ASSESSING APPROACHES TO STAKEHOLDER ENGAGEMENT IN REGIONAL CLIMATE IMPACTS MODELING: A CASE STUDY ANALYSIS

By

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To the Faculty of Washington State University:

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When I started my graduate school journey I had little understanding of where the path would lead, the ways in which it would challenge me, and the ways in which I would grow and change along the way. When I moved back to the US after two years as Peace Corps volunteer in Armenia and started my Masters degree I only knew that I wanted to continue learning and that I wanted to work toward positive change that would be lasting and bigger than myself. To me, there is no issue more fundamental to our existence than how humanity relates to the environmental systems that sustain us. So from these lofty (but not so well defined) aspirations, I set out on the long road of research, first as a Masters student at Clark University and then as a PhD student at Washington State University. I would have long ago lost my way and given up hope that I would ever have something new and meaningful to contribute were it not for the many people who have inspired and supported me along the way.

My committee has bridged disciplinary and geographic barriers to support my research. Over the course of researching and writing about stakeholder engagement in regional earth systems modeling projects I moved between several different social science disciplines. Allyson Beall-King, Amanda Boyd, Mike Brady, Jennie Stephens and Chad Kruger have encouraged me to think in new ways, to deepen my understanding of science and policy theories, and to develop practical skills related to workshop facilitation and project management. My advising committee members have been unfailingly patient, flexible, engaged and supportive.

Chad Kruger works tirelessly to improve communication among research institutions and agriculture industry professionals in the Northwest. I have benefitted greatly from observing Chad's approach to facilitating dialogue between individuals with diverse expertise. Chad is widely respected in the region as an advocate for meaningful integration of science and natural resource decision-making and it has been an honor to work with him. He has pushed me to consider my assumptions carefully and to present ideas with accuracy and clarity.

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As an economist engaged in the BioEarth project and as the lead PI on the WISDM project, Mike Brady's research has enhanced understanding of the factors that influence regional natural resource decision-making and the potentials for integrating economic and biophysical models. Mike's insights about distinguishing among different modeling approaches and representing diverse stakeholders' incentives to participate in environmental research processes have been very valuable in shaping ideas presented in this dissertation.

Jennie Stephens has known me since I arrived at Clark University as a Masters student in 2010. It is largely thanks to her encouragement and support that I have reached this point as a doctoral student. I’ve greatly enjoyed talking with Jennie about climate science and policy research questions. Her thoughtful feedback has been instrumental to my development as a thinker and as a writer. Jennie’s breadth of knowledge in the field of science and technology studies and her experience conducting interviews and focus groups to research climate science and policy issues has been invaluable.

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I have enjoyed being part of a team of WSU School of the Environment graduate students interested in exploring environmental change from a systems perspective and improving the quality of public engagement in academic research. Being a member of a team with Melanie Thornton, Korey Woodley, Kayla Wakulich and Jennifer Johnson has greatly enhanced my graduate school experience. I've been lucky to be a part of many different circles during my time as a PhD student at Washington State University and have greatly enjoyed working with students on the BioEarth project, especially Julian Reyes, Justin Poinsatte, Sarah Anderson, Keyvan Malek, Tung Nguyen and Kirti Rajagopalan. During my first year as a PhD student I learned a great deal from friends in the Rural Sociology Lab group at UI. Leigh Bernacchi, Stephanie Kane, JD Wolfhorst, Amanda Bently-Brymer gave feedback and shared resources and encouragement. Sanford Eigenbrode and Dianne Daley-Laursen supported Isaac Madsen's and my interest in creative approaches to build interdisciplinary dialogue in REACCH. I was lucky to spend time with REACCH project graduate students and Nitrogen Systems & Policy Integrated Research (NSPIRE) students, who took me under their wing and gave me the feeling of being part of a community despite my unusual interdisciplinary status.

I was fortunate to learn from many wonderful faculty members at WSU. Andy Ford's System Dynamics Modeling course shaped my approach to research and my career aspirations. Bill Budd and Steven Stehr's science policy seminar introduced me to important environmental policy literature and helped me situate my research questions in a broader social and political context. Jennifer Adam has done extraordinary work as the

BioEarth lead PI and I am grateful for her interest in my research and support of my work within our team. Fok-Yan Leung helped bring me to WSU initially and I'm grateful for his support of BioEarth's communication research component. Todd Norton provided valuable feedback on my researcher questions and methodological approach early on. Having the opportunity to collaborate on projects, including coordinating BioEarth workshops, developing the AgClimate.net website and writing an extension publication about interpreting environmental models with staff at the Center for Sustaining Agriculture and Natural Resources (CSANR) has been a highlight of my time at WSU. I've learned so much from working with Chad Kruger, Sylvia Kantor, Tara Zimmerman, Brooke Saari, Sonia Hall, and especially Georgine Yorgey.

I would also like to acknowledge the federal funding that supported the five-year BioEarth regional earth systems modeling research effort. BioEarth, including the work of the communication and stakeholder engagement working group, was funded by United States Department of Agriculture, National Institute of Food and Agriculture grant number 2011-67003-30346.

Beyond this large circle of academic mentors and colleagues who have supported me are my wonderful friends and family. Ralph Garono has been a mentor and friend ever since I worked for him trapping and identifying aquatic insets in the West Eugene Wetlands as a high school student. Judith Enders was a wonderful neighbor in Armenia, I'm so grateful for her warmth, wisdom and top-notch copyediting. Taylor Bortz and I have shared many adventures and had wonderful conversations about big ideas over the years. Heather Tomlins, Alex Najduch and Kate Gross are Clark University friends who have inspired and encouraged me since we met in Worcester. Leah Brandt, Hannah Brandt and Soren Newman made me feel at home during my time living in the inland Northwest. In Cambridge, we are fortunate to be surrounded by a large circle of friends who have supported me an academic and as a parent. I'm so grateful to Tiffany Sommer and Stephanie Andrews for having super cute babies and being like family to us.

My mom, Laura Duncan-Allen and my dad, Guy Allen have encouraged me to do things my way from the beginning and have made all of this possible with their love and support. My grandfather Andrew Duncan, the first member of my family to receive a PhD, was very proud of the work that he did in the OSU Horticulture department, and was always interested in what was growing at individual farms and gardens and the people connected to those places. Thanks to my brother Stuart Allen and his partner Leia Tyrell, my aunt Bonnie Duncan, and Allens, Duncans, Donaldsons, Travailles, Khachatryans and Vardevanyans far-and-wide I feel at home wherever I wander. Of course none of this work would have gotten done were it not for the patience and flexibility of my super cool step-kids Gus and Anouk and my incredible husband Jonathan Donaldson. I am grateful for all of your support, your wisdom, and your sense of humor on this sometimes-meandering journey.

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IN REGIONAL CLIMATE IMPACTS MODELING:

A CASE STUDY ANALYSIS

Abstract

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Chair: Allyson Beall-King

Scientific research is key to understanding complex environmental systems and informing decisions about natural resource management in the context of climate change. Environmental science research is, however, often conducted without active stakeholder engagement, and the result is typically development of new knowledge that does not directly serve the needs of individuals, industries and organizations that make decisions about environmental policy and resource management. Recent decades have seen rapidly expanding efforts to conduct environmental science research that directly informs government policies and private decision-makers' management plans, yet significant barriers remain in the pursuit of usable climate science. Strategies for effective collaboration among researchers and stakeholders, who have diverse needs and expertise, are not well developed. Metrics are needed for evaluating approaches to usable climate science production. This research advances understanding of how to foster effective

stakeholder engagement for usable climate science outputs, focusing on regional environmental modeling efforts based at universities. By tracking researchers' perceptions about stakeholder engagement over the course of a 5-year project, assessing stakeholders' information needs and perceptions of research and identifying characteristics of effective boundary-spanning organizations, this work suggests strategies for evaluating the effectiveness of efforts to produce usable climate science and identifies strategies for academic scientists to develop their capacity to bridge boundaries between research and decision-making.

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DEDICATION

This dissertation is dedicated to Anouk and Gus. I will never expect you to read this document from cover to cover, but I often think about the ways in which our approach to climate change mitigation and adaptation planning and policy today is shaping the world that you will inherit. I hope that we continue to improve the quality of information sharing among researchers and decision-makers and support forward-looking solutions to climate change impacts on our water resources, food systems and natural environment.

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CO-AUTHORSHIP STATEMENT

Chapter three of this dissertation is a journal article, *Diverse Perceptions of Stakeholder Engagement in an Environmental Modeling Research Team*, published in 2013 in the Journal of Environmental Studies and Sciences. I was the lead author on this publication. My analysis and organization of the paper were informed by critical input from co-authors Chad Kruger, Jennie Stephens, and Fok-Yan Leung. Georgine Yorgey's comments and feedback were also essential in crafting a clear and compelling account of the range of experiences and perspectives about stakeholder engagement among BioEarth researchers at the outset of the project.

Chapter four of this dissertation is an in-depth version of a manuscript titled *Climate Science Information Needs Among Northwest U.S. Natural Resource Decision-Makers,* which is currently in review. As with chapter three, co-authors contributed greatly to the final product. Jennie Stephens, Georgine Yorgey and Chad Kruger played a key role in the design of survey questions for stakeholders and discussion questions that formed the backbone of the BioEarth stakeholder workshops. Sonya Ahamed, a graduate student at the University of Vermont, co-coded workshop transcripts and workshop evaluation surveys with me. Her involvement assisted in defining overarching themes in stakeholders' input. Jennifer Adam, BioEarth's lead PI, provided essential insights about the ways in which stakeholders' input is informing research priorities.

CHAPTER ONE: INTRODUCTION

1.1 STAKEHOLDER ENGAGEMENT IN CLIMATE CHANGE RESEARCH

As the impacts of anthropogenic climate change on water resources, agriculture and natural and human systems intensify, there have been many calls for adaptation and mitigation measures that are informed by the best available science. These calls for scientifically informed decision-making come from many sectors including government officials, non-governmental environmental conservation organizations, political scientists and social theorists and science organizations (NRC 1999; Lemos et al. 2012; Kirchhoff et al. 2013). A very broad range of decisions could potentially be informed by climate science research conducted at academic institutions. This research considers "decision-makers" to be individuals or organizations who manage public or private natural resources, make policy decisions about land and resources, or influence entities that determine environmental management and policy directions. While there is a rapidly growing supply of environmental science information, a widely observed gap exists between scientific knowledge produced at academic and research institutions and application of that knowledge to inform natural resource decision-making in the public and private sector (Weaver et al. 2013; Lemos et al. 2012). The reasons for the gap between research and decision-making are multiple and may include: the complexity of climate information, uncertainty of projections, results reported at temporal or spatial scales that differ from the decision-makers' domain, and lack of specificity of the modeled scenarios to information users' particular decision contexts (McNie 2007;

Weaver et al. 2013). The challenge of conducting research that responds to and meets the needs of decision makers is particularly acute for research teams based at universities where finite funding cycles and a range of institutional demands make it difficult for research teams to design and implement strategic gap-bridging activities.

Although there is a widespread understanding that interaction among scientists and decision-makers increases the usability of scientific outputs, much remains to be done to overcome structural and social barriers to close engagement. Narrowing the gap depends on developing both a theoretical and a practical understanding how usable environmental science knowledge can be generated and applied in policy and natural resource management decision-making (Cash et al. 2003; McNie 2007). Social science research is a key component of the research needed to uncover and clarify practices that will ultimately bring the best available science to environmental decision-making (Kirchhoff et al. 2013). Involving diverse stakeholders and making their decision contexts (institutions, regulations, job constraints, etc.) more transparent to scientists is a necessary component of effective collaborations and development of genuinely usable climate science. There is a pressing need for research organizations and researchers to develop a more complete picture of who environmental decision makers are and what their needs are (Dilling & Berggren 2015). While many observers of the gap between research and decision-making have noted that institutional change is difficult and happens slowly, even incremental advances in the strategies employed for researcher-stakeholder interaction may lead to significant improvements in the usability of climate science and climate impacts information that decision-makers have available to them (Kirchhoff et al. 2013; McNie 2007).

The concept of boundary organizations emerged and evolved from business management literature to describe institutions that integrate research and policy communities (Guston 200l). The primary functions of boundary organizations are to communicate technical information across disciplinary divides and realms of expertise, to mediate decisions about research objectives and approaches, and translate information between research and decision-making spheres (Guston 2001; McNie 2007). Research is needed to understand how to create, manage, and replicate effective boundary organizations (McNie 2007). By analyzing institutional characteristics, group dynamics, management approaches and outcomes of usable science oriented research initiatives, a greater understanding can be developed of which practices and approaches support effective boundary-spanning efforts at academic institutions. A deeper understanding of who 'boundary-spanning individuals' are and how they communicate, translate and mediate across sectors with different needs and expertise is needed (McNie 2007).

This dissertation focuses on connections between scientific research and environmental policy. These connections are numerous and overlapping. Science policy decisions play a role in shaping research, which is communicated and transmitted within complex web of actors. Scientific knowledge then in turn plays a role in making policy decisions, which have social and environmental consequences. The relationships between research and decision-making have been studied from many disciplinary perspectives, including: natural resources sociology, educational psychology, public policy, environmental governance, science and technology studies, communication and more. Theories and methods from multiple disciplines are incorporated in this research to establish a unique research perspective.

This research falls under the umbrella of sustainability science, which emerged in recent decades as a transdisciplinary, practical applications-oriented field of study. The dominant questions guiding sustainability science research are: 1) how do nature and society interact? And, 2) how can social learning be promoted to guide nature/society interactions along sustainable trajectories? (Miller et al. 2014). Scientific research is socially constructed process. There is not a single, fixed framework for conducting research; rather, various approaches to organizing scientific inquiry and understanding of the relationship between scientific knowledge and environmental decision-making exist. Studying how science-policy relationships are understood and acted upon is an important step in developing more impactful, effective strategies for linking environmental research and decision-making.

Climate change presents some of the largest, most complex and most intractable challenges facing society globally. In this dissertation, regional climate change impacts initiatives at academic institutions are investigated to understand how those research teams interact with diverse groups of decision makers. There are many instances in which social actors making decisions about land and resource management could benefit from scientific information that is tailored to their specific needs. I hope that my work contributes to development and communication of climate science that is meaningful and usable for decision makers.

1.2 Overview of research questions and approach

The research presented here seeks to transition from theory to practice: by applying theoretical concepts about linking science and society to university-based research initiatives designed to bridge the gap between climate research and decision-making and assessing progress and outcomes, can effective operational tools and metrics be developed? This research involves in-depth investigation of BioEarth, a university-based regional climate change impacts integrated modeling initiative, and two related projects, WISDM and REACCH. These projects investigate overlapping questions about nutrient dynamics, water supply, and land use and climate change impacts in the Pacific Northwest and involve some of the same researchers, but they are each unique in their scope, leadership arrangement and approach to stakeholder engagement. Researchers and stakeholders involved in each of these projects were interviewed, surveyed and observed in meetings and workshops with the intent of tracking the following over time:

1. Perceptions about project goals, challenges, management/leadership and group dynamics
2. Attitudes about the relationship between science and decision-making
3. Concerns about environmental change and specific information needs (content and communication of information)
4. Learning (self-reported assimilation of new knowledge) and reflections about

development of new skills and/or expertise

A thematic analysis approach has been used to analyze observational notes, interviews and survey data to identify qualities of individuals, organizations and objects (models and research outputs) that facilitate bridging the gap between research and decision-making. Based on researchers' and stakeholders' statements, this work attempts to define the qualities enable individuals, organizations and objects to become boundary spanners and explore which actions and initiatives support development of individuals' and organizations' boundary-spanning capabilities. This interdisciplinary social science analysis of how environmental modeling teams operate is potentially meaningful and applicable for other regional climate change impacts research initiatives that aim to engage with non-academic stakeholders and produce usable outputs for decision makers.

1.3 Dissertation structure

The core research question addressed in this dissertation is: how can university-based research teams develop competencies in designing and managing stakeholder engagement processes to improve the usability of climate change impacts research and research communication? Chapter two includes an overview of the theoretical concepts underlying the study of usable climate science. This chapter discusses the relationship between science and policy and theories of science communication, interdisciplinary teams and organizational learning. The latter portion of chapter two presents the empirical background from which this dissertation has been developed, describing the history of climate science information use in resource management decision making.

Information about environmental concerns in the Northwest U.S. is presented along with the history and objectives of the BioEarth research initiative.

Chapter three is a reproduction of a published paper written with fellow BioEarth communication team researchers. This paper was published in the Journal of Environmental Studies and Sciences in 2013. The manuscript explores the question, "what are scientists' perceptions about stakeholder engagement?" based on a case study analysis of interviews conducted with the 18 BioEarth project co-PIs. Ideas about stakeholder engagement are discussed as they relate to researchers' disciplinary backgrounds and previous experience with actionable (applied) scientific research and extension and outreach. This chapters contributes to the understanding of how research teams define their stakeholders, identify individual stakeholders to work with and structure those interactions.

Chapter four is an extended version of a manuscript currently in review by the journal Environmental Management, also written in collaboration with fellow BioEarth Communication team members. This paper explores attitudes among a selected group of Northwest US natural resource decision makers who participated in BioEarth stakeholder workshops. The paper focuses on dominant environmental concerns, questions and information needs among decision makers in different sectors. The unique backgrounds, responsibilities, geographic areas, and areas of expertise of stakeholders are considered with respect to the kinds of climate science information they deem usable and their assessments of which temporal and spatial scales are of interest. This chapter considers ways in which stakeholder concerns and information needs are being incorporated into the BioEarth regional earth system modeling effort. This chapter concludes with a discussion of opportunities to enhance the usability of regional climate impacts models for non-academic decision-makers.

Based on an analysis of interviews and surveys conducted with BioEarth co-PIs at the beginning, mid point, and final year of the USDA NIFA-funded research effort and interviews conducted with BioEarth graduate students in the final year of the project, chapter five explores lessons learned about challenges and opportunities inherent in interdisciplinary environmental modeling research that seeks to provide usable outputs for decision-makers outside of academia. Based on an analysis of semi-structured interviews and detailed notes from research team meetings and stakeholder workshops, this research defines characteristics of effective boundary-spanning organizations and objects and to document how and to what degree individuals developed boundary-spanning skills. Attitudes among researchers and specific practices that contributed to boundary spanning efforts and factors that detracted from effective boundary spanning are discussed. Broadly, this chapter considers how BioEarth co-PIs' perceptions evolved over time and describes new skills and insights acquired over the course of the project.

In chapter six lessons learned as researchers move toward the conclusion of three overlapping regional research efforts are considered. The three projects compared are BioEarth, WISDM and REACCH. This chapter considers differences in how stakeholder engagement was conceptualized and approached in each project. Outputs of each project are discussed and researchers' reflections about those outputs are explored. This chapter concludes with recommendations about metrics to design effective stakeholder engagement approaches and monitor and evaluate project outcomes. This chapter provides recommendations for interdisciplinary environmental modeling and climate change research initiatives seeking to bridge gaps between academic science and natural resource decision-making.

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CHAPTER TWO: BACKGROUND

2.1 Climate science communication

This research focuses on one specific climate science communication context: communicating model projections to scientifically literate decision-making audiences in government agencies, NGOs and industry. Communicating relevant and actionable information about projected climate change impacts in managed and natural systems involves unique opportunities and challenges for academic researchers and the audiences with whom they are interacting.

Since the late 1980s, when substantial evidence of rising global temperature brought on by greenhouse gas emissions began to be publicized and discussed in policy circles, dialogue about climate change evidence, impacts and implications for society has been contentious and fraught with partisan associations (Moser 2010; McCright & Dunlap 2011). Self reported beliefs about global warming among Americans, as measured by Gallup Polls, reveal that Democrats and liberals are significantly more likely hold beliefs consistent with scientific consensus and express personal concern about global warming than are Republicans and conservatives (McCright & Dunlap 2011). While approximately 97% of publishing climate scientists agree that climate change is occurring and that it is caused primarily by human activities, this high level of scientific agreement was recognized by only 30 percent of the American public in 2010 (Leiserowitz et al. 2011). Even when there is agreement that anthropogenic climate change is real and presents a pressing danger for natural and social systems, there are conflicting views about the role that science ought to play in communications with policy decision makers, land managers and the general public (Moser 2010; Poortinga et al 2011). Associated with this are conflicting views on the role that climate science researchers ought to play in advocating for management and policy responses (Poortinga et al 2011).

Challenges that science communicators face in seeking to raise awareness and understanding of climate change risks include all of the following: 1) “invisible” causes of the problem—in other words the sources are many and dispersed and gasses that contribute to the greenhouse effect are not widely believed to be dangerous, 2) impacts that are distant in time and space, 3) lack of immediacy and direct experience of the impacts, 4) lack of tangible gratification for taking mitigation actions, 5) disbelief or misunderstanding of the basic science, 6) complexity and uncertainty about specific impacts and tipping points, and 7) limited attention spans of the public (Moser 2010; Leiserowitz et al. 2011; Akerlof et al. 2012).

Seeking to understand the ways in which climate science has been framed and transmitted via diverse channels to diverse audiences is a key component of the effort to increase the number of people who understand the scientific fact of climate change and it’s causes and are then motivated to take actions personally and politically to reduce greenhouse gas emissions and respond to impacts and risks. Until recent years there has been a widely observed tendency for news media to present anthropogenic climate change as an unresolved scientific question open for debate, with equal coverage given to perspectives that climate change is not occurring or is not caused by human actions (Nisbet 2009; Poortinga et al. 2011).

While the number of available accurate presentations of the science behind climate change has risen steadily in the past decade, communication research suggests that the Elaboration Likelihood Model, and the related Heuristic-Systematic Model, explain a tendency for peripheral, or heuristic, processing of climate science information, because people necessarily have limitations to the degree to which they are willing or able to engage with and evaluate a message (Marx et al. 2007). This limited "mental space" may contribute to members of the public maintaining attitudes about climate change that are not informed by the best available scientific knowledge (Marx et al. 2007). Scholars of science learning emphasize that future efforts to promote public understanding of and action on climate change must directly address the audience's perception of their own agency and their sociocultural context (Wibeck 2014). Researchers who look at risk communication recognize that accurate presentation of factual information alone does not motivate behavior change, there is a complex interplay of defense mechanisms and fear responses put into motion when possible future dangers are presented (Moser 2010; O'Neill & Nicholson-Cole 2009). The need to link everyday emotions and concerns to the potential for positive impacts at local scales is becoming apparent as these messages are found to be the most engaging (O'Neill & Nicholson-Cole 2009).

Climate models are highly complex and news media often misconstrues information about model uncertainty to imply that the models cannot usefully predict future changes (Akerlof et al. 2012). Akerlof et al. (2012) call for more explanatory texts for readers that improve how individuals understand what models are and how they're developed. When texts are rich in explanatory details about terms and processes readers gain greater understanding of the relevance of model outputs for decision-making. For educated audiences, messaging that explains what models are and how they are developed may help overcome lay mental models that equate uncertainty with a lack of credibility, and promote greater comprehension of this form of scientific inference (Akerlof et al. 2012).

The extent to which individual stakeholders participate in environmental change research, engage with model outputs and make decisions on the basis of that information is related to social and economic realities (Moser & Ekstrom 2010; Jantarasami et al. 2012; Akerlof et al. 2012; Archie et al. 2012). Different interest groups have variable incentives and motivations to accept the results from climate science research as salient, credible and legitimate (Cash et al. 2003; Ellenwood et al. 2012; Akerlof et al. 2012). For example, a producer who advocates for public financing of new water storage would have a strong incentive to argue that the scientific case for climate change is convincing and that changes to public infrastructure are necessary. This producer has in effect made the cost assessment that benefits-relative-to-costs of the storage project are higher in a climate change scenario where drought frequency and severity is intensified.

In addition to the observed phenomenon of stakeholders forming decisions about engagement with climate change impacts modeling processes based on perceptions of likely economic costs and benefits, other scholars have advanced theoretical models to explain variable levels of engagement with and trust in climate science. Cultural cognition research has defined possible barriers to planned climate change adaptation behaviors through all stages of the process (Moser & Ekstrom 2010; Kahan et al. 2012) The theory of cultural cognition of risk explains the tendency of individuals to form risk perceptions that are aligned with their values (McCright & Dunlap 2011; Kahan et al. 2012). Political science research explores how corporate spending on organizations, scientific consultants, and political speech can shape the landscape of climate science research and decision-making (Farrell 2016).

Government agency decision-makers are often faced with a challenge when considering climate change impacts models for regulatory or permitting processes, for example, because in this context their decisions must legally defensible. In some contexts policy decision makers are concerned that projections from climate change impacts models do not provide an adequate level of certainty (Jantarasami et al. 2012). Also, government agency decision-makers must be responsive to political will of supervisors and constituents (Jantarasami et al. 2012; Archie et al. 2012).

The "Six Americas" typology, based on thousands of interviews with a nationally representative sample of US citizens, was developed to explain the range of attitudes about climate change that range along a spectrum of concern and issue engagement

(Leiserowitz et al. 2011). At one pole are the "alarmed" citizens who are convinced of the reality and danger of climate change and are strongly supportive of personal and political actions to mitigate the threat (Leiserowitz et al. 2011). At the other pole is the "dismissive" group, who express certainty that climate change is not occurring and that no response should be made. Falling between these two poles are the concerned, cautious, disengaged and doubtful groups. While the demographics of respondents are not a predictor of which group they will fall under in the Six Americas categorization, the groups vary dramatically in their basic values and political orientations (Leiserowitz et al. 2011). A national survey asked members of the public whether they believed that congress should prioritize action on national climate risks and participants responded as follows: only 13% said global warming should be a very high priority for congress, 26% said high priority, 31% said medium priority and 30% said those concerns should be a low priority for congress (Leiserowitz et al. 2011). However, when asked how concerned they were about climate change impacts on *local* water supply, agriculture, forests, wildlife and public health, 80% responded that they were somewhat-to-very concerned (Leiserowitz et al. 2011).

Science communication must be strategic in order to promote the audience's technical understanding of climate change and affect audience perception of climate change impacts and how to respond to risks (Moser 2010). Attitudes about the role that scientists should play in advocating for social and political change in response to climate change adaptation and mitigation vary widely. While serving as director of the NASA

Goddard Institute for Space Studies, James Hansen popularized the concept that scientific reticence, or the tendency of researchers to qualify their research findings and to be very cautious in making claims about what constitutes proof, can inhibit the rapid policy response needed to address climate change (Hansen 2007). Many have promoted the notion that scientists must develop a wider range of communication skills and seek to ensure that their work is brought the bear in decision-making (Siepen & Westrup 2002).

In *The Honest Broker*, Pielke (2007) emphasizes that all science communication and engagement is political. It is political in the sense that it contributes to the bargaining and negotiating that goes into making any decision. Four idealized types of science engagement with policy that exist in a democracy are presented (Pielke 2007). The role of science and scientists varies according to issues at hand and institutional context. Understandings of how science informs decision-making (a "linear" or "diffusion" model of science communication vs. a "participatory" model) and understandings of role of expert opinion in decision-making ("pluralist" vs. "elite expert dominated") inform the role that scientists play in decision-making (Figure 2.1).

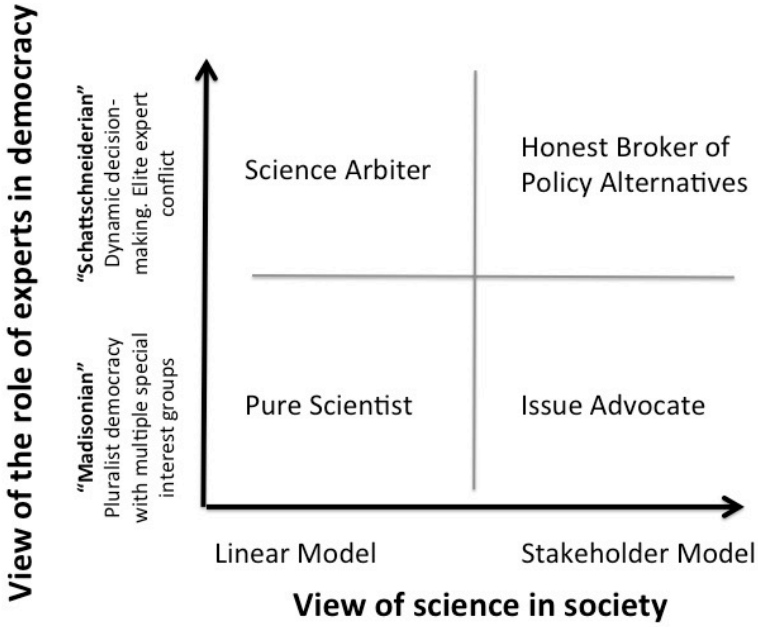

Figure 2.1 Four idealized roles for scientists in decision-making. Adapted from Pielke (2007).

In this framework, a pure scientist provides context-independent empirical research. In reality, very little science is conducted in a politically neutral environment and true instances of this role are rare. An issue advocate promotes a course of action based on scientific evidence with the goal of reducing the scope of choice. A science arbiter responds to questions that can be solved empirically. Thus a decision maker drives a discourse, and experts contribute information in a formal process of engagement (Sarewitz & Pielke 2007; Jasanoff 2009). An honest broker provides scientific information without seeking to limit the scope of choice. Pielke suggests that the honest broker role is best served by a panel of experts (Pielke 2007). Pielke argues for transparency in the roles played by scientists in political processes and cautions against a fifth model of stealth issue advocacy, in which a scientist or science panel advocates for a specific outcome under the guise of another role and thus invokes science as a wedge issue (Pielke 2007).

Biases in research may be introduced by the concerns and objectives of funders or stakeholders or by available resources and background and training of researchers. These biases should be acknowledged and communicated openly when scientists are effectively functioning as honest brokers (Pielke 2007; Sarewitz & Pielke 2007). The question of what effective communication looks like and how to develop the capacity to carry it out is a personal struggle for many climate scientists as well as for research projects and institutions as a whole (Siepen & Westrup 2002; Pielke 2007).

In the context of regional climate change impacts modeling, it is critical for the scientists and science communicators involved to reflect on how they are understanding, designing and managing stakeholder engagement processes. Only by fostering effective engagement can research initiatives improve the relevance and usability of their work and communicate effectively about inherent biases in the framing and assumptions of their research. This effective communication allows researchers in academia to inform policy makers without crossing into the realm of advocacy science, thereby maintaining perceived credibility of the research.

2.2 Environmental research and decision-making

In the early 20th century in the United States, the dominant thinking was that an essential function of the government was to fund "basic" scientific research that would be transmitted and "applied" by the defense, medical, agriculture and industrial sectors (Sarewitz & Pielke 2007). Vannevar Bush's 1940s *Science—The Endless Frontier* discusses "basic" and "applied" research and is often cited as emblematic of this early understanding of how research relates to policy decision-making (Kirchhoff et al. 2013). This early science-society model, which assumed a linear pathway from knowledge to decisions, dominated thinking about science funding for decades. Some suggest that representing mid 20th century science policy as a strictly linear process is a straw man argument, noting that there has always been a complex interplay between basic and applied research (Sabatier 1986; Kirchhoff et al 2013). This is worth noting, but it remains true that until roughly the 1970s "conducting science" was widely understood as the first step in a linear pathway toward "making a decision" (Sabatier 1986; Sarewitz & Pielke 2007). This has been called the liner diffusion model, in which science that is produced is presumed to be useful and usable for making decisions.

Beginning in the 1970s it became clear that the linear diffusion model was not adequate to supply relevant information about complex problems to the communities where decisions were being made (Kirchhoff et al. 2013). The linear model makes unfounded assumptions about the resources, capabilities and motivations of research users, especially when the research in question relates to environmental change and natural resource management, issues that are by nature complex or "wicked problems" (Sarewitz & Pielke 2007). In a handbook for science policy decision makers by Dilling et al. (2010) four basic myths about science policy decision-making are exposed and countered, summarized here:

1. A commitment to usable science for decision-making does not imply the abandonment of basic research.

2. There is no reason to avoid thoughtful planning in pursuit of explicit goals.

3. Sometimes we have adequate knowledge to address a problem, and additional research may not be the best approach.

4. In the case of controversial issues there is often debate over whether the science is "settled." But the scientific process almost never comes to final conclusions and often involves irreducible uncertainties. Waiting until "answers are clear" to communicate results to stakeholders is not feasible or desirable, in order for decision makers to benefit from science, they must be involved in research processes early and often.

Theorists interested in the science-society interface have come to recognize and value new modes of interaction between scientific research and decision-making, variants of which have been termed post-normal science, actionable science, civic science, sustainability science, and other conceptions which recognize that knowledge influences and is influenced by social practices, identities, discourses, and institutions (Anderson et al 2012; Bäckstrand 2003; Cash et al 2003; Kirchhoff et al 2013; Pielke 2007). These conceptions in various ways recognize that between science and society a mutually constructed forum exists in which producers and users of science shape facts about the natural world being studied (Kirchhoff et al. 2013). A concept closely associated with these evolving notions of the science-society nexus is that complexity of environmental problems requires more than one disciplinary view to solve them. New modes of research are needed to understand the far-reaching impacts of environmental issues and to incorporate multiple kinds of knowledge and expertise to address those problems (Collins & Evans 2008; Kirchhoff et al. 2013).

Key ideas that have emerged from the post-normal, decision-relevant science movement are multidisciplinarity, interdisciplinarity and transdisciplinarity. Multidisciplinarity refers to understanding a problem from the viewpoint of different disciplines, interdisciplinarity combines perspectives, methods, and ideas to foster innovation in ideas, solutions, and decision tools, and transdisciplinarity unites perspectives and ways of knowing, often across institutions, and forges a consensus approach to the process and methods of inquiry (Kirchhoff et al. 2013). Although interdisciplinary work has been widely upheld as an ideal and as a practice in the environmental research community, transdisciplinary is more contested because of the demands such an approach places on institutional resources and because it represents a radical rethinking of the role of scientists, as they may be compelled to work beyond the boundaries of the scientific approach that is familiar to them (Kirchhoff et al. 2013).

Increasingly, environmental change research policy is discussed in in terms of the “supply” of science information, and the “demand” for usable information (Kirchhoff et al. 2013; McNie 2007; Cash & Buizer 2005). The notion of supply and demand is borrowed from economics, where supply and demand are interrelated and co-determined

(McNie 2007). McNie (2007) observes that explicit demand for information by potential users of climate impacts information is rarely a strong determinant of the supply of scientific information. Kirchhoff et al. (2013) note that ensuring that the supply of scientific information is in line with the needs of decision makers requires attentive management, because in the case of environmental policy there is no "invisible hand" (Kirchhoff et al. 2013). Federal funding for environmental research in the US now frequently comes with the expectation of social relevance and actionability (Palmer 2012). There are myriad approaches to supporting decision makers' engagement in research, a growing number of codified strategies now exist including Participatory Action Research (Reitan & Gibson 2012) and Mediated Modeling (van den Belt 2004). A common feature is that there is iterative interaction between the research team and the intended community of users. The concept of decision support has been highlighted as a key strategic goal of the US Global Change Research Program, which specifically calls for "assessing decision maker needs, capabilities, and science requirements and identifying critical gaps in knowledge and options for a use-inspired research agenda" (McNie 2007).

For scientific information to be usable, decision makers must perceive it to be credible, salient, and legitimate (Sarewitz & Pielke 2007). In order for information to be deemed credible it must be presented in a manner that shows it to be accurate, high quality, supported by peer review, and funded by recognizable or established institutions (Sarewitz & Pielke 2007). To ensure the information is legitimate, it must have been produced and disseminated in a transparent, open manner free from political persuasion or bias (Sarewitz & Pielke 2007). To be salient, information must be context-specific for a decision-maker's ecological, spatial, temporal, and administrative scale (Cash et al. 2003; Sarewitz & Pielke 2007). Linking knowledge to action requires open channels of communication between experts in different areas and decision makers and often some degree of concerted translation work is required. Mutual understanding is often hindered by jargon, diverse experiences, and presumptions about what constitutes a persuasive argument (Cash et al. 2003).

In order to use information to inform decision-making three basic conditions must be present: 1) power to make a decision, 2) trust in the information, 3) a system for being able to access and use the relevant information (Kirchhoff et al. 2013). Many factors affect the use of information in policy decision-making, including: institutional barriers, the specific nature of decision and policy goals, the scale of information, the skills required to access, interpret and utilize the information and finally, and possibly most importantly, the level of trust between information producers and users (Cash et al. 2003; Dilling at al. 2010; Kirchhoff et al. 2013). The notion of trust in information is related to the concept of social capital. Social capital describes the value or benefits of social networks (familiarity and relationships with a circle of individuals and organizations) and the norms of mutual support and collaboration engendered by those networks. Learning and application of new knowledge take place in a social context and the established relationships and trust between groups, or social capital, matter a great deal in shaping what learning and decision-making will take place (Jones et al. 2012). The production and maintenance of social capital is a dynamic and time-intensive process that is shaped by organizational goals and leadership approaches (Jones et al. 2012; Kirchhoff et al. 2013).

Policy implementation, the process of policy becoming action, demands consideration because "policy does not implement itself" (Leach & Sabatier 2005). Frequently the academic conversation about policy implementation focuses on a debate about whether top-down mechanisms or bottom-up processes are more important in determining whether and how a policy is implemented (Leach & Sabatier 2005). In practice, it appears that both top-down processes, such as clearly articulated objectives and mandates from leadership, and bottom-up processes, such as stakeholder processes and on-the-ground bureaucratic efforts, contribute to the way in which environmental and natural resource management policies are structured and change over time (Leach & Sabatier 2005; Archie et al. 2012). The ways in which regional environmental policies are negotiated and the ways in which public services managers operationalize often ambiguous policies vary widely and merit further study (Archie et al. 2012).

In terms of responding to climate change impacts and vulnerabilities, a survey of adaptation policy development and implementation efforts in the US concluded that while new environmental coalitions and landmark court rulings have been important, the role of durable policy objectives such as the requirements of the Endangered Species Act in helping to set policy objectives should not be underestimated (Howlett & Cashore

2009; Berrang-Ford et al. 2011). Results suggest that adaptation policy is moving forward in some organizational contexts, although many barriers have been observed, including: competing priorities, lack of relevant data, and lack of clear governmental roles and lack agency funding and resources (Berrang-Ford et al. 2011). It has been suggested that the regional scale is where power lies to implement effective climate change adaptation policies (Dilling & Berggren; 2014; Wise & Frietag 2002; Steelman & McCaffrey 2013).

A mandate to consider climate change in decision-making has been in place since 2001 in the U.S. Department of the Interior, which includes the Bureau of Land Management, the National Parks Service, and the Fish and Wildlife Service (Ellenwood et al. 2012). The U.S. Department of Agriculture, which houses the US Forest Service, has had a climate change program since the late 1990s, primarily focused on research (Archie et al. 2012). Under a 2010 Executive Order from President Obama (Executive Order 13514) and in coordination with the Interagency Climate Change Adaptation Task Force all federal agencies are now formally required to "manage the effects of climate change" and annually submit a performance plan detailing their approach to adaptation, and mitigation (Archie et al. 2012).

In a 2010-2011 survey of state and federal land management agency staff in the interior Western US, climate change did not rank highly compared with other challenges (Archie et al. 2012). Even when agency staff personally ranked climate change as a high priority, they expressed frustration that their capacity to try to engage in the issue meaningfully was limited by resource constraints within their agency (Archie et al. 2012).

A challenge frequently noted by staff is members of the public are often not willing to accept certain impacts in exchange for certain benefits (Archie et al. 2012). Conflicting values of stakeholders, often associated with the multiple use missions of public land agencies, cause tension when dealing with management changes related to climate change (Archie et al. 2012).

2.3 Boundary organizations

All organizations by definition have boundaries defined by their scope and membership. Within organizations some people or within-organization groups may occupy boundary-spanning roles, serving as a link between the organization and the broader social and political environment (Aldrich & Herker 1977). Boundary-spanning roles entail processing information from the environment outside of the organization and representing organization activities to the outside environment. Boundary roles link organizations to their environments, whether by buffering, moderating, or influencing the environment (Aldrich & Herker 1977; Guston 2001). Sustainable organizations have a strong ability to learn and to perform according to changing contingencies in the environment, acting as both filters and facilitators (Aldrich & Herker 1977). The information that filters into the organization through boundary positions is often not raw data, but the knowledge and inferences of those occupying the boundary role, thus this type of information is difficult for anyone removed from the boundary to verify.

The term "boundary organization" has emerged to describe entities that specifically focus on negotiating the territory between two or more organizational cultures and norms.

Boundary organizations have three defining features: 1) they involve specialized roles and responsibilities for managing the boundary, 2) they have clear lines of responsibility and accountability to distinct social arenas on opposite sides of the boundary; and 3) they provide a forum in which information can be co-produced by actors from different sides of the boundary through the use of boundary objects (Cash et al. 2003; Guston 2001). Theories of boundary organization formation and structure are useful in understanding how environmental science knowledge can be communicated and co-produced by scientists in academia and diverse groups of stakeholders.

Boundary organizations "link different social and organizational worlds to promote innovation, support two-way communication among sectors and integrate production of science with user needs" (Feldman & Ingram 2009). Specific responsibilities of boundary organizations are communication, translation, and mediation (Cash et al. 2003). These functions can be institutionalized in boundary-spanning roles acting as intermediaries between the arenas of science and policy (Cash et al. 2003). Boundary organizations spanning the gap between science and policy can facilitate relationships and be brokers of the development and transfer of information. Boundary organizations may have a range of structures and approaches depending on the issue and goals at hand, they may be formal or ad-hoc communities of communicators, translators and mediators. As stabilizers, boundary organizations provide a means for producers and users of knowledge to work together to form a common point of reference and shared understanding while maintaining their separate identities (Clark et al. 2011; McNie

2013).

Boundary organizations facilitate the creation and transfer of usable knowledge and coordinate decision-making across boundaries of scale or levels of organization, for example, county, state, and federal jurisdictions (Cash et al. 2003; McNie 2013). NOAA's Regional Integrated Sciences and Assessments (RISAs) are a leading example of boundary organizations specially designed to facilitate usable climate science for decision-making (McNie 2013). McNie finds that RISAs, when functioning effectively, protect scientific work from bias and politicization (buffering) while maintaining ties to users who might rely on the research outputs to inform policy decisions (linking) (McNie 2013). RISAs are adaptive "learning organizations" able shift in response to users' information needs and input rather than narrowly defining research agendas in isolation from stakeholders and ultimately producing information that is not relevant and usable (Kirchhoff et al. 2013). Concepts of boundary organization structure and function can be applied to understand how cooperative extension programs linked to land grant universities in the US function as boundary organizations.

Theorists and observers of boundary organizations frequently note that single individuals often play key ''boundary-spanning'' functions, independent of their particular organizational affiliations (Aldrich & Herker, 1977; Cash et al. 2003; McNie 2013). Research is needed to understand how to develop and harness the boundary-spanning potential of individuals and organizations (Guston 2001; Vogel et al. 2007; McNie 2013).

Boundary organizations produce boundary objects, such as reports, conferences, maps, diagrams and models. Because boundary objects are coproduced by the worlds of science and policy, they gain authority in both. Boundary objects sit between two different social worlds and can be used by individuals within each for specific purposes without losing their own identity (Star & Griesemer, 1989). Models can serve as boundary object that facilitate discussion among parties with multiple interests and differences in perspective, methodology, preferences, values, and desired outcomes (Kirchhoff et al. 2013). In an iterative process of model construction, revision, and application opportunities for communication between model developers and model users are created. In the case of a European acid rain model developed in the 1990s, Cash et al. (2003) find that focusing on development of a model as a boundary object ensured that information outputs were salient to negotiators, credible to scientists from several nations, and legitimate in that they did not favor the interests of any one nation.

2.4 Climate change impacts models

Models represent essential features of natural phenomena, serving as abstracted or simplified representations of a physical object or a process (Box et al. 1978; Sterman 2002; Frigg & Hartman 2012). Models may depict and provide information about a process that can be observed in the world, or they may provide information about possible future behavior of a system or process. A model that explores the future is a simulation model. Process-based environmental modeling plays an increasingly important role in understanding potential regional implications of environmental changes

(Mass et al. 2003; Lemos et al. 2012). When applied and interpreted with care models provide approximations of system behavior and projections of future conditions. Modeling results are often most powerful when they move away from a paradigm of "prediction" towards an approach that explores a range of possible futures (Lemos et al. 2012; Weaver et al. 2013). This approach shifts the focus to understanding whether planned or possible management or policy strategies are "robust" and where vulnerabilities exist.

Process based models directly capture fundamental scientific features and relationships of the system being modeled, representing them mechanistically. This enables understanding causal relationships between system components (Thakur 1991; Fritts et al. 1991). Modeling happens progressively: researchers construct a model, they analyze and refine the properties and dynamics of the model, they assess the relationship between the model and reality, and they may apply the model with the aim of developing a better understanding of real-world phenomena (Weisberg 2007). Process based models are developed beginning with fine-scale relationships and processes that are represented numerically and aggregated to represent a larger complex system. For example, a process based model could simulate infiltration of rainfall into soil by mathematically representing how water moves through specific soil types according to characteristics that have been experimentally studied and defined, such as soil texture, relative proportion of organic matter and depth of soil layers. Multiple process-based models can be linked to represent an integrated system.

Regional climate change impacts models are typically weather-driven, meaning that they explore how precipitation and temperature events impact other environmental processes. Projections of future climate derived from downscaled general circulation models (GCMs) serve as model inputs to a regional climate impacts model (Abatzoglou & Brown 2012). In the process of downscaling, adjustments are made to general circulation models to better capture local forces, such as the rain shadow effect from the Cascade Range (Mote & Salathe 2010).

Model projections are not exact descriptions of what will happen; there is always some degree of uncertainty associated with them (Smith & Stern 2011). Uncertainty exists at multiple levels: epistemic uncertainty is incomplete knowledge of a system that is reducible with further experimental study whereas stochastic uncertainty is due to inherent variability of a system (Walker et al. 2003). It is not possible to quantify all forms of uncertainty; some expressions of what is unknown can only be stated qualitatively. However, when environmental modelers discuss uncertainty they are often referring to only the kind of uncertainty that can be quantified, in other words the range of model outputs, which have probabilities assigned to them (Walker et al. 2003; Hawkins & Sutton 2010). Some key sources of uncertainty in process-based models that explore climate change impacts on regional environmental systems include emission scenarios (and general uncertainty about human behavior and decision-making in the future), structure and parameterization of GCMs and regional environmental models, downscaling approach, and inherent internal variability of systems (stochasticity). Some of these may be explicitly addressed or shown in results, while others may not.

All models have associated assumptions embedded within them (Peterson et al. 2003). Decision-makers who are looking at model outputs need to understand the assumptions built into a model. Assumptions are also frequently found in scenarios, or storylines about a set of future conditions and trends. Scenarios are frequently used in models that simulate coupled human-ecological systems to explore model behavior under possible future conditions (Peterson et al. 2003; Weisberg 2013). A single model can be used to explore multiple scenarios. Generally, it is only possible to generate a relatively small number of scenarios because of limited computing and analytical power, as well as limitations on the time that modelers can reasonably invest in running scenarios. Analyzing how results change as assumptions change can also provide insight about the mechanisms that are driving the results, a process sometimes referred to as sensitivity analysis.

Modelers often hear that stakeholders would like climate models to become more certain and more accurate at scales relevant to specific decisions, but it is unclear to what degree this is possible (Dessai et al. 2009; Dilling & Berggren 2014). Investing in developing options that are robust to multiple futures may be the best way to move toward a modeling approach that meets the needs of decision makers (Lempert et al. 2004). Because stakeholders are responsible for managing specific resources, they tend to be concerned about how climate affects their particular sector–thus requiring information that is sector-specific (Dilling & Berggren 2014).

2.5 Stakeholder theory

Literature in the fields of business and organizational theory, political science, sociology, and anthropology explores stakeholder identification and stakeholder engagement. In organizational theory, stakeholders are defined as individuals or groups who can affect, or are affected by, the actions and results of a specific organization, initiatives, policies, or projects (Harrison & Freeman 1994). In management literature, stakeholder theory is centered on the idea that institutions should focus on meeting a broader set of interests than simply amassing profits for shareholders (Plaza-Ubeda et al. 2010).

In general for climate information initiatives, stakeholders can be considered as the individuals or organizations that may have interest and/or ability to use climate data and models in their decision-making. Involving stakeholders in the production of knowledge can be seen as an ethical requirement of businesses or institutions (Harrison & Freeman 1994; Deetz 2003). Working closely with stakeholders outside the academic community can be understood as a strategic necessity to ensure that consideration of up-to-date scientific information about climate change impacts and risks is taken into account in decisions about land and resource management and social policy (Plaza-Ubeda et al. 2010; Hegger et al. 2012).

Stakeholders can be classified in three broad categories: internal, external, and distal (Sirgy 2002). In the case of an environmental science research initiative, internal stakeholders include program administrators, principal investigators, graduate students, collaborating researchers and science advisors. External stakeholders include all individuals and groups who may be able to use the climate science data. Distal stakeholders are traditionally defined as groups with competing or conflicting interests to the internal stakeholder groups (Sirgy 2002). In the case of research and science communication initiatives, groups with directly competing interests may not be readily identifiable. Members of the general public or interest groups without a direct relationship to the research initiative may be considered, or may self-identify, as "non-stakeholders" although it is important to understand that even parties who do not see themselves as having a direct stake in the outcome of a research or science communication initiative may still have an economic, health, or social well-being interest in the larger environmental change issue (Harrison & Freeman 1994; Plaza-Ubeda et al. 2010).

An alternate definition and typology of stakeholders is based on the concept that in order to be a stakeholder, the group or individual must possesses one or more of the following relationship attributes: power, legitimacy, and urgency (Mitchell et al. 1997). Given the all-encompassing impacts of climate change, it could be argued that everyone and every organization has some legitimacy and power relationship with climate science information.

Reed et al. (2009) propose a typology of stakeholders in environmental decision making that is based on levels of interest in the issue at hand and levels of influence, or power in the decision making process. Figure 2.2 depicts these classes of stakeholders. All have a potential role to play in decision-making, but may be engaged in different stages and in different manners.

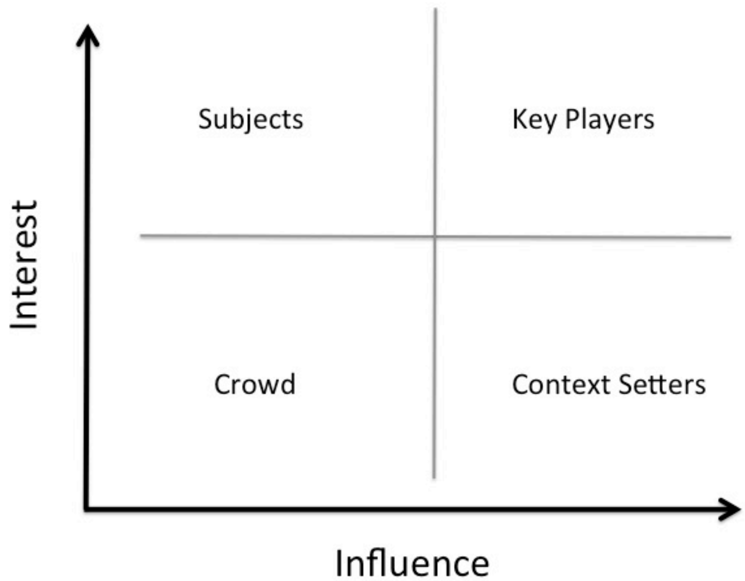

Figure 2.2 Classification of stakeholders based on "interest" and "influence". Adapted from Reed et al. (2009).

There are challenges associated with engaging stakeholders from the general public in environmental research and decision-making. Members of the public may not view themselves as having relevant expertise to contribute or a strong interest in the outcomes of research and management decisions (Deetz 2003; Rowe & Frewer 2005; Reed et al. 2009). However, there are situations in which the public's economic and social well-being are impacted by the directions of environmental research and management decisions (Deetz 2003). For example, it is ultimately taxpayers who fund construction of new public infrastructure, such as reservoirs, water treatment systems and riparian corridor restoration efforts.

The fact that taxpayers have specific information needs and priorities related to regional climate change adaptation and mitigation decisions is complicated by the fact that stakeholder engagement in research is more easily implemented when there is a high concentration of benefits or potential costs to stakeholders (Butler and Adamowski, 2015). In other words, stakeholder engagement process facilitators can more readily identify individuals and organizations with a *strong* stake in the knowledge generated and the perspectives represented. Also, those with a strong stake will more readily commit their personal time and resources to engaging in the process. Engagement in initiatives for useable climate science is lower for groups in which the potential costs or benefits of decisions are spread widely across a large number of people, even when the aggregate cost or benefit is large, for example in a water treatment infrastructure investment (Noland and Phillips, 2010; Butler and Adamowski, 2015).

In communicative action theory, Habermas et al. (1990) suggest participation should represent the full range of relevant stakeholders and equalize power between participants. Identification of stakeholders may need to expand beyond inviting those groups and individuals suggested by the facilitation team in brainstorming processes. Community leaders can be consulted from the beginning of the research process to help set the project goals and identify possible stakeholders (Rowe and Frewer, 2005). Seeking to expand and enhance frameworks to define who stakeholders are, Butler and

Adamowski (2015) emphasize that facilitators of stakeholder processes must be cognizant of power dynamics in society and histories of conflict or marginalization. When there is transparency in the engagement processes and clear communication of which stakeholder groups were consulted in framing questions and considering potential social and economic outcomes of decisions all actors in the process can better recognize potential gaps in the analysis.

In addition to grappling with the question of how to define stakeholders, institutions seeking to develop and communicate useable climate science data, information and decision-making tools must invest time and resources in establishing a plan for how stakeholders will be engaged (McNie at al. 2012). Potential roles of stakeholder in research are varied and can include any of the following: identifying research questions, sharing values, preferences, expectations and perceptions of risk, providing quantitative data or local expertise, commenting on research concepts, drafts and results, learning from the research process, and integrating research findings into a decision-making processes (Rowe & Frewer 2005; Bucchi & Neresini 2008).

2.6 Organizational learning and change

Organizational learning is the process of creating, retaining, and transferring knowledge within an organization. An organization improves over time as it gains experience. From this experience, it is able to create knowledge. The learning organization concept was coined by and examined in the research of Peter Senge and colleagues (Senge 2006). A learning organization facilitates the learning of its members and continuously transforms itself. Learning organizations develop as a result of the pressures of change within and outside the organization. A learning organization has five main features: 1) systems thinking, 2) personal mastery, 3) mental models, 4) shared vision and 5) team learning (Senge 2006). The theory of the learning organization encourages organizations to shift to a more interconnected way of thinking, becoming more like communities that members feel a commitment to (Senge 2006).

Knowledge is created at four different levels: individual, group, organizational, and inter-organizational (Senge 2006). Although knowledge is related to data and information, knowledge is something beyond data and information. Data are defined, objective facts. Information adds meaning to data through categorization, calculation, correction, or condensation. Knowledge is applied information, in other words it is information that is contextualized by experience, framing, value judgments and insight (Brattilana & Casciaro 2012). Experience is generated through exposure to and application of knowledge. Knowledge originates within organizations and is applied by units of an organization to evaluate and utilize experience and information effectively. Knowledge can become embedded in the routines, processes, practices, and norms that an organization engages in. Two distinct forms of knowledge exist: explicit and tacit. Explicit knowledge is codified, systematic, formal, and easy to communicate (Brattilana & Casciaro 2012). Tacit knowledge is personal, context-specific, and subjective (Brattilana & Casciaro 2012).

Researcher-stakeholder interactions may work to decrease mismatches between different kinds of knowledge and values, such as explicit and tacit knowledge. Interaction fosters learning, which may reduce conflicts between knowledge types by helping to transform and translate types of knowledge (Kirchhoff et al. 2013). As knowledge moves across disciplines, the process of interaction reshapes the perceptions, behaviors, and agendas of participants (Kirchhoff et al 2013). Song and M'Gonigle (2001) explore how working with local knowledge requires new skills, including diplomacy and negotiation that must be cultivated and developed over a long period of time.

Research on organizational change has improved understanding of the challenges inherent in knowledge development and implementation, there is a need for continuing development of understanding of how new learning shapes the activities of organizations and how that knowledge may transform the workings of the organization (Brattilana & Casciaro 2012). Scientists, policy makers, and the public must identify and work through epistemological differences (Song & M'Gonigle 2001; Brattilana & Casciaro 2012). Song and M'Gonigle (2001) put it as follows: "if science is the search for facts and truth, then policy is the struggle over ideas". This reinforces the idea that science and policy are separate domains with distinct forms of legitimization and different ways of producing and defining usable knowledge (Kirchhoff et al. 2013). Understanding how knowledge is defined, developed and communicated in different domains of expertise is essential to understanding how new initiatives can be put into practice (Collins & Evans 2008). To implement organizational changes, change agents may need to overcome resistance from other members of their organization and encourage them to adopt new practices

(Brattilana & Casciaro 2012). Change implementation within an organization can thus be conceptualized as an exercise in social influence (Brattilana & Casciaro 2012). Changes that diverge from the status quo are particularly challenging to implement, requiring change agents to distance themselves from their existing institutions and persuade other organization members to adopt practices that depart from the norms of their institutional environment (Brattilana & Casciaro 2012).

2.7 Climate Change Impacts in the Northwest US

The climate of the Pacific Northwest (PNW) is temperate, with a seasonal rainfall pattern of typically wet winters and drier summers. The region is known for old growth evergreen forests, and diverse agricultural products including wheat, wine grapes, and tree fruits. The topography of the region has a strong influence on local climates; the Cascade mountain range creates a rain shadow effect and results in drier conditions in the eastern PNW (Mote & Salathe 2010). The Columbia River is at the center of the Pacific Northwest ecologically and culturally. The Columbia River basin supports unique ecosystems and supplies water for agriculture, industry and communities in parts of seven U.S. states and Canada. The Columbia River and it's tributaries irrigate approximately 7.8 million acres of farmland and generate and annual average of over 16600 megawatts of electricity (Barber et al. 2012).

The dominant cyclical fluctuations in regional climate are related to the El Niño/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). In their warm phases ENSO and PDO increase the probability of warmer and drier winters than average

(Mote & Salathe 2010). Because temperature and precipitation tend to co-vary based on ENSO and PDO cycles, predications can be made about snowpack, streamflow, and forestry and agriculture impacts. ENSO and PDO effects will, in the coming century, continue to result in periodic cooling and warming patterns that persist for years to decades (Mantua et al. 2010). Longer-term impacts of climate change on ENSO and PDO cycles are not well understood (Mantua et al. 2010). Relationships between climate change and precipitation are complex and highly variable among different models and different sub-regions (Abatzoglou et al. 2014; Mote & Salathe 2012).

Consistent with global anthropogenic climate change trends, average temperatures in the US Pacific Northwest have increased over the 20th century (Abatzoglou et al. 2014). Climate models used in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) project that the warming rate for the Pacific Northwest region between 2000-2050 is 0.5°F per decade (Abatzoglou et al. 2014). By the 2080s, it is projected that the average annual temperature in the region will rise by 5.3°F relative to historical conditions from 1970 to 1999 (Mote & Salathe 2010; Wu et al. 2012). Air temperature increases during non-summer seasons are projected to occur more slowly than summer warming (Abatzoglou et al. 2014).

Temperature and precipitation extremes are projected to increase in the Northwest (Abatzoglou et al. 2014). Climate models for the region are unanimous in projecting that frequency of extreme heat events will increase and frequency of cold extremes will decrease (Dalton et al. 2013). National projections suggest that there will be more days above maximum temperature thresholds and fewer days below minimum temperature thresholds (Dalton et al. 2013). Future changes in precipitation extremes are more certain than changes in total seasonal precipitation. In the period averaged over 2041 to 2070, the number of days with greater than 1 inch of precipitation is projected to increase by 13% (+/- 7%) compared with the 1971–2000 average (Dalton et al. 2013).

Climate change contributes to and exacerbates many environmental concerns in the Pacific Northwest. A brief summary of the key concerns facing region's natural and managed systems follows:

1. changes in the timing and amount of water supply, which impacts the operation of dams, water availability for municipal and industrial use, water for crops and instream flows for fish and wildlife habitat;
2. changing crop water demand in response to increasing temperatures and atmospheric carbon dioxide;
3. water quality issues due to runoff and transport of nutrients from agriculture (dairies and fertilized crops) and industrial and urban pollutants;
4. changing geographic ranges of native and non-native species;
5. changing pest and disease pressures;
6. increased frequency and severity of wildfires;
7. air quality impacts tied to wildfires, transport of pollutants from Asia, wood smoke, diesel, and agricultural dust (Dalton et al. 2013; Allen et al. 2013; Rogers et al. 2015).

Specifics of the relationship between climate change impacts and the water cycle in the Northwest US will be discussed briefly. Columbia River basin watersheds can be classified as snowmelt dominant, rain dominant, or mixture of rain and snow dominant (Hamlet & Lettenmaier 2007). Snowmelt dominant watersheds occur are in moderate-to-high elevation inland areas where cool season (October--March) precipitation falls as snow. In snowmelt dominant the peak runoff lags behind the peak period of precipitation, since cool season precipitation is stored until springtime temperatures rise above freezing. Mountain snowpack from snowmelt watersheds supplies April--September stream flows that are important for migrating salmonids, irrigators, hydropower producers, municipalities, and other users. Rain dominant watersheds are generally in lower elevations on the west side of the Cascade Range. These watersheds receive little snowfall, and produce peak flows throughout winter. Mixed rain-snow watersheds located in mid-range elevations and receive a mix of rain and snow during the cool season. These watersheds, with average mid-winter temperatures near freezing, are sensitive to increasing temperatures, which shift winter precipitation toward more rain and less snow (Wu et al. 2012). Mixed rain-snow watersheds can experience more than one peak flow event throughout the winter and are susceptible to rain-on-snow events that can cause flooding in lowland areas (Hamlet & Lettenmaier 2007).

The distribution of these three classes of watersheds in the Columbia River basin is changing as a result of climate change (Hamlet & Lettenmaier 2007; Dalton et al. 2013). In the coming century, it is projected that there will be declines in snow dominant and snow-rain mixed dominant watersheds, and increasing rain-dominant watersheds (Dalton et al. 2013). Watersheds that shift from snowmelt dominant to mixed rain-snow dominance will experience reduced peak streamflow, increased winter flow, and reduced late summer flow. Watersheds shifting from mixed rain-snow conditions to rain dominance will experience less snow and more rain during the winter months. Under a scenario of high emissions, by the 2080s, a complete loss of snowmelt dominant basins is projected in the Columbia Basin (Dalton et al. 2013).

Summers in the Pacific Northwest region are relatively dry. The region has the lowest frequency of convective storms (storms that produce strong winds and heavy rainfall) in the contiguous United States (Mote & Salathe 2010; Chang et al. 2010). Increasing average summer temperatures and continued low summer precipitation in the region are expected to increase evapotranspiration rates (Chang et al. 2010). Combined effects of reduced snowpack leading to reduced snowmelt, low summer precipitation and high evapotranspiration have the potential to reduce stream discharge during the season of greatest water demand (Chang et al. 2010; Yorgey et al. 2011). Unregulated surface water supply at the mouth of the Columbia is projected to decrease by and average of 14.3% between June--October by the 2030s decade (Barber et al. 2012). Coinciding with this decrease in summer stream discharge is a projected 17.5% average increase in stream discharge from November-May in the 2030s due to a greater proportion of winter precipitation falling as rain (Barber et al. 2012).

Surface water temperature is determined by physical processes that cause heating or cooling according to short-term trends (hourly and daily processes) and long-term trends (annual and decadal processes) (Isaak et al. 2012). Short-wave solar radiation is the dominant warming factor in streams, but warming also occurs from long-wave atmospheric radiation, heat transfer between air and water, direct conduction from the stream bed, friction from water flow over the stream bed, and heat gains from precipitation and groundwater inputs (Isaak et al. 2012). Pacific Northwest stream temperature data from 1980–2009 were analyzed to assess trends in temperature in different categories of streams (Isaak et al. 2012). Statistically significant seasonal temperature trends were detected at all unregulated streams analyzed by Isaak et al. (2012), with a cooling trend apparent during the spring and warming trends during the summer, fall, and winter. The amount of warming observed was more than enough to compensate for spring cooling, causing a net temperature increase over the study period (Isaak et al. 2012). Increasing summertime thermal stress is expected to result in extensive range limitations for cold-water fish in the Pacific Northwest and to increase susceptibility to disease among salmonids (Wu et al. 2012; Mantua et al. 2010; Keefer et al. 2008). Earlier spring runoff caused by reductions in snowmelt will alter migration timing for salmon smolts in snowmelt-dominated streams (Mantua et al. 2010).

There is a water quality dimension in the water cycle. Water acts as a solvent, dissolving chemical compounds such as mineral salts. Dissolved and particulate substances are transported with water in the hydrological cycle (Kundzewicz 2008). The hydrologic cycle plays a major role in biogeochemical cycles of carbon, phosphorus, and nitrogen, as a solvent and a carrier (Kundzewicz 2008). Also, rivers and wetlands perform water purification functions, depositing or filtering out particulate substances (Kundzewicz 2008). Declining river flows decrease their dilution capacity, resulting in increased concentrations of effluents from point sources (van Vliet et al. 2013). Increases in water temperature lead to decreases in oxygen solubility and dissolved oxygen concentrations (van Vliet et al. 2013). Warmer waters also increase the toxicity of pollutants such as heavy metals to fish and other aquatic organisms (van Vliet et al. 2013).

Another linkage between changes in the water cycle and regional water quality arises because higher peak flows and increased wildfire activity will contribute to increased sediment and nutrient loads to rivers and streams (Chang et al. 2010). Increasing temperatures may affect the water quality in lakes and reservoirs by promoting earlier onset of thermal stratification and reducing mixing between lake layers (Dalton et al. 2013). These conditions often cause reduced oxygen levels in bottom layers and development of anoxic conditions. Finally, reduced summer flows may contribute to greater reliance on groundwater for drinking water, which could have public health implications, as groundwater is less clean than snowmelt (Kundzewicz 2008; Dalton et al. 2013). Increased recharge may also degrade groundwater quality by mobilizing salinity in soil profiles and flushing natural contaminants such as arsenic from groundwater systems (Taylor et al. 2013).

On an average year, the Pacific Northwest experiences dry conditions and some mild signs of drought, with periods of weeks with little or no rain (Bumbaco & Mote 2010). Changes in the water cycle are expected to lead to new forms of intensified drought. Bumbaco and Mote (2010) describe a range of different kinds of drought that may increase in frequency in the region: 1) low winter precipitation, yielding very low streamflow that primarily affected farmers and hydropower generation, 2) low summer precipitation and a warm winter primarily affected streamflow and forests, and 3) a lack of snowpack due to warm temperatures during significant winter precipitation events with a variety of different agricultural and hydrologic impacts (Bumbaco & Mote 2010). Understanding the role of changes in the water cycle as a driver of different kinds of drought is an important area of ongoing research in the region.

Grass-dominated prairies and oak savannas, which are adapted to periodic drought, may expand under future warmer and drier conditions. Sagebrush steppe systems, which are sensitive to precipitation patterns, may decline (Dalton et al. 2013). Expansion of invasive species, both native (such as western juniper) and non-native (such as yellow star thistle) may be facilitated by drought conditions that make them more competitive with native vegetation (Dalton et al. 2013). Forests already limited by water availability (mostly east of the Cascades) are expected to experience longer, more severe water-limitation under reduced summer and early fall precipitation, resulting in decreased tree growth. Wildfire activity in the Columbia River basin is projected to increase in response to drier summer conditions that reduce the moisture of soil and fuels (Dalton et al. 2013; Rogers et al. 2015). It is estimated that the regional area burned per year will increase by roughly 900 square miles from 1970-2000 averages by the 2040s (Dalton et al. 2013).

Results from a regional climate model simulation show large increases in the risk of floods in watersheds that are currently snow dominated from 2040-2069 relative to current risk. This is due to more extreme and earlier storms and the projected shift in precipitation from snow to rain (Salathe et al. 2014). Mixed rain-snow basins show high sensitivity to small shifts in temperature but no universal direction of change, with shifts in projected flood magnitude that range from a 30% decrease to a 30% increase (Hamlet & Lettenmaier 2007; Mantua et al. 2010). Currently, reservoir systems in the basin rely on the snowpack to act as additional water storage. Earlier snowmelt and peak flow will means that more water runs off when it is not needed for human use and that less water will be available to help satisfy early summer water demand (Dalton et al. 2013). Reservoir managers will have to confront complex tradeoffs between hydropower, irrigation, instream flow for fish, and flood control (Dalton et al. 2013). Urbanization of watersheds, tied to decreases in permeable surface area is expected to intensify flood risks associated with projected more intense precipitation events. Reductions in permeable surfaces, such as fields and woodlands, mean that vegetation and soils cannot absorb the rainfall and it flows into streams, resulting in floodwaters that rise and peak very rapidly (Dalton et al. 2013). Intense precipitation events are also expected to contribute to increases in sediment transport to streams (Dalton et al. 2013).

At the Columbia Basin scale in the 2030s water supply is projected to be sufficient to meet demands. However, at smaller watershed scales during some times of the year, for example in summer in in the Yakima basin, water supply is projected to be insufficient to meet demands (Vano et al. 2010; Yorgey et al. 2011). Linked models of cropping systems and hydrologic systems indicate that in the context of projected declines in summer water availability caused by reduce snowpack there may be extensive economic consequences for irrigated agriculture in the Columbia River basin (Barber et al. 2012). Farmers in some areas of the basin may be able to reduce losses by reducing production or shifting crops. However, earlier loss of snow cover and projected increases in the annual frost-free days in the region could increase the length of the growing season, thus increasing agricultural water demand (Yorgey et al. 2011). Irrigated crops and natural vegetation are likely to have higher evapotranspiration rates in the context of projected climate change, and thus will need more water (Yorgey et al. 2011).

Complex interactions between natural resource management policies and practices, regional development and climate change require ongoing scientific investigation (Dalton et al. 2013; Rogers et al. 2015). A wide range of Northwest US management decisions related to water rights, water storage infrastructure, nutrient management, cropping systems and tillage, rangeland management, timber harvesting, and wildfire management have potential to be informed by scientific understanding of the intersecting effects of regional decision-making and future climate change impacts (Rasmussen et al. 1998; Dalton et al. 2013; Rogers et al. 2015).

2.8 Regional earth systems modeling initiatives

BioEarth is a large collaborative 5-year project funded by the US Department of

Agriculture, National Institute of Food and Agriculture (2011-67003-30346). This project aims to develop an earth systems model that addresses climate change impacts on agriculture and forestry. The research will investigate climatic and anthropogenic impacts on nutrient cycling, water resources and air quality in the Columbia River basin and in the U.S. Pacific Northwest region as a whole. BioEarth is among a new generation of large environmental change research projects that is transdisciplinary and integrates stakeholder engagement as a key aspect of the proposed research plan (Godin & Gingras 2000; Cummings & Kiesler 2005).

The BioEarth research team comprises individuals from the disciplines of atmospheric sciences, biogeochemistry, agricultural sciences, hydrology, aquatic chemistry, economics, and environmental communication. These researchers are arranged within five working groups: modeling, cyberinfrastructure, economics, ecology and communication. The communication working group is tasked with developing mechanisms for interactive communication between model developers and practitioners throughout the project, including workshops, meetings, and a virtual Internet forum. A related objective of the communication team is to analyze the perceptions and understandings of stakeholders and scientists throughout the research process using surveys and interviews to track the evolution of perceptions of the stakeholder engagement process and of the utility and relevance of the model to decision-making.

The initial BioEarth project proposal described a plan for bi-directional communication to enable stakeholders to influence the research questions that are addressed within the model development process. A series of advisory workshops are to be conducted throughout the 5-year project with stakeholders from the agriculture and forestry sectors of the Pacific Northwest. With facilitation from experienced extension faculty on the communication team, project modelers will engage directly with stakeholders from a diverse array of government and industry groups in discussions of the model development process. Enhancing the relevance and utility of the BioEarth model within the forestry and agricultural sectors is an objective of these interactions between modelers and stakeholders.

As is typical of large transdisciplinary research projects conducted at universities, the BioEarth research team was assembled based on previously established working relationships among PIs and brought in individuals from other institutions and disciplines based on their known areas of research expertise. The collaboratively written proposal was tailored for a joint National Science Foundation -US Department of Agriculture National Institute of Food and Agriculture regional earth systems modeling funding opportunity. Stakeholder engagement and associated communication research was a critical and substantial part of the funded research proposal. Project communication is facilitated through four mechanisms: working groups meet regularly; monthly integration meetings provide an opportunity for cross-working group communication; the full research team of PIs and graduate students (from four different universities and two government research institutions) meets twice a year to share progress and make decisions about overall project direction; and an all-project email list-serve is used to update researchers on project progress.

The Watershed Integrated System Dynamics Modeling Project (WISDM) is also based at WSU and involves many of the scientists who are working to develop the BioEarth model. WISDM focuses on applying technical information from the integrated and computationally intensive process based BioEarth model into a user-friendly system dynamics model through collaborative modeling. The collaborative modeling process will work iteratively with stakeholders to create web-based simulation models of issues relevant to urban and agricultural systems in the Spokane and Yakima River Basins. Scenarios and interfaces are designed with stakeholders to ensure that information is relevant to specific stakeholder needs and questions. The overall goal for this program is to improve understanding of interactions between water resources, water quality, climate change, and human behavior in agricultural and urban environments, including exploring how primary water users can be involved in the research process to develop scientifically sound and economically feasible public policy. The approach is process-oriented in the sense that model scope and content is seen as dependent on the needs and interests of project stakeholders. Model structure and features were not decided upon when the process began. WISDM is designed to cconsider how changes in demand and supply-side economic conditions and climate change affect water use across space and time, and to consider how regulatory institutions may adapt as water becomes increasingly scarce.

The WISDM team involves 13 core PIs. The leadership structure is similar to the BioEarth project, and has changed over time as faculty move into new roles and new graduate students engage in the research. Compared to the BioEarth project structure working groups are somewhat less well defined, but there is a general structure of an economics working group, collaborative system dynamics modeling, and a hydrologic and terrestrial modeling group. The lead PI's approach tends to be to encourage groups to work independently with full-group or integrated activities and meetings arising organically as researchers have issues or questions to discuss, there is a less formal integration structure than in either REACCH or BioEarth.

The Regional Approaches to Climate Change and Agriculture (REACCH) project is funded by a USDA grant and is based at the University of Idaho. REACCH's mission is to improve the long-term profitability of the cereal production systems in the Pacific Northwest. REACCH includes efforts in research, extension, and education that integrate diverse elements including climate and cropping systems modeling, economics and agriculture, protection, and others in a transdisciplinary manner. REACCH uses computer simulations to explore possible impacts of climate change, changes and farming practices, and changes in economic conditions and policies, on the economic, environmental and social sustainability of agricultural systems in the region.

REACCH is larger than either BioEarth or WISDM in terms of the team size and budget, with 26 designated co-PIs and many affiliated researchers. There are seven objective teams: GHG monitoring, cropping systems, socio-economic, pests, weeds, pathogens, education, extension, integrated modeling, cyberinfrastructure as well as also groups focused on agro-ecological zones and life cycle analysis. Within REACCH the approach to stakeholder engagement is conceived of as being an advisory process, more oriented on the product of model scenarios than the process of an iterative conversation with regional stakeholders. The team is developing Regional Agricultural Pathways (RAPs), which describe future scenarios of social, economic and technological changes. Stakeholder input and comments are being sought, but the primary focus is on making those scenarios cohesive and compelling from an academic science perspective.

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CHAPTER THREE: DIVERSE PERCEPTIONS OF STAKEHOLDER ENGAGEMENT IN AN ENVIRONMENTAL MODELING TEAM

3.1 Introduction

A growing sense of urgency in addressing sustainability challenges is leading to increased motivation for environmental scientists to justify the societal influence of their research (Backstrand 2003; van Kerkhoff and Lebel 2006). Scientists are increasingly asked to consider not only the scientific credibility and adequacy of their work, but also its salience to the needs of the public and its legitimacy among stakeholders beyond their scientific peers (Cash et al. 2003). Stakeholder engagement is often conceptualized as communication of research results after the project is complete (Green et al. 2009), although the value of engaging with stakeholders during the knowledge production process is increasingly recognized (Callon 1999; Phillipson et al. 2012).

Coinciding with efforts to strengthen linkages between knowledge and action in environmental research (Kates et al. 2001; Stephens and Graham 2008), is the promotion of transdisciplinarity, an approach characterized by partnerships that cross boundaries among fields of research and modes of inquiry and between academic and non-academic actors (Kates 2002; Wainwright 2010). Most definitions of transdisciplinarity articulate an explicit incorporation of knowledge and goals of stakeholders that includes processes of mutual learning between science and society (Scholz et al. 2000). As increasing numbers of large transdisciplinary research projects involving engagement with stakeholders (Stephens and Graham 2010) are encouraged and supported, multiple anticipated and unanticipated challenges and opportunities for learning are emerging (Romsdahl and Pyke 2009).

With regard to climate change research, a “usability gap” has been identified; fostering new types of interactions between researchers and potential “users” of knowledge has been suggested as a way to narrow the gap between what scientists understand as useful and what decision-makers consider usable (Lemos et al. 2012). As research institutions and scientists respond to the call to generate usable research, many questions and uncertainties related to effective strategies for stakeholder engagement are emerging. These questions include: How should communication be structured? And, what approaches maximize mutual understanding and appreciation for different kinds of knowledge? (Cash et al. 2003).

A diversity of approaches to involving non-academic stakeholders in academic research has emerged. These approaches involve different types of researcher-stakeholder interactions and different potential for co-production of knowledge (Stephens et al. 2008; Voinov and Bousquet 2010; Palmer 2012). Participatory research has been defined as any research that integrates stakeholder knowledge into the research process (Blackstock et al. 2007). Participatory Action Research (PAR) is one evolving approach with a long history that entails researchers’ and stakeholders’ active engagement as members of a knowledge production collective focused on effecting social change (Greenwood et al. 1993; Kindon et al. 2008; Smith et al. 2010). Related approaches include knowledge co-operatives and competency groups involving researchers and local communities

(Phillipson et al. 2012). Another approach, increasingly applied in environmental problem solving, is group-based system dynamics modeling, variations of which include collaborative, participatory, and mediated modeling (van den Belt 2004; Antunes et al. 2006; Gaddis et al. 2007; Prell 2007; Becu et al. 2008). The process helps stakeholders understand connections and causal relationships between aspects of the human-ecological system being studied and has been applied in contexts of watershed planning and managing habitat for endangered species, for example (Beall and Ford 2010, Beall et al. 2011).

Among these multiple different approaches to stakeholder engagement, some research has reflected on the quality and type of interactions between researchers and stakeholders (Becu et al. 2008; Clavisi et al. 2013; Gourmelon et al. 2013). Within this work on researcher-stakeholder interactions, a limited amount of attention has been paid to researchers' perceptions of the value of the stakeholder interactions (Reed et al. 2009; Romsdahl and Pyke 2009).

Models have been referred to as "boundary objects" as they enable joint collaborative knowledge production by experts and decision-makers (Cash et al. 2003), and they have potential to provide "useful" tools that can play a translational role in communicating knowledge to stakeholders. Model development involves determining types and structure of both input and output information, and stakeholder engagement during, rather than after, the model design process has potential to enhance the salience and legitimacy of the model (Phillipson et al. 2012).

In the case of a process-based earth system model, development begins with a mechanistic representation of parts of the system as they change over time and then integrates human dimensions of the system after other model components have been linked (Bernholdt et al. 2005). The proposed stakeholder engagement approach for the process-based regional earth system modeling project in this study includes iterative meetings with diverse stakeholders who provide insights, guidance and feedback to the modeling team.

As stakeholder engagement in earth systems modeling becomes more frequently expected, understanding the range of researchers' perceptions of stakeholders and attitudes about the value of their engagement could help facilitate productive interactions. This paper reports on a study of scientists' perspectives on stakeholder engagement in the first year of a large and complex 5-year integrated modeling project addressing climate impacts on water and nutrient cycling in the Columbia River Basin. The modelers involved in this project are aware of plans for stakeholder engagement, but during the first year the mechanisms for this engagement are still evolving. Analysis of surveys and interviews conducted with researchers provides insights about breadth and variation of perspectives on the value of engaging with stakeholders. The paper begins with a review of research on stakeholder engagement and environmental modeling and background on the BioEarth project. Methods are then described, followed by a discussion of the results, and a concluding assessment of the implications of this study for transdisciplinary research projects that seek to address sustainability challenges by integrating technical academic modeling with close engagement with stakeholders.

3.2 Background

3.2.a Environmental Modeling

Modeling is a unique mode of inquiry. It has been suggested by some philosophers of science that modeling as a form of knowledge production is qualitatively different from experimental science, although the two modes of study often work in conjunction with one another (Frigg & Hartmann 2012). There are several forms of scientific models including: metaphors that explain abstract principles with concrete imagery, systems models which visually and/or mathematically represent system interactions, and process models which simulate change over space and time (Frigg & Hartmann 2012). While models need not be characterized as "fictions", scientific models should be approached with caution and awareness of inherent limitations, uncertainties, and simplifications (Frigg & Hartman 2012, Sterman 2002).

Earth systems models are a subset of process-based environmental models that use high-powered computing to simulate atmospheric, hydrological, and terrestrial processes over space and time and incorporate feedbacks among interrelated systems (Bernholdt et al. 2005). Since the late 1980s, earth system models have been employed to assess potential impacts of anthropogenic climate change on crop productivity and various other specific activities critical to society, but there is a recognized need to further develop earth systems models to enable better prediction of risks, to inform adaptation strategies for managing risk and to reflect growing understanding of climate-nutrient-crop dynamics (Rotter et al. 2011). A new generation of sophisticated earth system models employ economic modeling in conjunction with atmospheric and terrestrial process modeling, improving the ability of models to represent policy alternatives (Shackley and Deanwood 2003; Prinn 2012). To promote decision-making relevance, it is acknowledged that additional experimental testing of model outputs and enhanced regional specificity are needed (Rotter et al. 2011).

3.2.b Transdisciplinarity, sustainability science and large collaborative projects

As the complexity and interconnections among human-environment systems are recognized, funding agencies have been increasingly promoting and encouraging large collaborative research projects that are "transdisciplinary", crossing disciplinary and professional boundaries to integrate multiple different kinds of knowledge. The high degree of uncertainty associated with future environmental changes and societal responses to those changes results in a multiplicity of perspectives on how to adapt to and prepare for environmental change. While this breadth of perspectives allows for a diversity of strategies and priorities to be proposed and considered, this breadth also creates challenges for researchers seeking to integrate different perspectives in their work (Bucchi and Neresini 2008). There is a widely acknowledged need within academic institutions to build capacity to network and exchange information with representatives from government, industry, special interest groups and communities (Backstrand 2003; Cross and Smith 2007). The trending interest in science-based stakeholder dialogues has been partly driven by researchers themselves, but also brought about to a great extent by funding agencies and the general public's demand for greater accountability in science (Welp et al. 2006). To date, stakeholder engagement initiatives do not seem to be achieving their full potential of simultaneously informing research processes and improving decision support tools available to stakeholders (Wynne 1994; Holmes and Clark 2008; Voinov and Gaddis 2008). Additional attention to effective stakeholder interactions in environmental research is fundamental to narrowing the gap between useful and usable knowledge (Lemos et al. 2012).

Within large transdisciplinary projects, communication challenges among researchers from diverse disciplines must be acknowledged alongside the challenges associated with effective communication between researchers and non-academic stakeholders. Previous research has demonstrated that effectiveness of collaborative research involving academics from different disciplines is greatly enhanced by the development of shared concerns and objectives to motivate the effort, and the cultivation of an atmosphere of openness to new approaches and innovative modes of problem solving (Lélé and Norgaard 2005). In addition, improved understanding of the attitudes, assumptions, and objectives of the researchers from different backgrounds may help in the effective design and structuring of stakeholder engagement efforts.

Among recent changes in science toward increasingly collaborative and interdisciplinary approaches to research, calls for new ways of conceptualizing stakeholder engagement have encouraged actionable science with its focus on stakeholders' needs and interests (Palmer 2012). In addition, sustainability science, an emerging academic area that internalizes the link between knowledge and action and is defined by the problems it addresses rather than by the disciplines it employs, is expanding and influencing perceptions of the value of engagement in research (Kates et al. 2001; Clark 2007; Kajikawa 2008).

Within environmental model-based research, which has a goal of understanding complex environmental change and human-earth systems feedback processes, a paradox exists. To adequately represent the diversity and complexity of the dynamics of the earth's systems the research must involve people with diverse expertise. Yet as the complexity of model outputs increases, the pool of individuals who can interpret those findings decreases. A high level of technical expertise is necessary to understand complex models and to promote the application or usability of that research to decision-making.

3.2.c Stakeholder engagement

A stakeholder is generally defined as a person or a group who has an interest in an issue, policy, company, or other entity (Welp et al. 2006). The concept originates from business and management literature where a distinction is made between shareholders, or those who own the company, and stakeholders, those individuals or groups who are impacted by business activities or can influence the business environment (Welp et al. 2006). In part because there are many ways to define who the stakeholders are for any given research process, there are many possible varieties of stakeholder participation in science (Bucchi and Neresini 2008). Potential roles of stakeholder in research are varied and can include anything from identifying research questions; sharing values, preferences, expectations and perceptions of risk; providing quantitative data or local expertise; commenting on research concepts, drafts and results; learning from the research process; and/or integrating research findings into decision making processes.

Cooperative extension programs designed to connect university research with agriculture have a long history of effective stakeholder engagement work connecting local decision makers and resource managers with academic research (Bull et al. 2004). A current debate within the extension system focuses on whether the traditional communication strategies and programmatic mission of university extension services are viable in the modern context (Kalambokidis 2004; McDowell 2004; Franz and Cox 2012). Many factors have contributed to a diminished role of these extension programs including decreased funding, the changing landscape of American livelihoods, and new modes of communication and information exchange than render some of extension's traditional knowledge development and information sharing methods outdated (Kalambokidis 2004; Franz and Cox 2012).

Study of the perceptions and attitudes surrounding stakeholder engagement processes in current cutting-edge environmental science is in part an effort to re-envision traditional extension methodologies used by land-grant universities to bridge the academic and public and private decision-making spheres. Given the sustainability challenges facing the world, it is appropriate that academic institutions cultivate new opportunities to influence society by enhancing the quality of interactions with industry, government, and the non-profit sector (Probst et al. 2003). The possible mechanisms for enhanced linkages between academia and decision-makers at different levels are varied, but include, for example, engagement in policy-making, non-formal education, community development and planning, and technology assistance (Probst et al. 2003; McDowell 2004). Engagement of stakeholders external to academia is fundamental to many conceptions of transdisciplinarity (Scholz et al. 2000). As funding agencies and research bodies increasingly seek transdisciplinary approaches and require stakeholder engagement, learning from and expanding upon the approaches pioneered by extension services could be increasingly valuable.

The majority of case studies of stakeholder engagement in environmental research focus on decision making processes and highlight the role of stakeholders in interpreting scientific results and making resource management decisions on the basis of data and models (Shackley and Deanwood 2003; Dougill et al. 2006; Cash 2000). Under the rubric of "stakeholder engagement" a smaller body of work explores the role of non-academic stakeholders in framing research questions and actively participating in the development of new scientific and technical knowledge (Grimble and Wellard 1997; Hare et al. 2003; Welp et al. 2006; McNie et al. 2007; Prell 2007; Voinov and Gaddis 2008). A recent evaluation of the US NOAA's (National Oceanic and Atmospheric Administration) Regional Integrated Sciences and Assessments (RISA) programs, which are designed to produce useful information about climate for decision support, considers multiple aspects as critical to program effectiveness including identifying stakeholders' information needs, translating and communicating knowledge, situating social capital and building users' capacity to interpret and apply research findings, and establishing a flexible organization with strong leadership (McNie 2012).

There are few published accounts of researchers' reflections on stakeholder participation processes, yet several case-study reports focusing on stakeholder engagement in environmental research contain some discussion of scientists' attitudes about the process (Becu et al. 2008; Gardner et al. 2009; Prell et al. 2009; Reed et al. 2009; Romsdahl and Pyke 2009). It is clear that taking a participatory approach to model development provides both refreshing new perspectives as well as some frustrations for scientists (Reed et al. 2009; Romsdahl and Pyke 2009). Gardener et al. (2009) note that biophysical modeling cannot progress until the key issues of concern to be addressed emerge from the participatory process. And clearly it can be an unfamiliar experience for scientists to begin a project without knowing exactly what parameters will be modeled.

3.2.d BioEarth

BioEarth is a large collaborative 5-year project funded by the US Department of Agriculture, National Institute of Food and Agriculture (2011-67003-30346). This project aims to develop an earth systems model that addresses climate change impacts on agriculture and forestry. The research will investigate climatic and anthropogenic impacts on nutrient cycling, water resources and air quality in the Columbia River basin and in the U.S. Pacific Northwest region as a whole. BioEarth is among a new generation of large environmental change research projects that is transdisciplinary and integrates stakeholder engagement as a key aspect of the proposed research plan (Godin and Gingras 2000; Cummings and Kiesler 2005).

The BioEarth research team comprises individuals from the disciplines of atmospheric sciences, biogeochemistry, agricultural sciences, hydrology, aquatic chemistry, economics, and environmental communication. These researchers are arranged within five working groups: modeling, cyberinfrastructure, economics, ecology and communication. The communication working group is tasked with developing mechanisms for interactive communication between model developers and practitioners throughout the project, including workshops, meetings, and a virtual Internet forum. A related objective of the communication working group is to analyze the perceptions and understandings of stakeholders and scientists throughout the research process using surveys and interviews to track the evolution of perceptions of the stakeholder engagement process and of the utility and relevance of the model to decision-making. This paper reports on the results of one component of this participatory action research conducted by the communication group researchers.

The initial BioEarth project proposal described a plan for bi-directional communication to enable stakeholders to influence the research questions that are addressed within the model development process. A series of advisory workshops are to be conducted throughout the 5-year project with stakeholders from the agriculture and forestry sectors of the Pacific Northwest. With facilitation from experienced extension faculty on the communication team, project modelers will engage directly with stakeholders from a diverse array of government and industry groups in discussions of the model development process. Enhancing the relevance and utility of the BioEarth model within the forestry and agricultural sectors is an objective of these interactions between modelers and stakeholders.

As is typical of large transdisciplinary research projects conducted at universities, the BioEarth research team was assembled based on previously established working relationships among PIs and brought in individuals from other institutions and disciplines based on their known areas of research expertise. The collaboratively written proposal was tailored for a joint National Science Foundation (NSF)-US Department of Agriculture (USDA) regional earth systems modeling funding opportunity. Stakeholder engagement and associated communication research was a critical and substantial part of the funded research proposal. Project communication is facilitated through four mechanisms: working groups meet regularly; monthly integration meetings provide an opportunity for cross-working group communication; the full research team of PIs and graduate students (from four different universities and two government research institutions) meets twice a year to share progress and make decisions about overall project direction; and an all-project email list-serve is used to update researchers on project progress.

This research focused on understanding BioEarth researchers' initial perceptions of stakeholder engagement. It will inform the design of information exchange mechanisms between researchers and stakeholders and will assist in anticipating communication challenges and preparing engagement strategies. While the research presented here focuses on understanding researchers' perceptions of stakeholder engagement during the initial phase of the project subsequent research will assess the changing perceptions of both stakeholders and researchers throughout the duration of the project. The results of this research may contribute to preventing potential stumbling blocks associated with environmental science research that emphasizes transdisciplinary collaboration and a sustainability solutions orientation.

3.3 Methods

To assess researchers' perceptions of stakeholder engagement in this collaborative earth systems modeling project, a participatory action research approach was developed and carried out by the communication team. This study involved a brief questionnaire and a 30-45 minute semi-structured interview which was conducted by a Ph.D. student who is a part of the BioEarth communication team with each of the eighteen Principal Investigators (PIs) of the BioEarth project. The questionnaire, administered online, was used to obtain baseline information about BioEarth researchers' previous experiences and attitudes related to stakeholder engagement. Five simple Likert-scale (ranking) questions allowed for responses to be tabulated numerically and represented graphically. The questionnaire asked the PIs to self-report their frequency of interacting with stakeholders, level of satisfaction with previous stakeholder interactions, and perceptions about the importance of engaging various stakeholder groups at various phases of this project.

Following the questionnaire, interviews were scheduled with each of the PIs to obtain more in-depth information about perceptions of stakeholder engagement. During the interviews, each PI was asked to describe how they envisioned successful research outcomes for the project and how they perceived potential challenges, particularly challenges related to communication and stakeholder engagement.

Analysis of the interview transcripts emphasized understanding the range of researchers' perspectives. Coding of the interview transcripts was accomplished through the use of QSR International's NVivo 8.0™ qualitative software. The coding scheme was developed to assess PIs' perspectives on a series of overlapping topics including project challenges, communication pathways, goals, expectations, utility, novelty, stakeholder definitions, stakeholder buy-in, and timing. Within the coded text, three key themes emerged: goals and expectations, definitions of stakeholders, and project challenges. Analysis included clustering of similar PI responses related to these themes.

3.4 Results and Discussion

This section describes the professional diversity within the BioEarth research team, and then reports the survey results, followed by a discussion of the interview results.

3.4.a BioEarth Research Team Demographics

Among the eighteen PIs a diversity of professional roles are represented (Table 1). PIs have varying levels of previous experience with integrated biogeochemical modeling and stakeholder engagement. The BioEarth research initiative is composed of four working groups (some PIs are part of more than one working group): modeling (ten individuals); cyberinfrastructure (three individuals); economics (three individuals); ecology (three individuals); communications (four individuals). Three of the PIs are assistant or associate professors at partner universities other than WSU, and two of the PIs are affiliated with government research laboratories not based at universities. The remaining eleven PIs are WSU professors: eight are associate, assistant, or research professors; three of the WSU-based PIs are full professors and/or department heads (Table 3.1).

Table 3.1 *BioEarth Principal Investigators' Professional Backgrounds*

Sector	Institution	Faculty Position	No. PIs
Academia	Washington State University. Note: At Washington State University, 4 PIs have an Extension appointment that accounts for a range from 15-100% of the faculty member's total work responsibilities.	Full Professor	3
		Associate/Assistant Professor or Assistant Research Professor	10
	Clark University		1
	University of California Santa Barbara		1
	Oregon State University		1
Government	Battelle Pacific Northwest Laboratory		1
	National Center for Atmospheric Research		1

Five of the PIs are women and thirteen are men. Although gender was not explicitly considered in the analysis of researchers' perceptions in this study, the role of gender in interdisciplinary research, collaborative science, and stakeholder engagement is deserving of additional study. Recent research on the learning styles, work preferences and career behaviors associated with interdisciplinary research explores whether women may be more drawn to interdisciplinary research than men (Rhoten and Pfirman 2007). Future analysis could focus on the gender dynamics within the BioEarth project.

3.4.b Survey Results

The survey provided quantitative data about five topics: (1) researchers' frequency of interaction with stakeholders in their previous work; (2) researchers' satisfaction with previous stakeholder interactions; (3) number of interactions with stakeholders in the first year of the research project; (4) assessments of the value of engaging various kinds of stakeholders; and, (5) assessments of the potential for successful stakeholder engagement at different phases of the project.

BioEarth PIs have varying levels of experience with stakeholder engagement; half of the eighteen PIs reported occasionally working with stakeholders on other projects, five members of the research team have previously worked with stakeholders frequently or always, and three members of the research team reported rare or no previous work with stakeholders (Figure 3.1a).

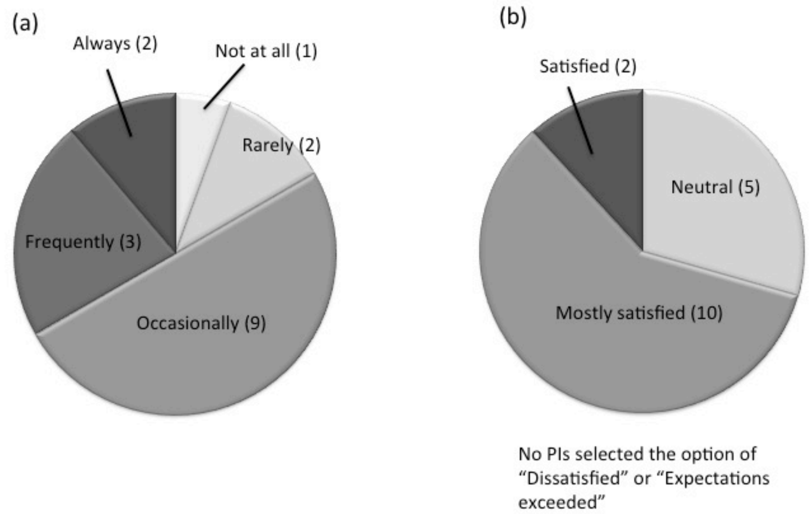

Figure 3.1 Previous experiences with stakeholder engagement from survey responses. *(a) frequency of researchers' previous interactions with stakeholders; (b) researchers' level of reported satisfaction in their interactions with stakeholders in previous research projects.*

Reported satisfaction about previous stakeholder interactions emphasized the middle ground; neither dissatisfaction nor having expectations exceeded were reported. Ten PIs reported that they were mostly satisfied, five reported that they felt neutral, neither satisfied nor dissatisfied with the process, and two responded that previous experiences with stakeholder engagement had been satisfactory (Figure 3.1b). One PI did not answer the question due to having no prior experiences with stakeholder engagement.

The survey results demonstrate variation in perceptions among PIs of the importance of different stakeholder groups to the overall success of the project (Figure 3.2). When each PI was asked to rank the level of importance (on a scale from 1-5 with 1 being low importance and 5 being high) of five specific types of predefined stakeholder groups (academia, advocacy, public, government and industry), the academic stakeholders were deemed the most important. Eleven of the eighteen PIs assigned the academic stakeholders an importance score of 5. Government and industry stakeholders were judged to be of relatively high importance for project success as well; the majority of PIs assigned a score of 4 or 5 to these categories. Advocacy groups such as NGOs and the general public were viewed by many BioEarth PIs as not important to the success of the project. These two stakeholder categories also show the greatest range in importance values assigned, indicating divergent views within the research team.

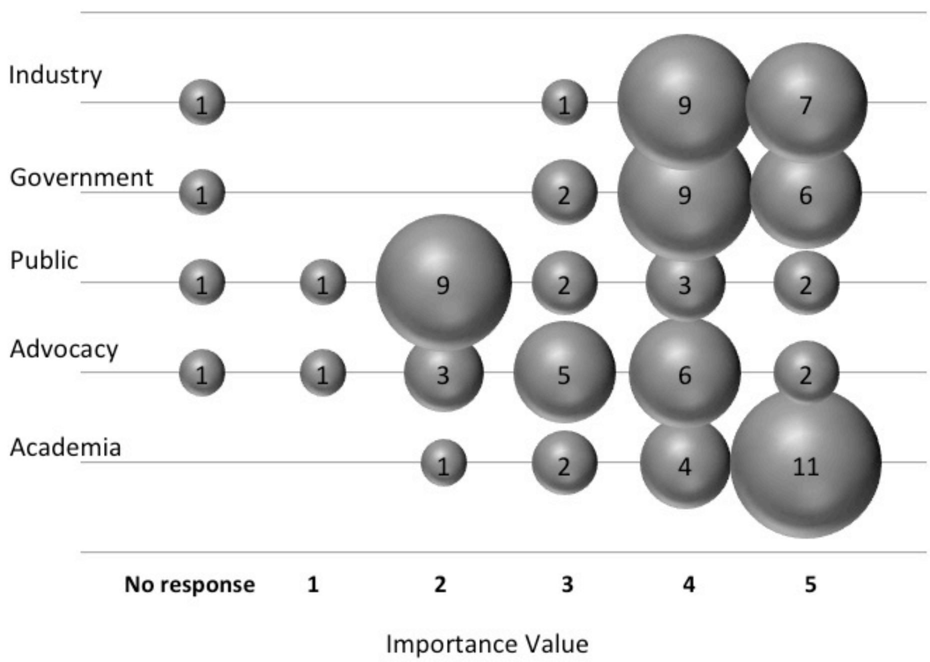

Figure 3.2 Perceived importance of engaging various stakeholder groups.
Five categories of stakeholder groups were presented and the eighteen co-PIs were asked to assign an importance score to each of five categories of potential stakeholder groups. A score of "5" represents critical importance to overall success of the project and a score of "1" represents no importance. The size of each circle represents the number of PIs who selected a given importance score for each stakeholder group.

When PIs were asked to assess the importance of stakeholder engagement at different phases within the five-year project, survey results show a general consensus that engagement in the middle years and at the end of the project was deemed most important for overall project success (Figure 3.3). Perceptions about the value of stakeholder engagement in the early phases of model development (year 1) were highly variable with a relatively even distribution of perceptions for each value score from 1 to 5.

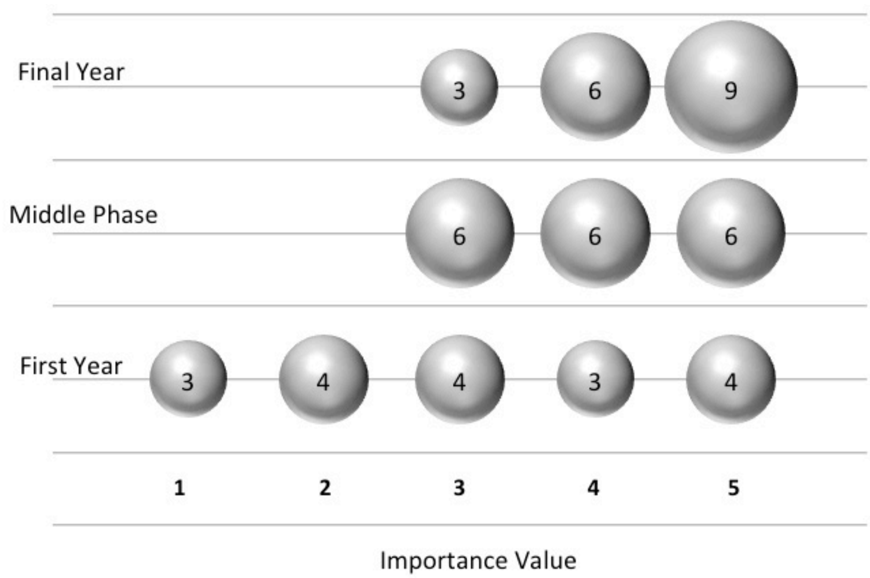

Figure 3.3 Perceived importance of stakeholder engagement at different phases of the project. *Survey respondents were asked to assign each of three discrete phases of the project an importance score with"5" representing critical importance to overall success of the project and "1" representing no importance. The size of each circle represents the number of PIs who selected a given importance score.*

3.4.c Interview Results

The results of the interviews reveal considerable variation in BioEarth researchers' definitions of project success, perceptions of stakeholder identities, and assumptions of likely project challenges (Figure 3.4). To represent the range of PIs' responses, circles sized to represent the number of PIs in each emergent cluster have been placed on a spectrum (Figure 3.4). With regard to project success, responses were distributed on a spectrum with one side representing definitions focused solely on technical capabilities and contributions to scientific knowledge and the other side representing definitions focused on the effective utilization of the model to informing management decisions (Figure 3.4a). With regard to the question of who are the stakeholders for this project, responses were distributed on a spectrum with one side representing a narrow definition focused on academic stakeholders and the other side representing broader definitions that included more general audiences (Figure 3.4b). With regard to the project's primary challenges, responses were distributed on a spectrum with one side representing responses focused on technical model integration issues and the other side representing challenges associated with communication and stakeholder engagement. Ten of the eighteen researchers highlighted challenges in both of these areas (Figure 3.4c).

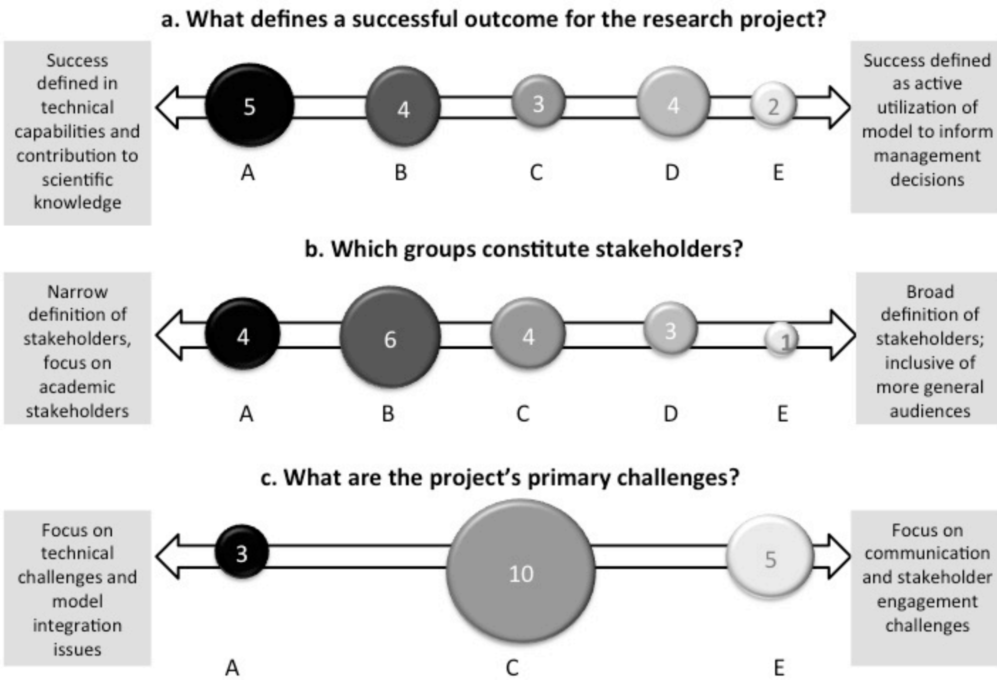

Figure 3.4 Continuum of researcher perceptions on 3 key thematic questions. *(a) What defines a successful outcome for the project? (b) What groups are stakeholders? and (c) What are primary challenges of the project? The circle size represents the number of PIs whose interview transcripts revealed answers clustering in specific places on the continuum.*

Trends in the placement of each PI's perceptions on the three continuums displayed in Figure 3.4 are apparent, such that respondents on the left of one of these continuums are likely to have a similar leftward placement on the two other continuums. PIs with a vision of project success focused on increasing technical modeling capabilities were likely to define members of academia as primary project stakeholders and focus their discussion of challenges on technical issues of model integration. PIs who related project success to model application by stakeholders in a decision-making capacity tended to define stakeholders more broadly and focus primarily on challenges associated with communication.

Table 3.2 represents each project PI's role within the project, their level of previous experience with stakeholder engagement in research projects, and the clusters that they were placed in along each of the three continuums (Clusters A and B are on the left, C is in the middle and clusters D and E are on the right side of the spectrums in Figure 3.4). This table demonstrates that researchers in the modeling working group tend to focus on technical outcomes when considering project success while the communication researchers prioritize decision-making utility for project success. Those with prior experience with stakeholders tend to be clustered in groups D and E for all categories.

Table 3.2 *PIs' Previous Experience with Stakeholder Engagement and Position on 3 Continuums*

Working Group Affiliation(s)	SURVEY		INTERVIEW CONTINUUMS		
	Frequency of previous stakeholder interaction	Satisfaction with previous stakeholder interactions	(a) perception of a successful project outcome	(b) perception of who stake-holders are	(c) perception of challenges
Communications	Always	Satisfied	E	B	E
Communications	Always	Neutral	D	D	E
Communications	Frequently	Satisfied	E	D	E
Economics	Frequently	Mostly satisfied	C	D	C
Modeling, Communications, Cyberinfrastructure	Frequently	Mostly satisfied	C	C	E
Modeling, Cyberinfrastructure	Frequently	Mostly Satisfied	D	E	C
Cyberinfrastructure	Occasionally	Mostly satisfied	A	A	C
Ecology	Occasionally	Neutral	B	A	C
Ecology, Modeling	Occasionally	Mostly satisfied	D	C	E
Economics	Occasionally	Neutral	B	C	C
Modeling	Occasionally	Mostly satisfied	A	B	C
Modeling	Occasionally	Mostly satisfied	A	B	C
Modeling	Occasionally	Mostly satisfied	A	A	C
Modeling	Occasionally	Mostly satisfied	A	B	A
Modeling, Ecology	Occasionally	Mostly satisfied	D	A	C
Economics	Rarely	Neutral	B	B	A
Modeling	Rarely	Neutral	C	C	C
Modeling	Not at all	N/A	B	B	A

3.4.c.1 Diversity of Visions of Project Success within the Research Team

Perceptions among BioEarth PIs of what would constitute success of the project have been divided into five categories along a continuum of those who prioritize the technical and scientific contributions on one end and those who prioritize the influence of the model on management decisions on the other (Figure 3.4a). Cluster A represents five of the eighteen PIs involved in the project who were strongly focused on benchmarks of success related to technical capabilities of the model, four PIs (cluster B) were focused in this direction but less strongly, three had a balance between these two viewpoints (cluster C), four prioritized influence on management decisions to some degree (cluster D), and only two PIs (cluster E) felt strongly that project success depended entirely on the ability of the model to influence management and policy decisions (Figure 3.4a). It should be noted that the PIs on the communication team are included in this analysis, and because of the nature of their role in the research project, these individuals are likely to be more concerned with stakeholder engagement than the other PIs.

The following interview excerpts exemplify the viewpoint that project success will be defined by new scientific understanding and enhanced technical capabilities without the expectation that the model will be relevant to non-academic stakeholders:

> "*We're developing a research framework… the model is not going to answer very specific questions. It's not going to tell you what's going to happen in the future" (co-PI 13).*

"The number of people who will actually be able to use the model is a pretty small number" (co-PI 5).

The PIs whose definition of success focused on technical integration of model components were generally interested in the model as a tool which would be refined in future research initiatives and modified for application in other settings. This group of respondents generally did not expect the model to contribute significantly to stakeholders' knowledge about regional climatic, ecological, or economic conditions nor did they expect the model to play an important role in discussions of natural resources policy. The quotation above (PI_13) also highlights concern regarding perceptions of how a regional-scale model can be useful to stakeholders making decisions at a local level. While regional scale information can inform decision-making at multiple levels, this researcher is demonstrating recognition that decision-makers may not be in a position to effectively utilize regional-scale information.

The six PIs in clusters D and E on continuum 3.4a focused their description of project success on the vision that stakeholders would use the model to support decision-making. The PIs who considered stakeholder participation and application of the model as critical benchmarks of success do not have homogenous views of who the project stakeholders are and at what point in the research process stakeholder engagement is most valuable. These researchers, who were clustered toward the end of the continuum focused on "informing management decisions", did all mention the need for simplification and clear communication of elements of the research in order for it to be accessible to non-specialists.

Regardless of how co-PIs defined a successful outcome for the BioEarth project, all participants recognized that this integrated regional modeling effort represents new and exciting research and that this project is likely to lead to other more sophisticated models in the future.

3.4.c.2 Concepts of stakeholder identities

Paralleling the diversity of opinions about what a successful project would look like, a spectrum of perspectives about how broadly “stakeholders” should be defined in the context of the BioEarth project was evident (Figure 3.4b). Four PIs (cluster A) expressed a narrow definition of project stakeholders; these participants identified academia as the sphere in which knowledge generated by BioEarth would be relevant. Six PIs (cluster B) expected that the research would be of interest to a small circle of academics and decision makers within government agencies already familiar with earth systems modeling. Four PIs (cluster C) had an intermediate viewpoint of how broadly project stakeholders should be defined, mentioning that industry, government and academia were the probable participants in the stakeholder engagement process. Three PIs (cluster D) broadened their list of potential stakeholders to include anyone who makes land management decisions in the region and NGOs interested in natural resources policy. At the far right end of the continuum, one PI (cluster E) defined potential stakeholders very broadly, suggesting that anyone living in the region of study should be regarded as a potential stakeholder.

Six participants mentioned that academics and non-academics outside the project are two distinct groups that require different strategies for engagement and information sharing. Individual PIs characterize and prioritize the involvement of these two groups ('academic stakeholders' and 'other stakeholders') differently, as expressed in the following quote:

> "*It would be nice if we could engage the bigger academic community perhaps by organizing a workshop of groups doing integrated earth system models… And then a second group of stakeholders would be people that can make use of the insights that will eventually fall out of the models that we develop" (co-PI 11).*

Four PIs expressed a broad definition of stakeholders by suggesting multiple different groups who could be involved in the stakeholder engagement process. These PIs with the broadest perceptions of relevant stakeholders are the same individuals who expressed the expectation that research carried out in BioEarth would lead to policy changes or aid in resource management decisions. These PIs were also among those who ranked all the suggested categories of stakeholders at an importance score of three or greater in the quantitative survey (see Figure 3.2). One participant said that if the project focused only on academic stakeholders and was not shared with groups outside of the scientific community, then project goals would not be achieved. The PIs with broad definitions of stakeholders tend to have some degree of a social sciences orientation in their own research. This suggests that the PIs whose own research does not integrate a social science orientation, i.e. those focused explicitly on the technical details of the modeling of the physical sciences, have very different expectations for stakeholder engagement.

When asked to identify key stakeholders for BioEarth, only three PIs explicitly mentioned the role of representatives from agriculture and forestry. Later in the interviews, when participants were questioned specifically about how agriculture and forestry sector representatives might be able to utilize the model, thirteen PIs explained facets of the research that may be applicable. Three PIs stated that making the model applicable to industry was not necessarily feasible or necessary (although this was a clearly stated goal in the project proposal that was successfully funded). Two PIs deferred from answering the question about the agriculture and forestry industry; one because of a lack of familiarity with the needs and priorities of those industries, and the other PI noted that it remains uncertain what kind of results the integrated model will yield, and explained that the specificity and certainty of research findings will determine their applicability. Of the thirteen PIs who described potential utility of the model to industries in the region, five participants included caveats in their response to clarify that only some portion of the model would be useful to stakeholders from these groups; concern was expressed about how stakeholders without technical scientific training would use detailed information from the model.

3.4.c.3 Concepts of project challenges

When asked about major challenges of the project, two distinct categories of challenges are evident in the responses: 1) challenges of communicating the scientific information to non-specialists and 2) technical challenges of model integration. At a basic level, both challenges arise from the need for a common language between people with different expertise and from the time and effort required to learn from others and share information. The challenges identified are interconnected and were referenced at multiple different phases in the interviews, i.e. not only when participants were specifically prompted to discuss the major challenges of the project. Three PIs (cluster A) focused the majority of their discussion of project challenges on technical issues, ten PIs (cluster C) discussed both categories of project challenge with equal frequency, and 5 individuals (cluster E) focused heavily on communication-related challenges (Figure 3.4c). In PI cluster groupings based on conceptions of project challenges, 3 distinct clusters emerged rather than the 5 clusters that emerged in the other continuums; to reflect 2 clusters at the extremes of the continuum and one large cluster in the center, the naming convention of "A", "C" and "E" was used to facilitate cross comparison with the other continuums. One researcher with a technical challenge focus (cluster A) noted:

> *"There's a challenge in actually providing really good information on future regional climate. The models today have a challenging time just predicting sort of global changes in climate and the earth system, and it gets more difficult when you get down to the regional level" (co-PI 4).*

Model integration is also a significant technical hurdle, as mentioned by this researcher (cluster C):

> *"There are the climate models and surface hydrology and economic models and they are usually defined over space and time, I think the biggest challenge is going to be that, working out space and time, how you break up space and time in a model. Which is difficult anyways, but then if you have to have multiple models and integrate them, and have them talk to each other and they all have different space and time elements, then it really becomes difficult" (co-PI 2).*

The question of how to go about engaging stakeholders and justifying the utility of the project to groups outside of the research team was mentioned frequently, most often among members of the research team who expected a model development process that would contribute to natural resource decision making and engage stakeholders in a meaningful way. Five researchers (cluster E) defined the project's primary challenges as communication with stakeholders and managing expectations. One PI from this cluster noted:

> *"Stakeholders want to know 'how many inches of water will be in this reservoir on this year?' and it's really difficult to provide that really specific information that they want with the accuracy that they want, so communication is huge" (co-PI 10).*

PIs grouped in cluster E on the "project challenges" continuum expressed awareness that facilitating stakeholder engagement in the research process will require sensitivity to conflicts of interest among different stakeholder groups:

> *"We are often faced with the need to balance one group's wants and desires with the desires of other people. That can often be uncomfortable, and it can often lead to a lot of misunderstanding" (co-PI 7).*

Additional difficulty, cost, time and effort associated with a large transdisciplinary collaborative endeavor were mentioned frequently when PIs were asked about project challenges. The challenges of collaboration and communication with other scientists are similar to and connected to the challenges of communication with stakeholders. One participant (cluster C), stated:

> *"In a collaborative project like this you just can't have investigators out doing their own thing. The outcomes are going to be much greater than the sum of any individual efforts that we could do and that's because of the synthesis we can provide by collaboration" (co-PI 18).*

But this potential for development of a model with capabilities and societal relevance that are greater than the sum of the parts of component models comes with a cost and additional challenges, as noted by another PI (cluster C):

> *"Everybody's busy, everybody has a lot of meetings to attend, lot of other demands on their time. But I think the fact that we strive for having frequent connections, is extremely important. Otherwise, we'll end up just*

doing 'island things', each one of us is doing something and the integration maybe will happen in a rush" (co-PI 13).

3.5 CONCLUSIONS

As environmental research continues to shift toward use-inspired, socially engaged, transdisciplinarity, there is potential to improve understanding of researchers' experiences and expectations of stakeholder engagement. Developing an understanding of researchers' diverse perspectives will enhance the research-practice landscape. While this analysis focuses on researchers from a single earth system modeling project, BioEarth is representative of an increasingly common type of large, collaborative environmental research project that integrates researchers from multiple disciplinary backgrounds and has articulated high expectations for stakeholder engagement. This study of researchers' perceptions reveals a lack of consensus among PIs involved in the same project regarding the value, type, timing, and expected outcomes of stakeholder engagement-- highlighting the social complexities of these emerging types of research projects.

The heterogeneity of researchers' perceptions of who the key stakeholders are and how they might interact with the researchers over the course of the project represents more variety than might be expected given the description of stakeholder engagement in the original project proposal. Some PIs retain the conventional research paradigm in which scientists communicate their results to stakeholders after the research has been conducted. These PIs do not tend to recognize value in stakeholders providing input early on in the project. Some PIs view the integrated regional earth system model that is being developed as a tool for decision-making, others describe the model as ‘preliminary’ and consider the central objective of the project to be addressing purely academic questions and building technical modeling capacity. The fact that roughly one quarter of the PIs in this research project consider their primary stakeholders to be other academics suggests that the goals of transdisciplinarity, with its emphasis on connecting to knowledge outside the traditional academic disciplines, are not equally prioritized and acknowledged by all members of the research team.

While surveys and interviews conducted in the first year of BioEarth demonstrate that a common vision of stakeholder engagement does not yet exist in this project, communication among the PIs in full-team meetings since the surveys and interviews has provided opportunities to move closer toward shared stakeholder engagement objectives. And as the project moves beyond its first year, a set of stakeholders with knowledge about the regional decision making context have been identified and will participate in a series of stakeholder advisory meetings with project PIs. Findings from this assessment of PI’s perceptions have informed the planning of these stakeholder advisory workshops.In an effort to facilitate dialogue and interactions among stakeholders and researchers, workshops will include a series of open-ended discussion prompts and digital-response multiple choice questions. Questions and discussion prompts have been developed with input from multiple PIs representing the different working groups.

Communication about earth systems model development poses specific challenges in stakeholder engagement due to model complexity and uncertainty (Rotter et al. 2011). Scientists who have expertise in developing computer-based earth system models often have less experience working with stakeholders outside academia than do economists, experimental environmental scientists, and academics with extension appointments. PIs with a social science background reported higher expectations for impactful stakeholder engagement than did those whose backgrounds were more exclusively technical. The tendency for modelers to value academic stakeholders' participation most highly is not surprising because most of their professional interactions are among other academics, and their professional communication skills are developed primarily with a focus on communicating with other academics. In contrast, experimental agricultural scientists may consider agriculture industry representatives as important stakeholders because they may have communicated with these actors in previous research. PIs with previous exposure to stakeholder engagement processes in which environmental and economic science were communicated and applied tend to have more broad and inclusive perceptions of relevant stakeholders and to place a higher value on stakeholder engagement early in the research process as opposed to thinking of engagement solely as communicating results after project completion. Given the diversity of PIs' perspectives and levels of comfort with stakeholder engagement, one of the keys to successful development of this regional earth systems model may for PIs with more experience interacting with stakeholders to work closely with the PIs who have a technical modeling orientation; thus creating a bridge between different approaches to addressing climatic and anthropogenic impacts on natural resources in the region. As such, successful stakeholder engagement is dependent on successful transdisciplinarity communication within the research team.

The potential for transdisciplinary sustainability science research projects to improve the understanding of regional human-environment interactions and inform decisions is large, but overcoming multiple challenges related to communication across disciplinary divides and between academics and non-academic stakeholders involves learning new approaches to research and communication. These new approaches may include: working in the early phase of research question development to identify stakeholders' information needs; developing shared vocabularies and new forums for translating and communicating knowledge; and working closely with stakeholder groups to increase organizational capacity to apply research findings. Through new experiences and increasing funding-related pressure, environmental scientists who are willing and able to learn new approaches to integrating stakeholder knowledge into their work are likely to be more successful as science that is socially salient and actionable is increasingly valued. The analysis presented here may contribute to overcoming potential communication barriers by encouraging modelers to place a higher value on working with stakeholders to develop decision-relevant outputs.

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CHAPTER FOUR: CLIMATE SCIENCE INFORMATION NEEDS AMONG NORTHWEST U.S. NATURAL RESOURCE DECISION-MAKERS

4.1 INTRODUCTION

4.1.a Characterizing the climate information usability gap

The notion of a "gap" between research and decision-making has emerged as a central trope in climate science communication literature. Potential users of climate science research may be unaware of the existence of the research, or they may be unable to access and interpret what is available (McNie 2013; Lemos et al. 2012; Weaver et al. 2013). There are missed opportunities to link the supply of scientific information with users' demands, and hence missed opportunities for science to inform policy (Sarewitz and Pielke 2007; McNie et al. 2015).

Meanwhile, in the climate science research community, there is a long lineage of calls for "usable science" from funding agencies, stakeholder groups, and research institutions. In 1999, the US National Research Council promoted a new model of research, led by users' concerns and key questions. This was in response to growing understanding that local knowledge and practices are not only frequent *sources* of environmental concerns but are also *resources* for addressing sustainability challenges (Miller at al. 2014). Building on the history of applied research in the US extension service, a recent resurgence of engaged research includes focusing on place-based science, collaborating with local communities to define research questions and objectives and focusing on the development of tools that link knowledge and action (US National Research Council, 1999).

BioEarth, a transdisciplinary integrated modeling project, is an example of a project that works toward bridging the gap between science and decision-making about natural resource management regulations and policies (Adam et al. 2014). The BioEarth research effort was funded in 2011 by the US Department of Agriculture, National Institute of Food and Agriculture (NIFA) under proposal number 2011-01177. As was stipulated in the call for regional Earth system modeling projects from NIFA, the proposal identified working closely with stakeholders and producing outputs relevant to the needs of agriculture and forestry decision makers as central goals. Research approaches in BioEarth can be conceived of as occurring at a mid-point along a continuum from fully "driven by science values" to fully "driven by user values" (McNie et al 2015).

Brewer and Stern (2005) defined key steps in producing usable research: 1) begin with user needs; 2) give priority to processes over products; 3) link information producers and users; 4) build connections across disciplines and organizations; 5) seek institutional stability; and 6) design for learning. There is an ongoing need for practical knowledge of how to create collaboration and more intensive communication between academic scientists and decision makers outside of academia (McNie 2013; Kirchhoff et al. 2013). In part, best practices are hard to define because local concerns, decision-making contexts and individuals' and groups' approaches to management and perceptions of risk are highly variable. Researchers must understand in more depth and detail natural resource managers' climate information needs, both in terms of the content and the delivery of information (Kirchhoff et al. 2013; Dilling & Berggren 2014).

The potential for boundary spanning organizations, such as University-based Extension Services and federally funded institutions such as NOAA Regional Integrated Science and Assessment (RISA) program, to foster communication and learning between climate science researchers and natural resource decision-makers is clearly established (Kirchhoff et al. 2013; McNie 2013 Miller et al. 2014: Kasperson 2011). This analysis of Northwestern U.S. natural resource decision makers' information needs explores one boundary spanning effort, seeking to understand how scientists and stakeholders can produce usable climate science information through a collaborative process. We consider the ways in which individuals, teams and organizations acquire and apply information about climate change-related vulnerabilities and impacts.

4.1.b Information about climate change impacts is of critical importance for natural resource managers

Climate impacts are already being felt in essentially every natural system and are projected to intensify through the foreseeable future. Questions about specific impacts, feedbacks, and opportunities for adaptation and mitigation actions are highly complex. Scientific understanding of these issues continues to evolve, and making this information relevant and accessible to natural resource managers is vitally important. Climate change information that is regionally and locally specific is essential because it is at these scales that specific risks and opportunities for action exist.

In general for climate information initiatives, stakeholders can be considered to be those individuals and organizations that have the interest and ability to use climate science information in their decision-making (McNie et al. 2015; Hegger et al. 2012). Potential roles of stakeholders in research are varied and can include any of the following: identifying research questions, sharing values, preferences, expectations and perceptions of risk, providing quantitative data or local expertise, commenting on research concepts, drafts and results, learning from the research process, and integrating research findings into a decision-making processes (Bucchi & Neresini 2008). There is widespread agreement that *early* stakeholder engagement in research and decision-making processes is essential to ensure that problem definition and approaches to research and decision-making are aligned with stakeholders' needs (Rowe & Frewer 2005; Reed et al. 2009; McNie et al. 2012). Key stakeholders in a research effort may change over time as new issues and concerns emerge and as contexts for action and decision-making become apparent (McNie et al. 2015). For the purposes of this study, stakeholders included decision makers from forestry, cropland and rangeland agriculture, water and air-quality sectors. Following Archie et al. (2012) the term "natural resource manager" is defined in this research to include those making decisions about public and private resources as well as those providing research, advice and assessments in support of decision-making.

Natural resource managers are a heterogeneous group with different interests, concerns and motivations; they hold a range of perspectives about the value and applicability of scientific research to their work. Nonetheless, most resource managers would agree that monitoring, or collection of empirical data about current conditions, is a source of credible information about the state of environmental systems. Scientific monitoring assessments and inventories are widely relied upon to document the environmental effects of federal agency actions, Environmental Impact Statements required under the National Environmental Policy Act (NEPA 1970) are a foremost example of this (Linkov et al. 2006).

Unlike environmental monitoring and other forms of field and laboratory research, modeling may be viewed with skepticism by some decision makers (Akerlof et al. 2012; Frigg & Hartman 2012). Models are, by definition, simplifications of real-world systems and processes. Models are the foremost tool used for understanding future conditions by making projections based on an understanding of the underlying processes at work and an assessment of likely future trends (Allen et al. 2015). Some individuals may be predisposed to view modeling with suspicion because of the potential for model outputs to suggest a need to change practices (Akerlof et al. 2012). Or in many cases, decision makers' skepticism about environmental modeling is rooted in the observation that weather forecasts and economic projections are "frequently wrong" - illustrating a lack of experience with models and limited understanding of about how model projections are generated and evaluated (Akerlof et al. 2012). To maximize the influence of environmental models for decision-making, effort is needed to understand who decision makers are as groups and as individuals and to communicate in a manner that is compatible with their expertise (Dilling & Berggren 2014; Archie et al. 2012).

4.2 Background on the BioEarth research project

BioEarth is a large collaborative 5-year project funded by the US Department of Agriculture, National Institute of Food and Agriculture (grant number 2011-67003-30346). This project aims to develop a model that addresses climate change impacts on cultivated cropping systems, rangelands and forest ecosystems and improves understanding of how resource management decisions affect earth system processes. The research investigates climatic and anthropogenic interactions with nutrient cycling, water resources and air quality in the U.S. Northwest region, focusing on the Columbia River basin (Adam et al. 2014). BioEarth is among a new generation of large environmental change research projects that seek to be transdisciplinary, with stakeholder engagement efforts incorporated in the research plan (Godin and Gingras 2000; Cummings and Kiesler 2005).

The BioEarth research team comprises individuals from the disciplines of atmospheric sciences, biogeochemistry, agricultural sciences, hydrology, aquatic chemistry, economics, and environmental communication. Team members with both scholarly and practical expertise in communication and extension collaborated with the rest of the research team to develop mechanisms for interactive communication between model developers and practitioners throughout the project. This effort included coordinating and implementing a series of six stakeholder workshops (Allen et al. 2013).

4.3 METHODS

4.3.a Format of stakeholder workshops

The BioEarth research team convened six workshops in different locations across Washington State between February 2013 and March 2015. Each workshop focused on a specific natural resource management issue: 1) water quality, 2) water supply, 3) air quality, 4) rangeland management, 5) forest management, and 6) carbon and nitrogen management. Workshops consisted of an introduction to the BioEarth modeling approach followed by discussion about participants' priority environmental concerns, information needs related to climate change and specific future regional modeling scenarios that would be impactful for their work. Complementing the discussion, multiple-choice questions were posed using Turning Point audience response technology, handheld devices that enable participants to anonymously answer questions and see the answers from other participants displayed instantaneously. This process provided participants with a sense of the range of opinions in the room, and catalyzed discussion. An average of 17 stakeholder participants and nine BioEarth research team members attended each workshop.

4.3.b Stakeholder selection process

BioEarth stakeholder workshop participants included professionals who engage with natural resource management issues on a regular basis. Some individuals were identified based on research team members' existing professional contacts and networks.

Additional individuals were identified through organizational and agency websites. Individuals with job titles similar to “director”, “program supervisor”, “policy analyst”, and “lead scientist” were invited to participate in workshops. In the process of recruiting workshop participants we engaged in snowball sampling, actively asking invitees to refer other potential participants. A total of 328 individuals were invited to six BioEarth workshops. Eighty-three stakeholders, or 25% of those who were invited, participated in workshops. Some stakeholders participated in more than one workshop, so there were a total of 100 instances of stakeholder participation. Percentage participation was consistent for all sectors invited (academia, tribal, federal, state or local government agency, industry or non-governmental organization). Table 4.1 describes the professional roles and employment sectors of participating stakeholders.

Table 4.1 *Professional Roles of Workshop Participants*

Professional Role	Sector	Number Attending
Public Resource Manager Involved in decisions about management of public lands, water resources and/or air quality. May play a role in developing site-specific management plans or enforcing regulations related to public land and resources.	Government	33
	NGO	1
Private Resource Manager Concerned with decisions about privately owned land and resources. May be a landowner, lessee (farmer or forester) or consultant advising about private land management decisions.	Industry	10
Researcher Conducts scientific research and/or analyzes data about regional environmental and natural resource issues. Work is centered on developing knowledge of systems, not directly involved in developing policies or policy implementation and evaluation.	Academia	6
	Government	7
	Industry	3
	NGO	5
Educator / Communicator Work is centered on sharing knowledge with various publics. Focused on issue awareness and education as opposed to direct involvement in resource management decisions. Includes traditional university extension work.	Academia	7
	NGO	1
Policy Advocate Represents an interest group (industry, community or environmental concern) in government policy decision-making processes.	NGO	9
	Industry	1
TOTAL		83

4.3.c Data Collection and Analysis

After the series of six issue-focused workshops was concluded, the BioEarth communication working group conducted a thematic analysis of stakeholders' information needs and stakeholders' reflections about participation in a climate science communication and engagement processes. Qualitative and quantitative data about resource managers' perceptions and information needs were drawn from: 1) transcripts of workshop discussions, 2) pre-workshop surveys, 3) responses to multiple-choice questions posed during workshops, and 4) post-workshop evaluations. Seventy-six of the 83 workshop participants completed pre-workshop surveys. Fifty-one participants completed post-workshop evaluation surveys. Emerging themes concerning environmental change concerns, information needs and future scenarios of interest were considered as they varied among participants with different professional roles and among participants focused on different natural resource management issues.

Researchers used QSR International's NVivo 10 qualitative data analysis Software to code workshop notes and written survey responses. Coding was carried out simultaneously by two researchers, one internal to the project and one who did not have any contact with project stakeholders beyond the analyzed documents. Codes developed by each researcher were compared, refined and clustered into thematic categories for analysis.

4.4 Results and Discussion

4.4.a Priority concerns related to environmental and socioeconomic change

At each workshop, clicker questions and discussion questions were posed to investigate the specific issues that natural resource decision makers were most concerned about. Highly ranked concerns identified at each workshop are outlined in Table 4.2. Prioritizing environmental and natural resource concerns is not straightforward because many issues are interlinked and overlapping. However, this table provides a useful summary of prominent issues that rose to the forefront of discussion at each workshop.

Table 4.2 *Highly ranked concerns at each BioEarth stakeholder workshop*

Workshop focus	Concerns discussed by participating stakeholders, listed according to overall priority ranking
Water Quality	1. Changes in amount and seasonality of precipitation, timing of snowmelt runoff leading to reductions in water quality 2. Erosion and sediment in waterways linked to forest management practices and changing riparian zone protection policies 3. Nitrogen and phosphorous loading; harmful algal blooms and impacts to drinking water 4. Impacts of water temperature change on native species (salmonid populations) 5. Urban runoff, linked to ongoing development and impervious surfaces 6. Pesticides, heavy metals in water, pollution from wastewater effluent
Water Supply	1. Reduced snowpack and earlier snowmelt leading to reduction in summer instream flows 2. Increasing out-of-stream demand for water linked to development and changing land use 3. Increasing irrigation efficiency and concerns related to “water spreading” and increased consumptive use 4. Management practices that do not jointly manage surface water and groundwater, conflicts between water management jurisdictions 5. Increased frequency of drought
Air Quality	1. Nitrogen deposition, impacts on ecosystem function, and cropland, forest and rangeland productivity

	2. Visibility and respiratory health issues from agricultural dust linked to tillage and land management practices 3. Air quality impacts on public health (chronic obstructive pulmonary disease, asthma, etc.) 4. Impacts of prescribed burning on air quality and fire cycle 5. Transport of pollutants from Asia 6. Ocean acidification as a result of SO_x and NO_x and water quality impacts from mercury and nitrogen deposition 7. Odor impacts from dairy industry
Rangeland Management	1. Soil moisture (timing and volume of water storage), increasing frequency of multi-year droughts and extreme precipitation events 2. Erosion due to changing seasonality and amount of precipitation, impacts of decreasing air and water quality (also linked to riparian zone protection policies) 3. Ranges of invasive plant species (cheat grass and medusa head), juniper and pinion encroachment as it impacts forage quality and overall ecosystem function 4. Intensifying wildfire frequency and severity 5. Wildlife-livestock interactions
Forest Management	1. Length of summer dry period and frequency and intensity of droughts, particularly in the inland areas of the Northwest (east of the Cascade Mountains) 2. Changes in wildfire frequency and severity and associated damage to soils 3. Pest and disease pressure; feedbacks between drought, fire, insects and disease 4. Climate change and management practices as they impact genetic diversity of forests and invasive species 5. Potential for increasing frequency and severity of ice and wind storms 6. Potential positive impacts of warming and increased atmospheric carbon dioxide on Northwest forests
Nitrogen and Carbon Management	1. Contribution of nitrous oxide and carbon dioxide emissions to greenhouse effect 2. Nitrogen runoff and leaching from synthetic fertilizer and organic amendments applied to crops 3. NO_x contribution to air quality issues, nitrogen deposition as it impacts forests and water quality 4. Carbon storage potential of croplands and rangelands—concerns about developing policies to support management practices that enhance carbon storage 5. Impacts of wildfire on carbon storage potential of forests

Analysis led to identification of the following four themes concerning key environmental, social and economic challenges facing the Northwest now and in the future: a) climate change will exacerbate many existing environmental issues; b) land use change and development are key issues facing the region; c) studies of the region's future should explicitly analyze social dimensions of change; and, d) impacts of decisions across jurisdictions and management sectors must be considered. These themes are explained in detail below.

4.4.a.1 Climate change will exacerbate many existing environmental issues

Across all six thematically arranged workshops and across all categories of stakeholders' professional roles we found a widespread perception that anthropogenic climate change in the Northwest U.S. is already occurring, will intensify in the coming century and will exacerbate existing environmental challenges in the region. The degree to which workshop participants make management decisions that explicitly consider climate change depends upon the sector they work in and their professional role.

Natural resource decision-makers face several limitations to explicitly incorporating climate change projections into resource management planning. For example, a representative of a federal land management agency stated that despite their personal assessment that climate change will impact ecosystem services and affect the forage available for livestock, there are significant obstacles to incorporating information from climate impacts models into some management decisions. Any adjustments to lease agreements must be legally defensible, and climate impacts model projections do not provide an adequate level of certainty. Along similar lines, some agency representatives felt they were unable to address climate change directly because of institutional priorities. At the air quality workshop a federal agency representative stated, "Regulators have to meet standards, that is their whole job. There is an economic cost to not meeting standards because lawsuits are a threat. Federal law establishes air quality standards, and we can't enforce polices (for example, policies pertaining to greenhouse gas emissions) beyond those standards".

While acknowledging the challenges of managing specifically for climate change, participating stakeholders were conscious of the many ways that shifting climate may affect existing environmental concerns in the region. At the workshop focusing on water quality issues, a federal agency scientist referenced projections of declining snowpack and reduced summer snowmelt runoff, saying, "Snowmelt is the cleanest water we get. If snowpack decreases, so does our supply of clean summer water and we'll need to make up with less clean groundwater. Groundwater water quality is more directly impacted by human activity, and we're going to have to use more groundwater to meet summer water demands". At the rangeland management workshop, two participants representing a family-owned cattle ranching business talked about challenges they faced in the context of climate change, with expected increases in the frequency and severity of drought. One of them said, "[This past year] there were lots of sleepless nights thinking about the drought and what we would do to feed the cattle. We may have dodged the bullet this year but can't be sure about next year". These concerns were compounded by the fact that in drought conditions the price of hay rises, severely impacting ranch economics. In the forest management workshop, concerns were expressed about the potential for drier, hotter summers, and the linkages between reduced soil moisture and wildfire frequency and severity. An extension forester said, “In systems where stand replacing fires were part of the ecology, fires increasingly behave very differently than they used to, sometimes causing permanent damage to soils”.

4.4.a.2 Land use change and development are key issues facing the region

Current and projected population growth and demographic shifts in Washington, Oregon and Idaho frequently rose to the forefront of discussions, with the dominant perception that these changes will lead to new pressures on the region’s natural resources. This was particularly true of workshops focused on forest and rangelands management where participants shared personal experience of seeing privately owned land converted from working lands to rural residential uses. An extension forester said, “In the next 15 years, we’ll see the transfer of large amounts of forestland to several owners, a new generation. This may facilitate parcelization of forests and conversion of land for residential, suburban development”.

Workshop participants who were concerned with agricultural systems were also quick to identify shifts in land use as an important factor in the region. One soil and water conservation district scientist said, “The issue of conversion of lands from agricultural to urban systems is huge. We also see major shifts from growing grass, and annual crop[s] to raspberries, which are perennial”. Shifting land uses will impact agricultural water demands and fertilizer and pesticide application regimes. There was also discussion about the changing demographics of farmers, for example in the dairy industry where market and regulatory pressures are likely to continue to favor large industrial operations that can streamline operations and small "craft" operations, but making the business climate inhospitable to mid-size family run dairy operations. Workshop participants made it clear that modeling scenarios that explicitly consider land use changes and evolving management practices would be necessary to have an accurate picture of how farming, ranching and forestry operations will impact, and be impacted by, environmental and natural resource concerns.

<u>4.4.a.3 Studies of the region's future should explicitly analyze social and economic dimensions of change</u>

Workshop questions designed to probe how integrated regional climate change impacts models might inform adaptation and mitigation activities led to discussions about the complexity of influencing social and individual behavior and choices. A federal agency water resources engineer said, "There is a sociology dimension to all of this discussion. We need to change the paradigm in which we operate…There is an assumption in climate change adaptation planning that we have to plan for the future based on the past, we have to give choices based on old solutions. It's hard to get people to think in a new way about approaches to problems".

Interest in linking economic and biophysical models was also frequently expressed, with participants encouraging modelers to consider patterns of adoption of new behaviors, technologies, public awareness and changing policy when developing scenarios to be modeled. For example, an air quality manager from a state agency said, "It would be really valuable to see the impact of large-scale shifts to public transportation on overall transportation emissions". A research analyst at an NGO said, "We should look at the potential for programs that pay landowners for ecosystem services and look at how layering different incentives could alter management". Some model features and applications suggested by stakeholders were more feasible than others in the context of the BioEarth project. For example, it may be possible to incorporate projected impacts of a policy into scenarios that are modeled, but it would be more difficult to model behavior changes that result from complex processes of public education. Workshops participants clearly expressed that incorporating sociological and political dimensions of change where possible (and openly acknowledging them where they cannot explicitly be incorporated in the model) would be useful.

4.4.a.4 Impacts of decisions across jurisdictions and management sectors must be considered

The theme of unintended consequences arising from management decisions that were anticipated to have beneficial social and environmental impacts emerged at every BioEarth workshop. Table 4.3 lists examples of observed and potential unintended consequences of management decisions that workshop participants discussed. The ability to understand feedback loops connecting different systems and to bring that understanding to bear in management decisions is not yet well developed. Interactions between systems are inherently difficult to manage for because of competing frames of reference and diverse institutional objectives among resource management institutions. Northwest U.S. decision makers who participated in BioEarth workshops are concerned about already-observed and expected unintended consequences and see critical information needs related to these interactions and feedbacks between systems.

Table 4.3 *Observed and possible unintended consequences of decisions*

Workshop focus	**Examples of unintended consequences of resource management decisions mentioned by participating stakeholders**
Water Quality	• Adding nutrients to localized areas (e.g. within a reservoir) to support fish populations worsens eutrophication issues elsewhere in the system
Water Supply	• Programs to promote adoption of technologies to enhance irrigation efficiency can lead to increased consumptive use (e.g. if farmers adjust their crop mix to more water intensive crops or expand their irrigated acreage).
Air Quality	• Restrictions on burning wood products for heat in the Northwest lead to greater reliance on natural gas, natural gas extraction has environmental consequences in other regions • Shifting from growing dryland wheat to oilseeds can diversify cropping, but also leaves less residue on fields, resulting in more emissions of ultrafine particulate matter
Rangeland Management	• Riparian restoration programs that demand complete cessation of ranch operations, aiming to protect vegetation near waterways, could lead to negative impacts on vegetation diversity
Forest Management	• Using underbrush from regional forests for biofuels production may remove nutrients from the watershed • Controlled burns reduce risk of massive fires, but may also contribute to air quality issues
Nitrogen and Carbon Management	• Anaerobic digesters built to address methane emissions from dairies may produce higher NOx emissions • Some dairies compost manure to fulfill nitrogen management plan guidelines, but composting manure in some cases contributes to water quality issues, ammonia emissions and GHG emissions • Regulations aimed at curtailing certain practices can lead industry to increase that practice in the short run, before regulations take effect. For example, just before laws restricting logging on steep slopes went into effect, many of those areas were logged

For some environmental issues, cross-jurisdictional planning is more thoroughly incorporated than for others. For example, air quality managers tend to be engaged in a high level of collaboration between agencies. This may be in a large part due to the nature of atmospheric processes, characterized by rapid change over large areas and issues that are not confined by political borders. We find that Northwest U.S. stakeholders who work on issues related to regional water are aware of and interested in connections between water supply and water quality, especially as climate change alters timing and flow of water. Awareness of these connections is emergent and not fully reflected in agency operations and planning. Understanding of these linkages could potentially be supported through integrated regional environmental modeling efforts such as BioEarth.

4.4.b Time horizon and scale of information needs

Depending on the environmental and natural resource systems that decision makers are focused on and the context in which they work, climate change information is most relevant when provided at specific temporal and spatial scales. At each BioEarth workshop, participants were asked to consider the time horizons, temporal scale, and spatial scale at which information about projected environmental impacts of changing climatic conditions and management practices would be most useful to them. Figure 4.1 shows how natural resource managers rated the usefulness of information about resource management practices projected at different timescales. Participants were asked to consider resource management practices pertaining to the specific environmental issue their workshop was focused on (i.e. air quality managers considered temporal scales of information about air quality management practices). Note that participants in the carbon and nitrogen management workshop were asked twice about useful timescales-- once about carbon management and once about nitrogen management.

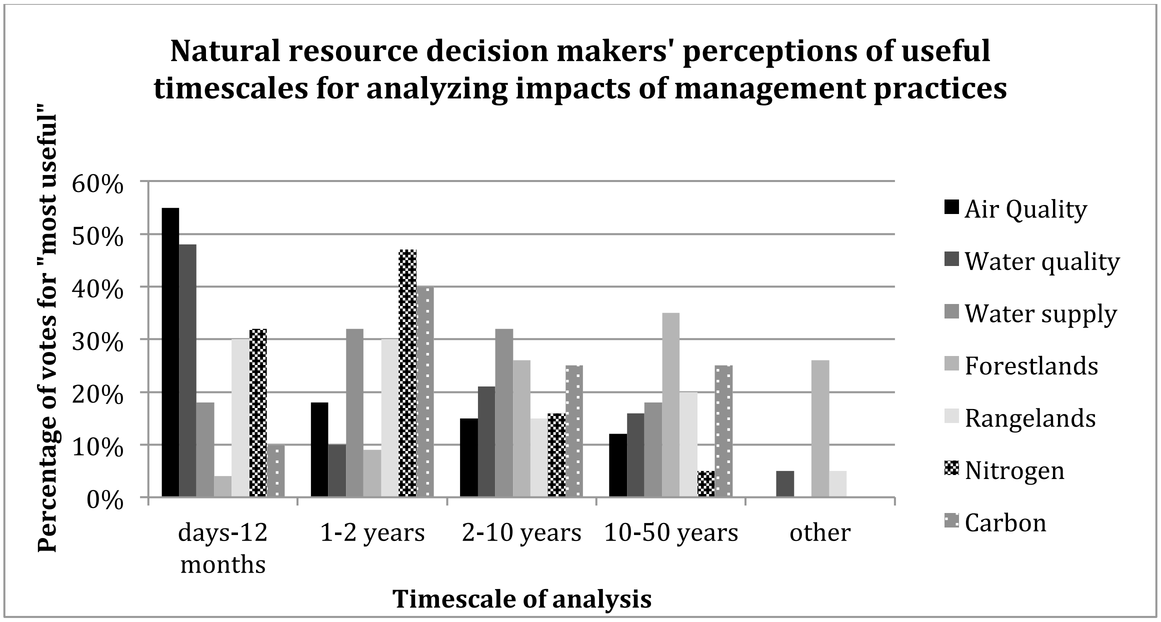

Figure 4.1 Percentage of votes for "most useful" for each timescale at which the impacts of management practices might be modeled.

Among air quality decision makers, 55% of the votes for most useful timescale for projecting the impacts of management decisions were for a sub-annual timescale. Similarly, among water quality decision makers 45% of the votes were for timescales of less than one year. This is likely at least in part because water quality and air quality are explicitly regulated according to federal and state laws, including the Clean Water Act and the Clean Air Act. For example, having projections of air quality at a fine temporal scale could thus directly inform decisions about when to restrict burning. In general, air quality and water quality managers who make regulatory decisions at government agencies require model projections at sub-annual to annual time scales.

Decision-makers surveyed about timescales for projecting the impacts of nitrogen and carbon management activities judged projections made on a timescale of 1-2 years to be most useful. In the case of nitrogen management decisions the second most useful timescale selected was days-12 months, while for carbon management issues the second most useful timescale selected was 10-50 years. This difference may reflect the fact that patterns in the transportation and deposition of nitrogen shift seasonally, while on the other hand, for resource managers interested in carbon sequestration potential of agricultural soils, relevant timescales are on the order of decades to centuries.

Rangelands management stakeholders' preferences of most useful timescales were fairly evenly distributed, reflecting the range of decisions that rangeland managers make—from moving animals in pastures seasonally to designing policies about riparian buffer zones over decades. Many stakeholders representing agricultural and rangelands industries said that information at long timescales (10 years or greater) was less useful than information at shorter timescales. Natural resource decision makers in industry may typically make planning decisions according to investment horizons, and will find model results most meaningful when they correspond to those time scales.

Management decisions associated with forests, both from a forest ecosystems conservation perspective and a forest products industry perspective, are generally made considering longer intervals of time because of the rate at which forests grow and the intervals at which decisions about harvesting and management are made. 35% of forest management workshop stakeholders said that the most useful time scale for projecting impacts of management decisions was 10-50 years. 25% selected “other” when answering this question and remarked that they were interested in the fate of forests in the next century and beyond.

When resource managers discussed spatial scales at which model outputs would be most relevant to their work, there was generally more interest in fine-scale and broad-scale outputs than in seeing “mid-scale” results presented. For example, in the water quality management workshop, participants were evenly divided as to whether projections at the land parcel/farm scale, river reach scale or watershed-scale would be most useful, while there was low interest in seeing medium-scale outputs, for example at the county level. Discussing the importance of fine-scale results, one representative of an environmental consulting group attending the water quality workshop noted that fine-scale projections of where cold-water zones occur in regional streams are needed in order to protect salmon habitat. At the same time that fine-scale model outputs are valuable for many specific land use and resource management planning applications, science educators, communicators and policy makers may benefit most from having broad-scale model outputs that present regional projections with uncertainty quantified and clearly communicated for a non-specialist audience.

4.4.c Expectations of climate modeling research

Workshop participants were asked about what they thought they would get out of BioEarth workshops and the overall integrated modeling effort in pre-workshop surveys. After workshops we asked stakeholders to complete an online evaluation survey designed to understand how those expectations evolved after hearing presentations from BioEarth scientists, discussing the challenges that they saw on the horizon and considering what scenarios and model outputs could potentially inform their decisions. Before workshops began the majority of participants made comments along the lines of a water resources engineer who said, “No expectations really, I am here to learn and provide input”. Several participants expected the workshop to be a learning opportunity, for example, “I expect to learn more about the modeling approach as it relates to agricultural air quality issues. Others regarded the workshop forum as a chance to “bring the research community together with NGO and industry stakeholders who can effect change”.

In post-workshop evaluations, typical stakeholder comments conveyed interest in BioEarth while expressing continued uncertainty about the ultimate relevance of the modeling effort to their work and decision making context, for example, “The usefulness of models of this expanse and complexity is uncertain, so I'm in a ‘wait and see’ mode”. Roughly 25% of the respondents were unreservedly optimistic. Said one stakeholder, “They will generate some really interesting results about present and future water quantity, quality and land use in the region. I will be paying attention to this work in the future and look forward to more news and results”. Another 25% of participants left the workshop with skepticism that the research project would yield meaningful outcomes for their work, for example, “I hope that there are tangible applications to a variety of users, but I fear this may not be the case”. When stakeholders’ information needs are highly specific, it is challenging to pursue modeling approaches and generate model outputs that are relevant to many diverse decision-makers.

Stakeholders' expectations should be viewed in light of typical sources of information upon which they base decisions. In the pre-workshop survey participants were asked, "What kinds of academic research and scientific data are most valuable and/or relevant to your decision-making?" Respondents selected all the options that applied to them: 57% percent of the votes were for earth and life sciences (hydrology, biology, crop and soil science, botany), followed by 17% for economics, 14% for policy, history and social sciences, and 8% for sociology and psychology. Another 3% of the votes were for "other". Written-in responses to the questions about the most valuable and relevant fields of study were toxicology, public health, epidemiology, and chemistry. The general tendency to rank information from earth and life sciences as most meaningful for natural resource management decision making is interesting to note given stakeholders' strong interest in seeing models that integrate projections based on economic, behavioral and sociological analyses of the region. This result points to continued need to integrate social, economic and biophysical knowledge and research approaches.

Before the workshop, stakeholders were asked to consider the question, "How well do researchers in academia communicate their findings to stakeholders?" After the workshop, they were asked, "Based on your experience at this meeting, how well do you think researchers communicated their work to stakeholders?" Participants' responses to these questions posed before and after the workshops are presented in Figure 4.2 below.

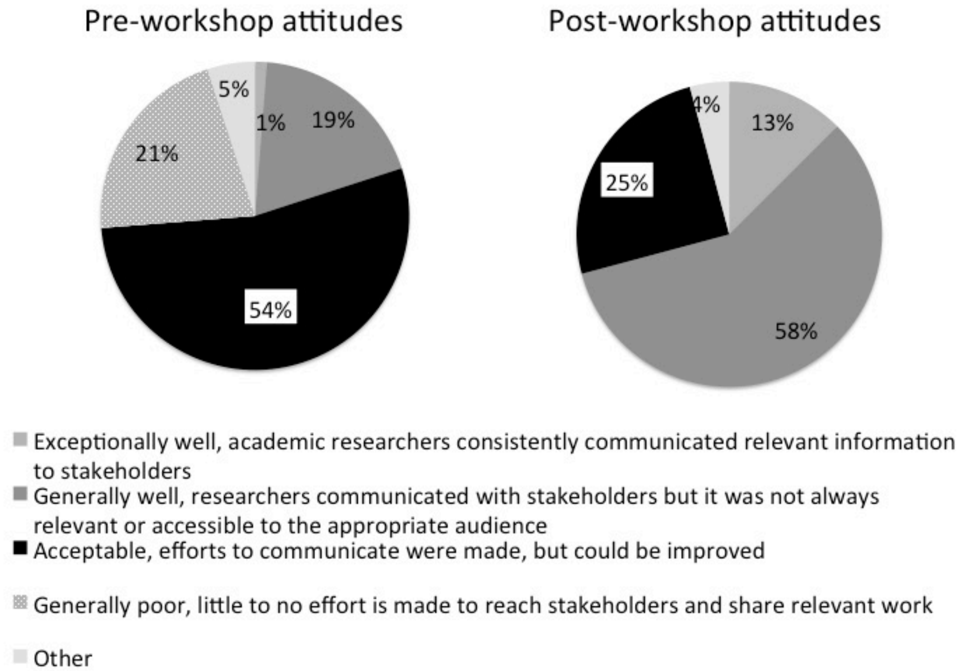

Figure 4.2 Workshop participants' pre- and post-workshop responses to questions about how well scientists communicate with decision makers.

The difference in responses to these two questions indicates that workshop participants on the whole had a markedly better opinion of that communication effort made in the context of this project than their general attitude about academic science. Whether the communication and stakeholder engagement process design for the BioEarth research project was optimal or not cannot be determined. However, we observe that having a communication strategy that deliberately seeks to address barriers between researchers and stakeholders, and that includes individuals with boundary spanning skills has a positive effect on stakeholder perceptions of academic science communication.

Participants shared many questions they were grappling with that they hoped the BioEarth modeling framework might help address. An NGO representative at the carbon and nitrogen management workshop asked, “Can we point to ways to reduce the N_2O emissions, and also understand the changes we’ll see in soil behavior with nitrogen and carbon as it gets warmer?” At the water supply workshop, a water resources consultant said, “If the model could give explicit, quantitative scenarios about soil carbon management in forestry, and how that affects water supply and water availability this would help policy makers make decisions”. While there were strong expressions of interest in seeing outputs of an environmental model that considers feedbacks and linkages between systems and considers socioeconomic change factors, workshop participants were cognizant of the challenges associated with using models for decision-making. A participating extension forester said, “People have concerns about transparency for models. They have an ingrained distrust of models. I would hope that one project output would be to bring people along in terms of developing a broad literacy of modeling, and how you (as a consumer) evaluate it… What a model is, and what it isn’t.” Even considering limitations to environmental model use in decision-making, there is strong interest in participating in climate change impacts research efforts based at universities to promote development of usable model outputs.

4.4.d Desired formats for learning and sharing information

Learning about how regional natural resource decision makers would like to see climate change impacts projections and other environmental modeling results presented and communicated was one of the central goals of the BioEarth stakeholder workshops. Before workshops participants were asked, “where do you generally learn about academic research and scientific information?” Respondents selected all options that applied to them; in total there were 149 responses (Figure 4.3). Participants’ most common sources of scientific information are reports in print and online. Direct conversations with academic scientists, extension specialists and experts not based at universities are also key pathways for stakeholders to learn about regional climate change impacts.

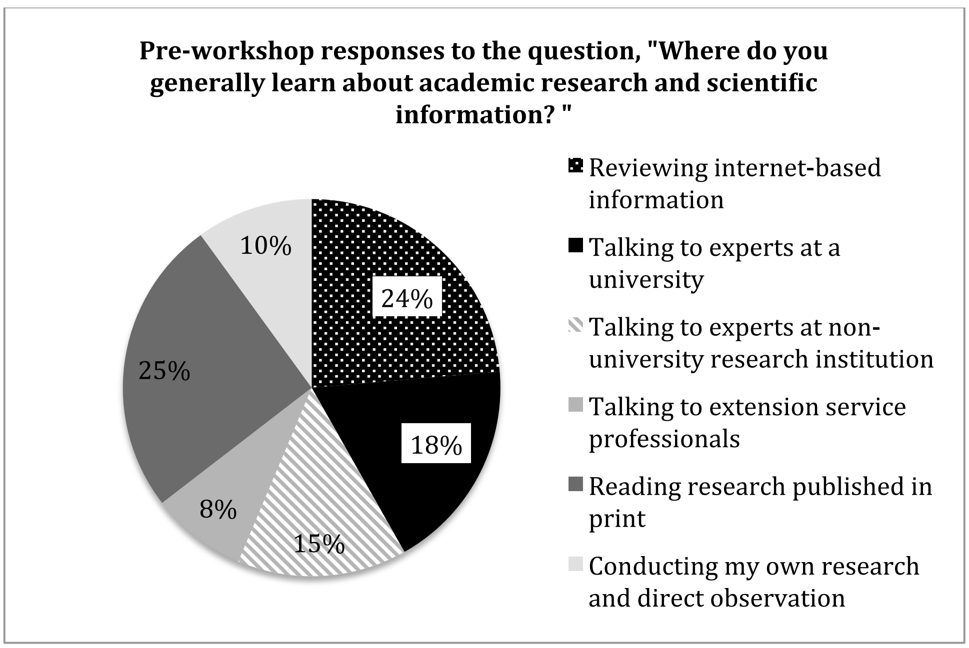

Figure 4.3 Stakeholders’ self-reported sources of scientific information.

In the water quality workshop a question was posed asking what kinds of scientific information about projected environmental effects of different management practices would be most valuable for decision-makers. The two highest-scoring categories were raw or un-interpreted data and model outputs (26% of the votes) and online decision support tools that allow manipulation of model inputs (23% of the votes). Peer reviewed publications (15%) and webinars about model results with the chance to ask questions of model developers (15%) were the next most frequently voted for options. Maps and data visualizations (8%), model outputs communicated in non-technical language, such as blog posts, extension documents and news articles (8%) and direct conversation or consultation with model developers (5%) were the less frequently selected preferred formats. These responses are consistent with the high level of technical scientific expertise of resource managers gathered at the water quality workshop, and may not be representative of stakeholders across the various workshops. Several participants remarked that choosing among possible options was a challenge because different mechanisms for communicating results are potentially useful for different audiences.

Stakeholders frequently made comments reflecting the value they placed on sustained collaborative processes between academic researchers and natural resource management stakeholders. A soil and water conservation district scientist who participated in multiple BioEarth workshops said, “To actually impact decision-making you have to have intimate knowledge of specific stakeholders’ decisions, for example, growers. You need to sit with them and understand how they make decisions to understand it well enough to see how science could be brought to bear on their decisions”. This quote attests to the value of making efficient stakeholder engagement central to climate research efforts and utilizing the boundary spanning skills of individuals trained as facilitators and science communicators. A forester said, “These questions are complex. Any models we have are likely to be inaccurate. Some credible way of demonstrating model accuracy is critical for developing stakeholder confidence”. Comments such as this underscore the need for education opportunities for academic researchers to hone communication skills and education opportunities for decision-makers to become better versed in environment modeling.

4.5 Conclusions

Feedback from natural resource decision makers who participated in BioEarth stakeholder advisory workshops demonstrates that integrated regional environmental modeling is of potentially great interest and utility to decision-makers. Opportunities exist at both local and regional scales of decision making to do integrated resource management that addresses feedbacks among various systems-- air, water, soil, etc. Thus, having credible climate change impacts projections at local and regional scales is vitally important. Northwest natural resource managers also have a strong interest in seeing accessible projections of regional change that go beyond biophysical modeling to consider economic, social and political dynamics including population growth and land use change. Stakeholders’ specific questions about future environmental change, scenarios of interest and desired formats for seeing model results communicated vary according to the different environmental systems they focus on as well as their professional roles and decision-making contexts.

Participants' feedback at BioEarth workshops shed light on some effective practices for stakeholder engagement. Coordinating efficient engagement activities depends on understanding the roles, responsibilities, and expertise of stakeholders and establishing partnerships with specific agencies, organizations and individuals over time. Having individuals with facilitation and science communication experience embedded in research teams is vitally important to cultivate those stakeholder relationships and support boundary-spanning activities. Workshops arranged around different environmental systems (water, air, forests, etc.) enabled generative dialogue among individuals who work in different institutional contexts but share overlapping expertise and concerns. These workshops were useful forums for identifying and distilling stakeholders' high priority information needs. Hearing stakeholders' specific, clearly defined questions about regional environmental change is vitally important for researchers who are seeking to develop decision-relevant applications of integrated environmental models.

In the course of stakeholder engagement efforts for BioEarth, the project's communication team refined the design of workshops and developed facilitation approaches that contributed to getting usable feedback about model development from stakeholders. The team observed that when researchers clearly presented basic information about how models operate and showed stakeholders concrete examples of similar models that have been applied to study environmental change, stakeholders were better able to provide actionable input to the research team. Posing focused, specific multiple-choice questions, which participants answered anonymously and saw results of instantaneously, enhanced discussions and generated quality input. One area for future research is to investigate whether educational tools about climate change impacts modeling for stakeholders enhance the actionability of input that they provide to environmental modelers in workshop setting, thus contributing to more usable model outputs for stakeholders.

Stakeholder input informed the evolution of the research approach in BioEarth. Many aspects of what the BioEarth project is and what it seeks to do have only became clear as researchers' time and resources have been invested in the research effort. The vision of a project that would fully interconnect separate terrestrial, hydrological and atmospheric models has evolved into a "modular model" vision. The project has shifted from seeking to capture all atmospheric, aquatic, terrestrial, and human decision making processes into one single integrated framework, towards developing the capabilities to pull in specific components of the earth system that are relevant to a decision-making process. In other words, the complexity of a particular BioEarth application should match the interconnectedness of the decision process under investigation. For example, many of the questions related to sustaining irrigated agricultural production did not necessitate full integration with an atmospheric model. Indeed, in some instances a more integrated modeling system reduces the accuracy of information needed to inform certain decisions. Stakeholder workshops provided guidance on the priorities of model development and uncovered certain processes that were missing. For example, the carbon and nitrogen management workshop uncovered the need to prioritize inclusion of tillage management, and the rangeland workshop uncovered the need to simulate seed generation in grasslands. Large interdisciplinary projects often take new directions several times between the proposal writing stages and the end deliverables. Importantly, in the case of BioEarth the changing approach was guided in part by the perspectives and needs of project stakeholders. We anticipate that the workshop results will continue to inform BioEarth activities for years to come, including not just in shaping priorities for model development, but also guiding instances of BioEarth application and scenarios, and how findings are communicated and disseminated.

An important outcome of BioEarth workshops is that researchers on the team have a better understanding of Northwestern U.S. natural resource managers' pressing questions about regional environmental change, decision-making contexts and constraints. Most of the stakeholders who participated in BioEarth workshops do not independently make resource management decisions – but instead influence decisions indirectly. And stakeholders who make natural resource management decisions do so within limitations related to agency or business mandates and resources and jurisdictional authority. Despite limitations to situations in which environmental model outputs can be explicitly incorporated in natural resource management decisions, stakeholders identified many areas in which regional climate change impacts model outputs would be of value to their work.

High priority recommendations that emerged from BioEarth stakeholder workshops include the following: 1) explore policy changes expected on the horizon; 2) incorporate changing technologies and management practices; 3) investigate impacts of land use change; 4) test the impacts of applying current best management practices vs. what are understood to be "worst practices"; and 5) explore possible unintended consequences of management decisions. While some stakeholders' information needs are beyond the scope of the BioEarth project, engaging in a dialogue about integrated environmental modeling and regional natural resource management was deemed by the modelers to be of great value. Understanding resource managers' contexts and constraints plays an important role in developing concepts for future research efforts and establishing a foundation for collaborative scientist-stakeholder partnerships.

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CHAPTER FIVE: LESSONS LEARNED ABOUT BOUNDARY SPANNING IN AN ENVIRONMENTAL MODELING TEAM

5.1 DEFINING THE NEED FOR BOUNDARY-SPANNING IN ACTIONABLE SCIENCE

In the context of complex, rapidly changing environmental concerns, providing scientific information about those concerns is often an incomplete step toward bring about changes in policies and management decisions (Sabatier 1991; Sarewitz et al. 2000; Kasperson 2011; Weaver et al. 2013). Lack of scientific knowledge about environmental problems is not so much a barrier to effective policy action as is lack of interpretation and synthesis of knowledge (Kasperson 2011). Actionable science, broadly, is research with the potential to inform decisions and improve the design or implementation of public and private sector policies, strategies, planning and behaviors (Meyer 2012; Palmer 2012). A shift toward explicitly considering the actionability of research is underway in many institutions. Research institutions seeking to provide actionable climate science information must consider the role of decision makers in shaping research questions and design appropriate approaches to presenting scientific information (Kasperson 2011; McNie 2013).

In the 21st century, universities, like organizations of all kinds, are operating in rapidly changing social, technological, political, economic and environmental contexts (Shockley-Zalabak 2011). Research institutions must adopt innovative approaches and be responsive to new information. Tensions inherent in conducting actionable decision-oriented research include all of the following: 1) differences between disciplinary specialization versus interdisciplinarity, 2) long-term research studies versus real-time knowledge production, 3) "basic" versus "applied" research goals and 4) autonomy of scientists versus science consultancy (Parker & Crona 2012; McGreavy et al. 2013; Lemos et al. 2014).

Boundary organizations exist at the interface of academic research organizations and resource management organizations (Guston 2001). Their role is to facilitate communication and collaboration between different kinds of organizations (Guston 2001). Scholarship of boundary organization formation and functions is rapidly developing (Guston 2001; Parker & Crona 2012; Kirchhoff et al. 2013; McNie 2013; Lemos et al. 2014). University-based actionable science research teams must be responsive to multiple different and competing constituencies, and can be understood as ad-hoc boundary organizations (Parker & Crona 2012). More research is needed to understand how boundary-spanning individuals effectively facilitate collaboration among researchers and non-academic decision-makers and utilize boundary objects such as models to communicate information (Parker & Crona 2012; Kirchhoff et al. 2013).

This chapter discusses evolving perceptions over a five-year period among members of an interdisciplinary team seeking to produce actionable regional climate science information. The chapter begins with discussion of relevant literature on the topics of boundary-spanning individuals, boundary organizations, boundary objects, interdisciplinary teams and organizational change. The methods section describes the participant observer approach used to collect data and thematic analysis methods used to analyze data. Strengths and limitations of these approaches are discussed. Next the results of a case study of BioEarth researchers are discussed. Accounts of researchers developing boundary-spanning skills are presented along with lessons leaned about models as boundary objects. The chapter concludes with recommendations for developing boundary-spanning capacity in research teams based on the experiences of BioEarth project researchers.

5.2 Boundary-spanning individuals

Scholarship of boundary organization formation and operation emphasizes that specific individuals with unique professional skills and roles are often instrumental in the success of boundary spanning activities (Feldman & Ingram 2009; Kirchhoff et al. 2013; Lemos et al. 2014). Broad expertise, along with strong communication skills can support organizations in building trust and the capacity to manage cross-boundary interactions. "Systems thinking" is a vital approach within organizations that span boundaries between different institutional cultures (Senge et al. 2015). Effective boundary spanning individuals use tactics to equalize power, avoid imposed solutions, and to manage conflict effectively. Consistent, strong leadership has been identified as a key element of boundary spanning success (Crosby & Bryson 2010; McGreavy et al. 2013; McNie 2013; Lemos et al. 2014). Three qualities define "systems leaders": 1) the ability to see the whole system--instead of only the constituent parts; 2) the ability to facilitate authentic reflection; and 3) the ability to move from a paradigm of "solving problems" to an approach centered around co-creation of a different future (Meadows & Wright 2008;

Senge at al. 2015).

Director of the National Socio-Environmental Synthesis Center (SESYNC), Margaret Palmer reflected on the need for scientists to "move out of their comfort zones" in pursuit of decisions informed by scientific knowledge:

> *"Science designed from the ground up to affect the behavior and decisions of non scientists focuses research in ways that can feel constraining at times but also empowering. Inevitably, it triggers new relationships among scientists, fosters new data and methods, and stimulates the most creative impulses of our research community"(Palmer 2012).*

5.3 BOUNDARY ORGANIZATIONS

There has been expanding emphasis on spanning boundaries between science and decision-making within government agencies, universities and research organizations (Parker & Crona 2012; McNie 2013; Kirchhoff et al. 2013). A prominent example of this can be seen in the 2012-2021 strategic plan for the US Global Change Research Program (USGCRP), which links federal agency climate change research efforts. The strategic plan defines "increasing scientific knowledge" as just one of four objectives; the other three USGCRP objectives are: 1) inform decisions, 2) sustain assessments, and 3) communicate and educate (USGCRP, 2012). This represents a shift from earlier USGCRP program goals that emphasized knowledge creation (Meyer 2012). Various kinds of boundary organizations that form a bridge between climate science research and decision-making activities include the USGCRP, NOAA-funded Regional Integrated

Science Assessments (RISAs), USDA-funded Climate Hubs, the NSF-funded National Socio-Environmental Synthesis Center (SESYNC), state-funded conservation districts, non-profit environmental decision-making mediation and research institutes such as the Meridian Institute and the Conservation Biology Institute, and land grant university-based extension programs.

Universities, or research centers within universities, can provide institutional support for boundary-spanning work (Parker & Crona 2012). However, universities differ from the ideal environment assumed by boundary organization theory because they do not typically have natural capacity to unite and mediate varied interest groups with competing demands (Parker & Crona 2012). In order for research efforts housed at universities to develop boundary-spanning capacity, effort must be invested in training and supporting boundary-spanning individuals who can facilitate dialogue with non-academic stakeholders and build bridges across divides in disciplinary cultures and institutional cultures (Feldman & Ingram 2009; Dilling & Lemos 2011; Parker & Crona 2012).

In order to use scientific information to inform decision-making actors must have power to make a decision, trust in the information and a system for being able to access the information (Kirchhoff et al. 2013). Meeting these conditions depends on production and maintenance of social capital (Jones et al. 2012). The term social capital refers to features that enable people to act collectively: networks, relationships, norms, trust and goodwill inherent in social relations. Building social capital and trust among decision-making communities and researchers is a time-intensive process (Jones et al. 2012; Kirchhoff et al. 2013). Organizations seeking to develop boundary-spanning capacity and promote collaborative knowledge development in contexts characterized by social tensions and power differentials must carefully consider potential implications of engagement for actors with less social capital (Jones et al. 2012). Stakeholders must perceive the potential value and benefit of participation in knowledge coproduction processes in order to be motivated to initially engage in boundary spanning efforts.

5.4 Boundary objects

Boundary objects allow members of different communities to interact and share knowledge, despite holding different perceptions of the object (Star & Griesemer 1989). Boundary objects can be things such as conceptual models, classification systems, maps and visualization tools. Regional scale climate change impacts models and their information outputs can be understood as boundary objects.

Global-scale models of climate change have been developed and refined for decades. There are rapidly expanding efforts to develop regional-scale Earth system models (EaSMs) to capture feedbacks between biophysical systems and socioeconomic conditions—encompassing technological development, policies, demographic shifts and management decisions (Webler et al. 2011; Weaver et al. 2013). Ongoing research efforts seek to improve the predictability of EaSMs at finer temporal and spatial scales (Weaver et al. 2013). Researchers and managers are calling for regional climate change impacts research to move away from an old paradigm of predicting impacts of climate change and toward a paradigm of identifying vulnerabilities and tipping points in environmental and socioeconomic systems (Weaver et al. 2013; Kasperson 2011; Kirchhoff).

There are untapped opportunities to provide specific types of climate change impacts boundary objects to specific groups of natural resource stakeholders, which would promote greater consideration of relevant science in decision-making (McNie 2013; Lemos et al. 2014; Haigh et al. 2015). Case studies nationally support the notion that greater energy must be invested in developing and linking models of environmental change and defining a role for a broader community of users (Webler et al. 2011; McNie 2013; Lemos et al. 2014; Haigh et al. 2015). Webler et al. (2011) suggest three specific questions that modeling research teams must consider in the design and development stages: 1) who should be using these models and how will they be introduced to the models and model outputs? 2) how should accuracy and uncertainties be communicated? And, 3) how can the utility of models for decision makers be assessed?

5.5 Interdisciplinary teams

Research that integrates multiple different areas of expertise and perspectives on system behaviors is necessary to address massively complex environmental and social challenges (Benda et al. 2002; Kasperson 2011; Kirchhoff et al. 2013; McGreavy et al. 2013). While there is an obvious need to integrate disciplinary knowledge to address complex problems, there are well-documented challenges associated with conducting interdisciplinary research in academia (Thompson 2009; McGreavy et al. 2013). Disciplinary experts, who are trained in specific theories and methodological skills often face communication barriers when communicating about their work with others from outside of their discipline (Benda et al. 2002; Sarewitz et al. 2000; Thompson 2009). There is value in describing behaviors that enhance collective communication competence (Jablin & Putnam 2000; Thompson 2009). Communication competence includes having knowledge of appropriate norms and rules and the ability to take different perspectives and encode and decode messages (Jablin & Putnam 2000).

Durfee et al. (2004) suggest that interdisciplinary teams typically progress through stages: First, the "mutually defensive" phase characterized by a reliance on jargon, discussions of measurements and indices, confusion about possibilities for progress, and mutual incomprehension (Durfee et al. 2004; O'Rourke et al. 2013). Second, teams learn to speak in concepts and discuss analogies to explain physical realities (Durfee et al. 2004; O'Rourke et al. 2013). Finally, research teams enter a phase of "storytelling", in which a mutual narrative is developed and generative conversations can occur (Durfee et al. 2004).

Thompson (2009), in an ethnographic study of an interdisciplinary environmental research team at a Western US university, found that processes foundational to communication competence include: spending time together, practicing trust, engaging in task talk and explicitly discussing language differences. Facilitation literature supports these recommendations for teams (Senge et al. 2005; Scharmer 2009). Processes that interfered with effective interdisciplinary collaboration included: expressing negative humor and sarcasm, debating expertise, communicating boredom, and jockeying for power (Thompson 2009). Achieving communication competence involves regular maintenance (Durfee et al. 2004; Jablin & Putnam 2000; Thompson 2009). Interdisciplinary research often requires an expenditure of time and energy that detracts from disciplinary work (Thompson 2009). Spending time in interdisciplinary group meetings “hashing out” different uses of technical terms, for example, may lead to considerable frustration among some scientists (Thompson 2009). The fact that interdisciplinary research can require large investments of time and energy and a tolerance for working through conflict underscores the importance of 1) leaders who can promote a unified project vision and 2) communicators who can facilitate knowledge sharing and synthesis among different areas of specialization (Jablin & Putnam 2000; Thompson 2009; Sharmer 2009; Senge et al. 2015).

5.6 ORGANIZATIONAL LEARNING AND CHANGE

The concept of Theory U, advanced by Scharmer (2009) is useful for conceptualizing the process that interdisciplinary research teams engage in when seeking to fulfill a boundary-spanning role and deliver actionable climate science information to decision makers (Figure 5.1). In the proposal writing phase scientists begin to conceptualize a problem, consider collaborators who will be able to provide disciplinary expertise and bring them into the planning process. As the team reckons with different mental models, disciplinary cultures and visions of the role of non-academic stakeholders the process must slow down and make room for “presencing” or connecting to sources of inspiration and original goals. In order to move forward out of this phase with new solutions, team members must enter a phase of intensive interaction and cross-talk to learn from one other and test approaches (Scharmer 2009; Senge at al. 2015).

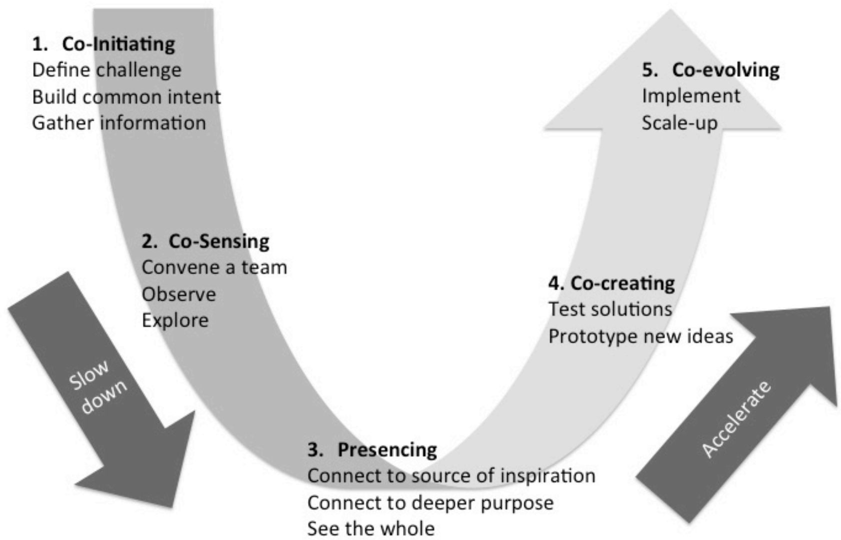


Figure 5.1 Theory U for interdisciplinary team research processes. Adapted from Scharmer 2009.

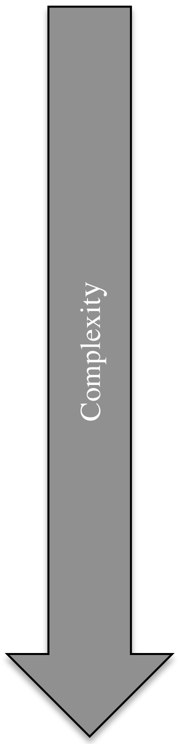
Interdisciplinary research teams can be viewed as learning organizations. A core value of a learning organization is continual updating and incorporating new information (Segalàs et al. 2008). An effective learning organization invests in leadership to assist individuals in finding purpose, facilitating structures for personal learning and getting feedback (Moilanen 2005). Measuring and evaluating learning at both the individual and the organizational level is challenging task (Novak & Cañas 2008; Edmondson 2000; Segalàs et al. 2008; Moilanen 2005). However, actively measuring learning can suggest concrete pathways for organizations to incorporate new knowledge and new practices

(Moilanen 2005). The process of evaluating organizational learning supports organizational change to face emerging challenges (Moilanen 2005, Senge et al. 2005; Scharmer 2009).

Discussions of difficult aspects of team processes may often be framed as stories of frustration, disappointment or disillusionment. However, when participants reflect on their experience working through challenges they also often identify insights about processes that led to new learning (or "ah-ha" moments) and development of new skills (Scharmer 2009).

Bloom's Taxonomy, developed by Benjamin Bloom and collaborators in the 1950s, is widely used framework for categorizing educational goals in K-12 and university instructional settings (Sosniak 1994; Marzano 2001). The taxonomy defines six levels of mental processing of increasing sophistication and complexity. The framework has been modified and elaborated upon by successive generations of educators (Sosniak 1994). Revised conceptualizations of Bloom's taxonomy have focused on dynamic, active processes associated with how thinkers encounter and work with knowledge (Sosniak 1994). Table 5.1 below classifies six levels of learning objectives and describes outcomes or products associated with those levels of learning. This table provides a framework for assessing researchers' developing understandings of stakeholder engagement. The following are examples of intellectual behaviors associated with engaging stakeholders in interdisciplinary environmental science research.

Table 5.1 *Adaptation of Bloom's Taxonomy. (Informed by Sosniak, 1994 and Marzano, 2001 with examples of relevant outcomes related to engaging with stakeholders to produce actionable climate impacts model outputs.)*



Levels of Intellectual Behavior Important in Learning	Actions	**Outcomes** *Examples of Products*
Knowledge	Recognizing Recalling	**Recall of specifics** *Name potential stakeholders, identify project goals*
Comprehension	Interpreting Summarizing Explaining	**Understanding of universals** *Articulate roles for stakeholders in research*
Application	Executing Implementing	**Understanding of relationships between ideas** *Design questions for stakeholders to respond to*
Analysis	Differentiating Organizing Attributing	**Hypothesis generating and testing** *Consider stakeholder recommendations, explore model development opportunities and approaches to inform non-academic stakeholder audiences*
Evaluation	Critiquing Assessing	**Consideration of information and formation of judgments** *Assess utilization of stakeholder input and feedback in model development*
Synthesis	Designing Creating	**Knowledge utilization and metacognition** *Develop tools and resources for stakeholders, evolve new research directions*

5.7 Methods

This section explores methods used to study researchers' evolving perceptions and development of boundary spanning skills. The structure of the BioEarth research team is briefly described and the role of the communication working is explained. Next, participant observation and thematic analysis methods are detailed. Mental modeling is described as an approach to analyze individuals' conceptualization of relationships among ideas. Finally, potential limitations of the research methods are explored.

5.7.a BioEarth as a case study

BioEarth researchers were arranged in five working groups, with several individuals having roles in multiple working groups. Periodic integration meetings and annual all-hand meetings were designed to facilitate team collaboration and synthesis of working groups' efforts. The five working groups are: 1) terrestrial modeling, 2) atmospheric modeling, 3) economic modeling, 4) cyberinfrastructure, and 5) communication and stakeholder engagement. The communication team sought to form a bridge for information sharing between modelers and a diverse group of agriculture and natural resource decision makers in the Northwest US. Within the BioEarth project a form of "ad hoc" boundary organization formation was undertaken, drawing on skills and resources from WSU's Center for Sustaining Agriculture and Natural Resources and a history of university extension programs. Researchers on the team with stakeholder engagement expertise designed an approach to incorporate stakeholder perspectives into the regional integrated environmental model development process and develop strategies for communicating model results to various groups of stakeholders.

Key questions addressed in this analysis include: How did BioEarth co-PIs' perceptions of stakeholders evolve over time? What new skills and insights did researchers acquire? What role did models play in bridging the gap between scientific research and decision-making? Tracking researchers' perceptions over the course of the project enabled assessment of what individuals learned and whether they developed boundary-spanning skills. Based on interviews with researchers, this research assessed the degree to which BioEarth models were utilized span boundaries between research and resource management communities. Practices that promoted boundary-spanning and challenges that arose during the research effort were explored.

5.7.b Participant observation

This research employed a participant observation approach with the goal of understanding BioEarth researchers' evolving perceptions (Corbin & Strauss 1990; Thompson 2009). The communication working group coordinated a series of stakeholder advisory workshops and produced synthesis reports describing key workshop findings. The graduate student participant observer within the communication working group participated in research meetings and recorded detailed observational notes. Notes covered technical research information being communicated as well as instances of confusion, tension and collaborative communication occurring within the research team. Between summer of 2011 and early winter of 2016, over 200 pages of typed detailed notes about the content of BioEarth research team presentations, discussions and interactions were recorded. Six stakeholder workshops were conducted, during which BioEarth researchers presented examples of process-based environmental model applications and outputs and learned from stakeholders about social and environmental change concerns and information needs. These workshops totaled approximately 40 hours, and resulted in over 60 pages of detailed notes. Corbin & Strauss (1990) suggest that the process of recording group interactions as a participant observer can enhance the researcher's awareness of subtleties in communication and encourage thorough, in-depth data collection.

Interviews were conducted with BioEarth co-PIs at the beginning of the project in July 2011 (18 interviews consisting of all of the original co-PIs), mid-point of the project in October 2013 (15 interviews consisting of all of the actively participating original co-PIs) and in the fifth year of the project funding cycle in November 2015-January 2016 (13 of the original co-PIs, plus two new co-PIs who became more active in the research effort after the mid-point interviews). Interviews followed a semi-structured format consisting of 12-15 questions with sub-prompts to elicit more specific information (Wolcott 1994; Kvale & Brinkmann 2009; Seidman 2013). The communication research group also conducted online surveys of researchers using multiple choice and Likert scale (rating) questions at the outset, midpoint and endpoint of the 5-year research program (Wolcott 1994).

Interview questions explored researchers' reflections about their role in the model development process and the degree to which stakeholder interactions informed their work and their learning. Researchers' descriptions of primary project challenges and understandings of stakeholders' information needs were tracked over the course of the project. In the fifth year of BioEarth, central questions guiding the interviews included: Have researchers developed boundary-spanning capabilities? And if so, what practices promoted development of those skills?

5.7.c Thematic analysis

Thematic analysis is the analytical methodology employed to synthesize and describe survey and interview data. Thematic analysis is a relatively straightforward form of qualitative analysis, and as such presents findings in a manner that is accessible to a broad audience of scientists trained in different disciplines and practitioners working at the interface of environmental science and decision-making (Wolcott 1994; Braun & Clarke 2006; Charmaz & McMullen 2011). Thematic analysis is useful in distilling messages and summarizing key features from a large body of data and informing policy and programmatic development (Charmaz & McMullen 2011; Braun & Clarke 2006). Thematic analysis is a poorly demarcated methodological approach, but is widely in qualitative social sciences research. Holloway and Todres (2003) identify "thematizing meanings" as a central skill across all forms of qualitative analysis.

Some descriptions of the process of identifying themes focus on "allowing themes to emerge organically in the analysis", emphasizing the concept that key themes should not be pre-determined by the analyst (Boyatzis 1998). In a departure from this focus on allowing themes to emerge organically from interview data, other scholars emphasize that researchers always play an active role in identifying themes, selecting which are of interest, and reporting them (Wolcott 1994; Holloway & Todres 2003; Braun & Clarke 2006). Thematic analysis has similarities to grounded theory analysis, but is not driven by the premise that analysis should be directed toward theory development (Holloway & Todres 2003; Charmaz & McMullen 2011).

NVivo 10 Qualitative Analysis software was used to code interview transcripts at the sentence and paragraph level and query relationships among codes. The interview coding process began with the graduate student researcher closely reading interview transcripts and identifying descriptive topics of discussion. Consistencies and changes in the interviews over time and consistencies and differences among researchers were considered. Common descriptive codes across multiple interviews suggest core themes in the data (Saldana 2012). Memo writing is an important component of thematic analysis (Braun & Clarke 2006; Saldana 2012). Memos are researchers' notes on comparisons of codes and emerging categories. Eventually a category saturates when no new codes related to it are being developed, and the researcher is able to identify core categories and axial categories (Saldana 2012). It is important in thematic analysis to be thorough and rigorous in analyzing data to consider how themes fit together and to take care to avoid claiming that there is a pattern in the data based on a few idiosyncratic examples (Wolcott 1994; Charmaz & McMullen 2011).

BioEarth researchers' survey responses at years one, three and five of the project were recorded in Excel spreadsheets and analyzed quantitatively alongside qualitative data. A collective mental model diagram of BioEarth researchers' experiences based on fifth year interviews was created to illustrate key common perceptions of project co-PIs.

5.7.d Mental models

Based on analysis of interview data, researchers' mental models of stakeholder engagement and boundary spanning processes were diagrammed. Mental models are personal understandings or "models" of systems that people carry in their heads and refer to in their decision-making (Gentner & Stevens 1983; Matheiu et al. 2000). Mental models can be represented visually as concept maps that make the connections between ideas explicit and illustrate causal relationships (Matheiu et al. 2000). Mental models are, like all models, simplifications. Our inability to "see" and internalize the entire system all at once limits the size and complexity of the mental models that we develop (Meadows & Wright 2008; Segalàs et al. 2008). Mental models are shaped by our experiences and filtered by our interpretations. Concept maps are tools for organizing and representing knowledge graphically. By naming key concepts and themes, considering relationships among ideas and representing those connections visually, frameworks of understanding can be developed and compared (Novak & Cañas 2008; Segalàs et al. 2008). When implemented effectively, concept mapping encourages reflection and promotes engaged, active learning (Edmondson 2000; Novak & Cañas 2008; Segalàs et al. 2008).

5.7.e Potential limitations of the research approach

A potential shortcoming of using a thematic analysis approach to analyze interview data and ethnographic notes is that it is often perceived to be less rigorous and less theoretically driven than grounded theory analysis, content analysis, narrative analysis or other qualitative research methods with long traditions of use (Wolcott 1994; Charmaz & McMullen 2011). Additionally, it should be noted that the graduate student researcher on the communication research team was the sole interviewer, coder and analyst of semi-structured interviews conducted with co-PIs. It is possible that another researcher would identify different concepts and themes in the data. However, frequent discussions about project challenges and instances of new insights or learning within the communication working group strengthened interpretation of fellow researchers' experiences.

The interviewer and analyst in this research was also engaged in the work of planning BioEarth stakeholder engagement workshops and synthesizing information from those workshops. It is likely that this dual role has influenced the interpretation of survey and interview data. Also, it is possible that co-PIs were selective in sharing their perceptions of successes and challenges in the research effort because of the interviewer's position as a graduate student within the project.

Relatively little research has explored processes of learning and changing attitudes among scientists and stakeholders as they engage in regional-scale earth systems modeling research (Kirchhoff et al. 2013). It should be noted that the individuals engaged as research subjects in this project are not necessarily a representative sample of all climate scientists and climate communication and extension practitioners in the region. This is a case study of one 5-year funded project based at Washington State University with collaborating researchers from several other institutions. In-depth exploration of changing perceptions and learning within BioEarth, however, may shed light on opportunities for effective boundary spanning in other environmental modeling and research contexts.

5.8 RESULTS

Results based on thematic analysis of interviews conducted with BioEarth co-PIs are divided into six sections: 1) mental models of interdisciplinary boundary-spanning research, 2) evolving definitions of a successful project, 3) perceptions of the role of stakeholders in research, 4) reflections about the process of utilizing stakeholders' input, 5) lessons learned about interdisciplinary team processes, and 6) reflections on BioEarth models as boundary objects.

5.8.a Mental models of interdisciplinary boundary-spanning research

Initial coding of the BioEarth co-PIs' interviews generated 65 codes related to researchers' experience within the BioEarth regional climate change impacts modeling effort. Common, prominent relationships between ideas that researchers identified are illustrated (Figure 5.2). This collective mental model of the BioEarth research team illustrates two central themes (challenges and new learning), which relate to seven sub-themes and 24 related topics. Arrows between topics show the directions of influence among topics.

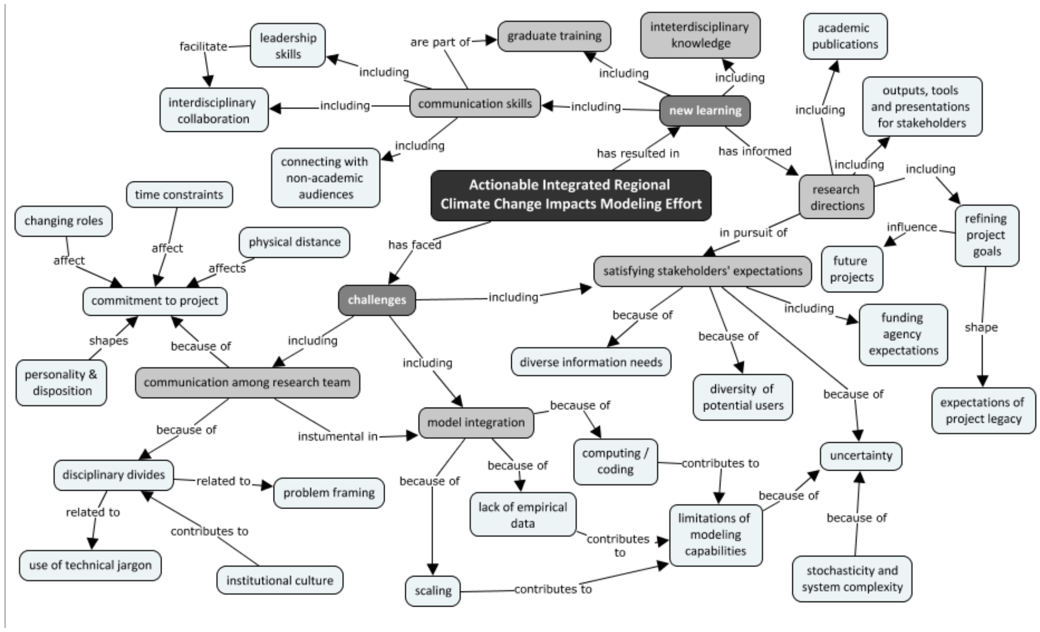


Figure 5.2 Illustration of BioEarth co-PIs' collective mental model of research effort challenges and new learning in the 5th year of the project. Connections and causal relationships among concepts will be explored in the following discussion sections.

In a report of researchers' perceptions of stakeholder engagement at the outset of BioEarth (see Chapter 3) the communication working group outlined three continuums representing researcher perceptions of: 1) definitions of project success—ranging from success defined as technical capabilities and contribution of new scientific knowledge to success defined as active utilization of the model to inform management decisions; 2) who the primary stakeholders are, ranging from a relatively narrow definition of stakeholders focused on academic researchers in related disciplines to a broad conception of stakeholders encompassing many kinds of decision makers, including the "common taxpayers" in the study region; and 3) perceptions of challenges within the research process, ranging from a focus on technical challenges to a focus on communication and stakeholder engagement. Those topics were revisited is mid-point and end-point interviews.

In the fifth year of the BioEarth research project, further consideration of the "continuums of perceptions concept" suggests that this framework is incomplete and insufficient to explain researchers' different visions of project goals, stakeholder engagement and project challenges. As the project progressed, researchers' mental models of goals, challenges and stakeholder roles became more complex. For example, several co-PIs reflected that the "technical challenge" of writing code for new processes is directly linked to the "communication challenge" of understanding which processes stakeholders are most concerned with.

5.8.b Definitions of a successful project

Managing emerging understandings of modeling capabilities and changing goals for specific outputs is a significant challenge. In the mid-point and fifth-year interviews, co-PIs discussed the challenge of balancing in-depth projections of climate change impacts with the fact that stakeholders in different roles have a diverse array of highly specific information needs.

> *"We get a diverse set of input which is hard to integrate or prioritize… We've talked about the potential of honing in a little bit more with one kind of stakeholder and one specific region or challenge. And so far we haven't had the capacity or the attention to do that. I think there's still potential for us to do that in a final year or two of the project, but that*

takes some strategy from our communication team and also the full research team in terms of where we want to go" (co-PI 3, 2013).

BioEarth PIs conveyed a mixture of disillusionment about goals not met and cautious optimism about final products toward the end of the project. There are tangible efforts underway to integrate specific model components and produce model outputs that will be salient and accessible for stakeholders, but a common refrain was, "I learned that producing actionable climate science is much harder that I expected". At the midpoint of the project, a co-PI said:

> *"A point of concern is the timeline of the project… We're to a point where other projects may have more clearly defined the scenarios or the specific questions they are going to address… If we don't spend more time discussing the integrated questions, and start putting together a set of scenarios that address those integrated questions soon then we'll run out of time, or not do a very good job answering those integrated questions" (co-PI 15, 2013).*

In the fifth year interviews, several of the co-PIs expressed regret that there was relatively little in the way of explicit integration of models of different systems to point to in the project, but underscored their hopeful outlook for future integration of BioEarth model outputs and tools that would be relevant to stakeholders:

> *"I think we still need to keep our eyes and ears wide open and provide relevant, unbiased information in a variety of different ways… In the*

absence of [correct] information from the university, [stakeholders] go anywhere they can to get it. And the risk is that if people don't come through the extension outlet, they go to the Internet, and they believe whatever they see" (co-PI 7, 2015).

The lead co-PI described how BioEarth project goals changed over time. There was increasing emphasis on linking models to address specific resource management information needs (a "modular models" approach) rather than a "comprehensive model" vision seeking to simultaneously link models of all the component systems. This researcher saw interactions with stakeholders as one of the key processes that had informed their vision for the project:

"We had to change the way that we were thinking about the modeling side of it, entirely. We went from having the idea that we were going to make this massive piece of code that was all integrated… it was really kind of impossible to do because every model had its own code, which constantly updates, and you don't want to have to keep updating this piece of code just because the models update. So it didn't make sense. But also because we never did really conceive of a particular application where we would use the whole thing at one time" (co-PI 14, 2015).

5.8.c Perceptions of the role of stakeholders in research

In surveys, BioEarth co-PIs were asked to assess the utility of stakeholder engagement at different phases of the research project. Only eight of the original 18 co-

PIs completed a survey at each phase of the research project. Among those co-PIs who completed all surveys, ratings on a scale of 0-5, with "0" representing there is no role for non-academic stakeholders at the beginning phase of research and "5" signifying that stakeholder input at the beginning phase of research is critically important to the project's success, the average rating of importance of stakeholder involvement increased from an average of 2.8 in 2011 to 3.9 in 2015. Researchers' assessments of the importance of stakeholder engagement in the middle phase (average scores ranging from 3.7-3.8) and end phase (average scores ranging from 4-4.3) were more consistent over the course of the project.

Widespread consistency in individuals' assessments of the importance of engaging different sectors of stakeholders in the BioEarth research project was observed at all stages in the project. Engagement with academic, government and industry stakeholders was rated as being highly important for project success, while engagement with NGOs was rated as somewhat less important and engagement with the general public was rated as relatively unimportant for project success.

In thinking about who stakeholders are, many co-PIs understood that federal agencies that fund research are among the stakeholders for whom model outputs may be relevant. Especially among atmospheric process modelers, who have a long history of working with regional government agencies via the Northwest AIRQUEST air quality forecasting research consortium, there is a direct link perceived between the ideas of a) funding agencies that support research and b) stakeholders who use research.

The co-PIs on the team with a background in economics consistently communicated an interest in considering the general public's policy preferences and the costs and benefits of natural resource management decisions. This may be a factor of disciplinary training that focuses on considering the trade-offs in decision-making.

> *"Usually the obvious stakeholders are those for whom benefits or costs are particularly concentrated. But when we're considering water issues that tend to deal with capital infrastructure that then requires public spending, everyone that lives in the region and that contributes financially to that is a stakeholder I think. So, often the groups who deal with us are either the policymakers and users of surface water are obviously included… But the representatives of the general public are not as well represented" (co-PI 10, 2013).*

BioEarth co-PIs vary in terms of how invested they are in the research process and the goals of supplying useable climate science information to stakeholders. Some researchers are more motivated and driven by the vision of decision-relevance than others, just as differences have been observed in researchers' level of interest and commitment to interdisciplinary teams. A co-PI clarified a perspective that they, and other modelers, would benefit from iterative, focused interactions with regional stakeholders. Essentially, they see this as a process that can't be successful without commitment to information transfer in both directions. There is value in explicitly scientists as stakeholders in actionable science research. This leads to a more complete conceptualization of the forums in which we are sharing information:

> *"You're using us but I think you could use us more. Don't be hesitant to totally embed us in what you're trying to do because you're (going to be doing more than) just informing… We're trying to say that we need the stakeholders to inform us about what we're doing, but for what you're doing you need us because we are your stakeholders" (co-PI 14, 2013).*

Several BioEarth researchers explained that their work had a long history of policy relevance. For example, one co-PI said that the issue-based workshops mostly confirmed what they already knew about stakeholder information needs and decision-making contexts. This co-PI, while they felt that they had not necessarily learned new information from stakeholder workshops, stated that summary reports and spreadsheets of input were a useful way to track which questions could be "checked off" within the BioEarth research effort.

A co-PI who focuses on extension for forest landowners expressed frustration that the project in it's final year had generated very little of substance that he could take to the specific decision-makers he works with in the field. This disconnect highlights how easily modelers may overestimate the ability of resource management decision makers, including extension professionals, to synthesize and interpret earth systems model outputs. Modelers do not always have the expertise to consider the specifics of stakeholders' information needs and produce highly specific analyses. At the same time, extension professionals do not always have the technical knowledge to interact directly with modelers and clarify outputs and implications. It is important here to note that the BioEarth project is not yet complete. Some of outputs synthesizing findings are still being planned, including a webinar series and final workshop. The BioEarth project can be seen as a foundation for future federally funded research efforts in the region, which will build upon research questions and working relationships established in this project.

Workshops were a valuable opportunity for academic scientists to interact with a broader community of government agency scientists and resource managers.

> *"Stakeholder meetings have led to new partnerships. Each of us has our own contacts, and now, through collaboration with people from different disciplines, I'm meeting different people in these agencies. So, now I frequently work with a federal agency atmospheric scientist, and I wouldn't necessarily have met her without BioEarth" (co-PI 18, 2015).*

Several co-PIs suggested that while they agree that stakeholder questions are important in principle to drive research, most of information needs that stakeholders have raised at workshops are too specific for BioEarth modeling efforts to directly inform decisions. One co-PI explained that they enjoy having opportunities to talk to stakeholders, but did not feel well equipped to make those connections or arrange forums for scientist-stakeholder knowledge sharing independently. This co-PI explained that they place a high value on the role of collaborators in extension and communication roles who can play a role in facilitating that dialogue. They noted that several outcomes of the stakeholder workshop were somewhat surprising and of great interest to modelers. For example, hearing that stakeholders desire more information about C sequestration in forests and rangeland vegetation dynamics shaped model development priorities.

In interviews conducted in the fifth year of BioEarth, eight co-PIs expressed the viewpoint that sustaining communication over time with stakeholders was key to producing actionable science and spanning the boundaries between research and decision-making.

> *"Building relationships and communication skills takes time, and is something that people can get better at with practice" (co-PI 19, 2015).*

Two co-PIs in particular emphasized that a central lesson they took from BioEarth was that stakeholder engagement as an ongoing process that doesn't start and end with a particular research project:

> *"You have to cultivate those relationships over time and use institutional resources to support that sustained collaboration" (co-PI 16, 2015).*

5.8.d Reflections on utilizing stakeholders' input

Following each BioEarth stakeholder workshop the communication working group prepared 3-4 page summary reports about stakeholders' primary concerns and information needs and shared those reports with fellow PIs and graduate students. The communication team also worked with co-PIs to produce spreadsheets of stakeholders' recommendations about model and scenario development. These spreadsheets were envisioned as tools to encourage researchers to interact directly with stakeholders' questions and consider specifically how their work might address those information needs. Reflecting on methods that were used to support researcher engagement with stakeholder recommendations, attitudes were mixed. Ultimately, roughly half of the co-PIs felt that summarizing stakeholders' information needs in this fashion is a potentially useful tool for research teams, while others were somewhat frustrated with the process. One co-PI who found the interaction with spreadsheets of recommendations to be of limited utility said:

> *"I had a really difficult time responding to the spreadsheets... It's actually a good illustration of how interdisciplinary work is difficult because a lot of the ways that the questions were approached or phrased or characterized were kind of orthogonal to the way I think, so its very difficult to feel like I was contributing anything when filling in cells in the spreadsheet there" (co-PI 9, 2015).*

Describing the challenge of managing expectations, another researcher explained:

> *"The level of detail that we're able to put in the model just isn't there. For example, the task you gave (a graduate student) and I to investigate invasive species. The way the model is written now there's just a grass and tree, and no way to assume a change in species specifically. These models take so much CPU time and input data and there are limitations on the kinds of questions we can address. We cant address change in cheat grass, because cheat grass isn't in the model" (co-PI 18, 2013).*

Other PIs expressed the opinion that the spreadsheet process had been a worthwhile endeavor. Some concern was expressed that researchers on the team interpret information needs in different ways and do not always understand model capabilities outside of their own area of expertise. Limitations in interdisciplinary knowledge may inhibit ability to see where research efforts overlap and define model development priorities. The lead co-PI reflected:

> *"I hate to say this because there were so many rows (suggestions) and it got overwhelming. But what if we had two or three people assigned to each row and then they did it independently and their responses were compiled? We would have gotten more of an accurate sampling of what we could do with responding to those suggestions" (co-PI 14, 2015).*

5.8.e Lessons learned about interdisciplinary team processes

Asked to reflect on what they had learned over the course of the project, a researcher noted that they gained an appreciation for how important it is to engage with stakeholders and understand their concerns about regional environmental change. This individual notes the explicit connection between stakeholders' information needs and the need for interdisciplinary research.

> *"It's good for researchers to learn about how stakeholders are thinking. Stakeholders are always going to be asking questions that transcend disciplines" (co-PI 10, 2015).*

Researchers often noted instances in which institutional culture gets in the way of synthesis of ideas across disciplines. One researcher contrasted their experience in BioEarth with a European research team they were affiliated with. They noted that American university culture does not seem to fully value collaborative work and that European institutions more readily ensured that components of each research effort built upon one another. Another co-PI commented that academic traditions and policies interfere with interdisciplinary research:

> *"Professors are usually not reviewed for doing collaborative research. The way tenure review works and the way people write letters they focus on whether this person is an expert in their field, they focus on their first author papers. If a person is very collaborative he or she can end up on a whole lot of papers but not showing up as carving a niche in terms of subjects and that can be problematic in the tenure review process and if those people never get to be tenured you never have those people collaborating at all levels" (co-PI 13, 2015)*

Some participants noted that aspects of personality affect attitudes toward interdisciplinary collaboration. Referring to Meyers-Briggs personality types and the distinction between "sensing" types (who focus on the immediate, practical, and logical) and "intuiting" types (who tend to be driven by an interest in patterns and strategy and have less interest in details), one co-PI said:

"If you're a sensing type, you typically don't like collaborative work, this has been shown with a high degree of confidence" (co-PI 14, 2015).

The co-PI explained that BioEarth benefitted from a shared commitment to collaboration, but that mutual understanding did not always come easily:

"We sat down for hours, Week after week after week… Hammering out jargon, hammering out methodology, to the point where we could have some clarity in what each other was doing and what our capabilities were and what things meant" (co-PI 14, 2015).

Discipline-specific terminology is frequently mentioned as one of the key challenges to navigate in interdisciplinary research. However, use of jargon was by no means the only significant hurdle in the effort to link models. A co-PI was quick to note that many major challenges came from a lack of relevant input data:

"Some of the components of the study that we did didn't fit together as well as I would have liked because of information deficiencies--deficiencies in data. So a lot of the difficulty that we had in our interdisciplinary work was not only conceptual" (co-PI 9, 2015).

Several members of the team noted that in any new interdisciplinary effort there must inevitably be a large up-front investment of time and energy devoted to talking across disciplines. These researchers agreed that BioEarth had paved the way for future collaborations by creating working relationships among specific individuals.

5.8.f Reflections on BioEarth models as boundary objects

BioEarth is characteristic of regional earth systems modeling efforts in that the project proposal identified producing actionable informational resources for natural resource managers as a central goal of the project. The research team grappled with questions about what kinds of model outputs could be produced and how regional decision-makers might interact with those outputs. BioEarth co-PIs did not all enter the project with the same expectations of how stakeholders might interact with models and model outputs. Over the course of the project new visions of project goals emerged, shifting from a vision of an integrated comprehensive model linking terrestrial, hydrologic and atmospheric systems to a vision of modular model components that could be brought together to explore projected outcomes of specific management decisions and evaluate possible unintended consequences.

Perceptions shared by BioEarth co-PIs in the fifth year of the project indicate that teams must navigate issues of model domain, scale and key processes before engaging in discussion about those topics with decision makers. Adding new processes and features to models was a major challenge, as was coupling models:

> *"Doing that kind of model coupling is really hard to do without lots of dedicated programmers. You know, we're all scientists training PhD students and Post-docs and they need to publish papers, they need to come up with scientific findings. But at the same time we need to come up with people who are really focused on improving the computational efficiency*

of these models, improving the visualization, solving bugs, improving specificity… we need to think of a way to do this where there is money and more of a tech support infrastructure" (co-PI 16, 2015).

Dealing with differences in the time scales at which various biophysical, sociopolitical and economic processes occur and are modeled requires new and creative approaches:

> "*The biggest challenge with this sort of modeling is when you're doing biophysical modeling and economic modeling is interacting in time and space. Biophysical models are made to work at fairly high spatial resolutions and over fairly short time steps. But economic models represent decisions that are made in more discrete terms… You decide what to plant once a year. Or you decide to invest in new capital like a more efficient irrigation system maybe even less than once a year" (co-PI 10, 2013).*

Managing the different spatial scales over which models are run is also a significant challenge in efforts like BioEarth:

> *"(Two fellow co-PIs) are leading a project on the nitrogen budget for the Northwest. One simple thing that we haven't resolved is they want to study the entire river basin, makes sense right? But in atmospheric modeling we like square grid cells, we like straight lines. So how do compromise because you want to do squiggly lines, you can do area average and what*

not, but how do you determining what is atmospherically transported into a squiggly shape? Just mathematically that's difficult to determine" (co-PI 13, 2015).

5.9 Concluding recommendations for boundary-spanning research teams

This case study analysis explored BioEarth researchers' evolving perceptions and learning over a five-year period. Descriptions of researchers' development of boundary spanning skills and lessons learned about models as boundary objects were presented. BioEarth co-PIs' experiences can inform the design of future university-based actionable research efforts and contribute to a developing understanding the characteristics of effective boundary organization function. Among BioEarth co-PIs, mental models of stakeholder engagement processes and project goals and challenges became more complex as research effort progressed. Grappling with challenges associated with interdisciplinary, stakeholder-oriented research led to new approaches and opened opportunities for strengthened networks of collaboration in the future.

Based on analysis of interviews and surveys conducted with 20 BioEarth co-PIs, this chapter makes recommendations for granting agencies, universities and individual researchers seeking to span boundaries between research teams and diverse stakeholders for actionable environmental modeling. These recommendations support previously published insights about effective boundary spanning. Four recommendations for university-based boundary-spanning research efforts are drawn from the results: 1) allow flexibility in research questions, team structure and timelines, 2) prioritize organizational frameworks that develop social capital among researchers and decision-makers, 3) create tools for assessing stakeholder input and prioritizing actions, and 4) create leadership and communication training opportunities for students and faculty. These recommendations are discussed in detail below.

1. Allow flexibility in research questions, team structure and timelines

Being responsive to stakeholder input depends on having flexibility research goals and building in time and resources for changing course as necessary. Modeling teams must revisit and update approaches as they learn more about stakeholders' information priorities and future scenarios of interest. In BioEarth, interactions with stakeholders led to evolving academic goals. The objective of model development shifted from creating a comprehensive integrated model to creating a modular model framework to address specific information needs. Sustaining communication over time with stakeholders was key to producing actionable science.

BioEarth co-PIs expressed growing understanding that relationships with non-academic stakeholders must be built over time and that those relationships require intentional planning and effort to maintain. This finding supports literature on boundary spanning organizations, which describes longevity over time as a key determinant of successful networks of information sharing (Feldman & Ingram 2009; Dilling & Lemos 2011; McNie 2013; Kirchhoff et al. 2013; Lemos et al. 2014). Accommodating the time and effort it takes to establish relationships with decision-makers and build trust and buy-in may require longer sustained collaborative research efforts than the typical two-five year funding cycle typically imposed by federal granting agencies (Dilling & Lemos 2011).

2. Prioritize organizational frameworks that develop social capital among researchers and decision-makers

BioEarth researchers frequently noted that finding balance between providing actionable information to specific stakeholders and addressing diverse information needs was a challenge. Perceptions of the utility of thematically arranged stakeholder workshops were mixed. Some researchers appreciated hearing from diverse regional stakeholders and stated that workshops promoted interesting dialogue about regional challenges and information needs. Other individuals suggested that the team's ability to rapidly produce specific decision-relevant outputs would have been enhanced by a more targeted, intensive approach to stakeholder engagement.

Actionable science research teams benefit from efficient forums for interaction with stakeholders. Researchers on the BioEarth team frequently expressed regret and some frustration that the project had not achieved success in developing an online forum for researchers and stakeholders to interact. Researchers' sustained interest in having tools for information sharing suggests that increased effort should be put into developing online forums for regional climate change impacts modeling.

It is possible that the Northwest US lack a critical mass of researchers and modeling-savvy climate science users whose information needs and areas of interest correspond with the questions that the BioEarth research team addressed. Another possible explanation for marginal success thus far in establishing an online forum for information sharing among researchers and stakeholders is that the idea was "before it's time". Emerging relationships suggest that while the idea of an active online forum may have been premature, investing more energy in building and sustaining networks could contribute to active, useful online tools.

3. Create tools for assessing stakeholder input and prioritizing actions

BioEarth co-PIs emphasized that there should be a focus on efficiency and transparency in communicating about stakeholders' information needs. The communication working group generated spreadsheets of stakeholders' recommendations and asked researchers to consider and prioritize those recommendations. This process had mixed results. Researchers generally expressed support for tools designed to encourage dialogue about connections between science questions and management and policy decision-making questions. Reflecting on the fifth-year outcomes, it may have been worthwhile for the stakeholder engagement and communication working group to put more emphasis on the spreadsheet process and demonstrate to researchers that their input was needed to sift through a large volume of stakeholder input and to identify model and scenario development priorities.

There is interest in continuing to think about strategies to make engagement with stakeholder input efficient and meaningful. Framing stakeholders' complex concerns and questions in a manner that researchers can respond to requires deep knowledge of stakeholders' and researchers' operating contexts and skillful communication. Despite the concerted attempt at boundary spanning in BioEarth, a misalignment between stakeholders' priority information needs and climate change impacts model development capabilities was apparent. The majority of information needs that stakeholders raised at workshops were too specific to directly inform model development and integration directions in BioEarth.

4. Create leadership and communication training opportunities for students and faculty

It is critical for research teams to invest time up-front on interdisciplinary training. While there is a well-documented phenomenon of researchers feeling "burnt out" by too many meetings, research teams should not underestimate the value of back-and-forth communication in the early stages of the research process to define mutual goals and in the later stages of the project to test possible approaches and iterate solutions. The importance of graduate training programs in supporting interdisciplinary, boundary-spanning research should not be overlooked. BioEarth co-PIs noted that many of the specific model development and model linkage projects were being investigated as graduate research projects. When graduate students collaborate across disciplines innovative approaches and tools emerge. This suggests that universities and research departments should continue to develop opportunities for graduate students to be trained to consider science--policy interactions.

In order to motivate interdisciplinary teams and build shared understanding of project goals and the relationships between team members' contributions continued leadership skills training should be a goal of universities and funding agencies. Project leaders need to be able to: 1) identify working styles and play to people's strengths, 2) delegate tasks and responsibilities, 3) embrace transparency and seek input and feedback from team members, 4) have a healthy understanding of when to assert authority and change course, for example to restructure a project or ask a team member who is not contributing to reconsider their priorities, and 5) support informal team building. Universities can support effective leadership in interdisciplinary actionable science teams by providing strong administrative support.

Based on an exploration of changing perceptions and learning among BioEarth co-PIs over five years, this chapter has sought to define practices and approaches that support university-based environmental research teams becoming effective boundary spanning organizations. This work sheds light on opportunities for training opportunities for boundary spanning leaders. Online forums for researcher-stakeholder interaction and efficient processes for researchers to learn about and prioritize stakeholders' information needs are recommended. It is hoped that this research will support emerging interdisciplinary, actionable science teams in designing research and stakeholder engagement approaches that utilize existing boundary spanning capabilities and seek to develop those capacities at the level of institutions, individuals and outputs.

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CHAPTER SIX: COMPARATIVE ASSESSMENT OF REGIONAL CLIMATE CHANGE IMPACTS MODELING INITIATIVES

6.1 Reflecting on outcomes of research projects

This chapter synthesizes reflections from researchers involved in three Northwest US environmental modeling initiatives. Roles of non-academic stakeholders in shaping project outcomes are discussed. Frameworks for assessing approaches to engaging stakeholders in regional climate change impacts modeling are emerging and are not yet well developed (Healy 2009; Feldman & Ingram 2009; Hegger et al. 2012; Kirchhoff et al. 2013). There is a need for university-based interdisciplinary research teams to develop metrics to evaluate decision-relevant climate change impacts research (Healy 2009; Collins & Evans 2008; Weaver et al. 2013). Perceptions of project outcomes toward the conclusion REACCH, WISDM and BioEarth are assessed, leading to recommendations about evaluation metrics for stakeholder engagement processes in regional climate change impacts research teams. The chapter concludes with thoughts about effective practices for overcoming common barriers to producing accessible, credible and actionable climate science information for diverse stakeholders.

6.2 Describing three Northwest US climate modeling initiatives

WISDM, BioEarth and REACCH are university-based research efforts in the Northwest designed to integrate the efforts of large teams of scientists with diverse expertise. All three projects were designed to engage stakeholders and provide decision-relevant outputs. Research questions, team structures, leadership philosophies and study domains are different but overlapping among the three projects. Individual researchers engaged in the projects brought unique philosophies about the role of stakeholders to bear in their work. A number of researchers are involved with more than one of these projects. Several individuals are involved with all three initiatives. REACCH, BioEarth and WISDM were funded within one year of each other (2011 or 2012) by USDA National Institute of Food and Agriculture (NIFA) Agriculture and Food Research Initiative (AFRI) competitive grants. AFRI grants were established by Congress in the 2008 Farm Bill (USDA NIFA, 2016). These projects seek to generate new scientific insight about interconnected aspects of environmental change in the Northwest US: inland cereal production systems (REACCH), watershed-scale water management institutions (WISDM), and water and nutrient dynamics in regional forestland, rangeland and cropland agricultural systems (BioEarth). The organizational structures and general approaches to stakeholder engagement of each of the projects are outlined in table 6.1 below.

Table 6.1 *Characterizing three regional environmental change modeling projects*

1. WISDM (Watershed Integrated System Dynamics Modeling): Feedbacks among biogeochemical simulations, stakeholder perceptions, and behavior *Mission:* Improve understanding of interactions between water resources, water quality, climate change, and human behavior in agricultural and urban environments. Explore how primary water users can be involved in the research process to develop scientifically sound and economically feasible public policy.	
Grant Information	USDA National Institute of Food and Agriculture AFRI Competitive Grant. Start: August 15, 2012. End: August 15, 2017. Grant no. 2012-67003-19805. Approx. $1.5 million. *http://portal.nifa.usda.gov/web/crisprojectpages/0230079-watershed-integrated-system-dynamics-modeling-wisdm-feedbacks-among-biogeochemical-simulations-stakeholder-perceptions-and-behavior.html*
Specific Objectives	• Understand how climate and land use changes have affected and will affect water quantity and quality • Determine agricultural practices such as changing crop mix, fertilization, irrigation, and tillage, that will promote agricultural productivity under an altered hydrologic regime while preserving water quality and minimizing GHG emissions • Explore possibilities for dam operation, as it might evolve to meet irrigation needs

<table>
<tr><td></td><td>Consider how changes in economic conditions affect water use across space and time, and how regulatory institutions may adapt as water becomes more scarce</td></tr>
<tr><td>Organizational Structure</td><td>13 co-PIs and at least 5 graduate students. Hydrologic/ terrestrial modelers, economic modelers and system dynamics modelers have limited interaction with one another. Leadership encourages working groups to pursue research questions independently with full-group or integrated activities and meetings arising organically as researchers have issues or questions to discuss. Less formal integration structure than REACCH or BioEarth.</td></tr>
<tr><td>Approach to Stakeholder Engagement</td><td>Four watersheds for study were identified in the proposal. Basin-specific approaches to stakeholder engagement evolved based on political context and research capabilities. Collaborative system dynamics modeling has been underway with water managers in the Spokane River basin. In the Yakima River basin one goal is to integrate existing models in a gaming format allowing public interaction with scientific research that has already been co-developed. Process-oriented in the sense that model scope and content is seen as dependent on the needs and interests of project stakeholders; a comprehensive approach was not specified when the research began.</td></tr>
<tr><td colspan="2">2. BioEarth (Biosphere-relevant Regional Earth Systems Model): Understanding biogeochemical cycling in the context of climate variability using a regional earth modeling framework

Mission: Develop a regional earth system modeling framework that improves understanding of water, nitrogen and carbon flows in the context of inter-annual and decadal climate variability. Inform decision makers' strategies regarding natural and agricultural resource management.</td></tr>
<tr><td>Grant Information</td><td>USDA National Institute of Food and Agriculture AFRI Competitive Grant. Start: April 1, 2011. End: March 31, 2016 (one year no-cost extension). Grant no. 2011-67003-30346. Approx. $3 million. http://www.reeis.usda.gov/web/crisprojectpages/0224991-understanding-biogeochemical-cycling-in-the-context-of-climate-variability-using-a-regional-earth-modeling-framework.html</td></tr>
<tr><td>Specific Objectives</td><td>Develop skill in linking models to address questions about biogeochemical cycles
Understand the information needs of regional resource managers
Explicate potentially important responses to climate variability
Explore potential unintended consequences of resource management decisions within the region</td></tr>
<tr><td>Organizational Structure</td><td>18 co-PIs, mostly based at WSU with 2 researchers housed at PNNL, 1 at OSU, 1 at UVM, 1 at UCSB. Plus several post-docs and roughly 15 Masters and PhD students. Researchers arranged into five working groups: terrestrial, atmospheric, economics, cyberinfrastructure and communication/extension. Project vision has evolved toward a modular model concept to address specific questions about impacts of management decisions in the context of regional change. BioEarth is frequently discussed as a foundation for future research efforts.</td></tr>
<tr><td>Approach to Stakeholder Engagement</td><td>Resource management stakeholders were identified based on established contacts and snowball sampling. Stakeholders were engaged to help define researchable questions. Issue-based workshops were held in years 2-4 of the project. Modeling tools were defined at the project outset; specific applications and scenarios of interest have been defined based interactions with stakeholders.</td></tr>
<tr><td colspan="2">REACCH (Regional Approaches to Climate Change and Agriculture) for the Pacific Northwest Coordinated Agricultural Project (CAP)

Mission: Model impacts of climate change, farming practices, economic conditions and policies on the economic, environmental and social sustainability of cereal production agricultural systems in the inland Northwest region. Conduct experiments on biological and physical processes in agricultural systems. Determine social and economic factors influencing agricultural management, technology adoption, and development of policy for climate change adaptation and mitigation. Introduce innovative agricultural approaches to agricultural stakeholders and to k-12 and university educators and students.</td></tr>
<tr><td>Grant Information</td><td>USDA National Institute of Food and Agriculture AFRI Competitive Grant. Start: February 15, 2011. End: February 15, 2016 (one year no-cost extension). Grant no. 2011-68002-30191. Approx. $20 million. https://portal.nifa.usda.gov/web/crisprojectpages/0224850-regional-approaches-to-climate-change-for-pacific-northwest-agriculture.html</td></tr>
</table>

Specific Objectives	• Establish an integrated framework for understanding climate and agriculture interactions in the region and build institutional capacity for continued research • Monitor soil carbon, nitrogen, energy, water efficiency and greenhouse gas production under current and alternative cropping systems • Conduct social and economic surveys and economic modeling to understand factors governing alternative system adoption • Examine implications of climate change for crop pests, pathogens, and weeds • Develop relevant curricula to train students at all levels to address climate change in agriculture • Provide stakeholders with information to respond to climate change
Organizational Structure	With 26 co-PIs, 11 project staff, over 40 graduate students and many other affiliated researchers; REACCH is the largest of the projects considered here. The primary institutions involved in the research effort are Washington State University, Oregon State University, the University of Idaho, USDA NIFA and USDA Agricultural Research Service (ARS). Researchers are arranged into 7 objective teams: GHG monitoring; cropping systems; socio-economic; pests, weeds and pathogens; education; extension; integrated modeling; and cyberinfrastructure. There are also sub-teams focused on agro-ecological zones and project life cycle analysis.
Approach to Stakeholder Engagement	The working group focused on agricultural economics defined Regional Agricultural Pathways (RAPs) scenarios. Input from a stakeholder advisory council was sought throughout the research process. Making the RAPs scenarios interesting and cohesive from a scientific perspective was a primary objective. The RAPs effort coincides with other social science research, extension and education efforts occurring in REACCH. Education and extension efforts were designed primarily with the expectation of influencing regional decision-making, not necessarily influencing model development or experimental research directions.

6.3 PROCESS-BASED AND PRODUCT-BASED APPROACHES TO STAKEHOLDER ENGAGEMENT

The traditional "deficit model" of science communication has been widely discredited as incomplete. The deficit model assumes that public decision-making on environmental issues is hampered foremost by a lack of adequate information (Wynne 1991; Kasperson 2011; Lemos & Rood 2010; Weaver at la. 2013). In reality, lack of scientific information is only one of many barriers to meaningful incorporation of science in natural resource management and policy decision-making (Sarewitz & Pielke 2007; Collins & Evans 2008; Kasperson 2011). Competing social, economic and political attitudes and priorities inform decision-makers' level of skepticism and willingness to act on complex environmental change issues including climate change (Kasperson 2011; Weaver at al. 2013).

Engaging public and private sector decision-makers in research is regarded as an essential step in moving beyond deficit model science initiatives (Sarewitz & Pielke 2007; Kasperson 2011; Kirchhoff et al. 2013). By involving non-academic stakeholders in the process of defining research questions and planning approaches for sharing outputs, research institutions enhance the likelihood that their work will be perceived as credible, salient and legitimate and will be utilized in management and policy decisions (Sarewitz & Pielke 2007; Lemos et al. 2010). It is important to ensure that climate change impacts questions are addressed at spatial and temporal scales that are relevant to decision makers. In order for model projections to be trusted assumptions embedded in models and scenarios must be with the expectations that decision makers have about future social, economic and political conditions (Feldman & Ingram 2009; Lemos et al. 2010; Weaver et al. 2013; Kennel 2013).

Scholars have suggested that climate science information is of limited ustility for decision-makers when researchers emphasize *products* such as reports and predictions (Cash et al. 2003; Weaver et al. 2013). When climate change impacts researchers focus on the engagement *process*, including mediation, translation, and trust building with stakeholders, research results are more likely to be usable (Cash et al. 2003; Stern & Brewer 2005; Weaver et al. 2013).

The traditional climate impacts research paradigm of making specific predictions and then specifying an action plan has been demonstrated to be of less value to decision-makers than the emerging robust decision making framework that focuses on identifying system vulnerabilities (Stern & Brewer 2005; Lempert et al. 2006; Weaver et al. 2013). In the context of deep uncertainty about future conditions, it is most meaningful to emphasize *processes of engagement* over creation of specific *research products* (Stern & Brewer 2005; Weaver et al. 2013). WISDM, BioEarth and REACCH can be understood as occurring on a continuum from a process-based to a product-based orientation regarding stakeholder engagement (Figure 6.1).

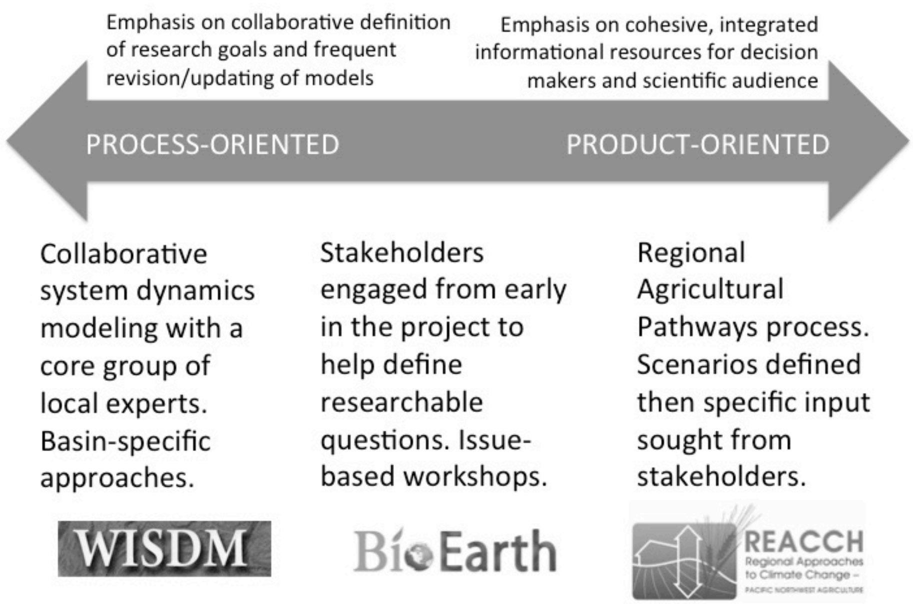

Figure 6.1 Three Northwest US regional climate change modeling projects, arranged on a continuum of approaches to stakeholder engagement.

6.4 Managing large collaborative projects

Complex social problems associated with managing human-natural systems require interdisciplinary collaboration and incorporation of a range of perspectives from management and policy-making communities (Mâsse et al. 2008; Miller at al. 2014; Morton et al. 2015). The concept of transdisciplinarity has been promoted to extend beyond interdisciplinarity to describe involving non-academic stakeholders, bridging a gap between research and decision-making spheres through a collaborative process (Tress et al. 2004; Morton et al. 2015). Science-of-team-science is an emerging area of study; sociologists, organizational communication researchers, psychometricians and others are developing frameworks and tools to assess team processes (Mâsse et al. 2008; O'Rourke et al. 2013). Research on adaptive architectures of integration (AAI), or flexible structures for collaboration in large transdisciplinary teams, explores how team managers can facilitate innovation and produce usable climate outputs for decision-makers (Morton et al. 2015). When transdisciplinary research teams are successful there are well-established group goals, strong connections among the efforts of collaborators, actively managed boundaries among disciplines, actively engaged non-academic stakeholders, and ongoing monitoring and adaptation (Morton et al. 2015; Hampton & Parker 2011; Kirchhoff et al. 2013; Allen & Stephens 2015).

Interdisciplinary project managers must seek a delicate balance between actively supporting team integration and information sharing and allowing working groups to operate with autonomy and flexibility (Hampton & Parker 2011; O'Rourke et al. 2013; Morton et al. 2015). Contributing researchers in in large collaborative projects often bring a commitment to work closely with diversity scientists and stakeholders, but do not always have the training, resources and experience to do so (Hampton & Parker 2011; Morton et al. 2015). Traditional metrics in academic settings used to evaluate scientific researchers for recognition and promotion emphasize individual accomplishments and peer reviewed publications (Mâsse et al. 2008; Schaefer et al. 2015). Researchers are not always incentivized to develop skills needed to conduct interdisciplinary research or to collaborate with non-academic partners (Palmer 2012). Developing those skills requires an investment of time and effort on the part of individual researchers and universities (Palmer 2012; O'Rourke et al. 2013).

6.5 Metrics for Evaluating Project Outcomes

This section explores ways in which individual researchers and research initiatives are typically evaluated and explores general guidelines for designing impactful evaluation metrics. There may be competing perspectives between universities and agencies that fund research on which metrics or outcomes are most important and what defines project success. Universities traditionally evaluate faculty for promotion and tenure on the basis of research, teaching, service and leadership on competitive grants. At many US institutions the highest importance is placed specifically on peer-reviewed first-author publications (Schaefer et al. 2015). Publications and written work for the academic community are also the primary pathways by which graduate students demonstrate their scholarship.

Funding agencies have processes in place to monitor and evaluate large interdisciplinary, actionable science initiatives. REACCH, BioEarth and WISDM, for example, submit annual progress reports to USDA NIFA, detailing: 1) the target audiences for research outputs, including specific stakeholder groups reached, 2) traditional research products including publications, presentations, and internal reports, 3) additional research products including activities, events, services, software tools, videos, maps, and websites, 4) accomplishments related to significant results, changes in knowledge, conditions and actions and new opportunities for graduate and professional development and finally, 5) problems encountered or changes made during the project.

Additionally, research projects that seek to produce actionable, stakeholder-driven research must respond the information needs of decision-makers, which do not always align with questions that are deemed to be of high scientific interest and significance. Often, natural resource management and environmental policy questions that stakeholders care about focus on understanding more about the implementation of practices and policies and evaluating alternatives, which is a different kind of question than that addressed in traditional research (Wynne 1991; Collins & Evans 2008; Weaver at al. 2013). Stakeholders' primary concerns and perceived information needs do not always align with research priorities.

Reconciling different perspectives on what defines a successful project is a challenge for individual researchers and for research teams as a whole. Scholars in the science-of-team-science field suggest that transdisciplinary teams should increase the level of energy invested in reflexive, participatory monitoring and evaluation of project outcomes (Cramb & Purcell 2001; Mâsse et al. 2008; Morton et al. 2015). Identification and tracking of performance metrics from within teams has been shown to encourage organizational learning, improvements in efficiency, and achievement of objectives (Cramb & Purcell 2001). Internal research project evaluation based on performance metrics may support gains in decision makers' use of relevant climate science information and researchers' and stakeholders' learning and professional growth (Douthwaite et al. 2008; Estrella & Gaventa 1998).

Individual research projects have unique objectives and thus must develop original metrics to assess accomplishments. Developing metrics can play a role in supporting a mutually shared vision of the team's mission and objectives (Cramb & Purcell 2001; Douthwaite et al. 2008). Researchers and stakeholders should work together to define quantitative, measureable goals (Cramb & Purcell 2001; Estrella & Gaventa 1998). This approach supports tracking achievements and identifying areas where more effort or resources are needed. The concept of "SMART" metrics is widely used to determine whether metrics used to assess outcomes are well defined (Estrella & Gaventa 1998). SMART stands for:

- *Specific:* Metrics are clear and focused, with mutually agreed upon definitions and assumptions.
- *Measurable:* Metrics are quantifiable and there is an established system for collecting and comparing project data. Binary "yes/no" assessments should be avoided.
- *Attainable:* Project objectives are achievable given timelines, available expertise and resources.
- *Realistic:* Objectives and metrics proposed for assessment are practical given systemic and organizational constraints.

- *Time-bound:* Specific benchmarks set on a timeline, with a clear plan for monitoring and evaluation.

6.6 Research approach

This research involves comparing co-PIs' perspectives from three projects. In winter of 2015 a total of 20 semi-structured interviews were conducted with co-PIs involved in WISDM, REACCH and BioEarth. Three co-PIs were engaged in all three projects. Four co-PIs were involved in WISDM and BioEarth simultaneously. Among researchers involved in just one of these research efforts, one was involved in only WISDM, four were involved in only REACCH, and eight were involved in only BioEarth. Interview subjects included individuals with backgrounds in atmospheric science, environmental engineering, biology, entomology, environmental science, sociology, economics and cooperative extension. Interview questions were designed to understand how approaches toward stakeholder engagement varied across different projects and how co-PIs conceptualized project challenges and project accomplishments.

6.7 Results

Based on thematic analysis of interviews conducted with WISDM, REACCH and BioEarth co-PIs, themes in researchers' reflections and lessons learned are arranged into two primary categories: approaches to stakeholder engagement and approaches to team management. Within each of these areas, core lessons are identified and described. The results section ends with a summary of variations in how stakeholder engagement and team management were conceptualized and approached in each project.

6.7.a Approaches to stakeholder engagement

This portion of the results section presents co-PIs' experiences of communicating and collaborating with non-academic stakeholders. There was considerable variation among projects with regard to approaches to stakeholder engagement. Co-PIs suggested that strategic engagement of new partners, (e.g. government, NGO and industry representatives) ensured a diverse communities had the opportunity to interact with researchers. A BioEarth co-PI said that the diversity of perspectives represented at BioEarth workshops prompted interesting discussions, but yielded a mixture of actionable and non-actionable recommendations. In the WISDM project, which pursued basin-specific approaches to stakeholder engagement, a working group of researchers collaborated closely with scientifically literate water mangers, who had a history of being involved with scientific research based in academia. REACCH co-PIs commented that their experience in the project had deepened their understanding of the importance of sustained engagement with stakeholders. Several co-PIs suggested that stakeholder engagement successes could be attributed to decades-long traditions of agricultural extension work in the region:

> *"There is a historical design in agricultural research, where research being done is driven by what you might call an iterative stakeholder relationship that's developed over time… Partners in that include growers, industry, agencies, but also the intermediaries like extension and conservation districts, where those relationships exist. And I think what*

> *strategically happened in the context of the REACCH project is, some of those relationships were resourced and built up or expanded, and new ones were connected" (co-PI 15).*

In addition to variations in approaches to stakeholder engagement between the three projects there was also variation *within* research teams in approaches to stakeholder engagement in research. For example, one REACCH co-PI described the project's "layered" approach to stakeholder engagement:

> *"There's a formal project advisory committee, which is really quite large and diverse, but then individual pieces of the project have their own levels of stakeholder engagement that range from fairly minimal, in some cases, to very intensive longitudinal studies-- grower, cooperator, partnerships, these kinds of things" (co-PI 15).*

One co-PI observed that individual researchers have different levels of willingness to transcend disciplines and engage with non-academic stakeholders:

> *"It simply comes down to relationships and the time available to invest in relationships that make you fulfilled as a person. People will tend to obviously build relationships with those of like mental models, of those with like interests. And there's a few, I think, few people that are very interested in crossing bridges all the time. (Co-PI 36).*

Researchers in all three projects identified ways in which objectives had evolved and shifted since convening planning meetings and submitting research proposals to

NIFA. Sometimes projects evolved because of researchers' changing priorities and the changing structure of working groups, and at other times research efforts evolved in response to stakeholders' changing priorities. Co-PIs across all projects discussed examples of instances when having a flexible approach to stakeholder engagement led to gains in usability of research for stakeholders. In the WISDM project, ongoing debates over water rights in one study region made the originally planned collaborative system dynamics modeling a less constructive and politically palatable option in the eyes of researchers:

> *"Revising how we approached this might have been a good idea. The political climate with respect to what agencies can and cannot do at any certain point in time is always going to be changing. And we can't always adapt to those changes [because of research plans established in grant proposals]" (co-PI 36).*

In another watershed, a WISDM co-PI felt that intensive engagement enabled their working group to be closely attuned to stakeholders' changing needs and priorities. Stakeholders were increasingly interested in the role that university-based researchers could play in communicating scientific information to the broader regional public:

> *"What we're being asked to do by agencies is to help them communicate with the public… So, this has been very interesting sort of expansion or deviation from a certain track that we expected." (co-PI 36).*

<u>6.7.a.1 Researchers recognize a need for innovation in stakeholder engagement</u>

Across all research teams, co-PIs expressed viewpoints in support of creative, innovative approaches to engaging stakeholders in research and frequently noted that incorporating these processes in research design requires time, effort and dedication of team members. Several co-PIs expressed frustration that some research outputs take several years to finalize and are less relevant to stakeholders by the time results are in a format that can be shared:

> *"Wheat production varies across the landscape. People often don't understand how differently the different regions respond, how incredibly variable it is based on soil, microclimates, mountains and rivers…. We're learning a lot through interviews with growers and I want to do this in the context of technology adoption… It just takes so long to do a good job and actually get it out there and peer reviewed and out where it can be accessed, we're working hard on that phase of it" (co-PI 44).*

This co-PI was hopeful that their project would continue and produce meaningful information for regional decision-makers about responding to environmental change, but that they saw an immediate need for "renegades" in the scientific community who are proactive about collaboration, introducing new perspectives, and sharing results with a broader community of stakeholders in real time. They advocated more engagement of younger generations in decision-making and more use of social media tools to connect with regional stakeholders.

6.7.a.2 Reflections on the value of early and iterative stakeholder engagement

Co-PIs frequently expressed that iterative communication with stakeholders over the duration of a research effort is important to keep scientists grounded in the potential relevance and applications of their work. Iterative communication with stakeholders involves non-academic participants giving feedback and input to modelers as well as modelers presenting new insights and knowledge to stakeholders. One co-PI explained that structured, iterative interaction with stakeholders helped maintain collaborative networks:

> *"It's been my experience that people are interested in the results of our research more than their input is informing my work… During the water quality workshop there were a number of people really interested in seeing what we knew about nutrient sources into the Columbia River and surprised by some of the results. And I think it was useful. I think it's kept us on the radar screen of agencies to a greater degree than if we hadn't had these meetings" (co-PI 8).*

Another BioEarth co-PI summed up an important lesson about the value of engaging with stakeholders early in the research process, saying that non-academic perspectives can help constrain the seemingly limitless array of possible regional scenarios that could be explored in models.

> *"There are a number of different adaptation strategies, when you think about farms. And we could send an economist in and make a series of assumptions, and then use a model to identify the optimal strategy. But*

that's only possible in very simplified settings and also doesn't account for differences across growers… A lot of the goal with BioEarth is to shape how the economic model reflect(s) which adaptation strategies farmers are more likely to take" (co-PI 10).

6.7.a.3 Benefits of understanding and supporting stakeholders' social capital

Researchers recognized ways in which the stakeholder engagement processes could promote networks of communication and collaboration in the region. A WISDM co-PI described how their work in a collaborative modeling process had revealed that stakeholders already have most of the key information about hydrological systems in the region that they need to manage the system effectively in the present. The area in which decision makers lack information is related to risks and vulnerabilities associated with future climate change impacts.

In many cases, management challenges are due not so much a lack of available scientific knowledge, but due to that knowledge not existing in a form that is accessible and actionable. Facilitated stakeholder engagement processes can enable decision makers to consider impacts of decisions holistically and promote exploration and modeling of unintended consequences of decisions.

Researchers must be cognizant of barriers stakeholders face to taking action on climate change adaptation and mitigation. There are many constraints on decision-making not directly tied to the supply of scientific information about climate change impacts and mitigation options:

"What's any particular state supposed to do on it's own? I mean they can pass some policy, but if neighboring states aren't following suit you don't even have a regional plan in place. Let along a federal set of actions that might be mandatory to help at a different level" (co-PI 42).

Sometimes, as was found by REACCH co-PIs, politicized views about climate change are a barrier to effective partnerships with agricultural stakeholders. On-farm demonstration projects are an important method for research teams to broach topics related to adaption with stakeholders who are skeptical about anthropogenic climate change.

"We want to meet the growers' needs foremost, but, in order to get to them with something like climate change, which is controversial and not necessarily resolvable in the field immediately, we do rely on a hierarchy of stakeholders. And so, we just kind of prepare materials and resources for anyone who wants to learn more about climate change and gain an understanding of it and help us and help them simultaneously understand the impact of climate on agriculture" (co-PI 42).

A BioEarth co-PI described ongoing interest in strengthening ties with specific stakeholder groups and assessing how model outputs could be made more accessible and usable:

"I feel like we don't necessarily know how we've had an influence because we don't have very strong lines of communication with everybody who

we've engaged with. So there could be indirect or direct influences that we may not even be documenting or be aware of. So, that adds an element of complexity" (co-PI 3).

6.7.b Approaches to team management

This portion of the results section presents BioEarth, WISDM and REACCH co-PIs' reflections about interdisciplinary team dynamics and challenges and successes related to managing these projects. Generally speaking, academics have little training in managing large projects. Thus, leading interdisciplinary research teams can be a significant challenge. Many researchers expressed that universities and funding agencies typically do not fully appreciate the investment of time and effort required for researchers to participate in interdisciplinary actionable research. Especially in terms of project leadership, managing a research effort requires a different skill set than that required for being s strong scientist. In interdisciplinary research teams there is a need to find balance between: 1) open communication and adaptability, and 2) efficiency, clarity and unity of the research effort. One co-PI summed up the challenge of large interdisciplinary research projects as follows:

> *"Even if you're working in different ways or on different timelines there's a lot of friction that can interrupt ability to meet goals… it's become clear to me that these mega-projects are not all great. It's a wonderful thing to receive such a large grant, so I don't want to complain or put that down.*

But I've never seen such organizational challenges to just keep everything afloat" (co-PI 44).

6.7.b.1 Levels of transparency in decision-making affect project outcomes

In one project there was a mutually acknowledged lack of collaboration between modelers trained in two different approaches. Both groups expressed that their fellow researchers often did not know what each other were doing and did not have open lines of communication. Reflections on leadership in the three teams demonstrate that one of the most challenging aspects of managing an interdisciplinary project is balancing openness and transparency of decision-making with a need for working groups to operate with some freedom and independence.

In some cases, lack of open channels of communication led to not being able to resolve research and modeling challenges in the ways that were hoped for at the start of the project. For example, one co-PI explained that their working group modified their approach based on a perceived lack of active collaboration and input from another working group:

> *"That slowed us down. But, you know, the good side of that was, she (the graduate student) understands the model pretty well. And so, this set of tools that she's developed because of the situation was not anticipated, but I think it's all pretty admirable" (Co-PI 36).*

This incident illustrates the vulnerability of interdisciplinary teams. Different team members' goals and research philosophies have to be carefully negotiated.

Sometimes, in seeking to maintain working group autonomy and ensure a simple, efficient process, a team leader runs the risk of shutting down dialogue about approaches and available resources to address a research question.

Lack of clarity about individuals' roles and responsibilities can be a source of tension within team. One co-PI expressed that the most difficult aspects of their work were tied to varying perceptions of what activities extension work should encompass:

> *"I don't have much of an opportunity to focus on just a couple things and do them well. You know, I get pulled in a lot of directions, so that's really frustrating for me" (Co-PI 42).*

6.7.b.2 Reflections on effective team size and structure

Several co-PIs noted that there are occasions when efforts within a small, focused, group of stakeholders and researchers lead to the highly productive exchanges, both in terms of actionable recommendations for the research team and usable climate change impacts information for a population of stakeholders. For example, BioEarth's rangeland management workshop had a small number of stakeholder participants (only seven), but was meaningful for establishing modeling priorities. Interaction in a small group setting paved the way for follow-up scientist-stakeholder collaboration. Researchers involved in all three projects explained that there were occasions when scientific progress and impactful engagement with stakeholders was carried out by a small sub-team of researchers.

Identifying an ideal research team size is not straightforward. Teams must be large enough to contain diverse expertise and small enough to ensure that decisions can be made efficiently and individual roles and responsibilities are clearly defined. There are many examples of interdisciplinary collaboration in WISDM, BioEarth and REACCH enabling researchers to address questions that would not otherwise be studied.

All three projects dealt with personnel turnover. This is perhaps an inevitable component of academic organizations, where researchers occasionally leave one project to move on to a new position, or their level of commitment to a research effort changes over time due to new responsibilities and interests. Turnover can lead to difficulties in maintaining research momentum and maintaining close ties with other working groups.

Often, lack of time to meet with and learn from other scientists is one of the biggest obstacles to effective communication. A BioEarth co-PI explained:

> *"Early on there was a lot of formal meetings setup, just to make sure people were reaching out to each other and kind of breaking down the boundary of being busy, because our biggest obstacle to interdisciplinary research… is the fact that we're juggling too many things" (co-PI 14).*

REACCH co-PIs reflected that graduate training in stakeholder outreach and extension had been a positive design feature of the project, but that results were uneven, with some students putting a high degree of effort into building relationships with non-academic stakeholders and others contributing relatively little. Co-PIs reflected that this feature of the project would have benefitted from more accountability and more training resources being built-in. Many co-PIs expressed optimism about the future of research in the region based in a large part of collaborative partnerships with other institutions and researchers from other disciplines:

> *"One of the really fun things is the chance to work across disciplines with other people. In REACCH especially, I think because of the structure with the different objective teams, and the annual meeting and the monthly integration calls. All of those things have really, I think, been pretty effective at getting folks together and getting them to talk across disciplines. And to move ahead, certainly for our specific part of REACCH we've established a lot closer ties with folks in crops and soils and bio-systems engineering than we had before" (co-PI 5).*

6.7.c Comparison of project features

This portion of the results section synthesizes core themes from co-PIs' reflections and self-assessments of learning. Table 6.2 presents a summary of variations in co-PIs' perceptions about stakeholder engagement and team management in REACCH, BioEarth and WISDM. Five aspects of interdisciplinary actionable science research teams are addressed. These aspects of teams correspond to the themes identified in co-PIs' interviews.

Table 6.2 *Summary of co-PIs' perceptions about stakeholder engagement and team management*

	Aspects of interdisciplinary actionable science research teams	WISDM	BioEarth	REACCH
Perceptions about approaches to stakeholder engagement	1. Satisfaction with stakeholder engagement processes	Intensive and productive collaboration with a small group of stakeholders. Not all researchers interacted with stakeholders.	Stakeholder workshops involved diverse actors in the region. Researchers learned about information needs and decision-making contexts but many of the stakeholders' questions were outside the scope of the project.	Multiple kinds of stakeholder engagement were pursued. Outcomes were mixed, some effective networks were developed but delays in research outputs led to some information being less relevant when shared.
	2. Outcomes related to collaboration with stakeholders	Collaborative modeling revealed that Spokane basin stakeholders already understand essential features of the watershed; their greatest current need is crafting environmental messages for the broader public.	The overall project goals shifted from a focus on a fully integrated regional model to modular models that could be employed to address specific questions. This was partially in response to seeking to provide information about possible unintended consequences of decisions relevant to stakeholders.	The stakeholder advisory committee that provided insight about regional agricultural pathways scenarios didn't strongly influence research directions. Several sub-projects worked more closely with stakeholder partners to test viability of new management practices.
	3. Lessons about working with stakeholders	Teams must be open to radically changing approaches in response to stakeholder needs. Working iteratively with a relatively small group of stakeholders can result in a model that is well understood and deemed usable by stakeholders.	There is a need to find balance between engaging many diverse stakeholders and promoting long-term partnerships where details of model development and scenarios can be explored collaboratively.	Agricultural stakeholders may find climate change research less compelling and less worthy of investing their time in because they see other management concerns as more pressing.
Perceptions about approaches to team management	4. Satisfaction with team communication	Lack of communication about group visioning and integration early in the project led to low levels of interdisciplinary integration. Researchers felt that essential information was not always communicated to them.	Team integration meetings and sector-specific stakeholder workshops helped facilitate interdisciplinary collaboration. More forums for efficient information sharing and cross-disciplinary learning would have benefitted the team.	The large and complex nature of the project led to some frustration with meetings and involvement in decision-making processes that did not feel relevant to everyone. Some researchers felt pulled between competing expectations about their work.
	5. Outcomes related to team	Relatively low levels of trust and information	Some new partnerships among researchers (and	Some new partnerships among researchers from

	structure	sharing among research team members. Sub-projects were pursued autonomously.	stakeholders). Modeling approach evolved to emphasize linking models to address specific questions rather than creating one fully integrated model.	different disciplines. There was also a sense that smaller teams might have been more efficient and productive. High personnel turnover in some working groups led to productivity challenges.

6.8 RECOMMENDATIONS FOR METRICS TO EVALUATE REGIONAL CLIMATE RESEARCH PROJECTS

Results reveal a diversity of approaches to conducting stakeholder engagement activities among research teams, as well as a diversity of individuals' approaches within teams. Researchers' experiences highlight the importance of designing flexible approaches to working with stakeholders so that research questions can be responsive to changing informational needs and changing political and social contexts in which stakeholders are operating. There is strong support for early and iterative stakeholder engagement in research that seeks to be actionable. Historical working relationships among academics and stakeholders affect the quality and productivity of collaborations. To the degree that long-standing relationships between researchers and decision-makers exist (for example, via university extension programs) trust and willingness to participate are strengthened. Understanding decision-making contexts and constraints and supporting stakeholders' social capital are understood to lead to more impactful project outputs.

Reflecting on interdisciplinary team dynamics and leadership, interviewees recognized that the skills required to manage a large collaborative project are different than skills and working styles traditionally fostered in academia. Comparison of project outcomes reveals that approaches to communication and levels of transparency in decision-making affect project outcomes and researchers' satisfaction with those outcomes. Teams must invest time and energy in interdisciplinarity learning and collaboration early in the process and revisit progress in synthesizing research efforts frequently over the duration of projects. Each of the three projects struggled with establishing effective interdisciplinary collaboration in different ways. Lack of critical information sharing and overly structured team meeting interactions were both seen as impediments to trust and productivity. Effective communication is essential to team collaboration.

A review of existing metrics for evaluating research project outcomes, challenges related to designing stakeholder engagement approaches, and challenges related to managing large interdisciplinary research efforts suggests that interdisciplinary climate change impacts research teams could benefit from crafting team-specific performance evaluation metrics. There are often competing perspectives on what metrics or outcomes are important among universities, agencies funding research and stakeholders. Teams must consider and balance these competing demands and define objectives related to synthesizing disciplinary knowledge and interacting with non-academic stakeholders to produce actionable information.

Interviewees were readily aware of the changing landscape of federal funding for environmental change research, which since the late 1990s has accelerated calls for interdisciplinary, actionable research. At the same time, responses from researchers in interviews reveal that there are many respects in which universities and individual research departments are modifying approaches to support more engagement with decision-makers outside of academia. Co-PIs commonly expressed the sentiment that university administrations could continue to make strides in rewarding extension and engagement activities with non-academic stakeholders. Researchers recognize the value in developing informational tools and resources that address specific information needs for decision makers even when those resource or tools do not represent a new publication.

By defining clear objectives related to which stakeholders participate in research, what kinds of results and tools are produced and to what degree science informs management and policy decisions, teams can assess their progress and address challenges as they arise. Internally, interdisciplinary research teams addressing complex social-environmental systems would benefit from defining stakeholder engagement objectives, measuring team progress against benchmark goals and monitoring learning. Research project managers could benefit from training in the use of evaluation of performance metrics to guide adaptive management and promote sustained relationships with non-academic stakeholders.

The following are suggested "SMART" metrics (Estrella & Gaventa 1998) for assessing stakeholder engagement processes in interdisciplinary actionable climate change impacts research teams:

1. Number of academic and non-academic stakeholders engaged. Measure new relationships established, duration of relationships and time phases at which stakeholders are engaged.

2. Diversity of stakeholders. Document and assess stakeholder areas of expertise, systems of interest, sectors in which they work, and the scope of management and policy decisions that they make.

3. Impacts of stakeholders' knowledge and perspectives on research efforts. Document stakeholders' information needs and which of those questions are being addressed with research outputs.

4. Adaptive project structure. Assess the degree to which team structures and research approaches have been modified and adapted in response to needs for new approaches. Document emergence of new networks and structures for sharing information. Along with this, teams should consider progress in addressing interdisciplinary questions and synthesizing disciplinary knowledge.

5. Learning and new understanding among stakeholders. Track project outputs, reports and tools produced for stakeholders. Surveys and longitudinal analysis can assess the degree to which those outputs and tools influence behavior and decision-making. This includes measuring the quantity, accessibility and use of specific tools and resources produced for stakeholders.

6. Learning and new capacities and capabilities within teams. Set goals for organizational learning and consider the team members' growth as managers, boundary-spanning communicators and researchers.

6.9 CONCLUDING THOUGHTS ABOUT ENGAGING STAKEHOLDERS IN CLIMATE CHANGE IMPACTS RESEARCH

Addressing complex environmental challenges depends on developing strong networks of collaboration among diverse communities of researchers and stakeholders. This dissertation has addressed the question of how university-based interdisciplinary climate change impacts research and modeling teams can develop competency in designing stakeholder engagement processes to generate usable research outputs for decision makers.

Based on a case study analysis of the BioEarth project and two related climate change impacts modeling projects in the Northwest US, WISDM and REACCH, this research has described how researchers perceive the role of stakeholders and how those perceptions evolve over time. Central climate change impacts information needs for Northwest US natural resource management decision makers were explored. Lessons about approaches to stakeholder engagement and approaches to managing interdisciplinary were drawn from an analysis of interviews conducted with research team members. Recommendations have been put forth about defining metrics for evaluating climate change impacts modeling research efforts.

There is a need for future research to test how interventions such as online forums for scientist-stakeholder dialogues, trainings in environmental modeling for decision-makers, and trainings in interdisciplinary team management for project leaders impact individual learning, project achievements and consideration of model outputs in decision-making. Building understanding of the contexts in which university-based scientists and diverse government, NGO and industry stakeholders conduct their work is critical in order to design initiatives for usable climate science information and tools. With greater investment of resources and energy in supporting knowledge sharing among researchers and nonacademic decision makers, a path toward meaningful incorporation of climate change science in regional decision-making can be found. Ultimately, this will support adaptive and collaborative natural resource management decisions and policies.

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APPENDICES

APPENDIX A. CONSENT FORM USED FOR ACADEMIC RESEARCHER STUDY PARTICIPANTS

CONSENT TO INTERVIEW
Stakeholder Engagement in the Development and Use of Earth Systems Models
Washington State University & Clark University

Purpose: The goal of this project is to investigate perceptions of researchers involved in the development of a regional earth systems model regarding opportunities for stakeholder engagement in the modeling process. Specifically, we are concerned with ways in which the model can support stakeholder decision-making related to agriculture, forestry, and resource management. Our aim is to revisit questions about communication and stakeholder engagement several times throughout the duration of the BioEarth project and use the information gathered to track opportunities for integrating stakeholder perspectives.

The study, which is a key component of the BioEarth project research, is being conducted by Chad Kruger (Director of the Center for Sustaining Agriculture and Natural Resources, Washington State University), Fok-Yan Leung (Assistant Research Professor at the Laboratory for Atmospheric Research, Washington State University), and Jennie Stephens, (Assistant Professor of Environmental Science and Policy, Clark University). Clark University graduate student Elizabeth Allen is assisting the research and is conducting interviews with each of the BioEarth Principal Investigators. This study, titled "The effects of close engagement between scientists and stakeholders on scientist and stakeholder perception" has been deemed exempt from review by the Washington State University Office of Research Assurances (IRB). Any questions about protection of human subjects participating in the study and adherence to ethical standards should be directed to Chad Kruger, director of WSU's Center for Sustaining Agriculture and Natural Resources, reachable at (509)663-8181 x242.

Requirements: The interview will take approximately 30-45 minutes of your time. Participation in this study is completely voluntary. Your decision whether or not to participate will not affect your current or future relationship with any of the organizations involved in this study. If you decide to participate, you are free to refuse to answer any of the questions. You can withdraw at any time. This interview will be audio recorded in order to insure that transcripts of the session are accurate. You may object to being audio recorded. After sessions are transcribed, the audio file or tape will be destroyed. We will stop and/or erase the recording at any point upon request. A copy of this form will be given to you.

Confidentiality: To protect your privacy and that of your colleagues, all transcribing will be done by researchers or professional transcribers. Data will be stored in a locked or password protected storage accessible only to researchers. Presentations, reports, and publications will focus attention on general findings about perceptions of stakeholder involvement. To the extent possible, individuals' contributions will be reported in ways that avoid identification of those individuals, unless you state your preference that we do so.

Please indicate your choice by checking one statement from the following list:

I prefer that any quotations from my interviews are used in the following way:

- □ quotes attributed to me and my institution
- □ quotes without attribution (research team will use language that does not identify you or your institution)

Statement from the Principal Investigator

I understand the nature of the study and voluntarily agree to participate in an interview about my experience and my perceptions of stakeholder involvement in earth systems modeling to be recorded through the use of field notes. I can refuse to be audio-recorded. In addition, I understand that I can stop the interview at any time; I can also request that audio file or tape and field notes be destroyed. I have had enough time to ask questions and have them answered. I have been given a copy of this form whether I agree to participate or not.

SIGNATURE OF PARTICIPANT ____ DATE _____________

PRINTED NAME OF PARTICIPANT ____________________________________

SIGNATURE OF RESEARCHER ____ DATE _____________

PRINTED NAME OF RESEARCHER ____________________________________

APPENDIX B. CONSENT FORM USED FOR STAKEHOLDER STUDY PARTICIPANTS

CONSENT FORM
Stakeholder Engagement in the Development of an Earth System Model
Washington State University

Purpose: One goal of the BioEarth project is to investigate perceptions of stakeholders involved in the development of a regional earth systems model. Specifically, we are focused on how the model can support stakeholder decision-making related to agriculture, forestry, and resource management. Our aim is to revisit questions about communication and stakeholder engagement with project scientists and stakeholders several times throughout the duration of the BioEarth project.

Research on communication and stakeholder engagement is being conducted by Washington State University graduate student Liz Allen with guidance and involvement of BioEarth Principal Investigators in the communications working group. This study, titled "The effects of close engagement between scientists and stakeholders on scientist and stakeholder perception," has been deemed exempt from review by the Washington State University Office of Research Assurances. Any questions about protection of human subjects participating in the study and adherence to ethical standards should be directed to Liz Allen, reachable at (774) 437-2819.

Requirements: Participation in this study is completely voluntary. Your decision whether or not to participate will not affect your current or future relationship with any of the organizations involved in this study. If you agree to participate, detailed notes from this meeting will be recorded and audio recording may be used. You may decline participation if you do not want your responses to be recorded. If audio recording is used for any part of the meeting, after the recordings are transcribed the audio file will be destroyed. A copy of this form will be given to you upon request.

Confidentiality: To protect your privacy and that of your colleagues, any audio recordings and the transcriptions will be available only to the research team. Data will be maintained in locked or password protected storage accessible only to researchers. Presentations, reports, and publications will focus attention on general findings about stakeholders' involvement and perceptions. To the extent possible, individuals' contributions will be reported in ways that avoid identification of those individuals, unless you state your preference that we do so.

Please indicate your preference by checking one box for each of the following statements:

Regarding recording of meeting proceedings and notes taken during the meetings:

- □ I consent to audio recording of the meeting
- □ I am opting not to be audio -recorded

I prefer that any quotations from my contributions during the meeting or pre-and post-meeting surveys are used in the following way:

- □ Quotes attributed to me and my institution
- □ Quotes without attribution (research team will use language that does not identify you or your institution)

Willingness to participate in a follow-up interview by phone:

- □ Yes, I am willing to participate in a post-meeting follow-up phone interview
- □ No, I do not want to be interviewed

SIGNATURE OF PARTICIPANT ____ DATE _____________

PRINTED NAME OF PARTICIPANT ____________________________________

APPENDIX C. SAMPLE STAKEHOLDER RECRUITMENT LETTER

Dear __________,

My name is Liz Allen and I'm a PhD student in the School of the Environment at Washington State University. On behalf WSU's Center for Sustaining Agriculture and Natural Resources and the BioEarth earth systems modeling initiative, I'm inviting you to participate in a stakeholder advisory workshop in Vancouver, WA on Thursday, March 12th. This workshop will be an opportunity for regional stakeholders to share their perspectives and insights with the WSU research team to ensure the final product is a current and useful tool for decision makers.

The BioEarth research team is developing a model of nutrient cycling and water dynamics in the context of climate variability and socioeconomic changes in the Pacific Northwest. Your participation in this workshop in needed to ensure that diverse perspectives are incorporated in the model development process. Our central goal is to produce model outputs that are relevant to the concerns and interests of stakeholders from government agencies, industry, NGOs and academia. Previous stakeholder advisory meetings have covered carbon and nitrogen management, water availability, rangeland management, forest management and regional air quality issues. In the coming 2 years we expect to host presentations of BioEarth research findings and model outputs that respond to some of the key concerns and issues of interest raised by our stakeholders. At the workshop, you will be invited to participate in a study of interactions among researchers and stakeholders. If you consent to participate in the study you will complete surveys before and after the workshop and a record will be made of your responses to discussion questions.

Travel funds are available on an as-needed basis. Please contact me if you would like more information about workshop logistics and available funding. Also, please share this announcement with colleagues who may be interested in participating.

Details:
Water Quality Stakeholder Workshop
Date/Time: Thursday, March 12th from 9:00-2:30
Location: WSU Vancouver campus

To confirm your participation or to decline the invitation, please respond to lizb.allen@wsu.edu or call Liz at (774) 437-2819. You can visit our website to learn more about BioEarth: http://www.cereo.wsu.edu/bioearth/

Sincerely,

Liz Allen, on behalf of the BioEarth Communication and Extension Team

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Liz Allen, Graduate Research Assistant
School of the Environment, Washington State University
lizb.allen@wsu.edu | (774) 437-2819

APPENDIX D. INTERVIEW PROTOCOL FOR BIOEARTH PIS

Case No. _________

Date ___________________________ Time __________________________

Location ____

Introduction

- Thank you for taking the time to discuss communication and stakeholder engagement as it relates to the BioEarth project.
- One objective of BioEarth is to support stakeholder decision-making related to agriculture, forestry, and resource management.
- We want to talk to principal investigators about their understanding of how stakeholders can be engaged in the development and use of earth systems models.
- We plan to revisit questions about communication and stakeholder engagement several times throughout the duration of BioEarth and use the information gathered to track opportunities for integrating stakeholder perspectives into the modeling process.
- If you consent, I will be taking notes and audio recording our conversation, but if you prefer that I not do one or both of those things, please indicate your preference. We can stop the recording or end the interview at any time.
- In any published discussion of our findings from the interviews, your responses will be anonymous unless you prefer to have quotes attributed to you. You may indicate this preference on the consent form.

Introductory Questions

1) What is your role in the BioEarth project?

2) How did you come to be affiliated with BioEarth? How does this project fit in to other work that you are doing? How is it similar to or different from other projects that you are working on or have worked on in the past?
   (Probing questions: in terms of size of the group? Number of different disciplines involved?)

3) What do you expect to result from this project?
   (Try to gauge how much they are thinking about stakeholder issues – applicability, results vs. process)

Internal Communication

4) How important is communication between researchers in this project? To what degree does communication factor into the outcomes (successes? failures?) of a project such as BioEarth?

5) What are your impressions of the systems for communication in place for this project? How would you like to see information about BioEarth shared?
   (Would it be internet-based? Face-to-face? Frequency of communication? Should there be a system in place to ensure that people communicate regularly and make information about what they are doing available to the group? Should the discussions among modelers be public – part of the same forum where stakeholders interact with modelers?)

Stakeholder Engagement

6) Who, in your view, are the "stakeholders" for BioEarth?

7) From your perspective, how should stakeholders be engaged in the project?

8) What, in your view, is the potential for stakeholder engagement in the component(s) of BioEarth that you are taking the lead on? For BioEarth as a whole?

9) From your perspective, what would make stakeholder engagement *easier*? What could be done to generate more *useful* stakeholder input?

10) How do you imagine that stakeholders from the agriculture and forestry sectors will be able to use the model?
   (Do stakeholders have unrealistic expectations because they don't know what is achievable?)

11) What do you see as the major challenges for the BioEarth project? Are there particular challenges associated with involving stakeholders in the development of a regional earth-systems model?
   (Are there significant barriers to involvement? To what extent is there a role for stakeholders in the actual development of the model? In the use and application of the model?)

12) To what extent do you think that interaction with stakeholders can improve acceptance of the BioEarth project's findings?

APPENDIX E. INTERVIEW PROTOCOL FOR WISDM AND REACCH PIS

- Goal is to understand outcomes of stakeholder engagement efforts within the project and identify lessons learned about interdisciplinary/ transdisciplinary research approaches
- If participant's consent is given the interview will be recorded, if you prefer not to be recorded or to end the interview at any time it will not affect your role in this project
- In any published discussion of these interviews, your individual comments will be anonymous, unless you prefer otherwise

1) Describe your role in WISDM (REACCH)
* Has your perception of the role that you play in the team changed or evolved since you began this project?

2) In addition to WISDM (REACCH), what other research, teaching and admin work are you engaged in?
    *How does this other work relate to your contribution to WISDM (REACCH)?
    *How is WISDM (REACCH) similar to/ different from other research projects you've been involved in?
    *How has the approach to interdisciplinary collaboration been different from or similar to WISDM (REACCH)?
    *What has worked well? Lessons for the future?

3) What do you expect to result from this project?
    *What would a successful project outcome look like to you?
    *Has your vision of success changed since earlier in the project? If so, how?
    *What do you think the lasting legacy of WISDM (REACCH) will be?

4) Do you think that WISDM (REACCH) has potential to play a role in helping improve decisions about regional natural resource management issues?
    *What kinds of decision makers might be able to learn from project outcomes?
    *what decisions might be influenced by research findings?

5) What are the major challenges within WISDM (REACCH) that you have encountered?
    *Interdisciplinary communication? Learning what other people are doing and working collaboratively?
    *Defining objectives and responsibilities?
    *If you could magically fix one thing about how the process works, what would it be?

6) Who, in your view, are the "stakeholders" for WISDM (REACCH)? How should they be engaged in the project?

7) In general, what role do you think that non-academic stakeholders should play in research that is conducted at academic institutions?

*How would this be different from the approach in WISDM (REACCH)?

* Can you think of approaches that could improve the quality of information transfer?

8) Can you think of some specific conversations or workshops/meetings you've participated in that suggested a new research question or affected your decisions about where to direct research/modeling efforts?

*Describe that interaction

APPENDIX F. QUESTIONNAIRE FOR BIOEARTH PIS ABOUT STAKEHOLDER ENGAGEMENT

1) Please rate on a scale of 0-5 the importance of involving each of these general stakeholder groups in BioEarth as ***contributors to the research process***. "0" signifies that there is no role for this group of stakeholders, "5" signifies that input from this group is critically important for the project's success.

A. Government agencies (federal, state, local, tribal) ______
B. Academics outside of the research team _______
C. General public _______
D. Industry (for example agriculture and forestry) _______
E. Non-governmental organizations _______

2) Please rate on a scale of 0-5 the importance of ***communicating model outputs and research findings*** to each of these general stakeholder groups in BioEarth. "0" signifies that there is no value in tailoring outputs for a particular group of stakeholders, "5" signifies that communicating findings to this group is critically important for the project's success.

A. Government agencies (federal, state, local, tribal) ______
B. Academics outside of the research team _______
C. General public _______
D. Industry (for example agriculture and forestry) _______
E. Non-governmental organizations _______

3) To what extent have you interacted with *non-academic* stakeholders in the context of an environmental change research effort since the launch of BioEarth in Spring 2011? (Consider all conversations, meetings and conferences where you were engaged in dialogue with stakeholders about research, not necessarily specific to BioEarth.)

A. Not at all
B. Rarely, 1-4 times
C. Occasionally, 5-10 times
D. Frequently, 11-20 times
E. Very frequently, more than 20 times

4) How satisfied have you been with your experience at BioEarth stakeholder workshops?

A. Expectations not met
B. Mostly Dissatisfied
C. Neutral

D. Satisfied
E. Expectations Exceeded
F. I have not attended a BioEarth stakeholder workshop

5) How satisfied are you with the overall approach to stakeholder engagement in BioEarth? (Reflect on your overall assessment of workshops, workshop summary reports, spreadsheets of stakeholder input and discussion about stakeholders' input at BioEarth team meetings.)

A. Expectations not met
B. Mostly Dissatisfied
C. Neutral
D. Satisfied
E. Expectations Exceeded
F. No basis to judge

6) Please rate on a scale of 0-5 your assessment of the potential for effective stakeholder engagement at each of these phases in a hypothetical 5-year interdisciplinary regional environmental modeling effort. "0" represents no role for stakeholders and "5" signifies that stakeholder input is critically important.

A. In the project's beginning (first year) _______
B. In the intermediate phase (years 2-4) _______
C. In the final phase (year 5) _______

APPENDIX G. PRE-WORKSHOP SURVEY FOR STAKEHOLDERS

1. Name:

2. Please briefly describe your job title and primary responsibilities:

3. In your current professional capacity, have you previously participated in workshops focused on academic research?
   - a. Yes
   - b. No

4. Has your decision-making been influenced previously by earth system modeling?
   - a. Yes
   - b. No
   - c. Not sure/ prefer not to answer

5. Which best characterizes the value of academic research in your decision-making processes?
   - a. Low value, academic research is generally not influential in my decision-making
   - b. Moderate value, academic research has some influence in my decision-making
   - c. High importance, academic research is highly influential in my decision-making

6. What kinds of scientific data are most relevant to your decision-making?
   - a. Economics
   - b. Sociology or Psychology
   - c. Earth sciences (hydrology, biology, crop and soil science, botany)
   - d. Policy/history/political sciences
   - e. Other:

7. How well do you think researchers in academia communicate their findings to stakeholders?
   - a. Exceptionally well, academic researchers consistently communicate relevant information to stakeholders
   - b. Generally well, researchers communicate with stakeholders but it's not always relevant or accessible to the appropriate audience
   - c. Acceptable, efforts to communicate are made, but there is significant room for improvement
   - e. Generally poor, little to no effort is made to reach stakeholders and share relevant work
   - f. Other:

8. Where do you generally learn about scientific information?
   a. Reviewing internet-based information
   b. Talking to experts at a university
   c. Talking to experts at non-university research institutions
   d. Talking to extension service professionals
   e. Reading research published in print
   f. Conducting my own research and/or direct observation

9. List some of your primary sources of scientific information:

APPENDIX H. SAMPLE WORKSHOP CLICKER QUESTIONS AND DISCUSSION QUESTIONS

Water Quality Questions for Stakeholders

Proposed Scope of the Workshop:
The beginning of the workshop will focus on a breadth of water quality issues in fresh water systems of the Pacific Northwest (PNW) – including those related to environmental change (e.g. climate, population growth, land use change, water supply and seasonality, nutrient dynamics, temperature, pests and disease) and social change (economic conditions, agricultural and forestry practices, land use policies and land value, development, regulatory policies). Objectives for this part of the meeting are to elicit stakeholder opinions about current and future issues of priority concern, and to better understand the scale and format of model outputs that will be helpful to decision makers in the PNW. Later in the workshop, we'll focus on gathering input about specific water quality management scenarios that stakeholders are interested in seeing modeled and examined within BioEarth.

Objective I: *To understand current and future concerns about regional water quality (environmental, health, economic, resource availability, other problems)*

FACTORS IMPACTING NORTHWEST WATER QUALITY

1. To what extent are you concerned about declining water quality in PNW freshwater systems?
    a. Not a matter of concern
    b. Relatively little concern
    c. Moderate concern
    d. Extreme concern
    e. Haven't thought about it

(Multiple-choice options for questions 2-17are the same as those in question 2 except where otherwise noted)

2. To what extent are you concerned about the impact of sedimentation in PNW waters?

3. To what extent are you concerned about nitrogen loading in PNW waters?

4. To what extent are you concerned about phosphorous loading in PNW waters?

5. To what extent are you concerned about dissolved oxygen levels in PNW waters?

6. To what extent are you concerned about primary productivity and organic material in PNW waters?

7. To what extent are you concerned about variability in water temperature in PNW waters?

8. To what extent are you concerned about impacts of pesticides in PNW waters?

9. To what extent are you concerned about the impacts of invasive species, pests and disease on PNW waters?

10. To what extent are you concerned about the impacts of pollution from wastewater effluent (e.g. inadequate treatment levels, antibiotics) on PNW waters?

11. To what extent are you concerned about the impacts of heavy metals and toxic chemicals on PNW waters?

12. To what extent are you concerned about effects of changes in the seasonality of water availability (including changes in precipitation and snowmelt) on PNW water quality?

13. Given the following list of factors that could impact PNW waters in the future, which 3 are you most concerned about?
    a. Sedimentation
    b. Phosphorous loading
    c. Nitrogen loading
    d. Water temperature
    e. Pesticides
    f. Invasive species, pests and disease
    g. Untreated pollution from waste water effluent
    h. Heavy metals and toxic chemicals
    i. Changes in seasonality of water availability (e.g. changes in timing of precipitation and release of snowmelt)
    j. Other (please mention)

MANAGEMENT DECISIONS

14. To what extent are you concerned about water quality impacts from conversion of lands to other land uses?

15. To what extent are you concerned about the impacts of current land management practices on water quality?

16. To what extent are you concerned about water quality impacts resulting from potential economic changes in the region (costs of production or prices for products)?

17. To what extent are you concerned about total maximum daily loads (TMDLs), their processes and impaired water body listings as related to water quality?

18. To what extent are you concerned about salmonid populations, habitat, and the Endangered Species Act (ESA) as related to water quality?

19. Are you concerned about other current issues impacting PNW water quality not mentioned above?
    a. Yes (please mention these during the discussion period)
    b. No

Objective I Open-ended Discussion Questions:

1. What concerns about environmental impacts on water quality do you have that weren't mentioned in the multiple-choice questions?
2. Why are the things you marked as your top concerns so urgent? (Why are some things less urgent?)
3. In your experience, what are the major sources of pollutants that you are most concerned about?
4. Are your concerns about Pacific Northwest waters in the future similar to or different than present concerns? If not, how are they different?
5. How do urban and agricultural management decisions affect regional water quality?
6. How do you see the relationship between water supply and quality in the region? Does the seasonality of water availability affect water quality?
7. Of the concerns mentioned, which would you classify as regional issues vs. localized issues? If localized, where are those impacts most strongly felt?
8. What do you see as best management practices—what solutions to water quality issues do you see on the horizon?

Objective II: *To understand stakeholders' perspectives on decision making and what constitutes useable information*

1. To what extent does scientific information that is available to you influence your decision-making? "Decision-making" may include direct or indirect decisions about land management, regulatory policies, or research and technology development.
    a. Not at all
    b. A little
    c. A lot

d. The primary driver

2. To what extent does your understanding of the impacts and severity of nutrient loading (nitrogen and phosphorus) impact your decision-making?

a. Not at all
b. A little
c. A lot
d. The primary driver

3. To what extent are you interested seeing models developed that quantify water quality for the purpose of developing water quality markets and introducing trading credits to benefit water quality in the region?

a. Not at all
b. A little interested
c. Moderately interested
d. Strongly interested

4. Water quality projections would help me most if such information were available on the following timescale:

a. Weeks
b. Months
c. 1-2 years
d. 2-10 years
e. 10-20 years
f. 20-50 years
g. Other

5. Information about projected impacts of water quality management practices would help me most if such information were available on the following timescale:

a. Weeks
b. Months
c. 1-2 years
d. 2-10 years
e. 10-20 years
f. 20-50 years
g. Other

6. Information about the environmental effects of different water quality management practices would help me most if such information were available on the following spatial scale:
(Select your top two choices.)

a. Parcel

b. Farm
c. Forest
d. River reach
e. County
f. Lake
g. Reservoir
h. Watershed
i. State
j. Columbia River Basin

7. Information about the environmental effects of different water quality management practices would help me most if such information were available on the following formats:
(Select your top two choices.)

a. Maps and data visualizations
b. "Raw" or "un-interpreted" data and model outputs
c. Online decision support tools that allow manipulation of model inputs
d. Model outputs communicated in non-technical language (blog posts, extension documents, news articles)
e. Peer-reviewed publications
f. Webinars about model results with the chance to ask questions of model developers
g. Direct conversation/ consultation with model developers

Objective II Open-ended Discussion Questions:

1. What specific decisions do you make that impact water quality? What information sources do you draw on in making these decisions? What are your highest priority information needs? Why do you feel that these are important?

2. What water quality goals drive your decision-making? Are TMDLs relevant to these goals and decisions? Sustaining salmonid populations?

3. To what extent are water quality management decisions driven by ecological concerns vs. economic concerns vs. concerns about social well being?

4. To what extent is climate change taken into consideration in water quality management decisions?

5. How does information about sedimentation impact your decision-making? What information about changing sedimentation dynamics is relevant to your decision-making?

6. How closely do you follow hydropower issues in the Pacific Northwest? How do issues related to energy generation impact water quality issues?

7. How closely do you follow changing wastewater treatment practices and technology? What information about changes in wastewater treatment is relevant to your decision-making?

8. What tradeoffs are you weighing when you make decisions that entail competing concerns?

9. What are some important gaps in scientific understanding of water quality in the region?

Objective III: *To guide the scenarios and issues the research team addresses in model development and application.*

Discussion question for Objective III:

1. Placeholder for 1-2 questions for Will and John to write that focus the feedback they'd like on FSPs.

2. Is our concept of a "scenario" consistent with your understanding of scenarios? Is a regional scenario approach potentially useful to you? If so, how?

3. Are there any specific scenarios (environmental, economic, management, investment, policy) that you would you like to see addressed in a model like BioEarth?

4. Do you have concerns about how future economic changes in the region may impact water quality? Population pressure and land use change? The relationship of human well-being and water quality? If so, can you elaborate?

5. What water quality-related management approaches, regulatory actions, or policy changes can you envision taking place in the future? When do you imagine those changes might occur? What questions do you have about the possible impacts (intended and unintended) of those actions?

6. What emerging technologies or approaches do you view as particularly effective or promising as a means to improve water quality in the region? What are the current barriers (technological, financial, political) to implementation of "best management practices" for improving water quality in the region?

7. Are there possible future “game changers” for Pacific Northwest water quality (for good or bad)? If so, what might these be?

APPENDIX I. POST-WORKSHOP FOR SURVEY FOR STAKEHOLDERS

1. What was your overall impression of the workshop structure and organization?
    a. Great
    b. Good
    c. Acceptable
    d. Ineffective

2. What was the most important thing you learned by participating in the stakeholder advisory meeting? What did you get out of participating?

3. What are your current expectations about the BioEarth project?

4. Do you have interests or concerns that you didn't have an opportunity to share at the stakeholder meeting? What didn't we hear?

5. Any suggestions for the improvement of future stakeholder advisory meetings?

6. How would you like to see modeling results presented and communicated?

7. Who else should we talk to who was not represented at this stakeholder meeting?

8. What value do you place on academic research in your decision-making?
    a. low
    b. moderate
    c. high

9. Based on your experience at this meeting, how well do you think researchers communicated their work to stakeholders?
    a. exceptionally well
    b. generally well
    c. acceptable
    d. generally poor
    e. other

10. Do you feel that there a gaps in scientific information available online? What additional kinds of online resources would be valuable to you?