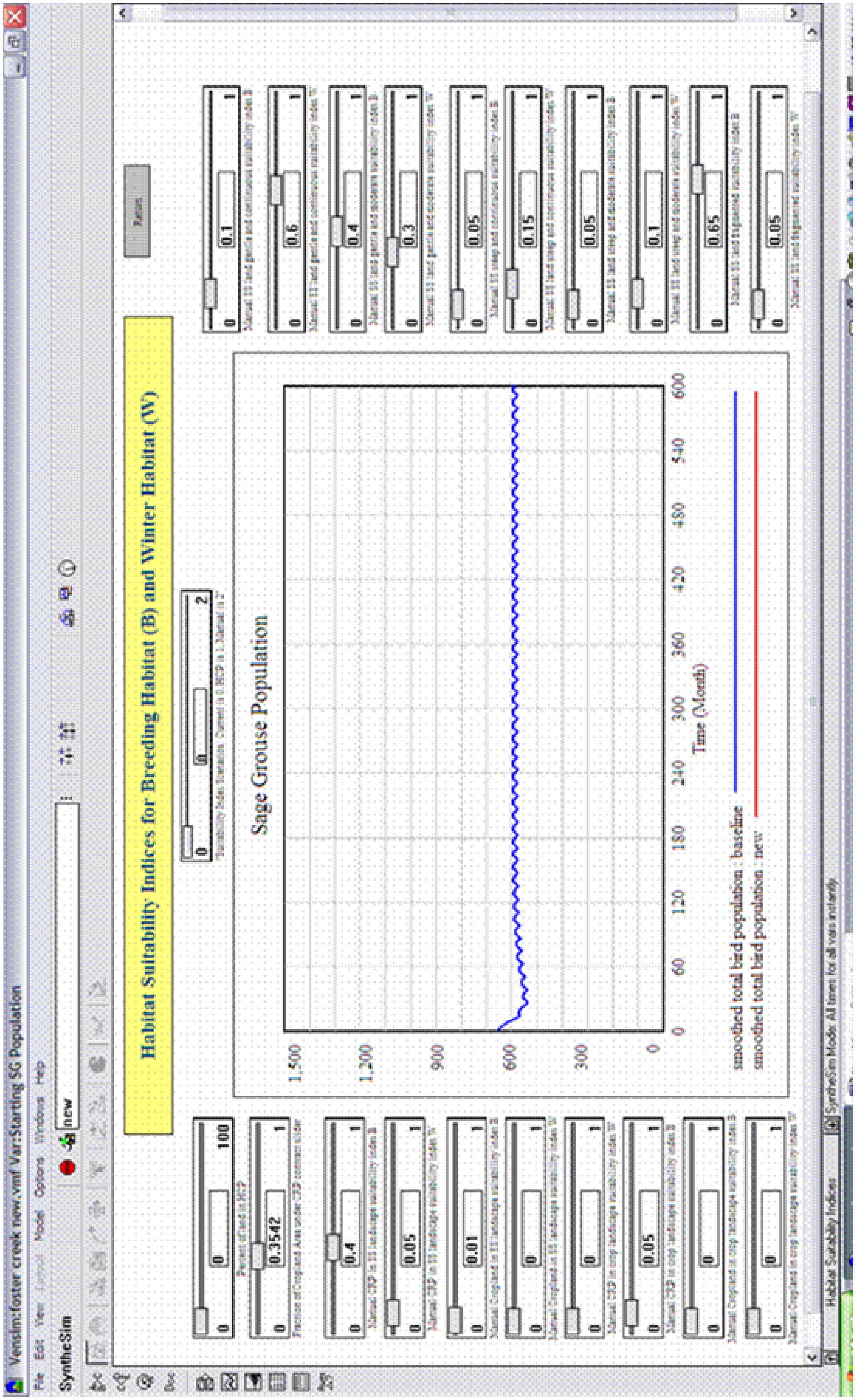

Vensim:Foster Creek (Gaming version).vmf Var:10 years
File Edit View Layout Model Options Windows Help
SyntheSim
new
Welcome to model operation with gaming mode! Please follow these simple steps to learn how to operate the model!
1. Click on the running man on the menu bar above (without the screen behind him) and look at the graph below! You will see a graph of the sage grouse population. You have now completed your first "run" of the model.
2. Next you will want to try a great feature of this software that lets you interact with the model. This mode of operation is called "gaming simulation". You will be able to see the graph changing in time blocks as you adjust a model input parameter with a slider that has been provided.
Sage Grouse Population
1,500
0
0 120 240 360 480 600
Time (Month)
smoothed total bird population : baseline
smoothed total bird population : new
3. Click the man kicking the ball. Say "Yes" if you are asked to overwrite existing data.
4. Click the arrow next to the stop sign. Now adjust the "slider" below by dragging the little box with your mouse, click the "go arrow" watch the graph! To adjust the number of months in the time block change the default of 48 months (next to "go arrow").
0 1
Fraction of Cropland Area under CRP contract slider
5. To STOP gaming simulation, click on the red stop sign.
6. Look down to the lower left hand corner of your screen. You will see a line that reads"Introduction to Model Operation". This is the view you are currently seeing. Click on this name to see a menu of all views in the model. By highlighting and choosing any view, you will be taken to that page of the model.
7. There are views that show bird biology and demographics and others that show land designations for sage grouse habitat. There are pages where habitat matrix numbers and economic data are integrated with bird demographics. There are control panels where you can interact with the model in synthetic simulation model.
8. There is one more very important thing you need to know! Do you see the menu line above with the "lock", the "hand" and the little "pac man" guy? BE CAREFUL, he blows things up! Make sure that the "lock" is the highlighted icon. If you want to look at any of our equations, highlight the y=x icon and click on the model variable of your choosing. ALWAYS leave the equations by choosing "Cancel".
Return
PLEASE NOTE!!!! THE MODEL STRUCTURE AND EQUATIONS ARE NOT "LOCKED"... AS IN, IF YOU CHANGE THEM, THE MODEL WILL CHANGE (YOU MAY CREATE MYSTERIOUS RESULTS). WE RECOMMEND THAT WHEN CLOSING THE MODEL, NEVER SAVE YOUR RESULTS OR THE MODEL WILL BE FOREVER ALTERED.
Introduction to Model Operation
SyntheSim Mode: All times for all vars instantly

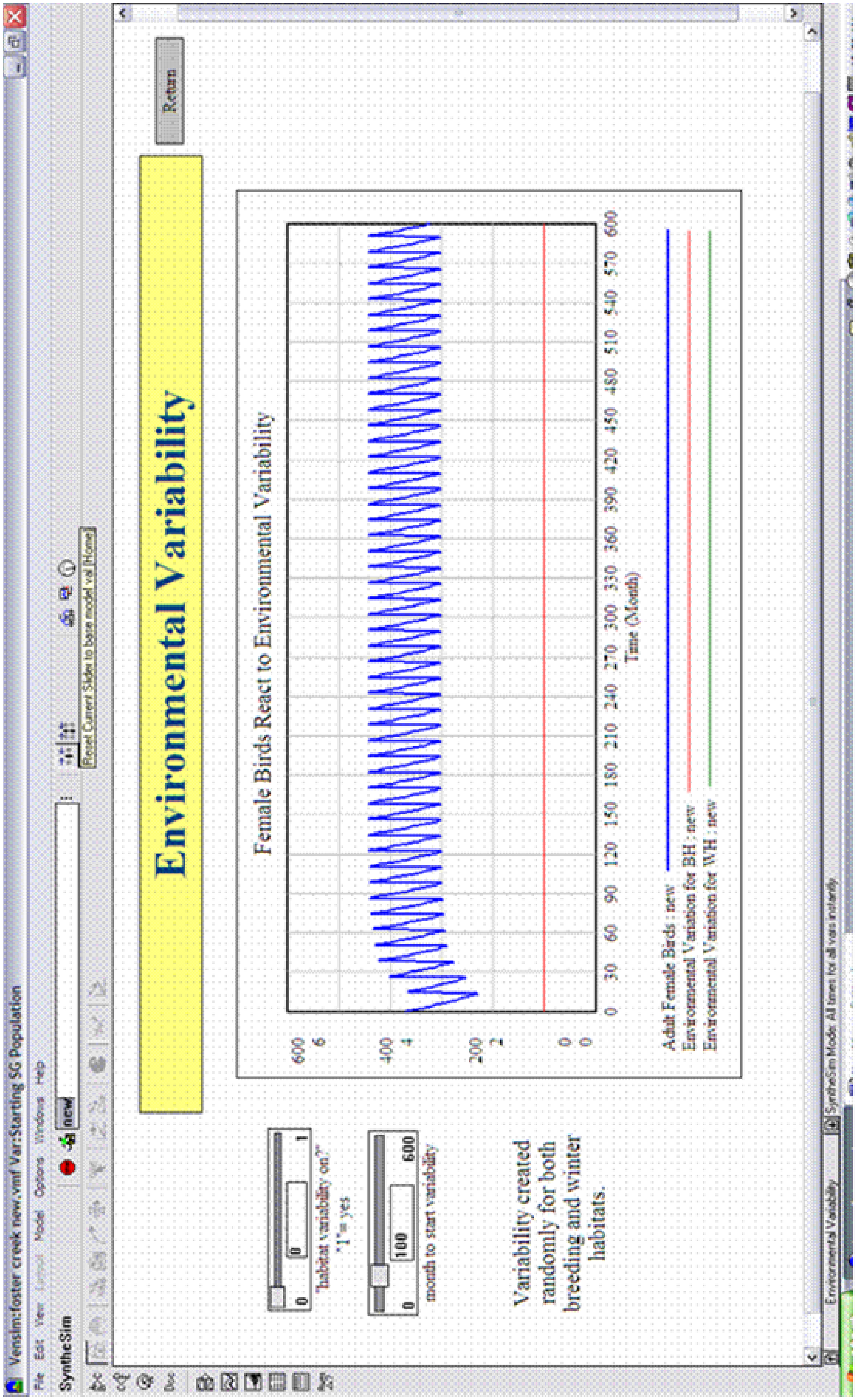

Vensim: foster creek new.vmf Var:Starting SG Population
SyntheSim
Sage Grouse Life History
Sage Grouse Population
1,500
1,200
900
600
300
0
0
60
120
180
240
300
360
420
480
540
600
Time (Month)
smoothed total bird population : baseline
smoothed total bird population : new
Return
To Female Birds
To Male Birds
Starting SG Population
average annual chick survival rate
average adult female annual mortality rate
fraction of successful females
eggs per hen
"Breeding habitat (BH) units required per bird (see note)"
"Winter habitat (WH) units required per bird"

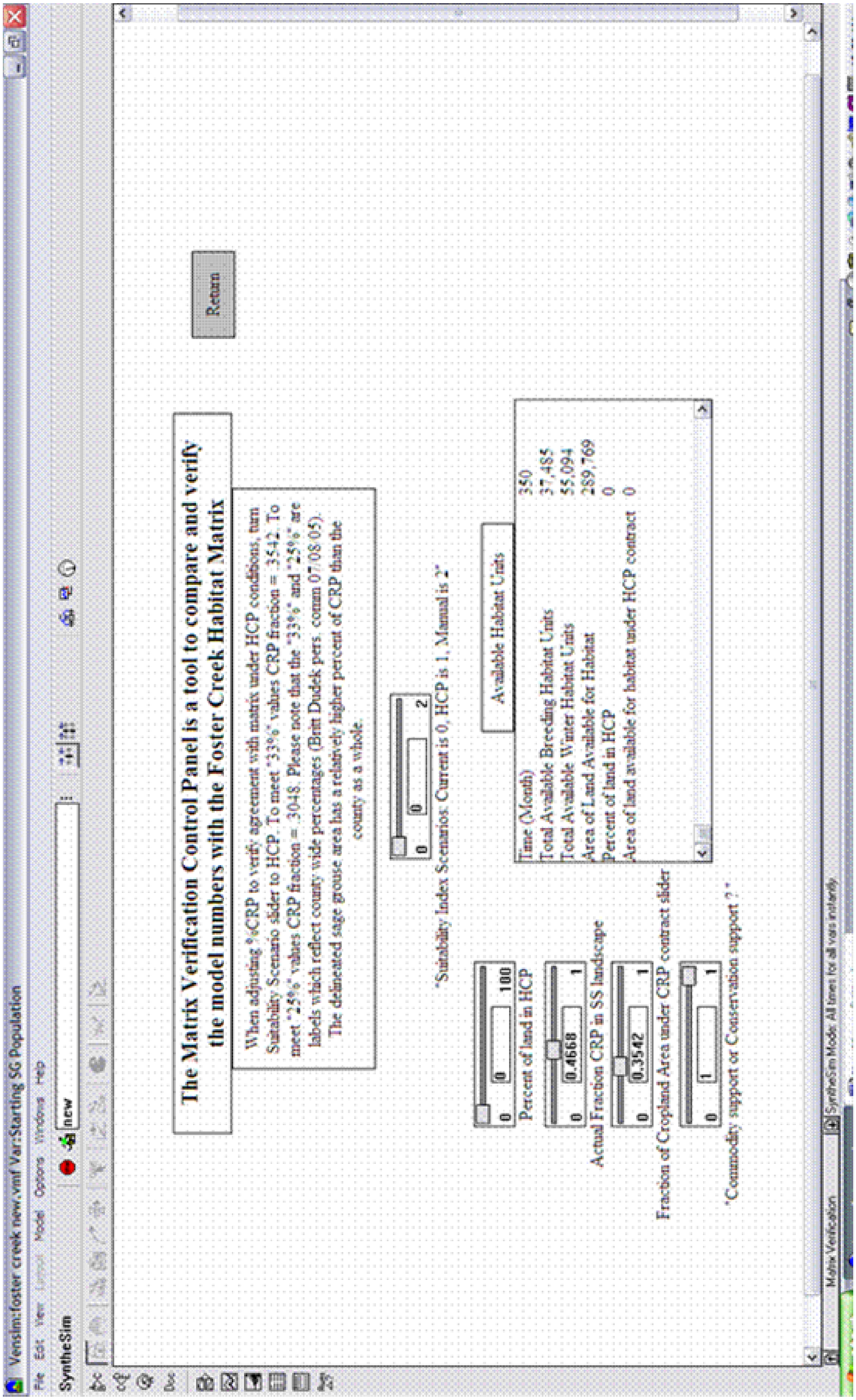

Land Use and Economics
Net Income per year from Wheat and CRP
Hectares of Wheat and CRP
Time (Month)
Net income from wheat per year : new
income from CRP contracts per year : new
Total Land in Wheat : new
Total contracted CRP : new
Bushels per acre slider
Wheat price per bushel slider
Wheat production cost per acre slider
CRP per acre income per year slider
Actual Fraction CRP in SS landscape
Fraction of Cropland Area under CRP contract slider
Return
To Cropland Management
To Wheatland and CRP

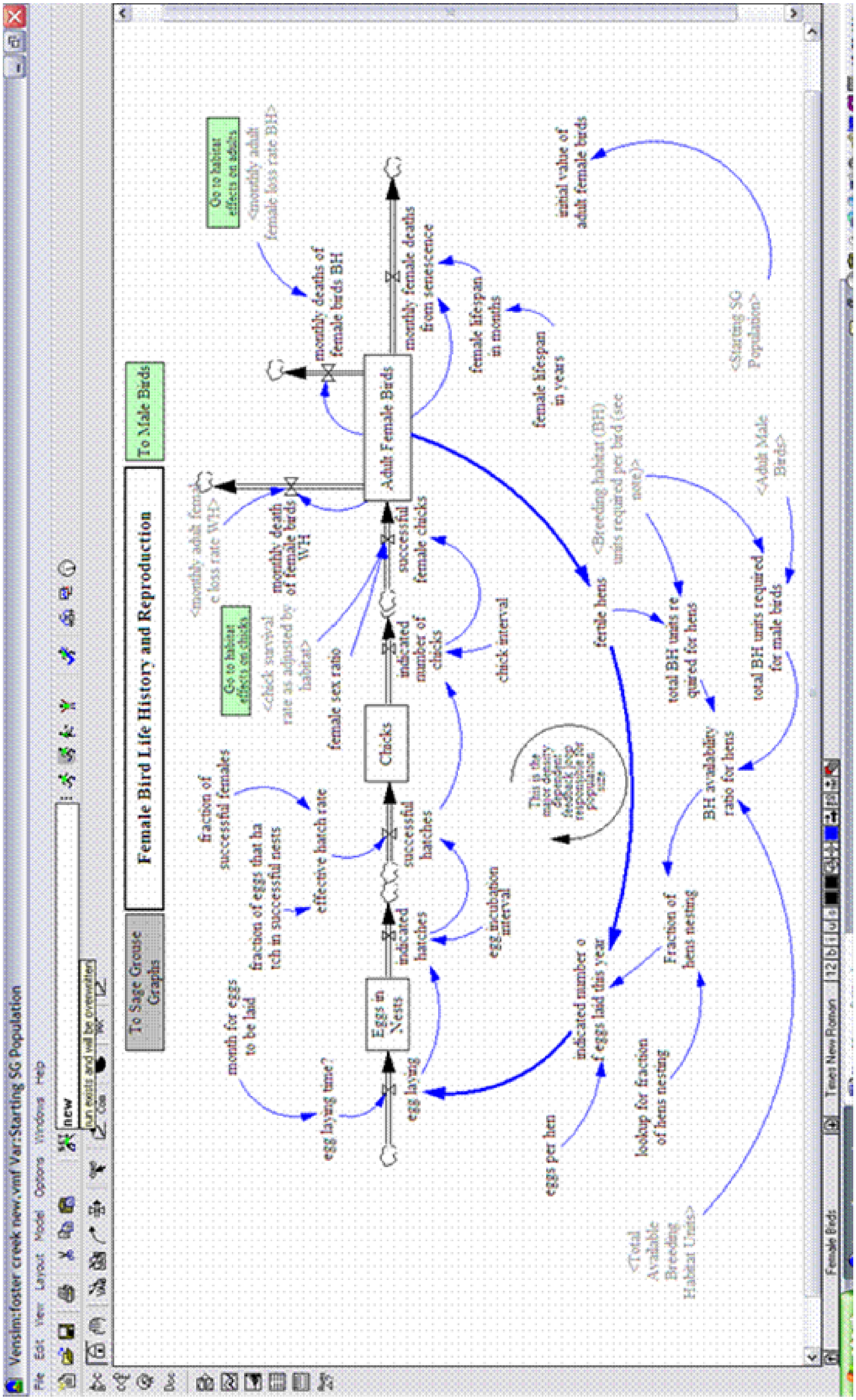

Vensim: foster creek new.vmf Var:Starting SG Population
SyntheSim
Habitat Conservation Plan
Sage Grouse Population
1,500
0
Time (Month)
smoothed total bird population : baseline
smoothed total bird population : new
Total Costs to Landowners for Inclusion in HCP(stacked)
5 M
0
Time (Month)

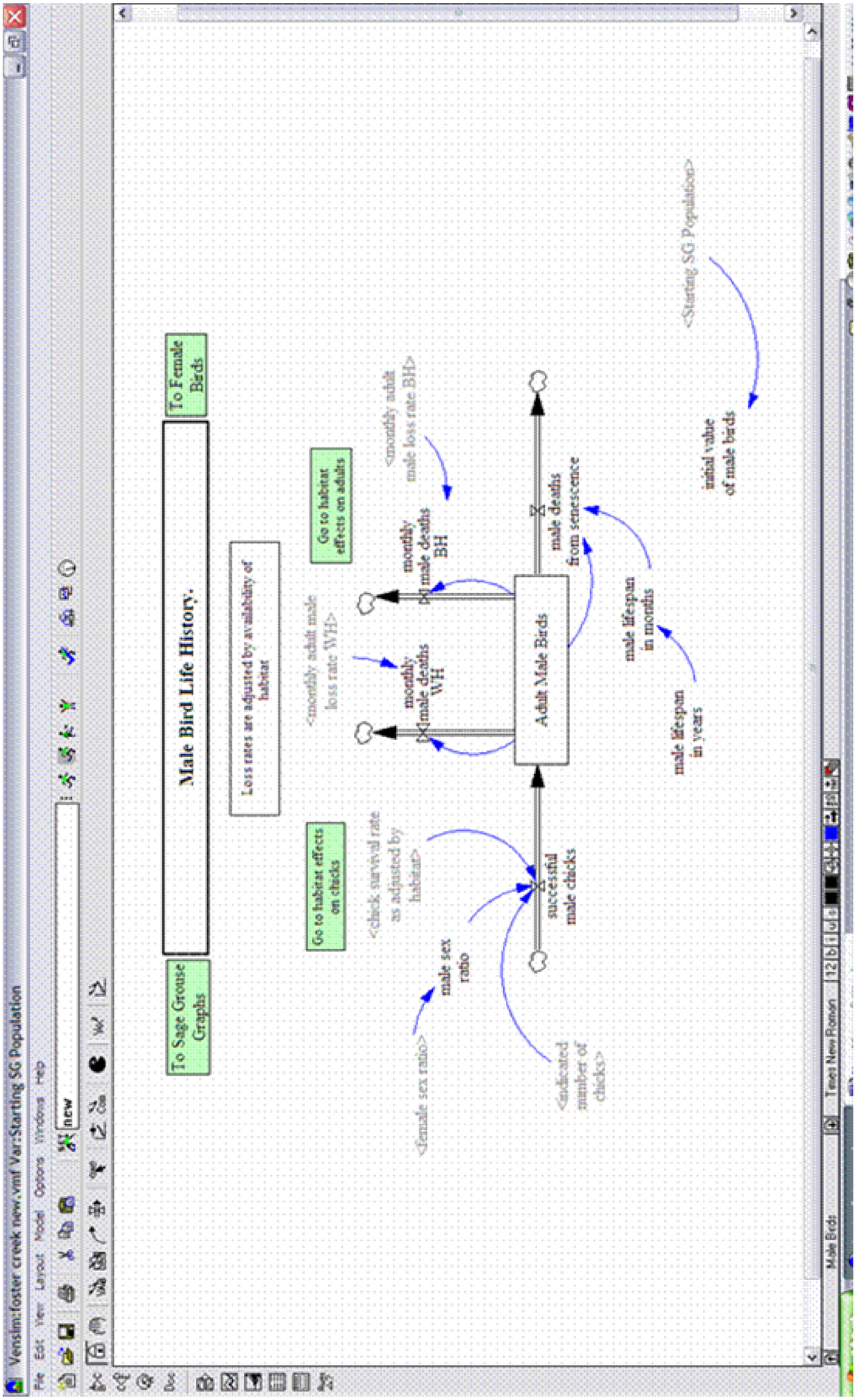

Vensim: foster creek new.vmf Var:Starting SG Population
SyntheSim
new
Conservation Reserve Program
0.3542
Fraction of Cropland Area under CRP contract slider
0.4668
Actual Fraction CRP in SS landscape
For 8% rangewide reduction in CRP set "Fraction of Cropland Acres under CRP contract slider to 0.3048.
To reduce that 8% CRP in shrub steppe areas only, reduce "Actual Fraction CRP in SS landscape" slider to 0.38.
Sage Grouse Population
1,500
1,200
900
600
300
0
0
60
120
180
240
300
360
420
480
540
600
Time (Month)
smoothed total bird population : baseline
smoothed total bird population : new
SyntheSim Mode: All times for all vars instantly
CRP

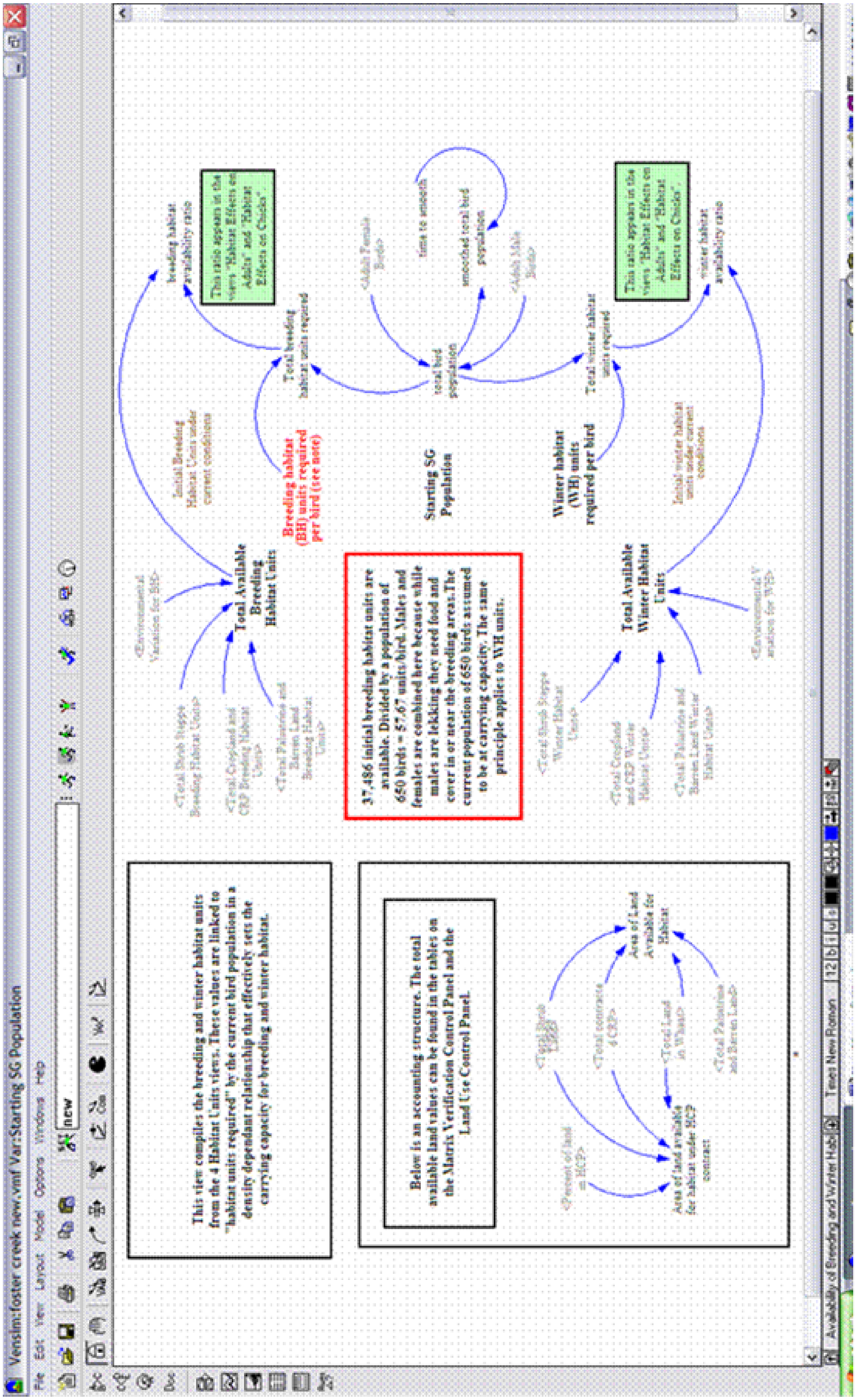

Vensim: foster creek new.vmf Var: Starting SG Population
SyntheSim
Habitat Suitability Indices for Breeding Habitat (B) and Winter Habitat (W)
Sage Grouse Population
1,500
1,200
900
600
300
0
0
60
120
180
240
300
360
420
480
540
600
Time (Month)
smoothed total bird population : baseline
smoothed total bird population : new
Reset
Habitat Suitability Indices

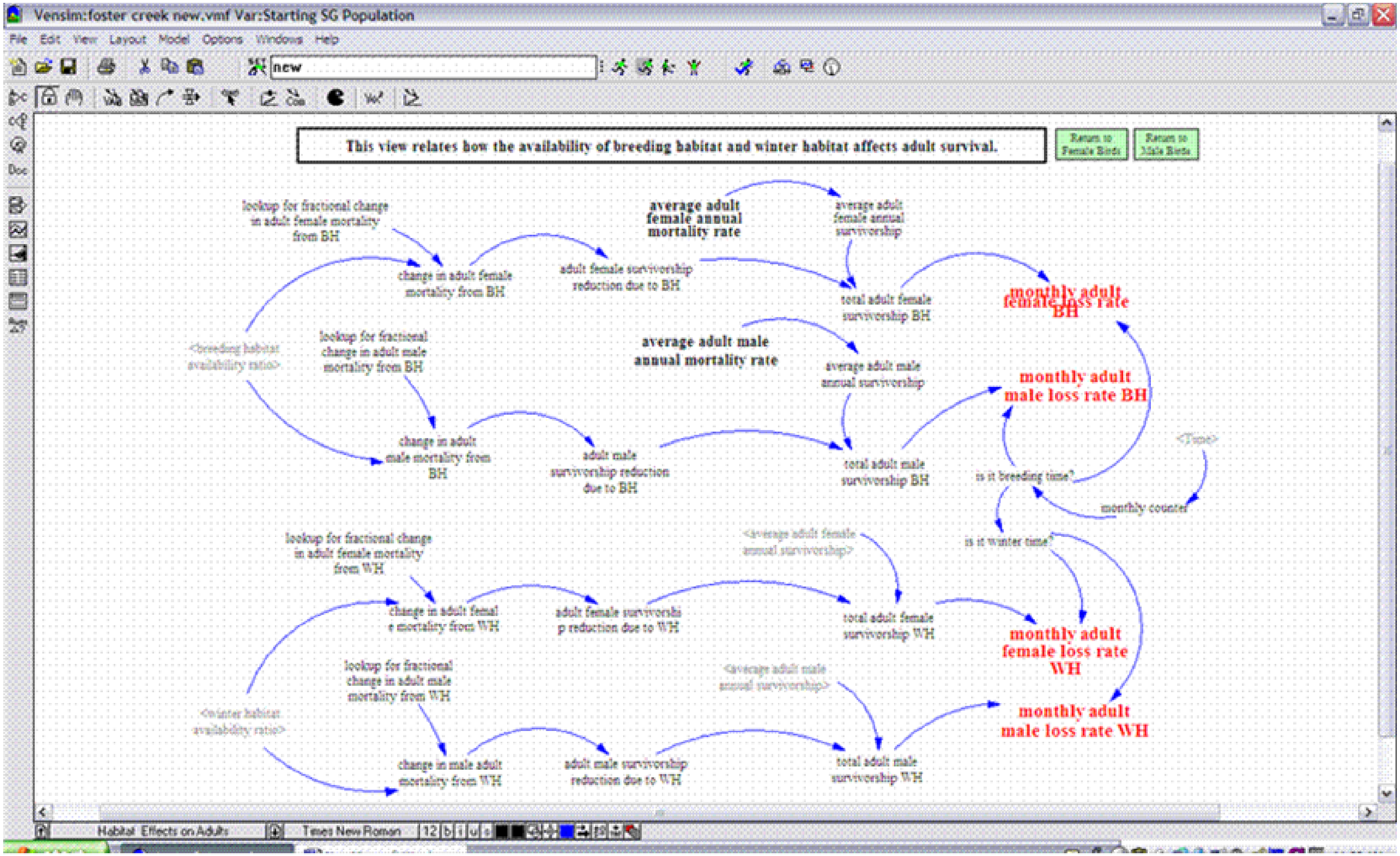

Vensim: foster creek new.vmf Var: Starting SG Population
Environmental Variability
Female Birds React to Environmental Variability
Time (Month)
Adult Female Birds : new
Environmental Variation for BH : new
Environmental Variation for WH : new
"habitat variability on?" "1" = yes
month to start variability
Variability created randomly for both breeding and winter habitats.
Return
Reset Current Slider to base model val (Home)


Vensim: foster creek new.vmf Var:Starting SG Population
The Matrix Verification Control Panel is a tool to compare and verify the model numbers with the Foster Creek Habitat Matrix
When adjusting %CRP to verify agreement with matrix under HCP conditions, turn Suitability Scenario slider to HCP. To meet "33%" values CRP fraction = .3542. To meet "25%" values CRP fraction = .3048. Please note that the "33%" and "25%" are labels which reflect county wide percentages (Britt Dudek pers. comm 07/08/05). The delineated sage grouse area has a relatively higher percent of CRP than the county as a whole.
Return
"Suitability Index Scenarios: Current is 0, HCP is 1, Manual is 2"
Available Habitat Units
Time (Month) 350
Total Available Breeding Habitat Units 37,485
Total Available Winter Habitat Units 55,094
Area of Land Available for Habitat 289,769
Percent of land in HCP 0
Area of land available for habitat under HCP contract 0
Percent of land in HCP
Actual Fraction CRP in SS landscape
Fraction of Cropland Area under CRP contract slider
"Commodity support or Conservation support ? "

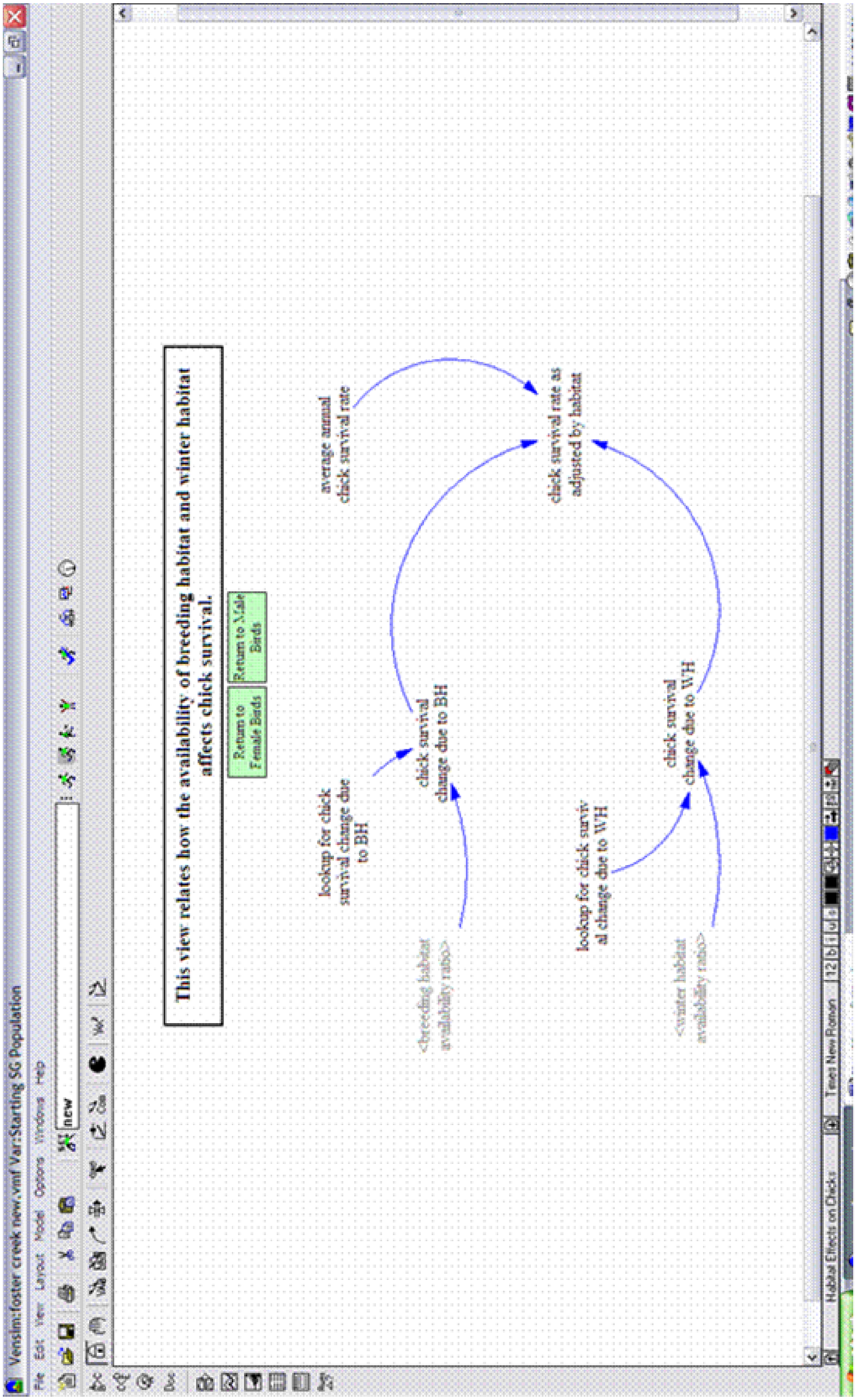

Vensim:foster creek new.vmf Var:Starting SG Population
To Sage Grouse Graphs
Female Bird Life History and Reproduction
To Male Birds
Go to habitat effects on adults
<monthly adult female loss rate BH>
Go to habitat effects on chicks
<monthly adult female loss rate WH>
<chick survival rate as adjusted by habitat>
month for eggs to be laid
egg laying time?
fraction of eggs that hatch in successful nests
fraction of successful females
effective hatch rate
female sex ratio
monthly death of female birds WH
monthly deaths of female birds BH
Eggs in Nests
egg laying
indicated hatches
successful hatches
Chicks
indicated number of chicks
successful female chicks
Adult Female Birds
monthly female deaths from senescence
egg incubation interval
chick interval
female lifespan in months
female lifespan in years
initial value of adult female birds
eggs per hen
indicated number of eggs laid this year
fertile hens
<Breeding habitat (BH) units required per bird (see note)>
total BH units required for hens
lookup for fraction of hens nesting
Fraction of hens nesting
BH availability ratio for hens
total BH units required for male birds
<Adult Male Birds>
<Starting SG Population>
<Total Available Breeding Habitat Units>

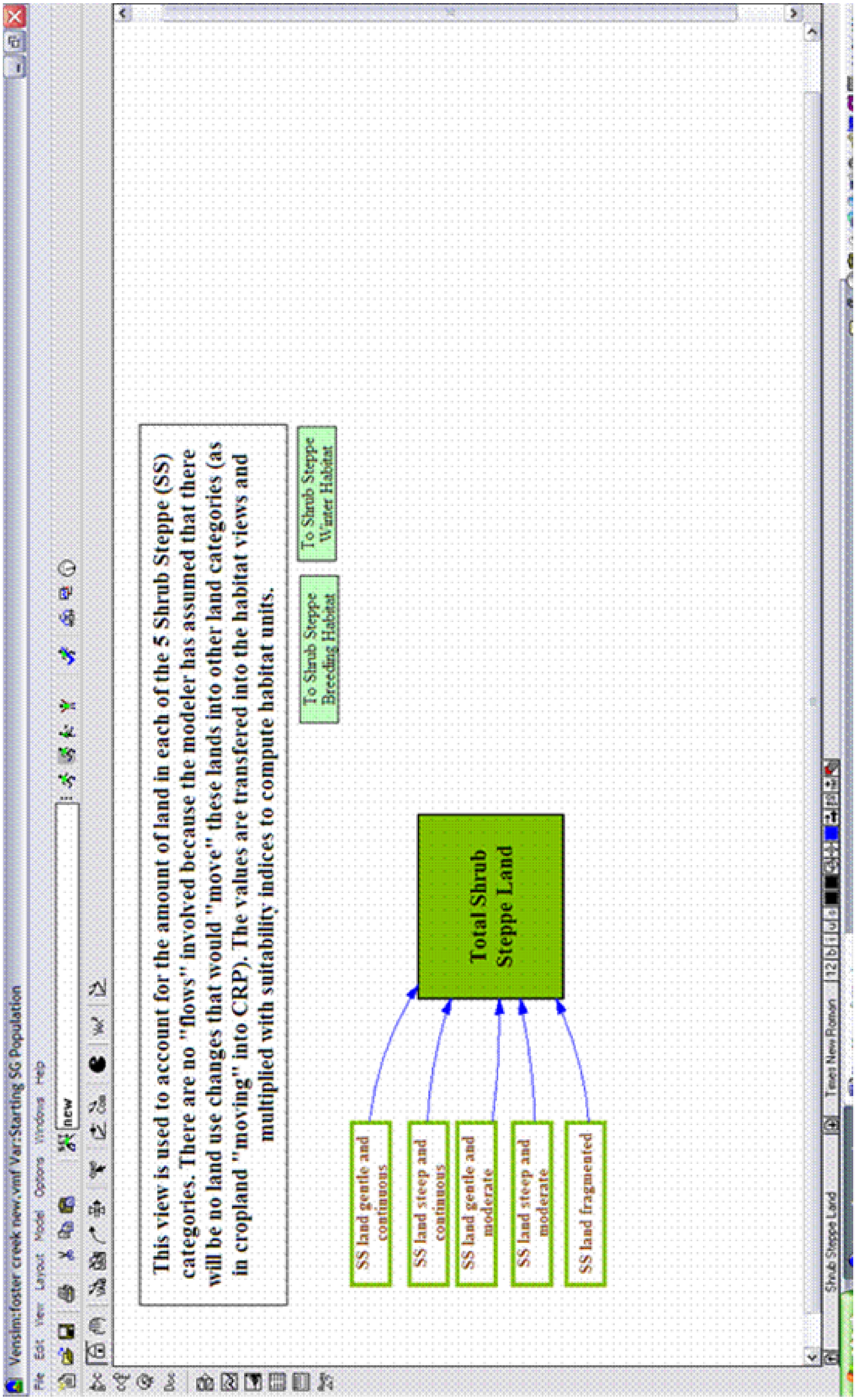

Vensim:foster creek new.vmf Var:Starting SG Population
To Sage Grouse Graphs
Male Bird Life History.
To Female Birds
Loss rates are adjusted by availability of habitat
Go to habitat effects on chicks
Go to habitat effects on adults
<chick survival rate as adjusted by habitat>
<monthly adult male loss rate WH>
<monthly adult male loss rate BH>
monthly male deaths WH
monthly male deaths BH
Adult Male Birds
successful male chicks
male deaths from senescence
male sex ratio
<female sex ratio>
<indicated number of chicks>
male lifespan in months
male lifespan in years
initial value of male birds
<Starting SG Population>
Male Birds
Times New Roman

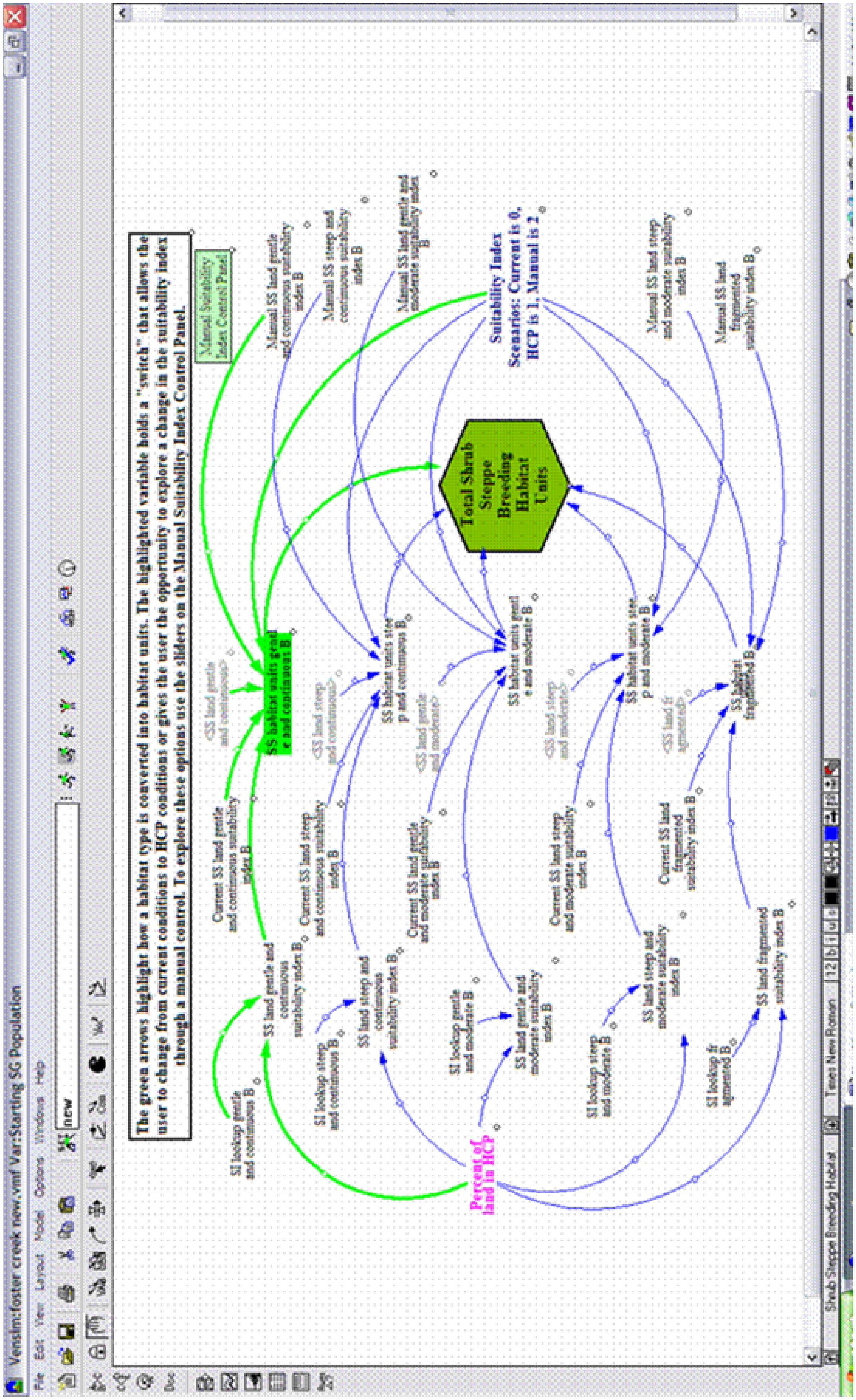

Vensim:foster creek new.vmf Var:Starting SG Population
File Edit View Layout Model Options Windows Help
This view compiles the breeding and winter habitat units from the 4 Habitat Units views. These values are linked to "habitat units required" by the current bird population in a density dependant relationship that effectively sets the carrying capacity for breeding and winter habitat.
Below is an accounting structure. The total available land values can be found in the tables on the Matrix Verification Control Panel and the Land Use Control Panel.
<Percent of land in HCP>
<Total contracts 4 CRP>
<Total Land in Wheat>
<Total Palustrine and Barren Land>
Area of Land Available for Habitat
Area of land available for habitat under HCP contract
<Environmental Variation for BH>
<Total Shrub Steppe Breeding Habitat Units>
<Total Cropland and CRP Breeding Habitat Units>
<Total Palustrine and Barren Land Breeding Habitat Units>
Total Available Breeding Habitat Units
Initial Breeding Habitat Units under current conditions
breeding habitat availability ratio
This ratio appears in the views "Habitat Effects on Adults" and "Habitat Effects on Chicks".
Breeding habitat (BH) units required per bird (see note)
Total breeding habitat units required
37,486 initial breeding habitat units are available. Divided by a population of 650 birds = 57.67 units/bird. Males and females are combined here because while males are lekking they need food and cover in or near the breeding areas.The current population of 650 birds assumed to be at carrying capacity. The same principle applies to WH units.
Starting SG Population
<Adult Female Birds>
time to smooth
total bird population
smoothed total bird population
<Adult Male Birds>
<Total Shrub Steppe Winter Habitat Units>
<Total Cropland and CRP Winter Habitat Units>
<Total Palustrine and Barren Land Winter Habitat Units>
Total Available Winter Habitat Units
<Environmental Variation for WH>
Winter habitat (WH) units required per bird
Total winter habitat units required
Initial winter habitat units under current conditions
This ratio appears in the views "Habitat Effects on Adults" and "Habitat Effects on Chicks".
winter habitat availability ratio
Availability of Breeding and Winter Habi
Times New Roman
12

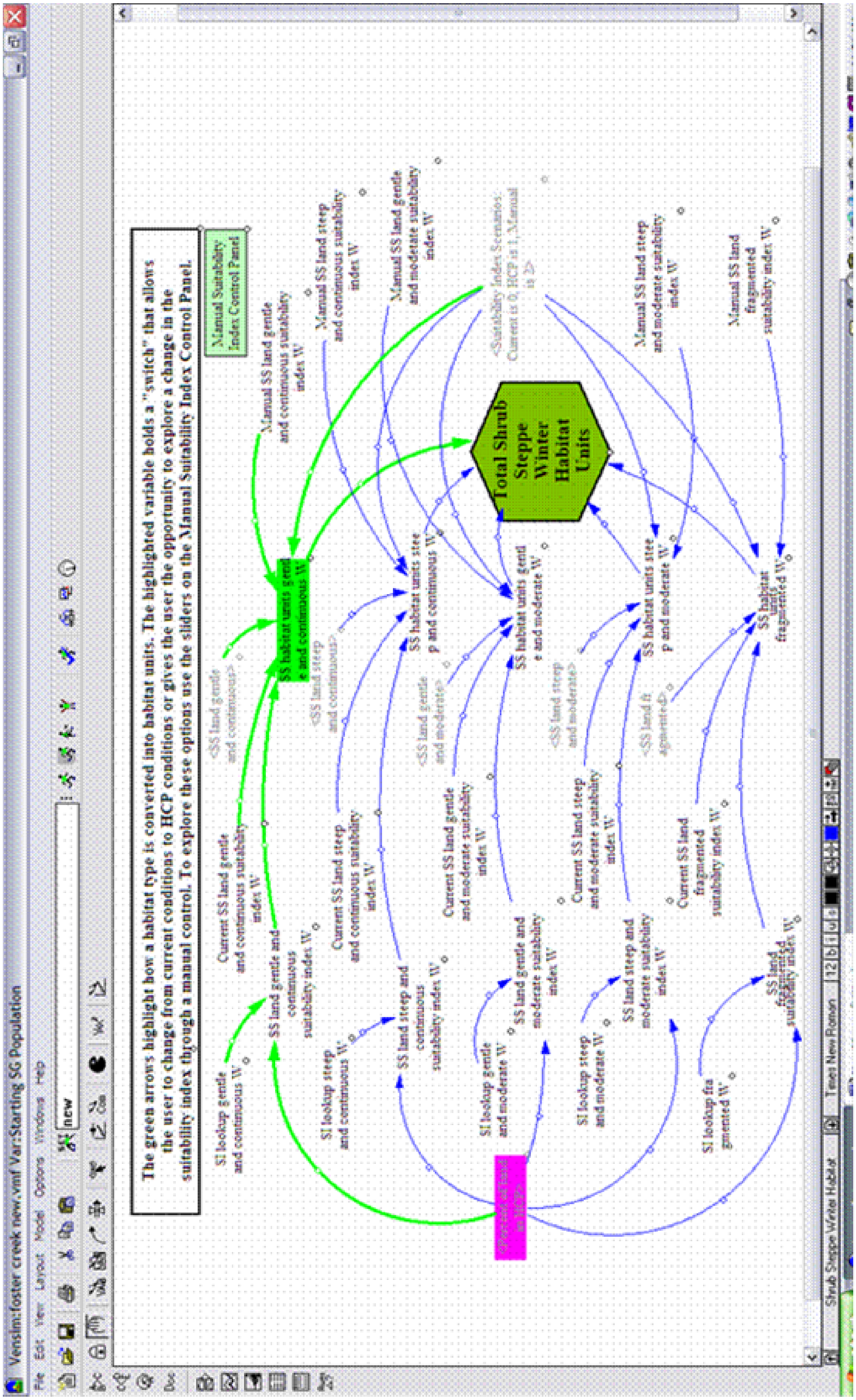


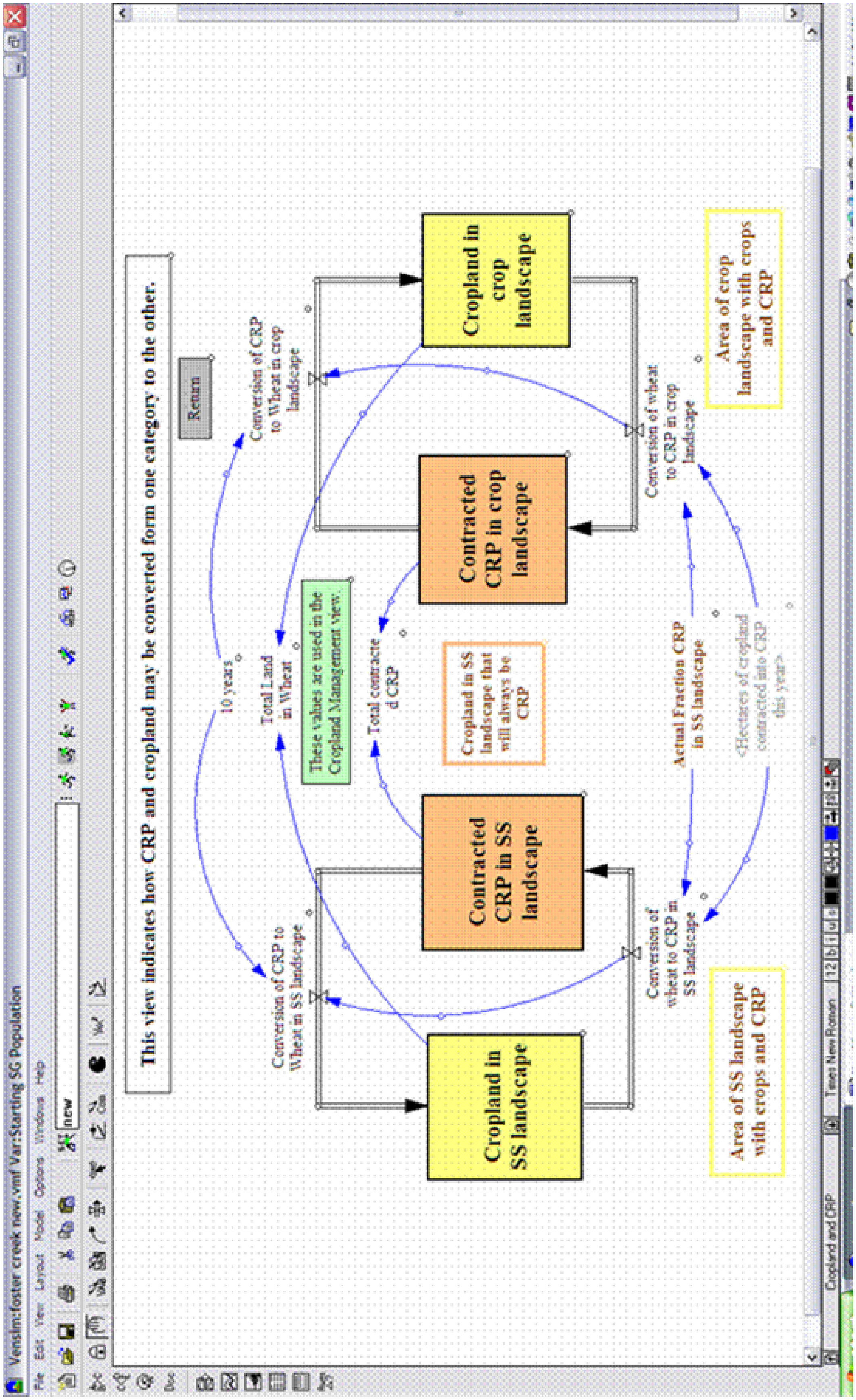
Vensim:foster creek new.vmf Var:Starting SG Population
File Edit View Layout Model Options Windows Help
new
This view relates how the availability of breeding habitat and winter habitat affects adult survival.
Return to Female Birds
Return to Male Birds
lookup for fractional change in adult female mortality from BH
change in adult female mortality from BH
adult female survivorship reduction due to BH
average adult female annual mortality rate
average adult female annual survivorship
total adult female survivorship BH
monthly adult female loss rate BH
<breeding habitat availability ratio>
lookup for fractional change in adult male mortality from BH
change in adult male mortality from BH
adult male survivorship reduction due to BH
average adult male annual mortality rate
average adult male annual survivorship
total adult male survivorship BH
monthly adult male loss rate BH
<Time>
is it breeding time?
monthly counter
is it winter time?
lookup for fractional change in adult female mortality from WH
change in adult femal e mortality from WH
adult female survivorshi p reduction due to WH
<average adult female annual survivorship>
total adult female survivorship WH
monthly adult female loss rate WH
<winter habitat availability ratio>
lookup for fractional change in adult male mortality from WH
change in male adult mortality from WH
adult male survivorship reduction due to WH
<average adult male annual survivorship>
total adult male survivorship WH
monthly adult male loss rate WH
Habitat Effects on Adults
Times New Roman
12

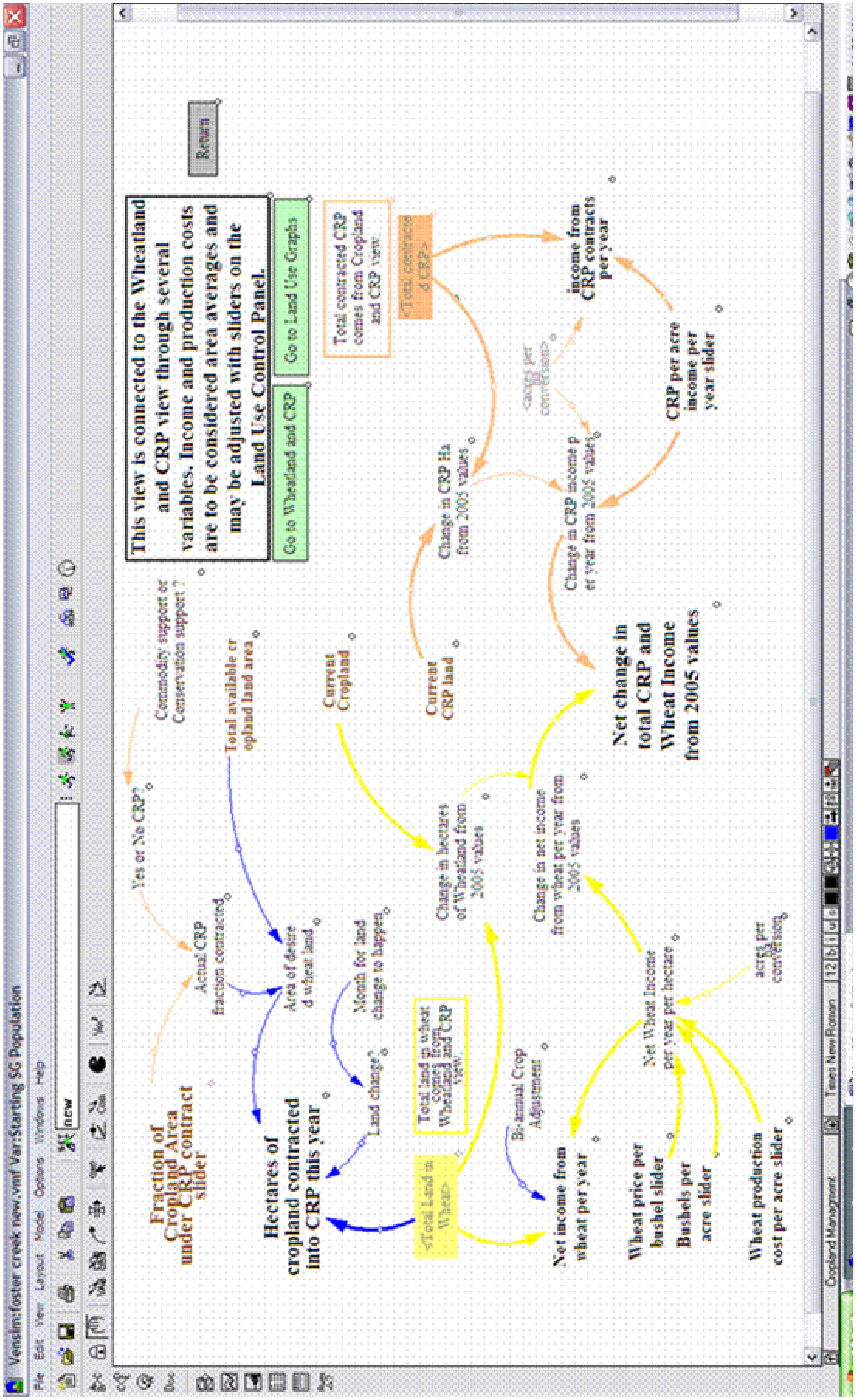

Vensim:foster creek new.vmf Var:Starting SG Population
This view relates how the availability of breeding habitat and winter habitat affects chick survival.
Return to Female Birds
Return to Male Birds
average annual chick survival rate
chick survival rate as adjusted by habitat
lookup for chick survival change due to BH
chick survival change due to BH
<breeding habitat availability ratio>
lookup for chick survival change due to WH
chick survival change due to WH
<winter habitat availability ratio>
Habitat Effects on Chicks
Times New Roman

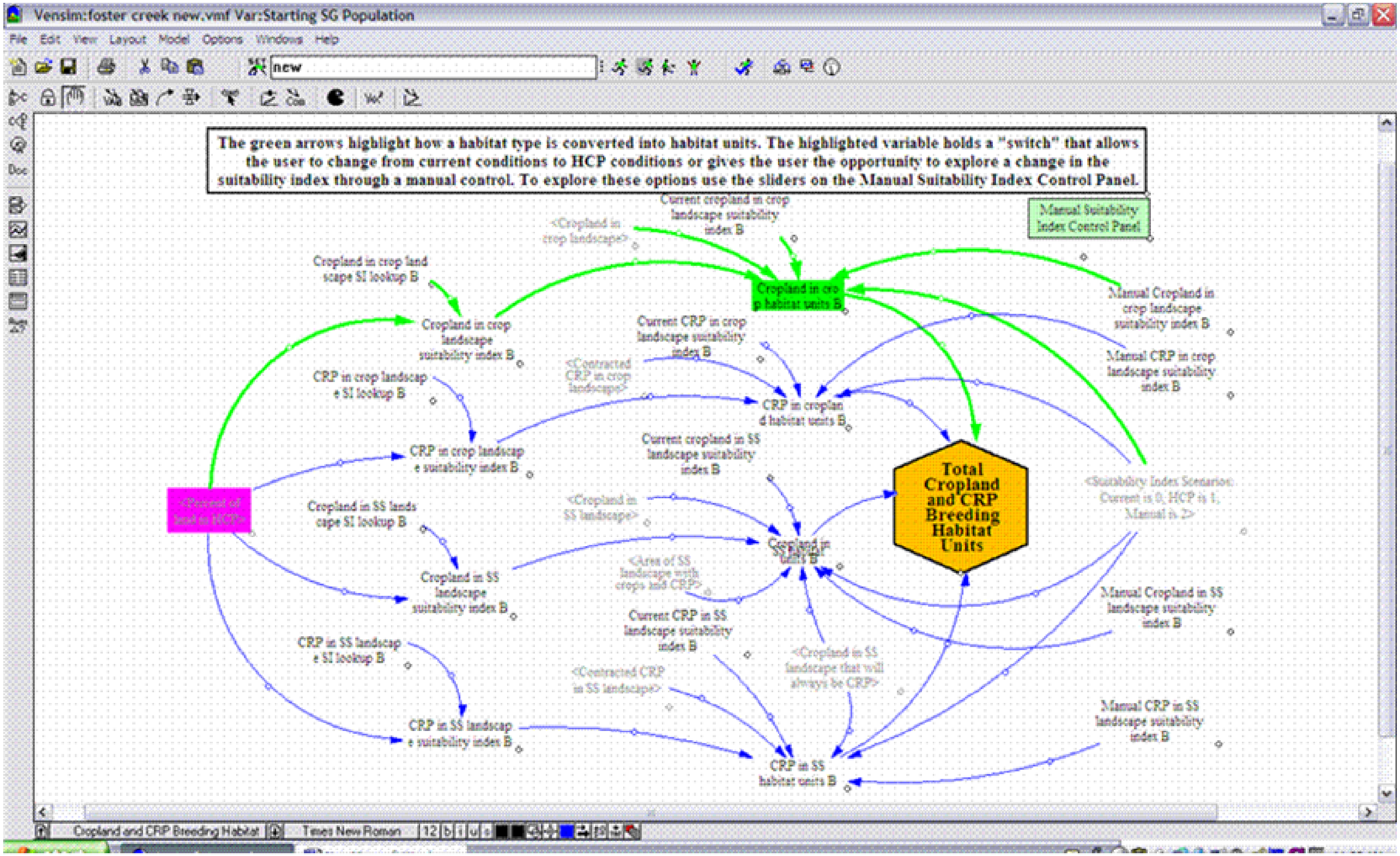

Vensim:foster creek new.vmf Var:Starting SG Population
This view is used to account for the amount of land in each of the 5 Shrub Steppe (SS) categories. There are no "flows" involved because the modeler has assumed that there will be no land use changes that would "move" these lands into other land categories (as in cropland "moving" into CRP). The values are transfered into the habitat views and multiplied with suitability indices to compute habitat units.
To Shrub Steppe Breeding Habitat
To Shrub Steppe Winter Habitat
Total Shrub Steppe Land
SS land gentle and continuous
SS land steep and continuous
SS land gentle and moderate
SS land steep and moderate
SS land fragmented
Shrub Steppe Land
Times New Roman

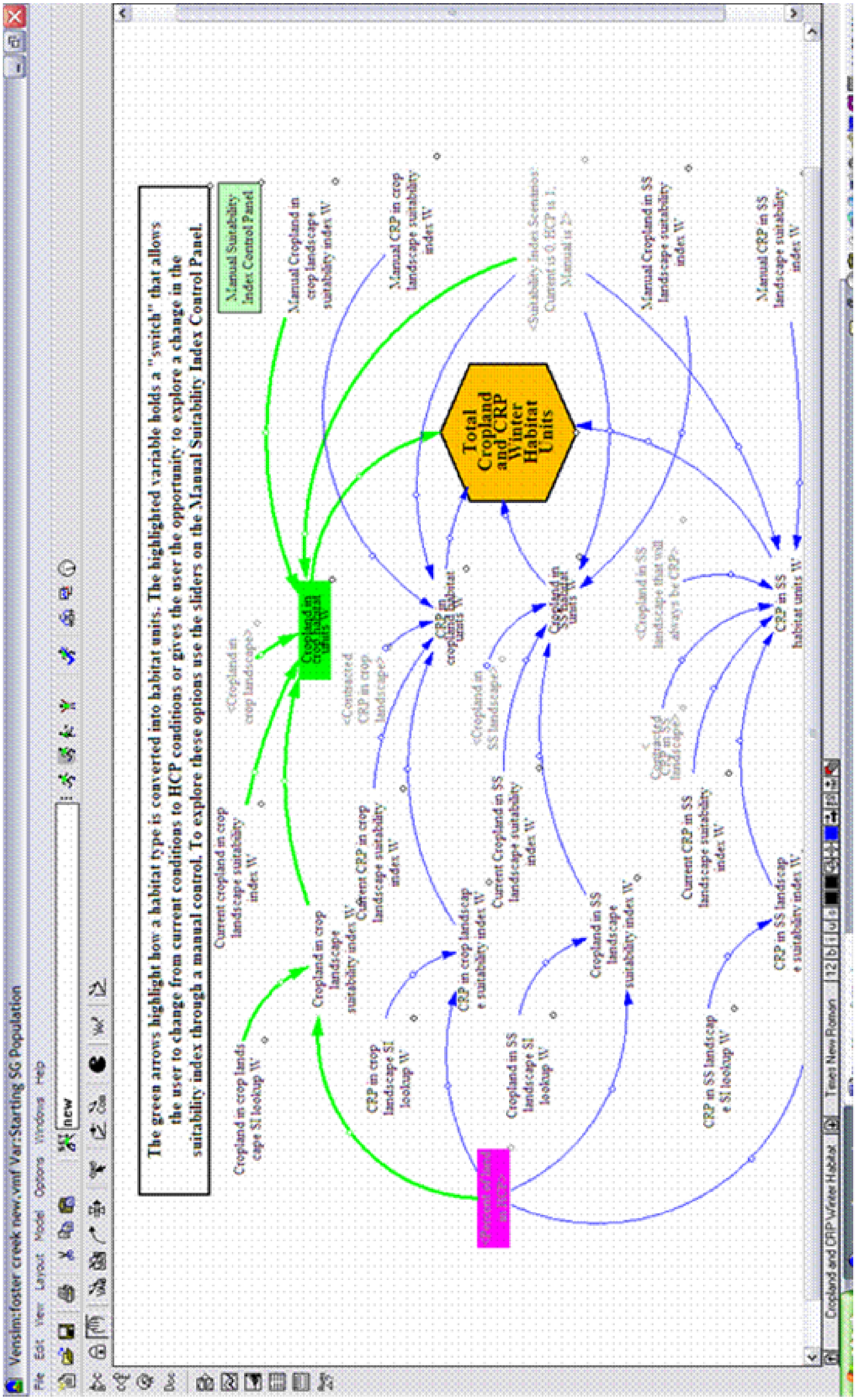

Vensim:foster creek new.vmf Var:Starting SG Population
The green arrows highlight how a habitat type is converted into habitat units. The highlighted variable holds a "switch" that allows the user to change from current conditions to HCP conditions or gives the user the opportunity to explore a change in the suitability index through a manual control. To explore these options use the sliders on the Manual Suitability Index Control Panel.
Manual Suitability Index Control Panel
SI lookup gentle and continuous B
SS land gentle and continuous suitability index B
Current SS land gentle and continuous suitability index B
SS habitat units gentle and continuous B
SI lookup steep and continuous B
SS land steep and continuous suitability index B
Current SS land steep and continuous suitability index B
SS habitat units steep and continuous B
Current SS land gentle and moderate suitability index B
SI lookup gentle and moderate B
Percent of land in HCP
SS land gentle and moderate suitability index B
SS habitat units gentle and moderate B
Total Shrub Steppe Breeding Habitat Units
Current SS land steep and moderate suitability index B
SI lookup steep and moderate B
SS land steep and moderate suitability index B
SS habitat units steep and moderate B
Current SS land fragmented suitability index B
SI lookup fragmented B
SS land fragmented suitability index B
SS habitat fragmented B
Manual SS land gentle and continuous suitability index B
Manual SS steep and continuous suitability index B
Manual SS land gentle and moderate suitability index B
Suitability Index Scenarios: Current is 0, HCP is 1, Manual is 2
Manual SS land steep and moderate suitability index B
Manual SS land fragmented suitability index B
Shrub Steppe Breeding Habitat
Times New Roman

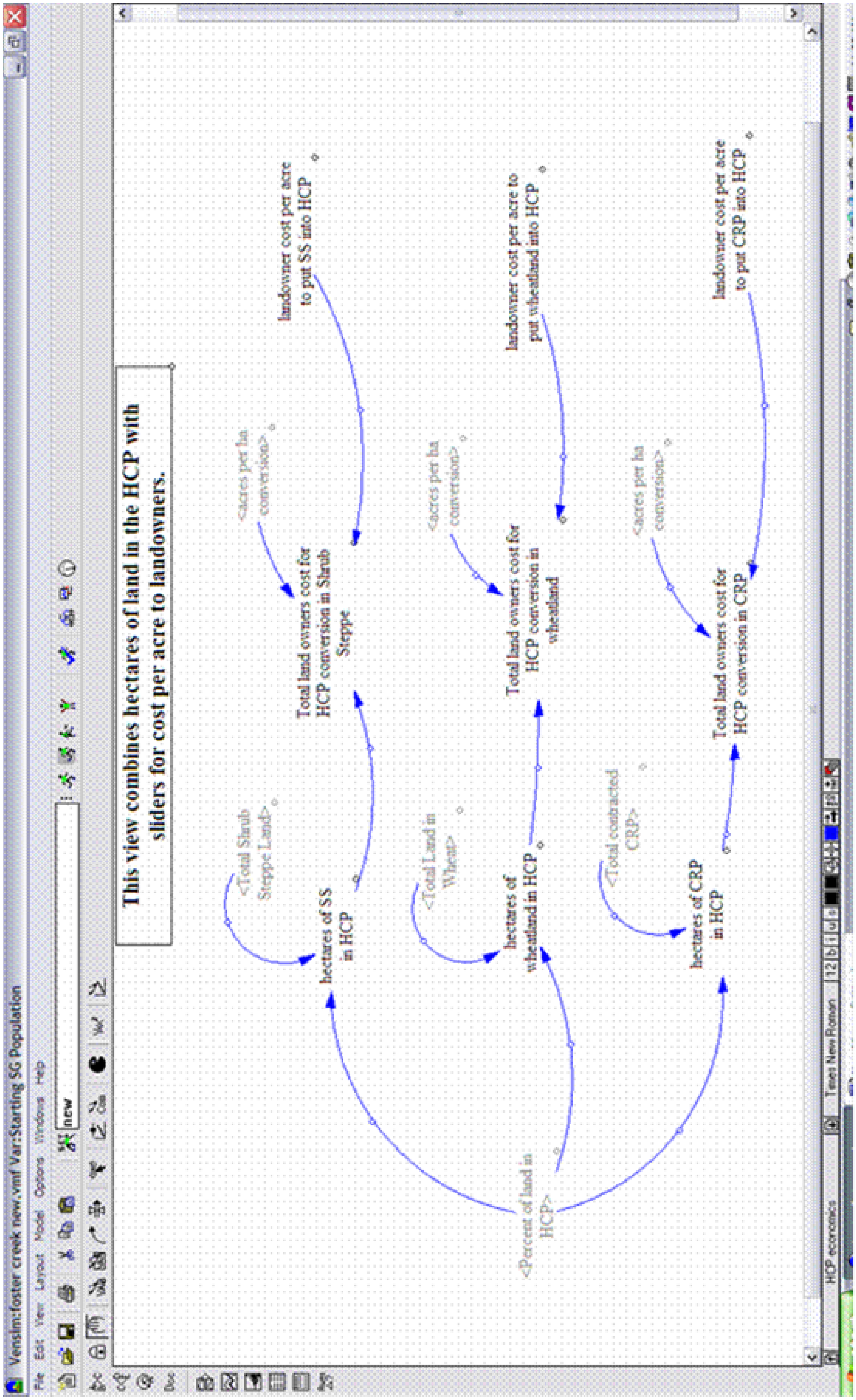

Vensim: foster creek new.vmf Var:Starting SG Population
The green arrows highlight how a habitat type is converted into habitat units. The highlighted variable holds a "switch" that allows the user to change from current conditions to HCP conditions or gives the user the opportunity to explore a change in the suitability index through a manual control. To explore these options use the sliders on the Manual Suitability Index Control Panel.
Manual Suitability Index Control Panel
Total Shrub Steppe Winter Habitat Units
SS habitat units gentle and continuous W
SS habitat units steep and continuous W
SS habitat units gentle and moderate W
SS habitat units steep and moderate W
SS habitat units fragmented W
SS land gentle and continuous suitability index W
SS land steep and continuous suitability index W
SS land gentle and moderate suitability index W
SS land steep and moderate suitability index W
SS land fragmented suitability index W
Current SS land gentle and continuous suitability index W
Current SS land steep and continuous suitability index W
Current SS land gentle and moderate suitability index W
Current SS land steep and moderate suitability index W
Current SS land fragmented suitability index W
Manual SS land gentle and continuous suitability index W
Manual SS land steep and continuous suitability index W
Manual SS land gentle and moderate suitability index W
Manual SS land steep and moderate suitability index W
Manual SS land fragmented suitability index W
SI lookup gentle and continuous W
SI lookup steep and continuous W
SI lookup gentle and moderate W
SI lookup steep and moderate W
SI lookup fragmented W
<SS land gentle and continuous>
<SS land steep and continuous>
<SS land gentle and moderate>
<SS land steep and moderate>
<SS land fragmented>
<Suitability Index Scenarios: Current is 0, HCP is 1, Manual is 2>
Shrub Steppe Winter Habitat

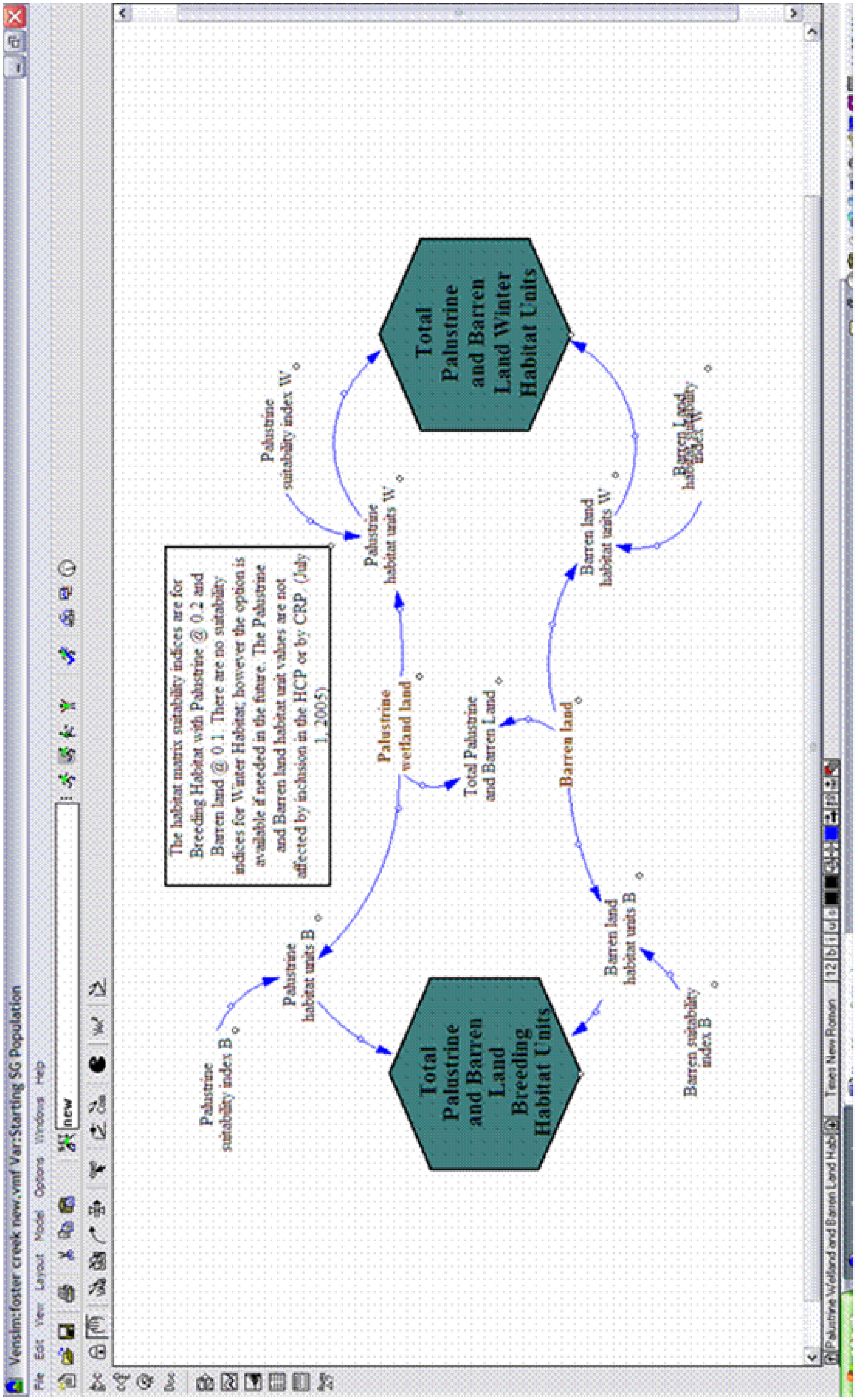

Vensim: foster creek new.vmf Var:Starting SG Population
This view indicates how CRP and cropland may be converted form one category to the other.
Return
Cropland in SS landscape
Contracted CRP in SS landscape
Contracted CRP in crop landscape
Cropland in crop landscape
Conversion of CRP to Wheat in SS landscape
10 years
Total Land in Wheat
These values are used in the Cropland Management view.
Total contracted CRP
Cropland in SS landscape that will always be CRP
Conversion of CRP to Wheat in crop landscape
Conversion of wheat to CRP in SS landscape
Actual Fraction CRP in SS landscape
<Hectares of cropland contracted into CRP this year>
Conversion of wheat to CRP in crop landscape
Area of SS landscape with crops and CRP
Area of crop landscape with crops and CRP

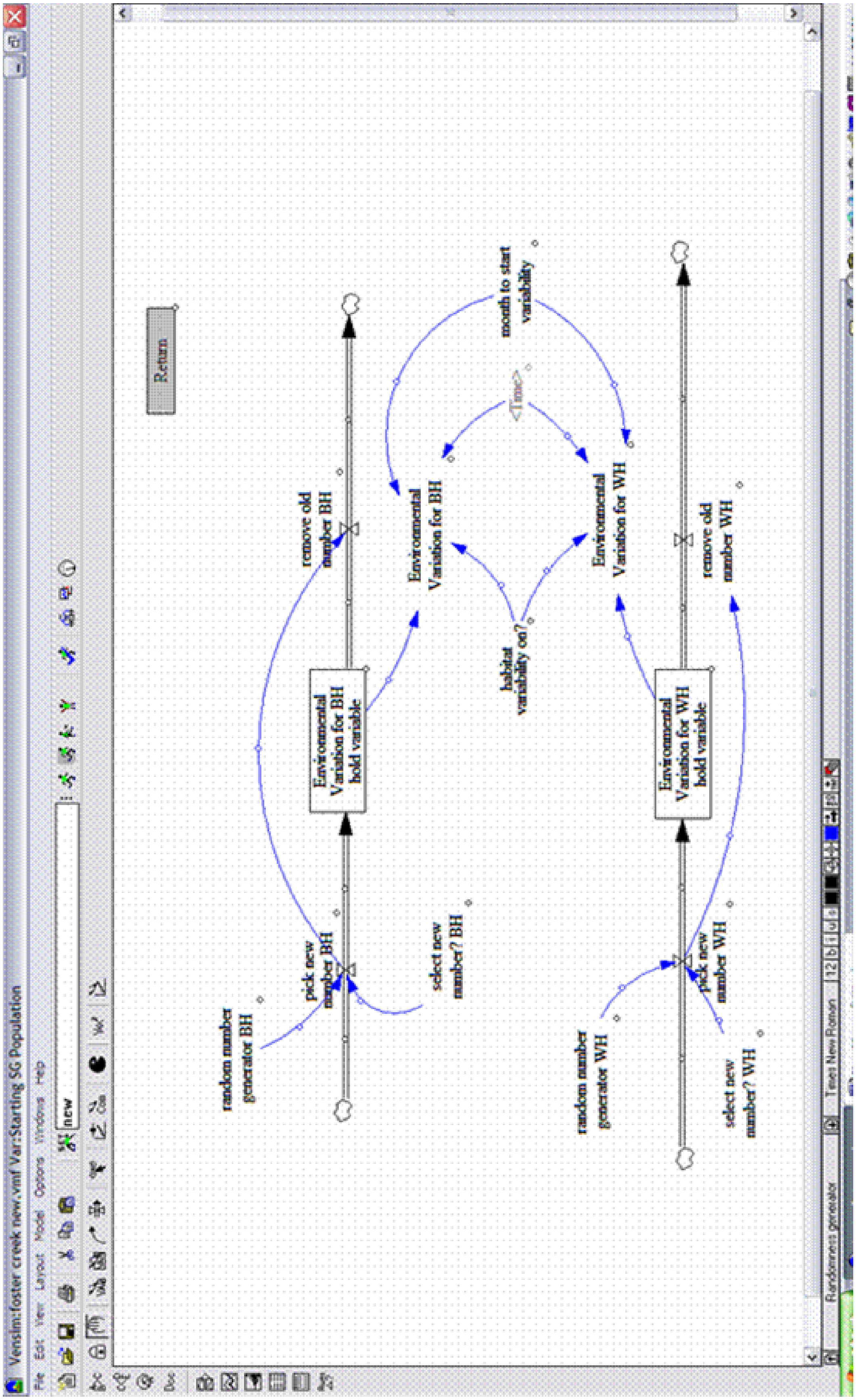

Vensim: foster creek new.vmf Var: Starting SG Population
This view is connected to the Wheatland and CRP view through several variables. Income and production costs are to be considered area averages and may be adjusted with sliders on the Land Use Control Panel.
Return
Go to Wheatland and CRP
Go to Land Use Graphs
Total contracted CRP comes from Cropland and CRP view.
Fraction of Cropland Area under CRP contract slider
Hectares of cropland contracted into CRP this year
Net income from wheat per year
Wheat price per bushel slider
Bushels per acre slider
Wheat production cost per acre slider
Net change in total CRP and Wheat Income from 2005 values
income from CRP contracts per year
CRP per acre income per year slider
Current Cropland
Current CRP land
Total available cropland land area
Commodity support or Conservation support ?
Yes or No CRP?
Actual CRP fraction contracted
Area of desired wheat land
Month for land change to happen
Land change?
Change in hectares of Wheatland from 2005 values
Change in net income from wheat per year from 2005 values
Change in CRP Ha from 2005 values
Change in CRP income per year from 2005 values
Net Wheat Income per year per hectare
Bi-annual Crop Adjustment
acres per ha conversion
Total land in wheat comes from Wheatland and CRP view.
<Total Land in Wheat>
<Total contracted CRP>
<acres per ha conversion>
Cropland Managment
Times New Roman
new

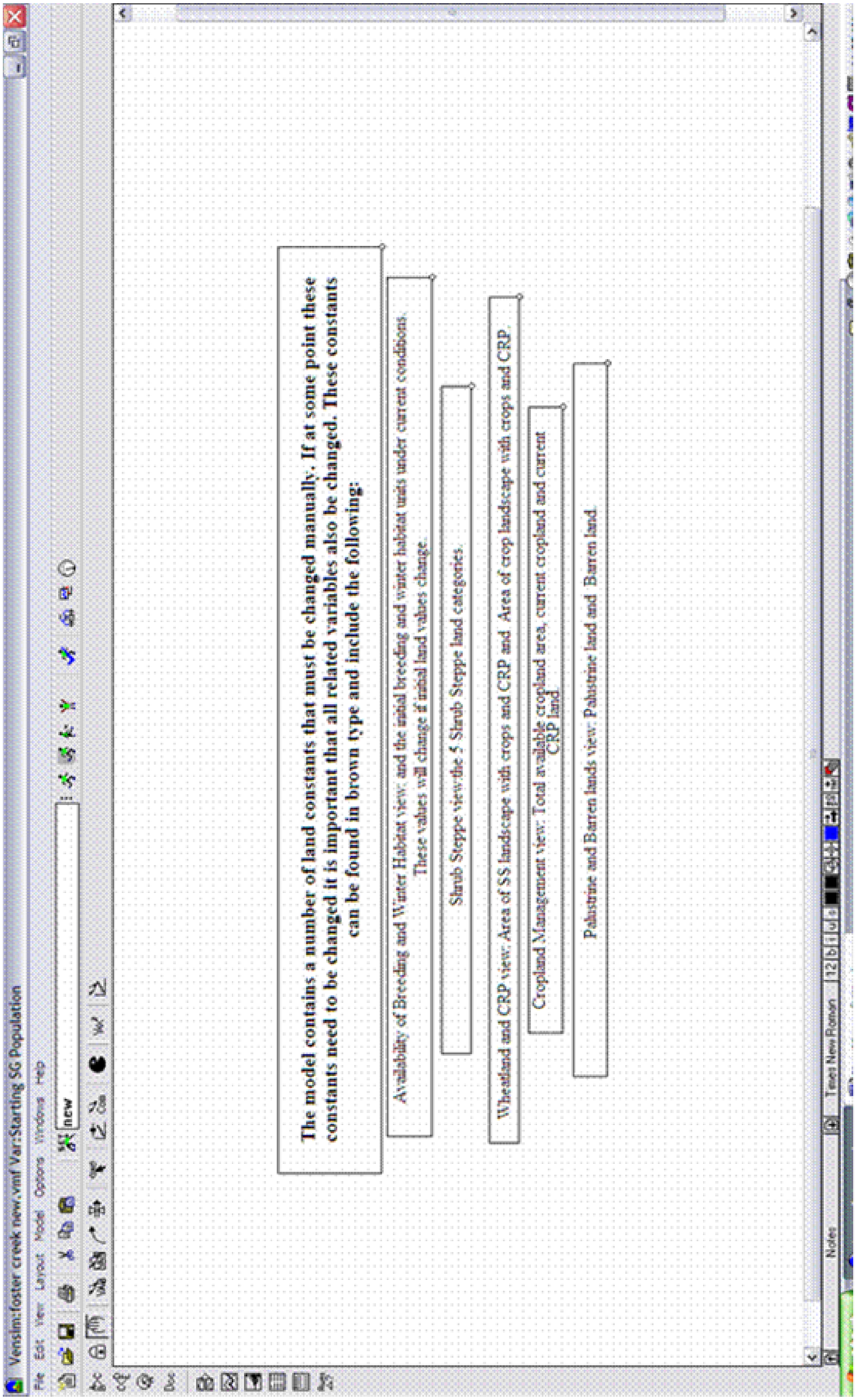

Vensim:foster creek new.vmf Var:Starting SG Population
File Edit View Layout Model Options Windows Help
new
The green arrows highlight how a habitat type is converted into habitat units. The highlighted variable holds a "switch" that allows the user to change from current conditions to HCP conditions or gives the user the opportunity to explore a change in the suitability index through a manual control. To explore these options use the sliders on the Manual Suitability Index Control Panel.
Manual Suitability Index Control Panel
Current cropland in crop landscape suitability index B
<Cropland in crop landscape>
Cropland in crop land scape SI lookup B
Cropland in crop landscape suitability index B
Cropland in crop habitat units B
Manual Cropland in crop landscape suitability index B
Manual CRP in crop landscape suitability index B
Current CRP in crop landscape suitability index B
<Contracted CRP in crop landscape>
CRP in crop landscape SI lookup B
CRP in crop landscape suitability index B
CRP in cropland habitat units B
Current cropland in SS landscape suitability index B
Total Cropland and CRP Breeding Habitat Units
<Suitability Index Scenario: Current is 0, HCP is 1, Manual is 2>
<Percent of land in HCP>
Cropland in SS lands cape SI lookup B
<Cropland in SS landscape>
Cropland in SS units B
<Area of SS landscape with crops and CRP>
Cropland in SS landscape suitability index B
Current CRP in SS landscape suitability index B
Manual Cropland in SS landscape suitability index B
CRP in SS landscape SI lookup B
<Cropland in SS landscape that will always be CRP>
<Contracted CRP in SS landscape>
CRP in SS landscape suitability index B
Manual CRP in SS landscape suitability index B
CRP in SS habitat units B
Cropland and CRP Breeding Habitat
Times New Roman
12


Vensim: foster creek new.vmf Var:Starting SG Population
The green arrows highlight how a habitat type is converted into habitat units. The highlighted variable holds a "switch" that allows the user to change from current conditions to HCP conditions or gives the user the opportunity to explore a change in the suitability index through a manual control. To explore these options use the sliders on the Manual Suitability Index Control Panel.
Manual Suitability Index Control Panel
Total Cropland and CRP Winter Habitat Units
Cropland in crop habitat units W
CRP in cropland habitat units W
Cropland in SS habitat units
CRP in SS habitat units W
Cropland in crop landscape suitability index W
CRP in crop landscape suitability index W
Cropland in SS landscape suitability index W
CRP in SS landscape suitability index W
Current cropland in crop landscape suitability index W
Current CRP in crop landscape suitability index W
Current Cropland in SS landscape suitability index W
Current CRP in SS landscape suitability index W
Manual Cropland in crop landscape suitability index W
Manual CRP in crop landscape suitability index W
Manual Cropland in SS landscape suitability index W
Manual CRP in SS landscape suitability index W
Cropland in crop landscape SI lookup W
CRP in crop landscape SI lookup W
Cropland in SS landscape SI lookup W
CRP in SS landscape SI lookup W
<Cropland in crop landscape>
<Contracted CRP in crop landscape>
<Cropland in SS landscape>
<Contracted CRP in SS landscape>
<Cropland in SS landscape that will always be CRP>
<Suitability Index Scenarios: Current is 0. HCP is 1. Manual is 2>
<Percent of land in HCP>
Cropland and CRP Winter Habitat
Times New Roman


Vensim: foster creek new.vmf Var:Starting SG Population
This view combines hectares of land in the HCP with sliders for cost per acre to landowners.
landowner cost per acre to put SS into HCP
landowner cost per acre to put wheatland into HCP
landowner cost per acre to put CRP into HCP
<acres per ha conversion>
Total land owners cost for HCP conversion in Shrub Steppe
Total land owners cost for HCP conversion in wheatland
Total land owners cost for HCP conversion in CRP
<Total Shrub Steppe Land>
<Total Land in Wheat>
<Total contracted CRP>
hectares of SS in HCP
hectares of wheatland in HCP
hectares of CRP in HCP
<Percent of land in HCP>
HCP economics


Vensim: foster creek new.vmf Var:Starting SG Population
The habitat matrix suitability indices are for Breeding Habitat with Palustrine @ 0.2 and Barren land @ 0.1. There are no suitability indices for Winter Habitat; however the option is available if needed in the future. The Palustrine and Barren land habitat unit values are not affected by inclusion in the HCP or by CRP. (July 1, 2005)
Palustrine suitability index W
Palustrine habitat units W
Total Palustrine and Barren Land Winter Habitat Units
Barren land habitat units W
Palustrine wetland land
Total Palustrine and Barren Land
Barren land
Palustrine suitability index B
Palustrine habitat units B
Total Palustrine and Barren Land Breeding Habitat Units
Barren land habitat units B
Barren suitability index B


Vensim: foster creek new.vmf Var:Starting SG Population
Return
random number generator BH
pick new number BH
select new number? BH
Environmental Variation for BH hold variable
remove old number BH
Environmental Variation for BH
<Time>
month to start variability
habitat variability on?
Environmental Variation for WH
random number generator WH
pick new number WH
select new number? WH
Environmental Variation for WH hold variable
remove old number WH


Vensim:foster creek new.vmf Var:Starting SG Population
The model contains a number of land constants that must be changed manually. If at some point these constants need to be changed it is important that all related variables also be changed. These constants can be found in brown type and include the following:
Availability of Breeding and Winter Habitat view: and the initial breeding and winter habitat units under current conditions. These values will change if initial land values change.
Shrub Steppe view:the 5 Shrub Steppe land categories.
Wheatland and CRP view: Area of SS landscape with crops and CRP and Area of crop landscape with crops and CRP.
Cropland Management view: Total available cropland area, current cropland and current CRP land
Palustrine and Barren lands view: Palustrine land and Barren land.

Appendix 5 - Information on Individual Models

		Sage grouse in Central Washington	Middle Rio Grande	Ria Formosa Natural Park 2003	Problem Bears in New York	Gloucester Fishery
		Beall, Zeoli, Ford	Tidwell	Videira (2)	Siemer and Otto	Otto and Struben
Process participants	# of modelers	2	2 modelers, 1 facilitator	1 primary, 4 assistants	2	2
	# of key contacts	2	1	1	3	3
	# of scheduled participants	Between 9-11	10-200 people at public meetings. 5-15 at modeling team meetings	Event #1: 70, Event #2: 37, Event #3: 23, Event #4: 33	10 (agency biologists, managers, administrators)	Between 3-8 participants at group meeting. One event with 15 people
	# of groups represented	9	5	60	1	3
Time	length of Project	3 months	~24 months	18 months	18 months	18 months
	time spent modeling	2.5 months	~12 months	8 months	9 months	7 months
	time spent with stakeholders	4 days; individual contact	2 hour modeling team meetings held every other week for roughly one year. Public meetings on quarterly basis	48 hours throughout 4workshops; individual contact for preliminary and post interviews and data collection	4 half-day workshops with full group; 3 sessions with subgroup; frequent progress reports; many individual meetings	4 half-day meetings with whole group, series of meeting with sub group and individual contact with NOAA and program director
Primary purpose of modeling process	group learning (L)				Shared learning about three bear management actions	Shared learning to explore feasibility of surimi plant
	management tool (M)	Management tool to assist with sage grouse conservation and recovery	Planning tool to balance regional water budget, explore alternative conservation strategies	Management tool		

		Okanagan Basin	Upper Fox River	Ria Formosa 2000	Baixo Guadiana River Basin	Upper Mississippi River
		Langsdale	van den Belt et al	van den Belt	Videira (1)	BenDor
Process participants	# of modelers	1 primary, 2 assistants	1	2	1 primary, 3 assistants	2
	# of key contacts	1	2	1	2	5
	# of scheduled participants	50 people attended at least one event. Each event 10-19 participants	~15	Event #1: 21, Event #2: 12, Event #3: 13, Event #4: 15	Event #1: 57, Event #2: 20, Event #3: 20	25
	# of groups represented	30	10	10	30	18
Time	length of Project	12 months	4 months	4 months	9 months	2 Months
	time spent modeling	10 months	48 days	43 days	4 months	2 Days (2 models; 'Blue' and 'Green' Models)
	time spent with stakeholders	5 full day meetings with "whole group"; series of half day sessions with sub groups; individual contact	48 hours	45 hours	18 hours throughout 3 workshops; individual contact for preliminary interviews and data collection	2 Days
Primary purpose of modeling process	group learning (L)	Shared learning: Exploration tool to discuss future management options	scoping big picture	scoping big picture	Group learning; problem scoping	Group Learning
	management tool (M)					

		Sage grouse in Central Washington	Middle Rio Grande	Ria Formosa Natural Park 2005	Problem Bears in New York	Gloucester Fishery
		Beall, Zeoli, Ford	Tidwell	Videira (2)	Siemer and Otto	Otto and Struben
Model parameters	model time frame	50 years	40 year calibration period and 50 year planning horizon	40 years	50 years	20 years
	stocks	10	20	40	16	28
	flows	18	48	65	30	26
	total # parameters	273	900	198	229	363
	need for peer reviewed data	High	Integrated data from many peer reviewed sources	Medium/Low. Based on a final questionnaire 14% participants referred to incomplete information, requiring more solid data.	Moderate	High
	spatial aspects	292,000 ha split into 11 categories	3-county region treated as single water basin	18,400 ha split into ecosystem types and urban categories	Calibrated to reflect northern NY (land area not specified)	Pelagic fish stocks in the North Atlantic; aggregated

		Okanagan Basin	Upper Fox River	Ria Formosa 2000	Baixo Guadiana River Basin	Upper Mississippi River
		Langsdale	van den Belt et al	van den Belt	Videira (1)	BenDor
Model parameters	model time frame	30 year simulations covering 3 time periods	1970-2020	1980-2020	45 years	50 Years, 100 Years
	stocks	9	6	24	15	5, 5
	flows	28	6	35	20	4, 6
	total # parameters	502	~100	~200	142	29 Converters, 58 Converters
	need for peer reviewed data	Info was printed in reports, which were not peer-reviewed. However, the team had an established history with stakeholders.	High	High	High. Based on a quality assurance protocol, 36 % participants referred to incomplete information, requiring more solid data	High
	spatial aspects	Approx 820,000 ha split into 3 water regions	500 ha homogenous	18,400 ha homogenous	2,089 ha of natural reserve area split in ecosystem categories	850,000 ha split into 3 categories, 850,000 ha split into 5 categories

Appendix 6 - Questionnaire

To fill gaps in information the following questions were asked of the modelers. Their answers are included with the questions.

phase	Facilitated problem solving		Participatory Modeling	Model building (Ford 1999)
A	Problem identification	→	Problem identification	Reference mode
B	Technical data reviewed and agreed upon	A	Parameter validation	key variables, inter-connections and feedbacks
C	Consensus		Model validation	Sensitivity analysis
D	Implement potential solutions	D ⋯→	Policy alternatives	Test impacts of policy

Question to modelers: At what phase in the table above do you feel you joined the group problem solving process? Did you work with the group through more than one phase?

Washington sage grouse: We joined in Phase D

Upper Mississippi: As modelers, we joined in Phase A – the initial problem definition procedures created a very broad problem that was not feasible to address in 2 days (the workshop time span). As a result, we worked with Stakeholders to focus the problem at issue embodied by the question – 'What is the impact of floodplain development on ecosystem functionality and health?' Here, development included Agricultural and Urban Development.

Middle Rio Grande: While the Water Assembly had defined the problem that wanted to solve (balance the water budget) they did not understand the physical system very well or what it would take to accomplish their goal. As the group developed the model together, I would say we started in Phase A and worked through Phase C.

Okanagan: The process was in mostly A, with some data & modeling having already generated some data. We went through to policy alternatives.

Upper Fox and Ria Formosa 2000: Personally, I find that model building helps because both the problem and the solution are identified and the model supports the discussion alternating between problem and solution – a characteristic of wicked or complex problems.

NY bears: This is a difficult question to answer in the context of my project. We started by forming a problem statement, but it wasn't as if managers had never thought of the problem—they had. The modeling exercise was embedded in a broader effort to manage emerging human-bear problems by a state agency.

Question to modelers: Did the relative percentage of quantitative values affect the comfort level of scientific stakeholders? Other stakeholders?

Washington sage grouse: Quantitative data was essential to the process yet at the same time participants were happy that we could include options to adjust that data with sliders on the interface.

Upper Mississippi: Yes – quantitative definitions were the hardest to understand for all stakeholders. ‘Development hurts the environment’ was a common accusation, but understanding how this worked quantitatively was much more difficult.

Middle Rio Grande: Everyone wanted more detail and wanted the most rigorous model possible.

Okanagan: Inputs weighed heavily on the physical system side of things, which the mostly technical participants were comfortable with.

NY Bears: Yes our team knew the limits of the data they could provide. Since they had no data on some questions and limited quality of data on others, they were reluctant to put too much faith into the final model.

Did you have a defined process script in advance? As in meeting 1: systems thinking…., meeting 2: software training…. meeting 3: Were you able to stick to your script?

Upper Mississippi: We did follow a broad outline for the workshop – with a schedule that carefully included plenary and parallel sessions interspersed throughout. The paper that I attached previously will give more detail on the exact structure and schedule.

Okanagan: Yes, because we were restricted by time and funding.

Upper Fox and Ria Formosa 2000: I use scripts as milestones and it is up to the group on how to achieve them. I will push from a qualitative toward the quantitative stage of model building. That doesn’t seem to come natural for a group and I believe it has value and may require more guidance then a group would natural take on.

NY Bears: Please see Siemer and Otto SD conference proceedings paper for answers to these questions. We followed Hines Standard Method for our project. We did use scripts, most of which were developed by George Richardson and associates. Though we used scripts and had a set structure in mind for the project, our engagement with the project team went on for much longer than originally expected. As you recommend, we were indeed flexible to the clients’ needs and that had major implications for the timeline. In our case, it created more tension and problem for the modelers (e.g., delayed my PhD, committed Peter to more involvement) than it did for the participants. Pulling this off within a reasonable timeframe is a very big challenge.

Example of hands on continuum chart sent to modelers

"Hands on" Modeling	**Sage grouse**	**Upper Mississ ippi**	**Middle Rio Grande**	**Okana gan**	**Upper Fox Ria Formosa 2000**	**NY bears**
Illustrated another model results only	Salmon model as illustratio n	No	Familiarize group with other models we have built	Salmon model as illustrat ion	Illustrated a preliminary model based on interviews with participants	Gloucester fishery project (Otto) used as an illustration of what our team might do.
Illustrated another model stock and flow diagram	Salmon model as illustratio n	No	Often used simple savings account (compound interest) or reservoir model examples	Salmon model as illustrat ion	Illustrated the Patagonia Coastal Zone Mgt model as an example.	Gloucester fishery project (Otto) used as an illustration of stock and flow diagrams.
Built simple stock and flow diagram *in front of* participants	No	Yes	Yes	Yes	Yes	No, we did that as an "off-line" activity, but we then discuss those structures and discuss how changes and corrections would be made based on participants' input and guidance.
Built simple stock and flow diagram *with* participants	No	Yes	Yes	No	Yes	No, but we went through multiple iterations of structure with participants, got their input, then went back to our offices to revise and rebuild structures that reflected participants' technical critiques.
Built *some* sectors of the model with participants	No	No	Showed sectors in detail but limited interactive building	No	Yes	Yes, we used workshops and iterative meetings to construct and verify causal loop diagrams. Those CLD's became the model sectors. Participants provided information to create look-up tables and other aspects of the model.
Built *all* sectors of the model with participants	No	No	No	No	Yes	Yes, we designed and suggested structures, but then confirmed and revised all structures with participant input.

In the chart below add the primary issues from your case study and their relationship to the information spectrum.

<table>
<tr><td></td><td colspan="2">Knowledge gained from analysis
(mathematics>physics>chemistry></td><td colspan="2">Biology>social science</td><td colspan="3">Knowledge gained
from interaction</td></tr>
<tr><td>Ford 1999</td><td>Physical laws</td><td>Controlled physical experiments</td><td>Uncontrolled physical experiments</td><td>Social system data</td><td>Social system cases</td><td>Expert judgment</td><td>Personal intuition</td></tr>
<tr><td>Middle Rio Grande</td><td>Physical laws</td><td>Results from high fidelity surface and groundwater models</td><td></td><td>Economic data.</td><td>Input on how system operated, what was important, what should be modeled.</td><td>Acceptable conservation alternatives.</td><td></td></tr>
<tr><td>Sage grouse</td><td>Land designations</td><td colspan="2">Biological parameters for life history</td><td colspan="3">Habitat to SG viability feedbacks Suitability indices based on field data from biological expert</td><td></td></tr>
<tr><td>NY Bears</td><td>Precipitation

*** the data in this row comprise only an example of an extensive list provide by modeler</td><td colspan="2">Biological parameters for life history and hunting mortality</td><td colspan="3">Number of households; surveys on bear-problem prevention; number of complaints</td><td></td></tr>
<tr><td>Upper Mississippi</td><td colspan="2">None – the model included fairly little analytical data. Future modeling efforts would include high levels of input from biological and ecological studies.</td><td colspan="2">Flows of land from rural to agriculture to urban.</td><td colspan="3">Essentially all other knowledge captured in the model was from interactions</td></tr>
<tr><td>Okanagan</td><td colspan="2">Knowledge gained from analysis:

Hydrology & climate futures; crop response to climate change</td><td colspan="2">Social System data:

population growth demographics</td><td colspan="3">Knowledge gained from interaction and Expert judgment:

reservoir operational rules; allocation priorities; existing laws/policies/ regulations; new policy ideas; treated wastewater pathways</td></tr>
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