

DEVELOPMENT OF AN INTERDISCIPLINARY APPROACH WITHIN
AN ACADEMIC SETTING TO ADDRESS COMPLEX
SOCIAL AND ENVIRONMENTAL ISSUES

A Project
Presented
to the Faculty of
California State University, Chico

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
in
Environmental Science
Professional Science Master Option

by
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Spring 2016

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ABSTRACT

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The project presents a new and unique analysis of how specific metrics developed to evaluate interdisciplinary research contributed to the interdisciplinarity of one academic team's efforts. Evaluation metrics used to assess the interdisciplinarity of the team included (1) the number of participants and disciplines (2) early collaboration and time provisions for team development (3) shared decision making and team alignment, (4) communication and mutual understandings and (5) institutional support. The metric used to evaluate the interdisciplinarity of the research approach included (6) the degree of discipline integration used in the research approach. The methods and processes of team development and the products of the interdisciplinary work were used to evaluate and summarize the team's efforts.

Interdisciplinary research is based upon a conceptual model that integrates theoretical frameworks from multiple disciplines to solve complex problems. Since the 1970's, an interdisciplinary research approach has been extensively used in a variety of applications in numerous fields of study and settings, including academia. One of the most imperative aspects to the success of future interdisciplinary work is evaluation of the factors that contribute to interdisciplinarity of team processes and research approaches, as this type of evaluation can highlight conditions which enable teams to work productively together to produce sound interdisciplinary research approaches in order to provide useful information for other similar interdisciplinary endeavors.

As part of the project conducted at the California State University Chico, Center for Water and the Environment, an interdisciplinary team formed to develop a research approach to address social and environmental issues of northern California. The team's interdisciplinary approach was summarized into a proposal which was submitted to the National Science Foundation, Coupled Natural and Human Systems Program in December of 2010. This project report evaluates that overall process and the effectiveness of the interdisciplinary approach.

CHAPTER I

INTRODUCTION

Project Background

For the most part, research in the United States (U.S.) has been conducted within specific disciplines. In the 1970's, specific disciplines began combining into new directions and the term “interdisciplinary research” (IR) emerged. Since then, IR has become a prominent focus of U.S. research [*Ledford, 2015*]. Single discipline work was not abandoned, but rather complemented by the addition of IR. Interdisciplinary research facilitated the movement of research beyond the collection of individually established facts that occurs with single-discipline research [*Aboelela et al., 2007*].

The increased focus of IR in the 1970's is in part due to an evolution in modern research toward greater complexity [*National Academy of Science, 2005*] and a shift in focus from basic research to societal problems in an effort to meet emerging complex challenges during that time [*Aboelela et al., 2007*], such as environmental protection, which required an approach that included more than one discipline, due to its complexity [*Ledford, 2015*]. The medical field also shifted to an IR focus because they too recognized the limitations of their disciplinary perspective when faced with complexity inherent in health care and health policy research questions [*Aboelela et al., 2007*].

Today, IR is still active, highly regarded in U.S. research, and could be considered the new ‘business (or research) as usual’ as seen in the more than 4,000 active National Institute of Health (NIH)-funded research projects, considered interdisciplinary in 2015 and as exemplified by Betsy Wilder, head of the NIH Office of Strategic Coordination who stated, “Our general sense is that interdisciplinary research has become a very standard way of doing science” [Ledford, 2015, p. 311]. Interdisciplinary research can be applied to almost every existing discipline where there is a need to solve a complex problem that a single discipline cannot adequately address alone. The breadth of potential applications of IR is clear upon review of the definition used in the project, borrowed from *Aboelela et al.* [2007]:

Interdisciplinary research is any study or group of studies undertaken by scholars from two or more distinct scientific disciplines. The research is based upon a conceptual model that links or integrates theoretical frameworks from those disciplines, uses study design and methodology that is not limited to any one field, and requires the use of perspectives and skills of the involved disciplines throughout multiple phases of the research process. (p. 341)

Interdisciplinary research and training through IR programs has become a focus at many U.S. universities. The focus of IR in academic settings may be due an increased call upon universities to produce collaborative IR focused on the larger societal needs from funders and policy makers [NAS, 2005].

Although IR has been highly regarded for the past 20 years throughout a variety of fields and academic settings, there are still gaps in agreement of what constitutes good / effective IR and how to evaluate its interdisciplinarity. The methods involved in IR and the processes of achieving interdisciplinary collaboration are not clear to outsiders, seldom reported, and generally remain undescribed, but could further

invigorate IR [Robertson *et al.*, 2003]. There has been an increase in the use of IR and literature regarding its evaluation. The number of reports and an expanding literature on the evaluation of IR may have resulted from requests for the identification of quantitative output measures for IR from the National Science Foundation (NSF), a large-scale national agency addressing larger scale integrating questions [Wagner *et al.*, 2011] or from the realization of the extensive time and associated cost required for successful IR. There are a number of methods noted in the literature for IR evaluation; however there is still a lack of consensus on a framework to evaluate interdisciplinary efforts. Sankar *et al.* [2007] report that a number of studies have used a variety of methods to examine the extent of commonalities and understanding among IR team participants including interviews and observational methods. Hall *et al.* [2008] note that the combined use of surveys, interviews, observations, and measures of archived products from IR efforts in evaluations, can provide a more thorough understanding of the collaborative processes and outcomes of IR than by using one method alone.

Purpose

The purpose of the project was to identify common IR evaluation metrics from the literature and use those metrics to evaluate the interdisciplinarity of one team and their research approach (the research design outlined in the research proposal), based on their team experiences, in an academic setting. This effort identified the conditions which enabled the team to work productively together and to produce an IR approach in this specific setting.

Scope

This project reflects the results of a paid internship served with the Chico State University (CSU Chico), Center for Water and the Environment (the Center).

According to the *CSU Chico Center* [2006], website:

As a Center of Excellence at CSU, Chico, [the Center's] mission is to connect people from across campus as well as outside of the university, respond to societal needs, expand competitiveness in the research of water and the environment, and to expand and explore out-of-classroom learning opportunities for undergraduate and graduate students. [The Center] collaborates with local, state and federal agencies, non-profit organizations, businesses and educational institutions, particularly within the CSU, Chico service region [the counties of Butte, Colusa, Glenn, Lassen, Modoc, Plumas, Shasta, Siskiyou, Sutter, Tehama, Trinity, and Yuba] in northern California. (para. 2)

A group of faculty, staff, and one graduate student from CSU Chico, developed an IR team (the team) to develop a research approach / framework to address environmental and social issues facing the north state of California. The team ultimately decided to submit a proposal to the NSF, within their Dynamics of a Coupled Natural and Human Systems (CNHS) program. The project summarizes factors that contributed to the interdisciplinarity of the team and the team's research approach. In the literature reviewed, other IR teams have reported factors that have contributed to the interdisciplinarity of their efforts. The project provided a summary of some of the factors and used the factors from the literature reviewed as metrics, to evaluate the experiences of the university IR team. This project reflects an analysis of the interdisciplinarity of the team and their research approach. The applied metrics provided a basis for an evaluation of the interdisciplinarity of two aspects of the IR team; (1) the interdisciplinarity of the team and (2) the interdisciplinarity of the research approach. The intention of the project was to provide useful information for other similar IR endeavors in academic settings.

Significance

The project provides a meaningful contribution to the broad and local field of IR in academic settings by providing a summary of metrics found in the literature that others have used to describe and evaluate the effectiveness and interdisciplinarity of research teams and research approaches, descriptions of the methods and processes used by the team to develop the IR team and the research approach, and by applying the metrics to the team efforts to evaluate the interdisciplinarity of the both the team and the approach. Conclusions about the interdisciplinarity of the team and the approach were drawn from the specific processes the team used and the products of those efforts. Additionally, recommendations were developed for others engaging in similar IR in academic settings.

Results, conclusions, and recommendations from the project may be valuable for other research teams in academic settings attempting to perform similar work such as forming IR teams or addressing similar complex research topics. The project may provide other IR teams useful information to consider about different research team or research approach design choices. In addition, other IR teams may learn from the description of the unique experiences of the IR team and the processes used and / or use the metrics provided to develop pre- or post-project evaluations to improve future IR approaches.

Limitations

Project limitations included a specific team and scope of research within the geographical and academic setting the team was working in. Therefore direct comparison to other IR teams may not be relevant, due to the specific setting the team worked within.

Interdisciplinary research team development was limited to partnerships within CSU Chico to foster local collaborations, showcase university strengths, and develop a strong, nationally recognized presence for issues relevant to northern California. Another limitation in the project included timing. The project internship was short-term in nature, approximately six-months in duration. The time limitation also included the fact that the evaluation was conducted post-project, using metrics found in the literature and was based on observations of team experiences and products versus the use of participant surveys or interviews. Another limitation to the objectivity of this project includes that the evaluation was performed by a participant of the team conducting an internship, as opposed to an evaluation from an outside observer.

CHAPTER II

LITERATURE REVIEW

Interdisciplinary Research Emergence in the U.S.

There was a strong focus on specific disciplinary research in the U.S. during the nineteenth and twentieth centuries. In the nineteenth century, academic disciplines surged in number and power after the second World War, as the U.S. boosted research support [*Ledford, 2015*], which quickly expanded the number of departments within universities nationwide. As disciplinary distinctions grew more robust, their members became more isolated from one another [*Wagner et al., 2011*]. Specific disciplines began repeatedly subdividing. *Ledford* [2015] discusses how, for example, “biology was split into botany and zoology, then into evolutionary biology, molecular biology, microbiology, biochemistry, biophysics, bioengineering and more” (p. 309). For the most part, much of the research in the U.S. was conducted within these specific disciplines. In the 1970’s, specific disciplines began combining into new directions and the term “interdisciplinary research” emerged and became prominent in the focus of U.S. research [*Ledford, 2015*]. By facilitating the movement of research beyond the collection of individually established facts that occurs with single-discipline research [*Aboeela et al., 2007*], disciplinary work was not abandoned, but complemented by the addition of IR.

There are a wide variety of reported reasons for the increased focus of IR in the 1970's. While some credit the rise in part to libraries for stockpiling subscriptions which improved researchers' access to journals in a variety of fields, literature reviewed by the National Academy of Sciences (NAS) Committee on Facilitating Interdisciplinary Research suggested that there was an evolution in modern research toward greater complexity [NAS, 2005]. Emerging complex problems of the 1970's shifted the focus from basic research to social problems during that time [Aboelela *et al.*, 2007] such as environmental protection, a complex issue requiring an approach from more than one discipline [Ledford, 2015]. In the medical field, Aboelela *et al.* [2007] believed that many researchers conducted IR because they too recognized the limitations of their disciplinary perspective when faced with complex health care and health policy research questions. Rosenthal [1992] reported that in the 1970s, there was a renewed interest in human ecology and lifestyles which spurred a renewed attentiveness to the social, cultural, and economic factors that influence disease control and chronic illness prevention. By the early 1990s, the notion of obtaining an understanding of the 'whole person' was also considered essential for successful medical treatment of disease [Rosenthal, 1992].

Interdisciplinary research prominence in U.S. research became more clearly stated in 1996 when the 'crossing of boundaries' was claimed as a defining characteristic of our age [Pisapia *et al.*, 2012]. The importance of IR was a continued theme published in statements such as, "boundary crossing has become a marked feature of contemporary research" [Klein, 2008, p. S121]. By 2003, the perspective of addressing research questions with an interdisciplinary approach was not at all considered a new concept and was commonly referred to as the 'mantra of science policy' [Robertson *et al.*, 2003].

Government agencies funded IR work in the 2000's, associated with the newly recognized value of IR. Even government officials such as Dr. Elias Zerhouni, Director of the NIH and Dr. Rita Colwell, Director of the NSF, the two largest federal funders of academic research, discussed the importance of IR [Rhoten, 2004]. The directors argued that “disciplinary ‘silos’ need to be broken” and that “interdisciplinary connections are absolutely fundamental [as] the interfaces of the sciences are where the excitement will be the most intense” [Rhoten, 2004, p. 8]. To facilitate IR, the NIH ran a program called the Roadmap for Medical Research from 2004 to 2012, to stimulate IR. This resulted in changes to recognize and award grants to multiple principal investigator collaborations on programs previously considered single-investigator grants, thus removing a disincentive to collaborate [Ledford, 2015].

By 2005, IR was also a strong focus for the NAS, self-described as a private, non-profit society of distinguished scholars formed to provide independent, objective analysis, and advice to the nation, conduct other activities to solve complex problems, and inform public policy decisions [NAS, 2016]. NAS addressed the growing interest and challenges associated with IR through publications providing, amongst other things, guidance on how to lower barriers to IR [Ledford, 2015; NAS, 2005]. The [2005] NAS report, *Facilitating Interdisciplinary Research* indicated that four powerful “drivers” contributed to the shift of IR as an integral feature of research [NAS, 2005]. These drivers were described as: (1) the inherent complexity of nature and society, (2) the desire to explore problems and questions that are not confined to a single discipline, (3) the need to solve societal problems, and, (4) the power of new technologies” [NAS, 2005].

By 2005, a variety of associations, including the American Geophysical Union, American Chemical Society, American Institute for Biological Sciences, and the American Political Science Association, also sponsored interdisciplinary collaborations and emphasized interdisciplinary analyses and activities at the edges of their represented disciplines [Wagner *et al.*, 2011]. Today, even academic institutions such as Harvard, “have begun to describe themselves using such terms as “collaborative”, “cross-school”, “interfaculty”, or even “University-wide,” while the Office of the Provost applauds and encourages all collaborative ventures [Harvard University, 2016, para. 2].

Interdisciplinary Research Defined

Disciplinary work is the underlying structure of IR. It provides crucial knowledge, methodologies, and tools for IR and transdisciplinary work [Klein, 2008]. Therefore, to understand interdisciplinary work, a definition of disciplinary work is useful. Darden and Maull [1977] define a discipline of science as having a central problem with relevant facts, explanations, goals, and theories related to the problem. Pisapia *et al.* [2012] also described how disciplines use borders to differentiate their work from others, formed by the assumptions, theories, techniques, tools, and methods of the discipline [Pisapia *et al.*, 2012].

There are numerous definitions of IR in the literature, thus it is important to define the term ‘interdisciplinary’ used for the focus of the project. The final definition of IR for the project stemmed from a comprehensive literature review of the numerous definitions of IR in the work of Aboelela *et al.* [2007]. Aboelela *et al.* [2007] proposed

the following theoretically based definition of IR based on interviews with researchers from various disciplines and a systematic review of literature:

Interdisciplinary research is any study or group of studies undertaken by scholars from two or more distinct scientific disciplines. The research is based upon a conceptual model that links or integrates theoretical frameworks from those disciplines, uses study design and methodology that is not limited to any one field, and requires the use of perspectives and skills of the involved disciplines throughout multiple phases of the research process. (p. 341)

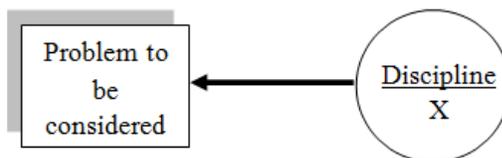
Simply involving researchers from various disciplines into the effort is not enough to make a research effort interdisciplinary [Aboelela *et al.*, 2007]. Their definition was used for the purposes of the project, as it provided the most clear, yet comprehensive description of the definitions reviewed.

A number of other terms are often used interchangeably with the term IR. While the terms describe the ways professionals work across disciplinary borders; they are used ambiguously on many university campuses, and among professionals and funders of research [Pisapia *et al.*, 2012]. The terms ‘multidisciplinary’ and ‘transdisciplinary’ are commonly used terms to describe research conducted in an interdisciplinary fashion. While disciplinary research uses one single discipline to address a problem, multidisciplinary research uses multiple disciplines to address a research question. In multidisciplinary research, each discipline brings their own systematic framework and methods to address the portions of the problem applicable to their own particular discipline. In IR while there are still a number of disciplines addressing the problem, the difference lies in the interaction between the disciplines and the overlap where each disciplines frameworks and methods must merge together to develop a solution that a single discipline alone could not. Finally, in transdisciplinary research, the

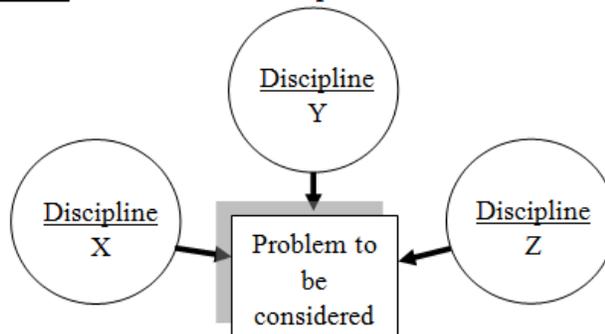
overlap and combination of disciplinary frameworks and methods exist; however at this joining intersection, the results of how to address the problem create an entirely new discipline. A visual depiction of the relation between the terms is found in Figure 1.

Interdisciplinary Research in Practice

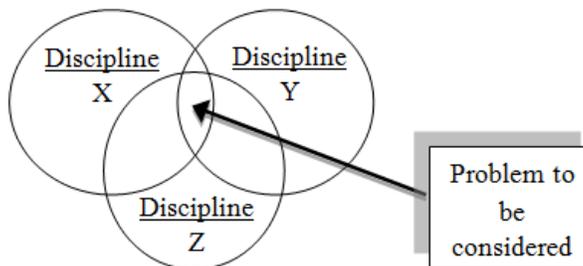
Interdisciplinary research can be applied to almost every existing discipline where there is a need to solve a complex problem that the single discipline alone cannot adequately address. Interdisciplinary research is used in both the medical and environmental fields. An example of IR used in a medical field, includes the study of drug or alcohol addiction [*Rosenthal, 1992*], where research in fields such as genetics, pharmacology, physiology, and neurobiology of drug abuse could combine to address the issue. *Aboelela et al. [2007]* also points out another specific example of IR in the medical field related to tobacco use and lung disease. They describe how the knowledge and discovery of the association between tobacco use and high rates of lung disease emerged and yet the discovery was not in itself sufficient to lead to the cessation of smoking. Tobacco use rates only lowered with additional research on risk assessment, motivation, and reasoned action in the program design with help from environmental and social science fields [*Aboelela et al., 2007*]. Other examples of IR includes studies on: cultural and behavioral aspects of specific diseases ranging from malaria to leprosy; social pathologies such as suicide and poverty; broad programmatic themes such as nutrition and family planning; and economics of health and health services, including health care financing [*Rosenthal, 1992*].

Disciplinary Research

Multidisciplinary Research addresses the same problem from more than one disciplinary perspective



Interdisciplinary Research addresses the same problem from more than one disciplinary perspective until they merge and the overlap creates new ways of looking at the problem



Transdisciplinary Research combines the disciplines used to solve a problem resulting in a new discipline being created

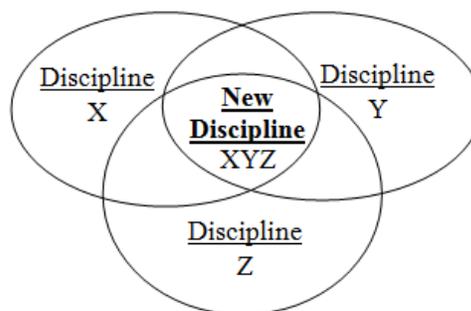


Figure 1. Definitions and relationships of the terms disciplinary, multidisciplinary, interdisciplinary and transdisciplinary

Source: Adapted from Pisapia, J., T. Townsend and J. Razzaq, (2012), Interdisciplinary research: Perceptions, Teams and Networks: Working Paper, Florida Atlantic University, Boca Raton, Florida and the University of Glasgow, Glasgow, Scotland, United Kingdom.

In the environmental field, understanding the ‘whole ecosystem’ is considered essential for resolving any specific environmental problem [Rosenthal, 1992]. One example of the role of IR in addressing environmental issues can be found in the study of climate change. *Xu et al.* [2016] describes how IR approaches in a variety of studies have been adopted to study climate change involving knowledge and skills from a broad range of disciplines including soil science, marine science, atmospheric sciences, plant physiology, ecosystem science, hydrology, and computer science. Interdisciplinary approaches have also been used to develop strategies for mitigating climate change, such as through greenhouse gas emissions reductions and adapting to the impacts climate change on society and natural systems [*Xu et al.*, 2016]. Additionally, the development of a long-term mitigation strategy involving reduced use of fossil fuels and harnessing renewable energy sources, has required the synthesis of knowledge from engineering, technology, and natural and social sciences [*Xu et al.*, 2016].

Interdisciplinarity in Academic Settings

Interdisciplinary research and training through IR programs has become the focus at many U.S. universities. Over 1,650 colleges throughout the U.S. currently have interdisciplinary studies programs [*Campus Explorer*, 2016]. This aligns with the fact that there has been an increased call upon universities to produce collaborative IR focused on the larger societal needs from funders and policy makers [*NAS*, 2005]. Many campus administrators responded vigorously with renewed energy and innovative organizational structures and have produced interdisciplinary centers, institutes, and

programs that have complemented and sometimes outnumbered traditional departments [NAS, 2005].

One such example of an IR center within a university is the Center at CSU Chico. The Center is recognized as a Center of Excellence at CSU Chico, aimed at operating as a hub for water and environmental research and education at the university with faculty, staff, and students drawn from diverse fields including agriculture, biological sciences, chemistry, economics, engineering, environmental sciences, geography, geological sciences, mathematics, social sciences, and statistics [CSU Chico, 2016]. The mission of the Center is to connect people from across and off-campus to respond to societal needs, expand competitiveness in the research of water and the environment, and to expand and explore out-of-classroom learning opportunities for undergraduate and graduate students [CSU Chico, 2016].

Importance of Method Transparency in Interdisciplinary Research

The project is, in part an effort to record and bring transparency to the processes of how the IR team formed and developed a research framework to address critical issues facing northern California. The literature reviewed describes that the methods used to achieve IR are typically not well described but fundamental to the field of IR. Although methods used to achieve interdisciplinary collaboration are often not clear to outsiders, seldom reported, and generally undescribed and under-prioritized, identification of the methods could further invigorate IR [Robertson *et al.*, 2003]. Nancarrow *et al.* [2013] agrees that little attention has been directed towards the actual processes of inter-professional development. Robertson *et al.* [2003] go onto state that the

lack of identification of the methods of IR makes it hard for others to assess the validity, trustworthiness, and reliability of the work and inferences drawn and it also makes it difficult for others to build upon the methods of the earlier groups work. They add that the actual work of IR teams should be observed and analyzed, and if done routinely, it could contribute to a system built to continuously improve IR methods. The one vital step forward in IR is to bring transparency to the methods of the processes of achieving interdisciplinary collaboration and this should become the focus of future work, as it could improve the rigor, accountability, and productivity of the research [Robertson *et al.*, 2003]. Other researchers could also benefit from access to the methods of IR as it could allow for development of ideas regarding how to replicate success, or avoid challenges or how to choose to carry out IR similarly or differently, which could result in an increased awareness and understanding of interdisciplinary work.

Evaluation of Interdisciplinary Research Projects

Increases in the use of IR have resulted in a number of reports and an expanding literature on the evaluation of the characteristics of successful IR. Interdisciplinary research requires time and money. Interest in the evaluation of IR likely resulted due to a realization of the extent of the time, energy, and financial expenditures required for its success. Identifying and understanding the conditions that facilitate or hinder effective collaboration is important, as the bridging of multiple disciplines can be expensive and labor intensive [Hall *et al.*, 2008].

Despite the emphasis of the importance of IR over the past 20 years, there is no clear agreement on what constitutes or underpins a good IR / effective team, what it

may look like, or the most effective way of delivering IR teamwork as there are no systematic frameworks around which the activities of IR can be structured [Nancarrow *et al.*, 2013]. Most studies focus on either the processes of IR or the outcomes, but there is a lack of data linking the two [Nancarrow *et al.*, 2013]. Contextual detail regarding effective IR team practice (i.e. context, team roles, and processes) is lacking according to Nancarrow *et al.*, [2013].

There are a number of methods noted in the literature for evaluation of IR to characterize the effective components of its success. Hall *et al.* [2008] note that the combined use of surveys, interviews, observations, and review of archived products of IR efforts in evaluations to identify components of effective IR, can afford a more complete understanding of collaborative processes and outcomes of IR than by using one method alone. Sankar *et al.* [2007] report that a number of studies have used a variety of methods to examine the extent of commonalities and understanding among IR team participants, including interviews and observational methods. While the methods may seem appropriate, considering that the interactions at the beginning of the IR work are often recognized after the work transpired, this type of study is very labor intensive [Sankar *et al.*, 2007]. One solution presented by Stokols *et al.* [2003] is for members of the research team to conduct the evaluations of the factors that contribute to the interdisciplinarity of a team themselves. Stokols *et al.* [2003] goes onto discuss that this method has produced some insightful accounts and is considered a useful strategy, however, it is not always practical to assume that researchers will have the time, expertise, or interest needed to conduct the evaluations. Gunnarsdóttir and van Dijk [2015] similarly used participant

interviews as an evaluation method, observations through attendance at workshops and meetings and also analyzed documents produced by teams and institutions in their work.

Hall et al. [2008] described two approaches that have been used for assessing the levels of collaboration and integration achieved by the members of research teams and centers to assess ongoing processes of collaboration and scientific synergy as they occur within particular settings and to evaluate the quality and scope of integration among multiple disciplinary perspectives) reflected in products such as grant proposals and published journal articles. *Hall et al.* [2008] used both process and product measures to gauge early progress toward cross-disciplinary collaboration (which was defined similarly to the definition of IR in the project) in their evaluations and discuss how the process and product research deliverables can:

. . . serve as markers of collaborative progress during both the initial and later phases of a cross-disciplinary initiative. Although product assessments do not capture the dynamics of cross-disciplinary collaboration as it occurs over time, the development of objective criteria for evaluating the integrative scope and quality of written products has the advantage of establishing standardized criteria that can be applied reliably and validly across a wide range of research and training projects. (p. S163)

The project presented an overview of factors that influenced the interdisciplinarity in other IR group efforts as noted in the reviewed literature and used those as metrics by applying them to the experiences of the team to evaluate the interdisciplinarity of the team and the team's research approach. The project presents a new and unique analysis of how specific metrics identified in the literature applied to the specific efforts of the team.

CHAPTER III

METHODOLOGY

Research Team and Research Approach Development Summary

An IR team and an IR approach were developed to address complex social and human issues in northern California. A post-hoc review of the team's experiences was used to summarize the development of the team and the approach and to evaluate the factors contributing to the team's interdisciplinarity and the interdisciplinarity research approach. Team experiences (methods and processes used) were directly observed and summarized from information that was collected and compiled from detailed notes, meeting summaries, email correspondence, a team resource website, and the products of team efforts. The products included writing assignments and draft and final proposals.

Evaluation Metrics

To evaluate the degree of interdisciplinarity of the team's efforts, the composition of the team, the processes used, and the resulting research approach / design, as described in the final proposal were evaluated. A review of the existing literature which described factors that have been beneficial or detrimental to other IR efforts are found in the results section of this document and descriptions of the evaluation methods used by others in the literature are found in the literature review section of this document. As previously noted, there is a lack of consensus in the literature regarding a defined set

of accepted metrics by which IR efforts, similar to the teams, are typically assessed. Therefore evaluation criteria were chosen because they were (1) commonly referred to in the literature reviewed and (2) applicable to the team's efforts.

The observed team experiences and products were reviewed through the lens of each criterion and evaluated based on how the criteria contributed to the interdisciplinarity of the team and the research approach. The criteria used to make this determination included quantitative metrics for the evaluation of the research team's interdisciplinarity. One qualitative metric was used to assess the interdisciplinarity of the final research approach (Table 1).

Interdisciplinarity of the Research Team

The metrics (Table 1) used in the evaluation of the interdisciplinarity of the team itself were quantitative and included information about the basic structure of the group including the number of participants and the number of disciplines found within the team. Other metrics focused on formation and maintenance of the team, which included bringing collaborators into the process early, allowing adequate time for collaboration, dialogue and networking between participants, and time for the development of relationships within the team. Another common metric identified in the literature used to evaluate interdisciplinarity of IR teams relates to the dynamics within an IR team including factors such as non-hierarchical relationships, shared decision making and shared power within the team, respect for other disciplinary frameworks, and a leader's ability to create alignment and develop commitment within the team. Communication was another metric used to evaluate the IR team and included good /

Table 1. Evaluation Metrics Used to Determine the Interdisciplinarity of the Team and the Research Approach

Aspect Evaluated	Type of Metric	Metric	Reference
Interdisciplinarity of Team	Quantitative	Number of participants, disciplines represented	<i>Henneman et al.</i> , 1995; <i>Pisapia et al.</i> , 2012, <i>Lyall and Meagher</i> , 2007; <i>Rhoten</i> , 2004.
	Quantitative	Bringing collaborators into the process early, adequate time for collaboration and dialogue between participants/ networking / development of relationships	<i>Nancarrow et al.</i> , 2013; <i>Aboelela et al.</i> , 2007; <i>Klein</i> , 2008; <i>Pisapia et al.</i> , 2012; <i>Rosenthal</i> , 1992; <i>NAS</i> , 2005; <i>Robertson et al.</i> , 2003; <i>Lyall and Meagher</i> , 2007; <i>Fisher</i> , 2004; <i>Ledford</i> , 2015.
	Quantitative	Non-hierarchical relationships / shared decision making and power, respect for other discipline's frameworks, leaders ability to create alignment and develop commitment within the team	<i>Henneman et al.</i> , 1995; <i>Klein</i> , 2008; <i>Ledford</i> , 2015; <i>Pisapia et al.</i> , 2012; <i>Rosenthal</i> , 1992; <i>Lyall and Meagher</i> , 2007; <i>Fisher</i> , 2004.
	Quantitative	Good / effective communication, development of a common language, shared understanding of the problem / mutual learning	<i>Henneman et al.</i> , 1995; <i>Nancarrow et al.</i> , 2013; <i>Aboelela et al.</i> , 2007; <i>Gunnarsdóttir and Van Dijk</i> , 2015; <i>Klein</i> , 2008; <i>Pisapia et al.</i> , 2012; <i>NAS</i> , 2005; <i>Robertson et al.</i> , 2003; <i>Fisher</i> , 2004; <i>Klein</i> , 2008.
	Quantitative	Institutional support / commitment [time credit, promotions, rewards, resources i.e. space, technological support, centers of IR, funding]	<i>Metzger and Zane</i> , 1999; <i>Aboelela et al.</i> , 2007; <i>Fisher</i> , 2004; <i>Pisapia et al.</i> , 2012; <i>Rhoten</i> , 2004; <i>Rosenthal</i> , 1992; <i>NAS</i> , 2005; <i>Robertson et al.</i> , 2003; <i>Lyall and Meagher</i> , 2007; <i>Hall et al.</i> , 2008.
Interdisciplinarity of Research Approach	Qualitative	Relationship between / integration of disciplines in research approach	<i>Sankar et al.</i> , 2007; <i>Gunnarsdóttir and Van Dijk</i> , 2015; <i>Klein</i> , 2008; <i>Ledford</i> , 2015; <i>Pisapia et al.</i> , 2012; <i>Rosenthal</i> , 1992; <i>Wagner et al.</i> , 2011; <i>Robertson et al.</i> , 2003.

effective communication, development of a common language, and a shared understanding of the problem through mutual learning. Finally, the degree of institutional support including factors such as resources, funding and rewards was used as another metric used to evaluate team interdisciplinarity.

Interdisciplinarity of the Research Approach

To evaluate the interdisciplinarity of the research approach, the integration of the disciplines used in the research approach was used as a qualitative evaluation metric. Disciplinary integration was focused on achieving an understanding of the degree of discipline integration from the written products. Table 1 provides more detail regarding the literature that discussed this metric.

CHAPTER IV

RESULTS

Summary of the Final Research Team and Research Approach

An IR team and approach was required for the work performed by the team. The nature of the issue addressed by the team required multiple researchers and disciplines to develop the framework for a solution. The complexity of the issue also required the integration of the disciplinary frameworks represented by each team member. The Appendix includes a brief overview of the final research proposal submitted to the NSF CNHS program which includes details of the research approach.

Interdisciplinarity of the Research Team

Number of Participants and Disciplines

Results of literature review. The first metric included a review of the how the number of researchers within the IR team contributed to the overall interdisciplinarity of the team. One significant attribute of collaboration is that two or more individuals are involved [Henneman *et al.*, 1995]. The number of team members (small or large) can also influence how interdisciplinary a team is. In a network analysis of six IR centers *Rhoten* [2004] found that while some interdisciplinary centers associated larger numbers of affiliates with greater rates of interdisciplinarity, data showed that it did not increase meaningful interdisciplinary activity. They found that small centers of less than 20

participants or small bounded networks within large centers of 50 or more researchers produced more connections than larger centers and regardless of group size; researchers did not tend to interact with more than 15 other researchers [Rhoten, 2004]. In the literature reviewed, the number of team participants found to be beneficial to the interdisciplinarity of a team is between two and 20.

Results of team efforts. The initial team consisted of four researchers, referred to as the ‘initial core team’. The IR team underwent an exhaustive effort to include numerous additional researchers who expressed an interest in, and a commitment to working on the issue within the research team. The effort to include additional team members was first conducted through a university-wide invitation to participate in project discussions at a large meeting held on campus. After receiving interest from approximately 46 individuals, outreach was conducted to another 30 targeted individuals based on a review of their expertise and research interest from the university website. This effort resulted in approximately 28 interested researchers attending the first large university-wide meeting. A larger but separate group of interested researchers who provided support and feedback to the initial core team, referred to as the ‘working group’ was formed approximately four months after the formation of the initial core group. The working group was comprised of approximately 24 individuals that expressed interest in the research topic and direction. The working group of researchers provided support and feedback to the core group as consensus building and meetings continued over the next two months. From the working group, three researchers were invited to join the initial core team and together formed what is referred to as the ‘final core team’ approximately five months into the overall process. The final core IR team was comprised of six team

members who contributed directly to the teamwork until final proposal submission to the NSF.

Results of literature review. Another portion of this metric included how the number of disciplines represented within the team influenced the interdisciplinarity of the team. Interdisciplinary research teams involve collaboration with members from more than a single discipline and include groups of professionals from diverse disciplines [Pisapia et al., 2012]. As Lyall and Meagher [2007] state, it is important to get the right balance of contributions from component disciplines. Rhoten's [2004] work also found there to be a greater rate of connectivity among researchers from disparate disciplines than similar disciplines. In the Nancarrow et al. [2013] study, characteristics of a good interdisciplinary team included teams with sufficient and appropriate skills and competencies. The number of disciplines represented in an IR team will inherently vary depending on the scope of the research; however the interdisciplinarity of a research team depends on contributions from multiple disciplines.

Results of team efforts. The team performed a thorough process of determining the disciplines to be represented in the final team in order to develop the most beneficial approach to address the research issue. In the first three months of team work, the initial core team represented the disciplines of landscape ecology, plant physiology, agronomy, volcanology, and education. After expanding the invitation to participate in the research project university-wide, approximately three months after in the initial core group began working together, the formation of the working group additionally represented the general disciplines of computer science, geography and planning, mathematics / statistics, economics, geosciences, biology, Geographical

Information Systems analysis, computer science, communication design, and agriculture. Once the final core team was established, approximately five months into the overall process, including addition of three researchers from the working group to the initial core team, the final disciplines represented in the research approach included landscape ecology, biogeography, land-use change, plant physiology, natural resource economics, applied statistics, rural and regional planning, and education. Some team members represented more than one discipline due to their academic backgrounds and expertise in multiple disciplines.

Early Collaboration and Time Provisions

Results of literature review. The second metric reviewed how the contribution of bringing collaborators into an IR team, early into the process of team development contributed to the interdisciplinarity of the team. Many researchers providing post-evaluation guidelines for IR teams have highlighted the importance of engaging integration of disciplines from the beginning of the project, to the interdisciplinarity of a team [Klein, 2008]. The first recommendation to team leaders in the NAS [2005] guide to facilitating IR is to “bring together potential research collaborators early in the process and work toward agreement on key issues” (p. 113). Other agree and state that early discussions involving IR colleagues, allow for the development of a team culture for their work and agreement on specific outcomes [Pisapia et al., 2012]. Rosenthal [1992] also discussed how one IR team in Brazil found that when the team moved as one almost from the beginning, and showed openness and readiness to consider and combine diverse concepts, their level of interdisciplinarity moved into a transdisciplinary effort.

Results of team efforts. The IR team attempted to bring collaborators from all potential disciplines into the process of team and research approach development early using a very thorough and inclusive process. The IR team was initially comprised of four faculty researchers each representing expertise in their own separate disciplines. After the initial core team formed, the expertise and research strengths of each member were shared within the team through a series of meetings that outlined each member's previous, current, and future projects and research interests over an approximate two month period. As the research topic developed and became more defined, the initial core team acknowledged the need to expand the research team, to add more participants and engage interest of other researchers from a broader set of disciplines. Approximately three months after the formation of the initial core team, advertisement of the core team's intention to pursue an IR research project was distributed to every faculty member at the university through official email correspondence from the CSU Chico Office of Public Affairs and Publications, in the Division of University Advancement. The advertisement included a description of the research topic, potential approaches to address it, funding sources under consideration, and an invitation to participate in a university-wide meeting to further discuss the ideas. The invitation attempted to establish effective university-wide faculty inclusion early into the process of the development of the team and the research approach.

The initial invitation intentionally sent university-wide in order to prevent unintended exclusion of faculty members who may have had strong interests in and expertise to contribute to the research effort, but were not identified from faculty and or department website searches. After initial responses from 45 interested faculty members

were received regarding the meeting, the core group recognized that a university-wide review of faculty members could potentially contribute to the interdisciplinarity of the research team. A targeted effort was made to research the backgrounds, research interests, and work experiences of faculty members across all disciplines within the university. The group reviewed faculty profiles on the university website for potential targeted inclusion. Consideration was given to faculty member's professional academic interests, and specifically to those who had personal research interests similar to those within the scope of the proposal topics as presented in the information on the university website. A document summarizing select potential participants was developed and distributed within the initial core group to assist in making a decision regarding the distribution of targeted invitations. An email was sent to an additional 30 select potential participants based on the alignment of their research interests with the research topics identified by the initial core team. A request to reply to the invitation, curriculum vitae, and short writing assignment were requested of those interested in participating in first university-wide meeting. The IR team asked these targeted potential attendees to provide a short synopsis of their views of how their areas of expertise could contribute to the specific research directions the group developed. Attendance at the large university-wide meeting included 28 participants representing five of the nine CSU Chico colleges including the colleges of (1) Agriculture, (2) Behavioral and Social Sciences, Engineering, (3) Computer Science, and Construction Management, (4) Natural Sciences and (5) Communication and Education. After conducting the large university-wide meeting, the larger working group was formed approximately four months after the formation of the initial core group. The working group provided support and feedback to

the core group. After a series of meetings and discussions within the working group to further refine the research approach, three additional researchers were brought into the initial core team to form the final core team approximately one month after the working group was formed. The final core team engaged in collaboration until the research proposal was submitted, approximately six months after the formation of the initial core team.

Results of literature review. The second metric also reviewed how the provision of adequate time for collaboration, dialogue, networking, and development of relationships within the research team contributed to the interdisciplinarity of a team. A tailored approach to optimize IR teamwork and collaboration building is important. The provision of time for the components of team development such as collaboration, dialogue, networking, and development of relationships are also viewed as important to a team's interdisciplinarity. Competence within an IR team is partially defined by how well consensus building and integration is managed and implemented [Klein, 2008]. One inherent challenge to collaboration is people who do not know each other [Fisher, 2004], therefore teams need to regularly invest time in the processes of team development and maintenance of how they are functioning [Nancarrow *et al.*, 2013]. Klein [2008] also noted that to avoid pushing an IR group to integration too quickly, time must be allowed for interaction among researchers, joint work activities, and shared decision making to build rapport and foster an understanding amongst researchers of how each discipline approaches a research question. Aboelela *et al.* [2007] systematically reviewed interdisciplinary literature in an effort to identify themes and components of successful IR in order to define IR. This work revealed that most IR teams identified the degree of

cooperation or interaction between members of the collaborative teams, such as the amount of contact between team members and the degree of information sharing as critical components in defining IR [Aboelela et al., 2007]. The Nancarrow et al. [2013] study also reviewed several IR teams in the medical field to determine the characteristics of a good / effective IR team. They found that there is a need for teams to regularly invest time in the processes of team development and maintenance of team functioning and that patience, nurturance, and time are required to build relationships for collaborations to occur [Nancarrow, 2013]. Time for dialogue and networking between team members are key components of IR. Klein [2008] states that time must be allowed for interaction and joint work activities among team members of an IR team, and that this time for clarification and negotiation of differences can reduce misunderstandings and strengthen conditions for consensual modes of work. Klein [2008] continues this point by stating that competence in IR is defined partly in terms of how well consensus building is implemented; therefore, evaluation must consider how well communication is fostered, including networking among different disciplines.

Results of team efforts. The IR team held numerous meetings and discussions over the approximate six-month time period spanning the formation of the initial core team to proposal submission by the final core team. In-person meetings occurred on a frequent regular basis, throughout the duration of team efforts, usually weekly and sometimes more frequently with a portion of the team members that were available. Meetings within the initial core team occurred over a two-month period before the top project ideas were even ranked by team members. Dialogue among the initial core team members continued from the start of the discussions until consensus on the research

approach was finally reached, approximately four months after formation of the initial core team. At times, meetings within the first three months of working together were focused on joint work activities, such as ranking and condensing top ideas and planning and conducting the university-wide meetings. Time was devoted, particularly within the first five months of the team's progression to understanding one another's disciplines, research interests, and backgrounds. Other joint activities that occurred throughout the entire duration of team efforts included analysis and discussions of other research studies. During a portion of the meetings that were held within the first five months of teamwork, journal articles and research studies that were applicable to the IR team's research approach were distributed to group members for review and then analyzed by the team. During the final month of teamwork focused on writing and submitting the draft and final proposals, time was also devoted towards dialogue for agreement on the language of the final written product.

Shared Decision Making and Team Alignment

Results of literature review. A portion of the third metric reviewed identified the contribution of shared decision making to the interdisciplinarity of a team. The importance of shared decision making and collaboration between team members is noted in the literature as a key component to the interdisciplinarity of a team. *Henneman et al.* [1995] shares Kraus' [1980] perspectives that collaboration is described as a cooperative venture based on shared power and authority, that it is nonhierarchical in nature, and assumes that power within the team is based on knowledge or expertise as opposed to role or function. The definition of collaboration in this context includes having respect for

the unique qualities and abilities of each professional within a team and using joint decision-making processes [Coluccio and Maguire, 1983 as cited in Henneman et al., 1995]. In the work of Pisapia et al. [2012] involving participant perspectives of IR, respondents identified that team decision making was a required process for team cohesion. Nancarrow et al. [2013] described that an effective interdisciplinary team functioning at a high level utilizes communication strategies that promote intra-team communication, collaborative decision-making, and effective team processes.

Results of team efforts. Throughout the complex, multi-stage process of developing the IR team, team members shared in most of the decision making processes. Matters were at times decided by only a portion of the team in attendance; however any decisions made were available for debate, further discussion, and / or amendments, if needed. Key topics identified by the group within the first two months of team discussions were prioritized by the team, if the topics also complemented the university's mission and provided service to the region. Also within this time period, a shared decision was made within the team to review existing literature to identify a model approach, based on what had already been done both with respect to the topic and to the region. The team agreed within the initial two-month time period of teamwork, that a review of case studies specific and relevant to the region would also be valuable to the team. Additional background research was crucial to topic development and to help further refine the best approaches to address the team's research questions. In the first two-months of work together, the team agreed on the type of background research needed and collectively acknowledged that the next logical steps in developing the proposal were to focus the ideas emerging from this effort to a local specific level, prioritizing what was

possible and realistic with time, budget, and participation constraints. After review of first two months of meeting notes and discussions, the team collectively created a list of the top ideas that had been generated during that time in order to choose a specific research approach. In the third month working together, the initial core team then jointly decided on combining related ideas and ranking them in order to determine which topics would be presented at the university-wide meeting. After the university-wide meeting was held, and the working group formed, a thorough review of potential additional core team members from the working group was held, and the initial team collectively decided within the fifth month of working together, whom to invite into the final core IR team. In the last two months of work before final proposal submission, consensus was made to develop the approach of the research and the language of the proposal. The activities of the team described above highlight the broad range of shared decision making that occurred within the team.

Results of literature review. The other portion of the third metric relates to the contribution of respect, alignment, and commitment between researchers to the interdisciplinarity of a team. Respect for other team members, respect for the frameworks of the disciplines represented within an IR team, and a leader's ability to create alignment and develop commitment within an IR team are noted in the literature as important in successful IR team dynamics. Collaboration requires that individuals are acknowledged by fellow team members for their contributions to the process and it requires that individuals share responsibility for outcomes [*Mailick and Jordan, 1977* as cited in *Henneman et al., 1995*]. *Pisapia et al. [2012]* states that the key to a successful interdisciplinary team is mutual trust and respect. They continue by stating that if

interdisciplinarity is to thrive in the university at a team level the ability to establish alignment and commitment among participants is often the difference between success and failure [Pisapia et al., 2012]. Interdisciplinary research team leaders should be able to create direction, alignment, and commitment within the team before engaging in the leadership of an IR team [Pisapia et al., 2012]. Along these same lines, Pisapia et al. [2012] points out that the closer a IR leader is to the team members, the more they should work with the people rather than the research itself or the products of the work, and that a leaders coordination influences actions that bring colleagues together around a common set of values and goals to rise above individual differences to see the venture as a whole. Pisapia et al. [2012] states this concept well:

A key to success in interdisciplinary research is to organize around the concept of a working alliance where there is agreement on direction, tasks and commitment...where leaders execute coordination and collaboration actions by focusing on the process more than the content of the work to engage their colleagues in the work rather than telling them what to do... Working in an alliance is different than working in a group. Within a group, participation is defined by professional roles. While there is a common function or focus no one person can speak for others. In an alliance, participation is based on a shared common purpose to which team members hold themselves mutually accountable to other members, thus individual members can speak for the others. For these alliances to be successful, professionals must learn to work with each other and to learn from each other as they move from individual and group work to teamwork. (p. 13)

Results of team efforts. Throughout the entire process of working together, members of the initial core and final core team displayed a deep level of respect for one another's disciplinary frameworks by engaging in meaningful discussions at length about them, inquiring about differences amongst them, and providing explanations to one another about how the framework of each members discipline could contribute to the research team and approach as discussions about merging disciplinary frameworks

emerged. The team leader also fostered team alignment by engaging team members to participate in joint activities such as literature and case study reviews, background research, and large university-wide meeting plans and implementation activities within the first three months of working together. Commitment to address the social and environmental issues of northern California was apparent and likely the driving force behind the commitment of team members. Over a six-month period, team members collectively dedicated hundreds of hours to brainstorming sessions, meetings, discussions and the development of written products.

Communication and Mutual Understandings

Results of literature review. The next metric included a review of how good / effective communication and the development of a common language and shared understanding of a problem through mutual learning influenced the interdisciplinarity of a team. Communication is cited throughout the literature as being a valuable component to successful IR. “Communication, and being in-communication, is key to the necessary dynamism in keeping a shared study environment alive and going forward”

[*Gunnarsdóttir and van Dijk, 2015, p. 8*]. *NAS [2005]* discusses how leaders can catalyze the integration of disciplines with effective communication skills. *Henneman et al.*

[1995] provides more detail regarding what effective communication skills are and their importance as one of the main factors promoting collaboration within an IR team.

Effective communication skills require members to listen to other's perspectives, while still presenting their points of view, in order to contribute to the planning of the project and to negotiate constructively with one another [*Henneman, 1995*]. The amount and frequency of communication as well as the type of and degree of communication between

team members is important in IR. In terms of the amount and frequency of communications, *Klein* [2008] points to the importance of the ongoing and systematic communication of researchers, in that it increases the ability for integration, reduces the likelihood of integration shortfalls, and also that it can reduce misunderstandings through clarification and negotiation of differences, which can strengthen consensus building. In discussions of the degree of communications between team members, a spectrum of communication is described by *Aboelela et al.* [2007] along a continuum of integration from (1) team members remaining loyal to their respective disciplinary languages, (2) team members learning each others' terminology, or (3) members developing and using a common language. When languages are shared amongst researchers along with the practices and methods of the research, to create a 'trading zone' of ideas and methods, collaborations succeed [*Robertson et al.*, 2003]. At the end of the spectrum, closest to integration, is the development of a common language amongst researchers from differing backgrounds. *Rosenthal* [1992] found that the boundaries of IR were transcended when a common language was developed between disciplines to facilitate a shared conceptual framework. He goes on to note that while this level of communication and collaboration is important for successful IR and has the most potential for originality [*Rosenthal*, 1992], it's often the least practiced due to the level of difficulty in developing it [*Robertson et al.*, 2003]. According to *NAS* [2005] one difficulty in developing a common language in a timely manner, involves differences in culture or customs, shared values, understandings, and relationships that pervade a discipline, i.e. the differences in cultures of mathematics and biology departments in that potential collaborators may find it challenging to find agreement on concepts such as "proof" and "precision."

Results of team efforts. The team's extensive dialogue contributed to effective communication within the group. The dialogue resulted in meeting summaries, joint writing activities, ranked research ideas, and agreement on the final funding source within the first three months of teamwork. Development of the final research team and research approach collectively written by multiple team members within the last two months of the team's efforts were results of good / effective communication, highlighting the ability of the team to develop a common language and shared understanding of the problem through mutual learning.

Institutional Support and Commitment

Results of literature review. There are many barriers to IR including institutional and disciplinary structures that operate against effective interdisciplinary collaboration [Fisher, 2004]. In the NAS [2005] report, the survey results suggested a widespread awareness of barriers to IR with over 71 percent of respondents to the Individual Survey and 90 percent of respondents to the Provost Survey reporting a belief that major impediments to IR existed in their institutions. Findings from the NAS [2005] study on the facilitation of IR identify that while many institutions are pursuing IR research, education, and training, they are hindered by traditions and policies governing incentives, and opportunities valuable to those engaged in the work, such as promotion, tenure, and resource allocation.

The need for institutional support in accomplishing successful IR is a common theme in the literature. The lack of institutional support for IR is challenging to its success [Sankar et al., 2007]. Successful careers of researchers are dependent on successful research within their disciplines, measured by publications and the ability to

obtain grants, which puts the careers of researchers (especially untenured ones) at risk if they are to propose research programs that move across disciplinary boundaries [*Metzger and Zane, 1999*].

In contrast to IR, success in multidisciplinary research is due in part to team members publishing single-authored products in their own disciplinary journals regarding their portion of the work to further their own career advancement as tenure decisions emphasize [*NAS, 2005*]; however, interdisciplinary researchers note that it is difficult to get their papers into top-tier disciplinary journals [*Ledford, 2015*]. Information sharing networks within IR teams may often produce alternative journal publications, as equally important as publications within single disciplines but with less appreciation and reward from universities [*Rhoten, 2004*]. Researchers who have focused on basic questions in their own fields obtain recognition and honors while the rewards for those working within cooperative teams outside of their disciplinary framework are found namely in the satisfaction of contributing directly to solving real world problems and improving human well-being while at the same time developing new ways of thinking and analyzing research problems [*Rosenthal, 1992*].

Strong interdisciplinary programs can only exist where strong disciplinary programs already exist, as IR requires support from the administration and faculties of the research universities [*Metzger and Zane, 1999*]. Supportive academic institutions, sufficient funding, and satisfying career opportunities are essential requirements in the movement of research from multidisciplinary to IR [*NAS, 2005*]. In *Nancarrow's* [2013] work, participants identified the importance of individual returns on team work in interdisciplinary teamwork, which included good financial rewards and opportunities for

career development. In the work of *Hall et al.* [2008] on IR teams, results of participant surveys found that as perceptions of institutional resources increased, collaborative productivity increased, inferring that institutional resources may provide the stable foundation that enables researchers to more effectively address the challenges of IR. Additionally, removal of competition for scarce resources may facilitate greater trust, an essential prerequisite for effective collaboration and cohesion among members of an IR center [*Hall et al.*, 2008]. Interdisciplinary centers need to be well-funded and they need to have an independent physical location and intellectual direction apart from traditional university departments [*NAS*, 2005].

The top three recommendations to IR institutions from survey respondents in the *NAS* [2005] report were to “foster a collaborative environment, to provide faculty incentives including hiring and tenure policies that reflect and reward involvement in IR, and to provide seed money for IR projects”.

NAS [2005] provided a vision of interdisciplinarity in academic settings which includes beginning with simple steps to promote collaboration, such as creating more opportunities for faculty to work with students, allocating seed money for space where interdepartmental partnerships can begin (including a strategy to help young centers while they seek long-term support) and / or to include a plan to broaden institutional participation in IR through university-wide meetings and discussions.

Traditional academic systems for hiring, tenure, promotion, space allocation, and other rewards may constitute a substantial barrier to IR as most systems are controlled by departments, resulting in faculty often receiving credit for research performed within their departments and receipt of little or no departmental credit for IR

teamwork outside the department [NAS, 2005]. NAS [2005] also notes that institutions can assist faculty to overcome IR barriers by:

- Developing incentives that allow faculty to continue their education in fields complementary to their own;
- Creating mechanisms for interdisciplinary work or projects to be evaluated by panels on which multiple disciplines are represented;
- Providing more opportunities for faculty to learn from students and postdoctoral scholars in other fields
- Using seed money to fund sabbaticals and visiting-scholar grants for faculty to work in multidisciplinary groups. (p. 102)

Additional reforms that institutions can apply, applicable to facilitating IR for faculty in academic settings noted by NAS [2005] include:

- Reward structure: Faculty who conduct Interdisciplinary research need professional recognition comparable with that given to faculty who conduct single-discipline research;
- Faculty evaluations: Academic leaders can make special efforts to overcome departmental or disciplinary bias in reviewing;
- Faculty are treated fairly when they are evaluated on the basis of all their work—not just the work in the discipline of their home departments;
- Publication credit: Faculty benefit by receiving institutional credit for work reported in journals or conferences outside their specialties or in interdisciplinary journals;
- Allowance for long startup times: Universities can be flexible with respect to time in their tenure-review processes or allow longer probationary time for nontenured faculty when some or all of their contribution is interdisciplinary;
- Curricular integration: A curriculum that allows formal placement of interdisciplinary research on the teaching agenda provides a strong, visible endorsement.(p. 102)

Results of team efforts. The IR team worked within an academic setting that provided a moderate amount of institutional support. The Center was the major pillar of support and resources for all team efforts. The Center provided the venue for important collaborative activities to occur within throughout the entire process. The Center provided physical space for meetings, support staff, and access to tools such as a computer, printer, whiteboards, a projector / screen, and a phone for conference calling. Center staff had a

prominent role in the team and participated instrumentally in all facets of the teams efforts from the initial formation to proposal submission. The Center also provided seed funding through a competitive resource pool which contributed towards expenses of the university-wide meeting and a small amount of faculty compensation. The CSU Chico Office of Research and Sponsored Programs (RESP) was another institutional support system for the IR team. Staff from both the Center and RESP provided the team guidance and support by providing external funding program searches, assisting with proposal review and submission, and helping to foster collaboration within the team and also between the respective organizations and the team. Additionally, RESP organized and hosted seminars at the university regarding IR post-project.

The Deans of all colleges represented within the final core team were supportive of team efforts throughout the duration of all teamwork. Department chairs of those represented on the team were verbally supportive and also approved the faculty course / time credits and team-teaching opportunities presented in the final proposal. Departments within the university were generally supportive of IR efforts, as highlighted in team discussions, and were particularly supportive of new untenured researchers. The Environmental Science, Professional Science Masters (PSM) program at CSU Chico was also supportive within the university by providing the team access to an intern for the PSM project requirement of the graduate degree.

Interdisciplinarity of the Research Approach

Integration of Disciplines in Approach

Results of literature review. A number of articles discussing evaluation of IR refer to *Klein's* [2008] "Guiding Questions for Integration" created for pre-evaluation of grant proposals present a number of evaluation questions aimed at fostering integration.

Some of *Klein's* [2008] proposed questions are as follows:

- Is the spectrum of disciplines and fields too narrow or too broad for the task at hand?
- Have relevant approaches, tools, and partners been identified?
- Is the structure flexible enough to allow for shifting groupings of individuals and context-related adaptations, deletions, and additions?
- And, is there a unifying principle, theory, or set of questions that provides coherence, unity, or both? (p. S119)

While the evaluation questions listed above may be useful in determining if the stage is set for integration to occur, they do not assess the root question of whether or not integration within a research approach did or did not occur.

Evaluation of interdisciplinarity within a research approach is more complex than performing an evaluation of the interdisciplinarity within a research team, in part due to the fact that it is difficult to gauge the degree of interdisciplinarity of the product alone, without understanding and considering the degree of disciplinary integration the IR team engaged in to generate an interdisciplinary product. The process of integration is more difficult to observe and measure than are the results of the processes constituting IR, which may explain why literature evaluating IR has focused more on the outputs of research rather than the processes of integration [*Wagner et al.*, 2011]. While there is less of a consensus in the literature reviewed regarding how to measure or evaluate the degree

of integration or synthesis within a research approach than there is for measuring the team itself, key themes have emerged from the review.

The degree of knowledge integration and the degree of communication through interactions between researchers appear to be the most widely discussed in the literature reviewed. Integration of knowledge, ideas, and methods is widely considered the root of interdisciplinarity [*Klein, 2008; Pisapia et al., 2012; Wagner et al., 2011*] and therefore an important consideration in any evaluation. Whether integration takes place within an individual's mind or within a group, it is a cognitive process, requiring a valid assessment of the interdisciplinarity of the research to involve some indication of the degree or extent of knowledge integration that took place as the research was being conducted [*Wagner et al., 2011*]. As *Wagner [2011]* states, "Qualitative measures seek to detect integration in research processes, to assess the value of the outcomes of collaborative work, and to develop causal inferences about the factors that influence highly valued outcomes" (p. 17). Methods to increase knowledge integration in groups include mutual ignorance of other disciplinary perspectives and the merging of perspectives to create a new hybrid way of thinking [*Miller and Mansilla, 2004* as cited in *Wagner, 2011*] and could be used as metrics for evaluation.

The work of *Hall et al. [2008]* included use of qualitative measures to evaluate the degree of cross-disciplinary integration and conceptual breadth of written outputs from IR and transdisciplinary teams based on participant self-assessments. Results of this work found that key factors leveraging integration included a balance in weaving perspectives together into new whole, reaching effective synthesis and antecedent conditions for readiness [*Hall et al., 2008*]. Frequent opportunities for

communication, structural support, and a transdisciplinary ethic are noted as antecedent conditions for readiness of interdisciplinarity by *Klein* [2008].

Communication, interaction, and cooperation between members are also noted as a requirements for integrated IR. *Aboelela et al.* [2007] note in their literature review that there is an apparent existence of a continuum from multidisciplinary to interdisciplinary to transdisciplinary defined partially by the level of synthesis / integration of the research and also the degree of communication, interaction, and cooperation among researchers. Very little, if any, cooperation between researchers is required for IR with low degrees of synthesis whereas modes of IR with even a moderate degree of synthesis between disciplines require ever-greater degrees of interaction between researchers [*Aboelela et al.*, 2007]. In modes with a moderate degree of synthesis, team members will often share a research problem and interact with one another but still employ their respective disciplinary methods, conceptual frameworks, and languages [*Aboelela et al.*, 2007].

Transdisciplinarity requires the greatest synthesis of approach. In this mode, teams not only share a common question but also often share and borrow methods, create a common conceptual framework, and either learn each other's disciplinary language or create a new common language.

Results of team efforts. The IR team conducted a high level of interaction, collaborative and communication throughout the entire team process as described in detail in earlier sections, as well as a strong integration between disciplines to develop a highly integrated product, the final grant proposal submitted to the NSF CNHS program. The final product of the team's efforts displayed integration between climate change,

hydrology, and land-use change fields of study by presenting three frameworks, the first framework to model how different climate change scenarios would affect hydrology and result in different land-use change scenarios in northern California. In the proposal the results of scenarios developed from the first framework would be used in conjunction with results from the second framework. The second framework used a participatory stakeholder survey approach aimed at understanding multi-scaled perspectives of water uses, environmental and resource management needs, land-use / cover change decisions, and their linked socio-economics within northern California. The first and second frameworks were presented to be used in conjunction with a third framework in which agricultural parcel-level data on the biophysical environment, water extraction, and economics would be collected along with available aggregated government data, to capture complex surface / groundwater use choices, land-use decisions, and land-use / cover change dynamics.

The results of the analyses from the three frameworks described above in conjunction with formal surveys and existing aggregated data would then be used to synthesize and develop a comprehensive compilation of a current understanding of water sources, water uses, and water trends for a specific region within northern California. Team members each representing different disciplines within each of the three frameworks had to learn extensively about the frameworks of other team members disciplines in the last two months of work together before submission of the proposal, in order to develop a plan for the integration of the numerous disciplinary frameworks. The meeting and discussion summaries from the team's efforts throughout the entire duration of their work together, as well as the draft proposals and the final proposal during the last

month of work together, all provide evidence of the extent of knowledge integration that occurred during the process of developing the approach and as a result of team efforts.

CHAPTER V

CONCLUSIONS, RECOMMENDATIONS AND SUMMARY

Interdisciplinarity of the Research Team

Number of Team Participants and Disciplines

The small group size of the IR team contributed positively to its interdisciplinarity. The team was small enough that team member schedules could be coordinated, which allowed most team members to meet on a regular basis to develop relationships with one another in order to then develop the research approach. The meetings were productive, allowed for collaboration and discussion about the research agenda, and produced tangible products within the limited time frames of the scheduled meetings. Consensus of the research approach was agreed to relatively quickly, (less than six months), due to the reduced amount of time required in gaining a consensus among the six final team members. Less time was required to develop relationships, find a common language, and develop consensus on the research approach with a small number of team members. Small team sizes are recommended in order to expedite some of the important processes that must occur to form an IR team in an academic setting.

The number of disciplines represented in the IR team also contributed positively to the interdisciplinarity of the team. The research topic addressed by the team was complex,

requiring the involvement of a number of disciplines in the final approach. In the early stages of team formation, only a portion of the final disciplines were represented by members within the team. To expand the expertise base, faculty from across the university were invited to participate and contribute to the research approach. Specific individuals were also considered for inclusion into the final team based on their written descriptions of how they viewed their specific expertise contributing to project efforts. Once the research topic was further developed, the team recognized the need for additional disciplinary representation and recruited more expertise to the team. After the IR team submitted a proposal to the NSF to request funding for the designed research project, the team received comments back from reviewers. Proposal reviewers commented that the work proposed was truly interdisciplinary and offered the necessary expertise to conduct the work given the strengths of the qualified individual members involved. One recommendation regarding representation of multiple disciplines in an IR team in an academic setting would be to include all pertinent disciplines in the discussions and in particular to include them early on in the team formation process even if the research topic is not finalized, rather than identifying gaps and filling those with the appropriate expertise after the topic is more fully developed. This approach could contribute to the interdisciplinarity of the team earlier in the team formation process, potentially resulting in a more integrated approach between the multiple disciplines.

Early Collaboration and Time Provisions

The processes the team used to begin collaborations early in the process of team development contributed to the interdisciplinarity of the team. By evaluating the expertise in the initial team and determining the additional disciplines needed to address

the research question in the early stages of project planning, the team was able to increase the number of disciplines represented in the final team which brought more perspectives to the final approach as well. A recommendation would be to continue this process of bringing collaborators in early, if not earlier than the team did, to bring more interdisciplinarity to the team sooner.

The extensive time allowed for networking and dialogue between team members also contributed to the interdisciplinarity of the team. Frequent meetings over a two-month period of dialogue among team members moved the development of the team and research approach further, until eventually consensus on the research approach was reached. This time provided team members the ability to network with one another, and to understand one another's disciplines, research interests, and backgrounds. One recommendation in regards to provision of time for team dialogue includes providing a two-month minimum time period for frequent dialogue and networking with team members meeting on a weekly or bi-weekly basis and provide adequate time for new team members to undergo the same process at length with existing team members if deadlines are not an opposing factor. Another recommendation may be to expand this time for dialogue to occur in venues outside of the university setting, potentially structured as a retreat, to allow for a more relaxed structure where team members can speak freely and build relationships in ways they may not be able to on campus during a typical busy workday with competing tasks and potential distractions.

Shared Decision Making and Team Alignment

The process of using shared decision making within the team likely contributed to the interdisciplinarity of the team. First, the fact that this method was used to choose team members inherently added variety to the representation of disciplines within the team and research approach. Use of shared decision-making also likely kept the initial team members interested and committed to the project as each team member's disciplinary perspective was represented and therefore contributing to the team's interdisciplinarity. Shared decision-making also provided a sense of ownership for the development and progression of the research project topic which also helped to keep team members engaged over time. Shared decision making regarding whom else to invite to join the initial core team resulted in the increased variety of disciplines represented within the final team versus if this decision had been made by one of only a few team members. A recommendation in regards to shared decision making would be to engage in shared decision-making as often as possible considering time constraints and make it clear to all potential team members at the onset of team formation that this method will be used. Another recommendation may be to discuss and agree upon an alternative method of decision making in the event that consensus cannot be reached within the team so that progress can still be made when challenging decisions are to be made and there is a potential for split decisions to occur.

The respect among team members for one another's disciplinary frameworks and the alignment and commitment within the team contributed to the interdisciplinarity of the team. Respect for other's disciplinary frameworks was built by mutual learning.

This effort resulted in team members more clearly understanding the basics and details of each other's disciplines. This contributed to each member's interdisciplinarity that was then being contributed to team efforts. The joint activities discussed earlier also helped foster an alignment and commitment within team members which contributed to the team's overall interdisciplinarity. Each opportunity for these collaborative activities resulted in a deeper understanding of each team member's discipline, provided opportunities to display commitment to the team, build rapport and trust amongst team members and likely spurred additional ideas on how to merge the disciplines. Recommendations would include that IR teams engage in joint activities that promote mutual learning and understanding of one another's respective disciplinary frameworks. Review of specific case studies within represented disciplines on the team and / or review of case studies that highlight an IR approach between disciplines similar to those represented on the team could be particularly beneficial.

Communication and Mutual Understandings

The team's ability to effectively communicate, develop a common language, and develop a shared understanding of the problem through mutual learning contributed to the interdisciplinarity of the research team. The common language developed within the team allowed for team members to increase their understanding of the other disciplines represented within the group, which resulted in mutual learning amongst the disciplines in order to determine how to merge the approaches of each discipline and overlap them to address the research problem. One recommendation would be to encourage various forms of communication early in the process and as frequently as possible, including verbal and written communication as well as use of graphical

demonstrations and comparisons to visually display similarities and differences between disciplines and their approaches of a solution to the issue in order to better communicate and foster the development of a common language. Provision for the opportunity for all team members to communicate equally is also another recommendation as one of the key components to effective interdisciplinary communication and collaboration.

Institutional Support and Commitment

The institutional support from the Center, RESP, the Deans, Department Chairs and departments represented by team members, and the intern contributed to the interdisciplinarity of the team. The venue, space, and resources from the Center were essential in keeping meetings centrally located on campus and convenient to attend, which promoted attendance from team members representing multiple disciplines. The team may not have been able to recruit the expertise it did without the resources the Center provided including space and staff support. Staff from the Center and the intern contributed to numerous efforts to increase the interdisciplinarity of the team, including but not limited to providing summaries of meeting discussions and decisions, review of potential team members, the planning and implementation of the university-wide meeting, and all subsequent meetings throughout the development of the project. RESP staff provided advice on increasing the interdisciplinarity of the team which was implemented. One recommendation would include the provision of additional time credit and seed funding for faculty involved in IR teams during the team formation and brainstorming stages, before proposals were funded, as this could further contribute to IR efforts in academic settings. The involvement of students and / or interns to provide support to all of the processes described above is also recommended.

Interdisciplinarity of the Research Approach

Integration of Disciplines in Approach

The integration of the disciplines in the research approach contributed to the interdisciplinarity of the research approach. The extensive amount of interaction, collaboration, and communication between team members contributed to the knowledge integration that occurred within the team. The high level of knowledge integration ultimately influenced the interdisciplinarity of the final product, the final proposal submitted to the NSF CNH program.

Proposal reviewers agreed and commented that the IR team was qualified and likely to produce creative interdisciplinary science, including a strong integration of social sciences with landscape ecology and global change biology. While the final product was limited in length by the program page limits, and limited by time due to proposal submission deadlines, the interdisciplinarity of the research approach could have been improved by investing more time in development of the details of how the components within the frameworks would be integrated, specifically how the climate change and land-use models would be merged and / or how they would mutual inform one another. Likewise, details regarding the integration of the results of the participatory stakeholder input with the other two frameworks used would be useful in further highlighting the extent of the interdisciplinarity of the final research approach. This last step in developing the strategy of integration may have increased the integration of knowledge for all team members.

Project Summary

Although U.S. research has historically for the most part been conducted within specific disciplines, the term “interdisciplinary research” emerged in the 1970’s, as single-disciplines began splitting into new directions, combined with other disciplines. Since then, IR has become prominent in the focus of U.S. research [*Ledford, 2015*] and is used in a variety of fields and academic settings including one IR team effort at CSU Chico through the Center. While there are still gaps in agreement of what constitutes good / effective IR and how to evaluate its interdisciplinarity, the combined use of measures in evaluations can provide researchers with an understanding of some of the key factors that contribute to the interdisciplinarity of an IR team and an IR approach.

This project reflects the results of a paid internship served with the CSU Chico Center. A group of faculty, staff, and one graduate student from CSU Chico, developed an IR team to develop a research framework to address environmental and social issues facing the north state of California. The team ultimately decided to submit a proposal to the NSF, a large-scale national agency addressing larger scale integrating questions, within their CNHS program. The project summarizes factors that contributed to the interdisciplinarity of the team and the team’s research approach. The project provided a summary of factors found commonly in the literature and used the factors as metrics, which were applied to the experiences of the IR team. This project reflects an analysis of the interdisciplinarity of the team and their research approach. The applied metrics provided a basis for an evaluation of the interdisciplinarity of two aspects of the IR team; (1) the interdisciplinarity of the team and, (2) the interdisciplinarity of the research approach. The intention of the project was to provide useful information for

other similar IR endeavors in academic settings. All of the factors used as evaluation metrics were found to contribute to the interdisciplinarity of the research team and research approach. Minimal recommendations were provided due to the successfulness of team efforts, however a few were noted. Small team sizes are recommended in order to expedite some of the important processes that must occur to form an IR team in an academic setting. Another recommendation would be to include all pertinent disciplines to the discussions and in particular to include them early on in the team formation process, even if the research topic is not finalized, rather than identifying gaps and filling those with the appropriate expertise after the topic is more fully developed. This approach could contribute to the interdisciplinarity of the team earlier in the team formation process, potentially resulting in a more integrated approach between the multiple disciplines. One recommendation in regards to provision of time for team dialogue would be to continue to employ this process with at least a two-month minimum meeting on a weekly or bi-weekly basis and provide adequate time for new team members to undergo the same process at length with existing team members if deadlines are not an opposing factor. Future efforts may consider expanding dialogue to occur in venues outside of the university setting, potentially structured as a retreat to allow for a more relaxed structure where team members can speak freely and build relationships in ways they may not be able to on a university campus, during a typical busy workday with competing tasks and potential distractions. Engagement in shared decision making is recommended as often as possible considering time constraints as well as making it clear to all potential team members at the onset of team formation that this method will be used. Another recommendation may be to discuss and agree upon a backup method of decision making

in the event that consensus cannot be reached within the team so that the project can continue to move ahead in times of challenging decisions, where split decisions may occur. In terms of institutional support, if additional time credit and seed funding for faculty involved in IR teams were provided before proposals were funded, it could further contribute to IR efforts in academic settings. While the final product was limited in length by the program page limits, and limited by time due to proposal submission deadlines, the interdisciplinarity of the research approach could have been improved by investing more time in development of details of how the components within the frameworks would be integrated, specifically how the climate change and land-use models would be merged and / or how they would mutual inform one another. Likewise, details regarding the integration of the results of the participatory stakeholder input with the other two frameworks used would be useful in further highlighting the extent of the interdisciplinarity of the final research approach. This last step in developing the strategy of integration may have increased the integration of knowledge for all team members.

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APPENDIX

FINAL TEAM AND RESEARCH APPROACH SUMMARY

The proposed project was to explore the intersection between climate change, exurban pressure, land-use decisions, water availability and use, and agriculture on Sacramento River Valley's (SRV) future economic sustainability and biocompatibility (agricultural resilience and issues of quality of life and carrying capacity). The team proposed a research direction that was to explore not only the patterns and processes that link natural-human systems and the feedbacks between them for the SRV, but also the feedbacks between different organizational levels that influence the human-environment interactions.

The exploratory research would set the stage for the long-term over-arching goals of the project to explore how natural systems and expanding population centers and irrigated agricultural systems in the SRV will be forced to continuously evolve or adapt in response to and as a result of driving conditions which span globally (climate change, agricultural export conditions), regionally (water transfers, human migrations, endangered species and habitat restorations) and locally (land-use change, habitat restoration, county general development plans, farm economics, water use).

To explore how the coupled natural-human systems would interact and provide feedbacks into both systems, five exploration objectives were identified that would contribute directly to providing the necessary stakeholder information and data to begin to address the complexity of the SRV. The objectives included were to:

- (1) Develop scenarios of SRV land-use under different climate change scenarios, using state of the art climate models;
- (2) Build a holistic participatory stakeholder framework for engaging the multi-scaled diversity of water users and managers to understand water uses, environmental and resource management needs, land-use/cover change (LUCC) decisions and their linked socio-economics;
- (3) Collect parcel level data on the biophysical environment, water extraction, and economics along with available aggregated government data to categorize and to capture complex surface/groundwater use choices, land-use decisions and LUCC dynamics;
- (4) Compile and analyze existing information to create a comprehensive synthesis of our current understanding of water issues for SRV;
- (5) Build a strong interdisciplinary team of researchers to engage in timely research in the SRV by facilitating the contact, interaction and collaboration on research activities.

The project was intended to begin to document and assess important parameters required to reliably forecast land-use change and behavioral patterns driving that change. The project included the planned development of databases to populate interactive, predictive models to aid resource managers, land-use planners and policy makers. Additionally, agricultural practices were to be incorporated, for growers to predict how management practices may affect their economic bottom line and the environment. Workshops were planned to be conducted that would be important in

establishing and expanding networks that would aid data collection of local decision making leading to changes in landscape composition and structure. The proposed work would develop interactive and predictive models, transformative tools for planners and policy makers.

The ultimate goal of the project was to develop functionally sound models usable by planners, growers, policy makers and others that would ensure the high quality of life associated with the SRV, while still being able to sustainably serve greater California's water needs.

For this exploratory proposal, two counties were selected, Butte and Glenn Counties, within the SRV to serve as a pilot study area for method development for the modeling framework and the initial participatory stakeholder framework. The long-term goal was to apply lessons learned from the exploratory project to the entire SRV (21 counties).

Project goals would be accomplished through the development of a scientifically rigorous multi-functional model (for land-use planning) utilizing inputs from economics, social and environmental sectors to address agricultural resilience and biocompatibility in the SRV region. The model was designed to be user-friendly, participatory and accessible to stakeholders. Model and tool development was anticipated to be a multi-year process to support accessibility to and implementation of a scientifically sound planning application, which would contribute to informed and prospective decision making in California's water and agricultural production heartland. The exploratory project proposed was intended to be part of the future research framework used to guide the eventual development of integrated local and top-down

driven co-evolutionary multi-agent system models coupled to dynamic economic models, to capture complex water use and LUCC dynamics of a tightly coupled natural-human system.

The long-term research questions included:

- (1) How will 21st-century rural restructuring in the fertile irrigated agricultural valleys of the Western U.S., water use efficiencies in agriculture and climate change, together with changing international export markets, local county general plans, and water/environmental policy environments, affect land-use patterns at various scales ranging from the SRV as a whole, counties and sub-catchments to individual farm parcels? How will this change the geography of irrigated agricultural production with parallel exurban developments?
- (2) Under what water / environment policies, county general plans, and agricultural commodity and land prices does landscape change induced by long term drought cycles and climate change generate a positive or a negative feedback through changes in water use in irrigated agricultural landscapes and county land-use zoning frameworks?
- (3) Would the complex synthesis of rural exurban development, transition to multifunctional farms, habitat restoration for endangered species, and increasing demands for water transfers, and climate variability expand or diminish the agricultural production and ecosystem service generation capacities of the SRV?
- (4) When a significant water use decision is undertaken (i.e. transfer of surface water, intensive groundwater withdrawal, or a land-use change from agricultural to

urban) what are the external impacts of this decision, and how do they ripple through the economic and ecological system?

(5) What are the cumulative economic and environmental costs of water transfers in the area of origin? Under what conditions do these costs diminish or increase over time, (i.e., how do short run and long run impacts differ in terms of economic and environmental resilience?).

Final Funding Source / Program

The final funding source chosen by the team was the National Science Foundation (NSF) Dynamics of Coupled Natural and Human Systems (CNHS) program. The CNHS program was one of four funding opportunities contributing to the NSF's portfolio of activities supporting the overarching Science, Engineering, and Education for Sustainability (SEES) program aimed at generating the discoveries and capabilities in climate and energy science and engineering needed to inform societal actions that lead to environmental and economic sustainability.

The CNHS program aims to support basic research and related activities that enhance fundamental understanding of the complex interactions within and among natural and human systems, with special emphasis placed on the coupling between human and natural systems. The focus of the CNHS program is on the complex interactions among human and natural systems at diverse spatial, temporal and organizational scales. CNHS seeks to advance basic knowledge about the system dynamics -- the processes through which systems function and interact with other systems, hence CNHS-supported projects must examine relevant natural and human

systems. Proposals for this program could not focus solely or largely on either human systems or on natural systems, they had to examine the full range of coupled interactions and feedbacks among relevant systems.