ECOLOGICAL BOUNDARY-SETTING IN MENTAL AND GEOPHYSICAL MODELS

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Project Summary

When agencies and the public direct their attention to an environmental problem, they explicitly or implicitly bound that problem by associating it with a particular system at a particular scale. Proposed research will focus on the problem formulation phase of the decision process and on the role of spatial modeling in that process. The objectives of this research center on identification of modeling approaches that identify and clarify environmental problems in public decision making. Two aspects of such problems are: (1) the boundary and scale decisions made by geophysical modelers in their attempt to represent the system of concern; and (2) the mental and cultural processes by which stakeholders identify temporal and spatial boundaries in the process of formulating and articulating a shared concern. The latter processes are hypothesized to be shaped by individual and social values that invigorate the public to respond to an environmental problem. A framework for understanding and articulating these values will inform the formal modeling process undertaken by those attempting to resolve shared resource problems.

Two key types of values will be emphasized: (a) "sense of place values"—values that residents associate with a locality; and (b) spatial dimensions of equity issues, as private and public decisions may create differentials in the quality of life within and across physical and political boundaries. Sense of place is hypothesized in the context of experiential discounting as critical to the development of individual and social identities that frame the way environmental problems are experienced, informally bounded, and formulated. Similarly, values derived from relative social status are important in determining the spatial boundaries used to characterize and articulate environmental problems.

Three case study areas, where team members have established a research presence, have been chosen to apply this framework: St. Louis, MO, Chicago, IL, and Atlanta, GA. A comparative lens will be used to examine formulation of three types of environmental problems: sprawling land use patterns, management of water quality and quantity, and brownfield redevelopment.

A variety of methods will be developed and employed to study the processes by which individuals and interest groups identify, articulate, and modify perceived boundaries of environmental problems. Selected methods of garnering information about stakeholders' mental models include elicitation of perceptions through interviews, discourse analysis of documents, and revealed preference valuation. These methods will be combined with the use of agent-based GIS modeling techniques to represent such information geographically and to provide linkages between social scientific data and geophysical models as a way of clarifying the role of space-time boundaries in the articulation of environmental problems.

This proposal is for a collaborative research effort between Georgia Institute of Technology's School of Public Policy and the University of Illinois' Department of Geography. The Georgia Tech team comprises a range of expertise at the interface of ecological and economic dilemmas faced by public stakeholders. The University of Illinois team offers expertise in spatial dynamic modeling of urban sprawl, brownfield redevelopment, and agent-based techniques for capturing the evolution of perceptions in the social context.

The broader impact of this proposed project will be an enhanced ability to integrate diverse perspectives of the ecological problems at hand as exhibited by these case studies. This impact crosses the constituent disciplines of geography and public policy, as well as the myriad of stakeholder domains in addressing ecological problems. The intellectual merit of this study derives from rigorously developing and applying innovative empirical methods to pressing environmental problems, improving our understanding of the spatial dynamics/modeling of society's most complex problems.

PROJECT DESCRIPTION

1. Theoretical Foundation

1.A. The Problem of Problem Formulation

Rittel and Webber (1973) proposed a useful distinction between *benign* and *wicked* problems, characterizing benign problems as problems having a single answer such that, when that answer is discovered, its correctness is obvious to all concerned. They argued that many benign problems in planning and environmental protection, such as designing adequate sewer systems or timing traffic lights, have been solved by formal modeling and technological innovation, but that many of the remaining problems faced by municipalities and agencies must be understood as *wicked problems*. Wicked problems were described as having no definitive answer and as having *no definitive formulation*. The analysis of Rittel and Webber was prescient, for today's decision scientists readily admit that correct problem formulation is the most difficult and least understood aspect of public decision making (Keeney 1996, Keeney and Raiffa 1976, Winterfeldt and Edwards 1986, Corner et al 2001, Coenen et al 1998, Gregory et al 2001, Gregory 2002, Hanne 2001, Yu 1979, Wooley and Pidd 1981, Mintzberg et al 1976, Abaulsamh et al 1990, Perry and Moffat 1997, Taket and White 1997).

Various decision theorists have tackled the problem of problem formulation from three broad perspectives. First, Keeney (1988, 1992, 1996) and collaborators (1996) emphasize value-focused problem formulation. Second, Simon (1955, 1982), von Neumann and Morgenstern (1944) emphasized a focus on alternatives in problem formulation. Finally, many decision scientists focus on the process of deliberation involved in problem formulation (Janis and Mann 1977, Kahneman and Tversky 1979, 1982, 1988, Kahneman et al 1992, Gregory and Keeney 1994, Gregory et al 1993, 2001, Gregory and Failing 2002, Henig and Katz 1996, Buchanan et al 1998, and Wright and Goodwin 1999). All three perspectives in decision-making require some means of setting the spatio-temporal bounds of decision problems in problem formulation.

Rittel and Webber (1973) describe wicked problems, paradoxically, as problems for which the correct problem formulation can only be established *after* the problem has been solved. Participants in the decision process—who come to the problem with very different perceptions, interests, and values—will inevitably characterize the problem in different ways. The consequence of this process is that the operational solutions devised rely on bounds established through the course of decision-making and negotiation, "after the problem has already been tamed "(Rittel and Webber 1973, p. 162). To acknowledge this consequence is to recognize the importance—and the recalcitrance—of problem formulation when the problem involves competing interests. This proposed research is predicated on the suggestion of Rittel and Webber that an important category of public decisions—wicked problems—are so recalcitrant *because competing interests and values lead to competition among affected parties over how to properly formulate the problem*. Different interest groups employ differing *models* of the problem at hand. Research is thus proposed to illuminate the role of values—individual and social—in problem formulation.

C*onflicting values* lie at the heart of wicked problem formulation, making goal-finding "an extraordinarily obstinate task." Rittel and Webber saw "social processes as the links tying open systems into large and interconnected networks of systems, such that outputs from one become inputs to others. In that structural framework it has become less apparent where problem centers lie, and less apparent *where* and *how* we should intervene even if we do happen to know what aims we seek (Rittel and Webber 1973, p. 159)." Decision-making agents in these open systems face ever-expanding boundaries to incorporate externalities, or to arbitrarily impose artificial boundaries not reflective of the underlying processes. Under these conditions, determining the *scope* of a problem is critical.

In environmental problem formulation, socpe determinations include many *spatio-temporal boundary questions* as a key aspect of problem formulation. This research postulates that the values of individuals and groups affect problem formulation, especially with respect to the setting of boundaries for the system of analyses. Setting boundaries to a problem then determines what data and information will be necessary to solve the problem: "The information needed to *understand* the problem depends upon one's idea for *solving* it (Rittel and Webber 1973, p. 161)."

The prescient work of Rittel and Webber provides four premises on which the proposed work will proceed:

1. Many environmental and planning problems are recalcitrant (wicked)—their problem formulation is inherently controversial.

2. These problems are so recalcitrant *because* they involve human values and conflicts of interest at the problem formulation stage.

3. Conflicts about values often express themselves in problems of how to *bound* the system to be analyzed.

4. Setting system boundaries determines what one must know in order to solve the problem.

1.B. Sense of Place in Geographic Decision Making

Many environmental issues are inherently spatial (Bockstael 1996; Norton, 1995) , and analyzing spatial aspects of environmental problems has become increasingly sophisticated. The use of Geographic Information Systems (GIS) in applied environmental economics is now commonplace as spatially explicit modeling becomes the norm. At the union between theoretical models of spatially referenced human behavior and empirical models employing rich spatial datasets lies the notion of a "sense of place." Understandings of sense of place shape the appropriate scale and scope of observation by participants and the term "Sense of place" thus has potential as a key *bridge term* connecting the discourse of geophysical modeling with spatially sensitive studies of values by social scientists.

The use of GIS to formally incorporate spatially referenced observations – about geophysical *and* social phenomena – offers a shared platform for social scientists and geophysical scientists to address wicked environmental problems, by making explicit the connection between values and spatial modeling. It thus brings the problem of problem formulation under a bright spotlight--but it of course does not solve it. The geographer Tuan (1977) said that having a sense of place requires also a sense of the space around the place, and this suggests that boundaries limiting the space of a place are integral to the notion of place itself. Tuan's point is relevant to the proper use of GIS: participants in an environmental decision process must formulate their own version of "the" problem, and they must do it *from* some *place*, or spatial perspective. Since space around a place is integral to how the place itself is experienced, the imposed boundaries of a place are key to problem formulation—and determinative of the data needed to resolve the problem at hand. Dramatically richer spatial data on air quality, for instance, does little to inform whether to model at the level of community, airshed, Metropolitan Statistical Area (MSA), or state. The researcher is still left with deep-rooted modeling problems of determining what constitutes a neighbor (Smith 2001) or what spatial scale to select (Anselin 2001).

Emerging techniques in agent-based modeling coupled with GIS enable multiple scales of analysis to be captured at once. Simulation of individual spatial behavior enables both fine resolution and aggregate snapshots. Though a single snapshot is fixed in scale, the underlying model may represent processes operating at a variety of scales. While a variety of studies have explored the possibilities of GIS and agent-based modeling techniques (Gimblett 2001) as applied to land-use change concerns (Parker et al 2002), few studies that bridge the spatial and temporal domains adequately address the domain of human decision-making (Agarwal et al 2002). While spatio-temporal geophysical processes can now be represented with greater richness of detail, it is the human decisions affecting these processes that represents the new frontier in modeling. Indeed, this frontier in transcending scale problems has the potential to provide the foundation for a new science that is capable of representing multiple perspectives (Henrickson and McKelvey 2002).

2. Research Objectives

The proposed research will develop and employ social science techniques for dealing with spatiality to address the general subject of problem formulation as a weak point in decision analysis. More specifically, the work will focus on the role of *perceptions* and *values* in the determination of boundaries, exploring two parallel but complementary aspects of spatio-temporal questions affecting problem formulation. The first aspect is the problem of how geophysical modelers set spatio-temporal boundaries in the process of model-building. Simultaneously, parallel work will examine how social perceptions and values are embodied in expressing spatio-temporal boundaries as incorporated into community goals through public discourse. These two parallel lines of research thus begin from different disciplinary and methodological starting points, but pursue complementary objectives—to understand the role of spatial models in problem formulation.

The study of geophysical modeling focuses specifically on boundary-setting choices by modelers of geophysical processes. With tools for identifying the array of subjective boundaries reflective of social perceptions and values driving a management program, decisions as to how to bound geophysical models can be better tailored to the multitude of constituent values. Such decision support tools could contribute to enhanced understanding of shared environmental problems. By focusing on the formal decisions about bounding systems and subsystems in their geophysical models, these decisions can be made the locus for linking formal models to more place-based, local and regional models. The proposed work will develop a system of empirical tools and analytic concepts that will allow us to gather and analyze geographically sensitive information about values and geographical (place-based) identities of citizens who engage in collaborative processes at different scales.

The proposed research distinguishes between two motivations for model building (however intertwined in practice), drawing on a useful distinction in two aims of scientific study: curiosity-driven models are constructed to develop and explore disciplinary methods and tools, and are usually directed at maximizing predictability by the use of ever-more sophisticated modeling techniques, while mission-oriented models begin with a problem—usually a planning or management problem—and attempt to use available methods and develop new ones to illuminate an identified problem (Funtowicz and Ravetz 1990, 1991a, 1991b, 1995; Rotmans, 1998; Beck et al 2002). For example, many communities embroiled in controversies about how to manage an important resource such as an estuary have built, with the help of scientists, managers, and technicians, mission-oriented models with the express purpose of clarifying agreements and disagreements about the functioning—and the proper management—of the system. Curiosity-driven models are often developed in abstract contexts such as academic disciplines, while mission-oriented models are shaped to fit a pre-existing problem. Whether mission-oriented models are developed for enhanced understanding (descriptive), to improve communication (communicative), or for solving problems (normative), they must be reasonably transparent and capable of evaluation by seriously interested stakeholders to improve problem formulation and public decision making (Funtowicz and Ravetz 1995).

This work contends that construction of a mission-oriented model could serve as the locus of an intelligent public discussion about values—about what is valued, locally—by focusing public discussion about values and goals via an explicit and well-publicized discussion of *boundaries* to be set in the model. This contention will be tested by the building of a prototype model for the study of spatio-temporality in problem formulation. The model would include heuristics about how participants in collaborative management practices can better identify place-based values and articulate goals that are appropriate to their sense of place. Communities that develop a mission-oriented model can use this heuristic prototype to illuminate the spatial aspects of how they bound the space they live within. (Wondollek and Yaffee, 200x). Such a model could eventually serve as a heuristic guide to problem formulation, given development of innovative tools for geographically sensitive data gathering.

The prototype model will be comparable to two strands of similar modeling attempts made previously. The first kind of models, predicated on chance, can be referred to generally as models of *decisions under risk and uncertainty* (Fischhoff et al. 1981, Beck 1992, Gilroy 1993, Gregory 2002, Morgan et al. 1992, Morgan et al. 2002, Stern and Fineberg 1996). The second category of models, for choices under more controlled circumstances, relate to the concepts of *integrated management* (Rotmans and van-Asselt 1998, Schneider 1997, Van Asselt et al. 1996, Rothman and Robinson 1997, Ravetz 1998, Kasemir et al. 1999, Grant 1997) and *adaptive management* (Downs and Kondolf 2002, Holling 1978, Lee, 1993; Holling, Gunderson, and Light, 1995; Norton 1999, Norton and Steinemann 2001, Walters 1986, Cortner and Moote 1999, 1991). Models developed under these two broad categories – decisions under risk and uncertainty, and integrated and adaptive management – share the assumption that mental and cultural models affect the spatio-temporal scales on which the stakeholders conceive a decision problem. There has been little systematic study, however, of how and on what basis the spatio-temporal scales embodied in modeling decisions are chosen or justified.

In curiosity-driven supply modeling, decisions as to how to bound a natural system for study and decisions regarding the internal structure (physiology) are made for a combination of scientific reasons (based on existing knowledge of hydrology, energy flows, etc.) and methodological reasons (availability of data, fashions in modeling techniques, etc.). In contrast, the purpose of mission-oriented demand modeling is to illuminate public policy issues and disagreements about management of a natural system or resource. To speak of any situation as a public policy *problem* is implicitly to recognize that important values exist that are not currently being properly served. This research holds that an effective mission-oriented model will reflect in its structure the production functions for valued services, products, or features of the relevant systems.

Given the premise that an important aspect of the problem of problem formulation stems from questions of how to bound the system associated with the problem at hand, and given that social values affect how people conceive and *bound* management problems, an important question emerges. Where would one turn to find evidence or justifications for choosing one set of boundaries and physiological structures over another in the development of mission-oriented models? If the proposed framework is correct, the answer to this question must include some reference to the social values pursued by the various stakeholders and interest groups contesting to define and resolve the problem. Simply relying on multiple models with different bounds does not solve the problem because it is driven by competing values that imply differing perspectives on the problem. The objective of the proposed research is to explore this important and under-studied area at the intersection of geophysical sciences and policy analysis.

Two key types of values will be emphasized: (a) "sense of place"—values that residents associate with a locality; sense of place values can be associated with a person or community's identity (Norton and Hannon 1997; 1998) and there is empirical evidence that care and concern decays across space (Hannon, 1987; 1994). Sense of place is critical to the way environmental problems are experienced, informally bounded, and formulated. (b) spatial dimensions of equity and fairness issues, as private and public decisions may create differentials in the quality of life within and across physical and political boundaries. Similarly, values derived from relative social status are important in determining the spatial boundaries used to characterize and articulate environmental problems.

Three case study areas, where team members have already established a research presence, have been chosen to apply this framework: St. Louis, MO, Chicago, IL, and Atlanta, GA. A comparative lens will be used to examine formulation of three types of environmental problems: sprawling land use patterns, management of water quality and quantity, and brownfield redevelopment.

The prototype model developed in this research will make explicit the formal choice of the spatio-temporal scale at which these various environmental problems are conceived and how they are modeled. Comparison of these scales will enable spatio-temporal decisions of modelers to be viewed as decisions that must be sensitive *both* to the empirically observable facts of the system to be modeled (hydrology, energy flows, risk levels, etc.) *and* to the overlapping but competing interests of stakeholders. By putting these spatio-temporal modeling decisions facing demand modelers in the spotlight, the interplay of scientific information about systems with the contested values that constitute wicked problems can more readily be studied.

While this description of the topic and research objectives identifies an important and under-studied area (of great importance if modeling is to be useful in clarifying complex and wicked environmental and planning problems), proposed research recognizes few accepted and well developed methodologies available to study spatially dependent values. Empirical methods to measure "sense of place" are at present inchoate. Accordingly, a major element of this research will be to experiment with existing and newly developed methods and techniques to study locally based values, including both sense of place values and spatially sensitive equity issues.

A variety of methods will be developed, adapted and employed to represent the informal processes by which individuals and members of interest groups identify, articulate, and modify perceived boundaries of environmental problems. Selected methods of garnering information about stakeholders' spatio-temporal "models" include elicitation of perceptions through interviews, discourse analysis of newspaper stories, and revealed preference valuation. These methods will be combined with the use of GIS and agent-based modeling techniques to represent such information geographically and to provide linkages between social scientific data and physical models as a way of clarifying the role of space-time boundaries in the articulation of environmental problems.

3. Hypotheses

Important public policy debates over wicked problems emerge because groups with different interests conceive problems differently. These problems have a spatio-temporal dimension and this research is predicated on the idea that significant problems in problem formulation derive from the fact that individuals and groups with different values will often bound the perceived problem differently. These subjective boundaries in turn contribute to the wickedness of recalcitrant problems and bedevil mission-oriented modelers who attempt to provide models that are useful for understanding and resolving contentious public disagreements about how to manage resources. Cynically, subjective boundaries of wicked problems enable the barrage of models designed to serve particular interests and fuel the dissonant public debate.

The proposed research team contends that effective representation of geophysical processes implicated in disagreements over wicked problems that arise in resource management must incorporate information about environmental and resource values of participants as well as scientific information about the structure and processes of the geophysical system involved (Beck et al 2002). In prior research on disagreements about the management of Lake

Lanier (a multi-purpose reservoir North of Atlanta studied in a four-year Environmental Protection Agency Water and Watersheds project), researchers from the proposed team observed that stakeholders from different interest groups conceptualize the *pollution* of Lake Lanier in very different ways. The team informally described this phenomenon by saying that individual participants in management discussions often *talk past each other* (a characteristic of debates over wicked problems) because they have different *mental models* of the processes of change affecting the Lake. For example, resident members of the Lake Lanier Association (an environmental watch-dog group) understood degradation of the Lake as a function of rapid development and inadequate sewage treatment facilities, while professional water managers emphasized other sources of pollution such as chicken and hog farms in the watershed. Examples such as this convinced researchers that perceiving problems at differing scales is one cause of stakeholders "talking past" each other. And, while it may be possible to reconcile these multi-scaled perspectives on "the" problem, doing so involves solving just the type of wicked problem addressed here.

These differences in *mental models* have a clear spatial aspect, as residents generally focused on ephemeral post-precipitation run-off events that cause spikes in fecal coliform counts in particular "arms" of the Lake, while professionals *modeled* the problem of water quality as a watershed-sized problem. While one could attempt to create a formal model for both processes, the existence of such models would not resolve which of the models captures the *real* problem, because the problems are conceived at different spatio-temporal scales. Formal models necessitate articulation of assumptions that allow the leap from mental to geophysical modeling. Some interaction of assumptions about causal relationships with commitments to social values result in individuals employing differing mental models of "the problem" of pollution in Lake Lanier, partly because the problem requires a normative stance for resolution. The researchers thus conceptualized individuals in the community as having subjective mental models of the problem of pollution in Lake Lanier. Mental model can be defined as the network of causal and factual relationships an individual adopts in order to understand the flow of perceptions and in order to incorporate new information (Doyle and Ford, 1998).

Further, since the differing mental models of individuals seem to vary systematically (e.g., according to interest group membership), it was suggested that the value commitments and social concerns of participants reflect, at a group level, *cultural models* (Kempton et al 1995). Cultural models are understood as models that associates share, making communication about shared interests and goals possible. This concept is analogous to the shared vision articulated on the path from mental models to systems thinking represented by Senge (199x) in the context of organizational learning. By treating the *shared* models of those who identity with an interest group (such as charter-boat captains, employees of the Army Corps of Engineers, and members of environmental groups) as *cultural models*, the underlying values that cause participants to model the problem of pollution differently can be articulated. Moreover, putting such concepts into practice can improve collective understanding of how wicked problems arise, how differing values perpetuate wicked problems, and how differing mental and cultural models can lead to differing ways of bounding problems. These bounding issues, and the value sets associated with them, thus serve as an entrée into the study of the role of values in making wicked problems wicked, and improve our ability to formulate these problems and thereby improve communication.

Based on this conceptual apparatus, this research proposes the following general hypotheses. These hypotheses will be operationalized and tested with respect to a variety of problems in our case study areas, as articulated in Part 4 of this proposal.

Hypothesis I: Individuals formulate and understand environmental problems (including the assumption of spatio-temporal bounds to the problem) based on mental models that reflect their personal values and context.

Hypothesis II: Individuals who enter public debate about the management of resources in their area as members of an interest- or stakeholder- group are likely to share with their cohorts a cultural model that bounds the public management problem faced.

Hypothesis III: Wicked problems are so recalcitrant and resistant to shared understanding of the problem because participants (as individuals and groups) face the problem employed in varied mental and cultural models—with different spatial bounds—that are reflective of differing values and interests of these participants.

Hypothesis IV: Choices of spatial bounds (as represented in mental models of participants and researchers) have profound implications for our understanding of the problems of interest: water management, urban sprawl, and brownfield redevelopment.

Hypothesis V: "Sense of place" is observable both directly and indirectly, and may often not be related to the spatial bounding selected in problem formulation (in practice or by modelers).

4. Methodology

4.A. Background: The conclusions of Rittel and Webber, and the confirming work of others, have called into question the ability of decision analysts to formalize decision problems and to create algorithmic solutions to important environmental and planning problems. They have made it very difficult to imagine how one would base decisions regarding wicked problems algorithmically. We can learn from an algorithmic decision analysis, but analyses of outcomes—such as a Cost-Benefit Analyses—can only identify trends and effects. They cannot ensure that the problem will be formulated in all its complexity. It follows that decision analysis will often have to focus on improving *decision making processes* and on developing process heuristics (Simon 1977, Holtgrave et al. 1994, Norton and Steinemann 2001) rather than on applying algorithms or optimization programs.

Environmental valuation studies benefit from being embedded in ongoing public controversies, and by being considered an aspect of *adaptive management*, a strategy that recommends undertaking management experiments to reduce uncertainty and encourage social learning (Norton and Steinemann, 2001; EPA, Science Advisory Board, 2000). By making the evaluation of environmental change endogenous to adaptive management, and by considering the development of models as means of understanding and communication within an inclusive, participatory, adaptive management process, it is possible to see the choice of appropriate boundaries and time-scales as open to public discussion and debate. This debate can be seen as an opportunity for social learning about community values, but also about the physical and social systems that produce those values. Similarly, the process of developing better tools for measuring values that are important in problem formulation can be considered as part of the process of adaptive management, where learning is embedded in open public discourse (Norton and Steinemann 2001). While decision science can offer no algorithmic solutions to wicked problems, a careful analysis of decision contexts may improve framing of questions in a way that encourages social learning. As noted in the Research Objectives section, above, an objective of the research is to offer heuristic guidance for considering choices that reflect public values in the structure of models that are designed to represent the natural and social systems associated with those problems.

We have made the case that the processes of problem formulation are badly understood. The process of choosing a perspective and delimiting boundaries of the system to be analyzed and managed is inextricably linked to the difficulties of problem formulation. These conclusions cause us to focus on the role of sense of place values, values that are often not fungible across space. It is our goal to do as much as possible to improve understanding of the role of perspective, place, and space, and to develop tools so that communities can explicitly address—and learn about—the role of spatio-temporal bounding in the formulation of environmental problems. We will concentrate on two ways in which values become spatially referenced, and where that referencing may be crucial to our "modeling" of an environmental problem. First, we will try to operationalize the difficult term, "sense of place," by identifying and measuring attachments to, and identification with, places and spaces (boundaries). Second, we will try to understand how differential provision of valued environmental goods—questions of environmental equity--may be affected by natural and social barriers. Better understanding of these two areas will affect our ability to think spatially during the difficult process of problem formulation.

4.B. Case Studies and Case Study Methodology

This project will develop and implement a variety of empirical methods designed to address sense of place and mental models used in problem formulation for wicked environmental problems. These empirical methods will be applied primarily in three metropolitan regions facing pressing environmental problems with significant water and social dimensions: Atlanta, Chicago, and St. Louis. This project's research methods, applied to these three areas, enable a comparative case study method to illuminate the role of sense of place, mental models, and (spatial) problem formulation.

The selected greater metropolitan regions have encountered very different environmental and social change. Atlanta's rapid and recent urban sprawl stresses water resources today and augurs even greater conflict in the future. Much of the political debate and activity has reflected strong place-based values and often divergent mental models of the problem at hand. The Chicago area faces different water concerns and social pressures, although no less daunting. Concerns over water supply and quality, and the maintenance of the Lake Michigan shoreline, pose serious challenges to numerous government agencies and constituents – often with profoundly spatial implications. The St. Louis region in Missouri and Illinois faces difficulty in resolving local environmental concerns and taming sprawl, as desire for economic urban growth has resulted in competition between municipalities to offer incentives for development. Fragmentation of agricultural lands by low-density development accelerates conversion of those lands, while many brownfield sites in impoverished areas such as East St. Louis remain abandoned. While sufficiently different to allow useful comparisons, these greater metropolitan regions possess environmental issues common to the vast majority of the nation's population today. These wicked problems are likely to only grow more urgent and recalcitrant in the future.

A comparative case study method will be employed, by studying three regional communities, communities that have struggled with varying degrees of success to protect their valued water resource. A fourth, background case study, of the Chesapeake Bay region, will be used as a paradigm of the kind of "spatial social learning" that may be necessary to move toward solutions—and better problem formulations—of wicked problems. This historical example will help provide context in which to examine the spatial nature of the problem formulation in each of the three primary cases. Each of the specific empirical methods employed in the different case studies will be discussed in further detail in the next section. The various methods develop and implement new and emerging social science techniques. They employ different data sources and integrate multiple disciplinary approaches and literatures. The results of this research will inform these particular cases and provide a test-bed for these methods

Background Case: Chesapeake Bay: While many problems remain, the cooperative efforts of four states and the District of Columbia, together with private foundations and the federal government, to address water quality problems in the Chesapeake Bay stands as one example where important progress has been made in addressing a complex environmental problem. When the nature and seriousness of the problem of nutrient loading of the Bay waters was indicated by an important EPA study (EPA, 1983), there was a rapid response from throughout the region. Chesapeake Bay is a useful example both because it is well studied, but also because it is an area rich in "sense of place." Once a threat to the Bay was perceived, adoption of a watershed-scaled problem formulation emerged and people's conceptions shifted to focus on larger processes affecting Bay water quality. For example, popular regional journalist Tom Horton, wrote: "We are throwing out our old maps of the bay. They are outdated not because of shoaling, or erosion or political boundary shifts, but because the public needs a radically new perception of North America's greatest estuary. (Horton 1987, pp. 7-8) Today's significant, if partial, success in managing Bay water quality resulted because states, agencies, stakeholders, and the general public did in fact experience spatial social learning just as Horton said they must. While disagreements still occur regarding the management of the Chesapeake, they are usually addressed against the backdrop of a presumed priority that the bay as a whole system must be protected. This consensus implied—given widely shared values placed on the system—that the problems had to be addressed at the watershed scale. As Horton recognized, the re-formulation of the "maps," the policy focus on the whole bay rather than states, regions, or municipalities, the introduction of scientific information about the processes leading to over-nutrification of the bay, and the adjustment of the socio-ecological consciousness of the public were inseparable aspects of the development of a new "cultural model" for the bay and its many tributaries. In this case, people's sense of place apparently interacted dynamically with scientific information that the bay was threatened not only by point sources but also by nonpoint sources, and quickly "learned" that the problem must be addressed systemically, at the watershed level. As a result, a multi-state compact was signed, far-reaching legislation was enacted within states, and the public response to a "wicked" problem was vastly improved.

Case Study 1: Atlanta, GA*:* It is interesting to compare the well-documented case of the Chesapeake with the management problems encountered in the Chattahoochie/Flint watershed, which feeds Lake Lanier, a large lake formed by Buford Dam, an Army Corps of Engineers' project completed in 1957. While the scientific data and modeling of Lanier shows the same kind of systemic threat caused by the same combination of point and nonpoint sources of pollution embedded in a rapidly urbanizing watershed (Beck et al 2002), the municipalities and counties around Lake Lanier have acted mainly to maximize their own good--in tax base, growth, etc. decisions--not the Bay as a whole, as all independent municipalities, etc., seek their own interests. One might say that their sense of place is grounded in municipalities and counties--artificial sociopolitical boundaries--and not with the "Lanier watershed".

Lake Lanier is a classical example of anthropogenic intervention in the Chattahoochee watershed system. The multi-purpose Lake Lanier reservoir was engineered by the Army Corps of Engineers to cater for the human demands for power production, drinking water supply, navigation, flood control, recreation, fishing and tourism. While it is questionable whether Lake Lanier efficiently attained the multi-purpose objectives as conceived by the Army Corps, the unintended consequences of this anthropogenic intervention in the ecological system of Chattahoochee watershed poses long-term risks that might lead to un-sustainable environmental change in Southeastern US.

The anthropogenic intervention not only has an impact on the dynamics of natural hydrological systems (mainly affecting the states of Georgia, Alabama and Florida), it is also causing irreversible changes in the land-use patterns of both upstream and down stream areas of Lake Lanier, as urban sprawl in the form of bedroom communities and even industry moves Northward along the two interstates flanking Lake Lanier. The flora and fauna of the eco-system around Chattahoochee river is becoming ever more fragile as some of the recent studies show (Kundell, et. al., 1998). Biodiversity loss is still unmeasured.

The demographic dynamics of the region have stressed the eco-system surrounding the Lake . At the regional scale, human population has grown more than fourfold since the original decision was undertaken to build Lake Lanier. The socio-economic dynamics around the Lake have resulted in the rising demand for clean drinking water (which was not correctly forecasted by the Army Corps), higher contamination of upstream tributaries due to nutrient run-offs from intensive agriculture, rising real estate prices around Lake Lanier, poor waste water disposal and above all rising levels of pollution in the downstream waters.

While rapid growth across the Northern Arc—which cuts right across Lanier—is accompanied with increasing land use disparities between the wealthy Northern suburbs—which expand by rapid development of expensive gated communities, often with minimum lot sizes, and the Southern suburbs—which are already burdened by Hartsfield International Airport, a major landfill, and countless brownfields and toxic sites. As sprawl moves Northward, the spatial footprint of Atlanta is further distorted, making it more and more difficult for residents to identify with the Atlanta region as a whole.

Environmental justice – the equitable distribution of environmental impacts across groups and communities – presents numerous difficult policy problems in the Atlanta region. The siting of locally unwanted land uses (LULU) and noxious facilities has often been associated with racial discrimination. In Atlanta, environmental justice is now associated with subtler forms of disparate impact: environmental inequity via suburban sprawl (Bullard et al 1999). Others decry inequity of access to Atlanta's environmental amenities, such as urban parks (Keating 2001). In their efforts to regenerate its urban core, as in many other major urban centers, Atlanta's urban developers have targeted brownfields for redevelopment. As some sites are selected and remediated, while others remain as environmental blights in communities, questions of environmental justice and the spatial distribution of brownfield redevelopment are raised. While these concerns form a long list of problems, they all share a spatial aspect, and they all have at least rough analogues in the other metropolitan areas we will examine.

Case Study 2: Chicago, IL: *Water* quality in Lake Michigan often captures headlines, as environmental, public health, and race issues collide over beach closures. The nature and maintenance of the Lake Michigan shoreline in Chicago is inescapably spatial – water flows in certain directions and fecal indicator bacteria congregate in particular locales. Yet the residential distribution in Chicago follows unmistakable patterns as well. The possibility of unfortunate coincidence of minority populations and unsafe water quality leads to complicated questions of ultimate causes and appropriate policy responses. Ought the problem be formulated on a beach-by-beach basis, in light of the City's shoreline revetment and maintenance activities, taking into account the entire MSA's water supply system, or something still larger? Might optimal policy prescriptions run afoul of a sense of place as southsiders are prevented from using their beaches?

The ecological resources of the greater Chicago area are well documented if not recognized by nonresidents (see Bright et al. 2002 for a brief description of area residents' attitudes). Yet Chicagoans often possess a strong sense of place defined subtly by environmental features. The geographic bounds of the "neighborhood" and the greater community in which Chicago residents live are often related to the natural and built environments. These relationships can affect the popularity and effectiveness of conservation policies enacted.

Chicago's history has rich environmental influences (Cronon 1991) as well as social, political, and economic factors. As much as any political machine or industrial base, geography and space have long driven the city's development. From its origin as a connection between the Great Lakes and the Mississippi River, to its hub-and-spoke rail system radiating from a downtown hub along the river, to the Army Corps of Engineers reversing the flow of the Chicago River, to the redlining of blacks to certain southside neighborhoods, Chicago's geography has played a central role in its development. Understanding this geo-historical legacy is crucial to understanding contemporary environmental problems. The spatial dimensions of equity in the distribution of hazardous waste sites and brownfields in Chicago, for instance, follows directly from past industrial activity (Baden and Coursey, 2002). Blacks were historically forced to live far from industrial employment centers, which are now brownfields, while newly arriving Hispanics opt for cheap land near these abandoned industrial corridors.

Case Study 3: St. Louis, MO*:* The St. Louis metropolitan area has been an area of focus for some of the researchers (Hannon and Metcalf) in investigating the drivers and impacts of urban sprawl. Environmental and social justice dilemmas are acute particularly on the eastern (Illinois) side of the Mississippi River in the floodplain area that has historically been home to low-income workers supporting the plethora of manufacturing firms that dot the landscape. Many of the older industries have now abandoned these sites for alternative venues, leaving a legacy of brownfields that are costly to investigate, let alone remedy. The remaining industries continue to violate EPA standards, particularly in the industrial village of Sauget that pollutes directly into the neighborhood of Rush City, part of East St. Louis. Incentives for industries to clean up are few, and incentives for economically drained East St. Louis to welcome any investor, regardless of the pollution impact, are many. The case study of St. Louis is relevant to contrast with others because those who are most affected by pollution, lingering brownfields, and sprawl are also those whose voices have not been heard. In an area where people struggle to get by, protecting the environment appears as a luxury, not a basic need for life.

Illinois communities east of St. Louis have had a history of heavy industrial dependence, reflected in such town names as Granite City, Monsanto (now Sauget), and National City. The location of such communities in the Mississippi floodplain ensured low property values as floods frequently damaged properties. The communities thus housed recent immigrants and the working poor. Industrial powers dominated municipal governments, leaving behind any notion of a democratic government (Theising 2003). Such dependence on industry brought increased vulnerability to turns in the tides of capital, as industrial sites were abandoned for newer or fewer factories elsewhere. While many industrial communities remain, East St. Louis is no longer an industrial community. It is an abandoned community, where the largest employer in the area is a hospital and abandoned gas stations are a common sight despite proximity to interstates.

Because the residents who remain in East St. Louis are nearly all African American and the majority live under the poverty threshold, issues of inequity across race and class are tightly intertwined. Although environmental pollution in the area is profound, as EPA-designated brownfield and Superfund sites abound, residents focus first on the struggle for survival. The city is currently courting incineration facilities and other industries looking for spaces in which to expel odors and other waste, while relying on workforce access. Even a facility that offers less than a handful of jobs is viewed as a boon to the city government, long depressed in deficits from its tax base. While they have shared concerns about the future of their hometown, residents of the Rush City neighborhood of East St. Louis would prefer to reinvest in their own community rather than endure displacement and deference to further industrial dominance and pollution. That they have resisted displacement thus far reflects their community strength. What solutions are best for East St. Louis, and what role regional stakeholders should play, in addressing the isolation of poverty that has accompanied sprawl and abandonment remain unclear. Proposed investigation of alternative perceptions of abandoned spaces in the St. Louis region is expected to provide insight to the dynamics of persistent inequality and the levers for change toward a more sustainable future.

4.C. Techniques and Measures

The Challenge of this research will be to develop finer-grained methods for social science research, methods that can discover local variation in both values and spatial identities. Such methods have not yet been fully developed, or at least not applied to the task of identifying boundaries appropriate to mission-oriented models, so a major portion of our task will be to consider and choose a suite of techniques that will be applicable to the somewhat different problems faced by different regions. Our strategy will be to experiment with both direct and indirect techniques to identify the place identities and related sense of place values that shape the bounding of environmental problems in public discourse, and to use agent-based GIS as a tool of integration.

The proposed research utilizes a variety of methods to identify stakeholder perceptions and values, and to connect these conflicting perceptions with a greater understanding of the ecological problem at hand. To do so requires both direct elicitation and indirect derivation of such perceptions and values followed by integration of the geophysical with the social using agent-based GIS techniques. The connection of these mixed methods constitutes much of the inventiveness of this proposed work, further articulated in Part 5 of this proposal.

4.C.1 Direct Elicitation of Stakeholder Mental Models

Hirsch and Metcalf will develop and test methods of elicitation using intense interviews of a small number of participants in each of the case study areas. Such interviews involve participant preparation of visual collages to represent their experience with the spatial problem at hand, followed by a storytelling-focused interview (Zaltman 1997, Christensen and Olson 2002). Interviews will be analyzed to reveal participants' mental models with respect to content (the system of concern) and structure (organization of content in memory). Individual-level data will be used to further develop theories of sense of place in the context of experiential discounting, under the guidance of Hannon and Norton as extensions of prior theoretical foundations (Norton and Hannon, 1997; 1998; Norton, 2003). Aggregation of the individual data for a stakeholder group creates a collective cognitive map. Such aggregation will lead to the representation of stakeholders' mappings in each of our applications (water management and brownfield redevelopment problems in each of the case cities), where each of the collective cognitive maps' robustness will be assessed.

An alternative method of eliciting mental models will be adapted by Zia from Morgan, et al (2002) using an open-ended interview technique to elicit mental models about spatio-temporal boundaries of risky decision problems being confronted as development intensifies in the Chattahoochee/Lanier Watershed. This methodology begins with interviews of technical experts in the problem area to review current scientific knowledge about the processes at hand and corollary risk levels. Influence diagrams constructed from these interviews help to formalize the expert view of the problem. Then open-ended interviews, shaped by the constructed influence diagrams, with non-technical stakeholders will be conducted to elicit beliefs about risk and scale. A final confirmatory questionnaire captures the beliefs from the open-ended interviews and the expert model. The questionnaire will be administered to larger groups as sampled appropriately from the intended audience to estimate the prevalence of specified beliefs and perceived scales of environmental problems. Directly obtaining evidence on stakeholder mental models, and identifying patterns across groups, will enrich current models of environmental models in our areas of application.

4.C.2. Indirect Derivation of Spatial Preferences from Empirical Data

Noonan will apply expertise in econometric analysis of empirical data to test spatial hypotheses of the housing market as an indicator of "sense of place." Using rich spatio-temporal data for residential property sales in Chicago during the 1990s, the spatial variation in Chicago housing markets can be articulated using hedonic price analysis. Combining econometric analysis with GIS delivers spatially detailed information about the ways in which consumers tie properties to *places* in a broader sense. This *revealed* *preference* approach utilizes market behavior as identifying a sense of place across different types of properties and associated buyers.

The revealed preference approach will enable measurement of the spatial extent of environmental impacts on residential properties (e.g., Acharya et al 2001, Hannon 1987; 1994). The effects of such environmental concerns as hazardous facility and open space proximity, and variation of river quality on property value can be quantified using the hedonic analysis of the property data. Moreover, the influence of central cities versus edge cities on property value can be identified with this technique, and extended from Chicago to the other cases in question using data from the Multiple Listing Service (MLS). The result will be a mapping of place-based values in the three case cities' housing markets, with emphasis on spatial extents of LULUs.

In addition to the hedonic property analysis, historic census data will be employed to identify critical differences in socio-economic groups that occur at the regional Metropolitan Statistical Area (MSA) scale. Shifting patterns of housing development and isolation of poverty-stricken areas (often the most polluted areas) will thus be identified over the course of recent history (1970-2000) in each case area using the Neighborhood Change Database developed by GeoLytics. Metcalf and Noonan will utilize this database to inform case comparisons.

Spatial modeling of environmental equity concerns exemplifies the wickedness of environmental problems. There are no clear answers to fundamental spatial modeling questions in the problem formulation stage. At what spatial resolution ought the analysis be conducted? What determines the geographic scope or bound to the analysis? Answers cannot be found by reference to policy, which does not specify any scale or scope for analysis. Social science theory has offered either little or mixed guidance in this regard. In practice, studies of environmental equity reflect this lack of a coherent, consistent approach to spatial modeling. In the absence of theoretical guidance as to the appropriate scale, the researcher's choice of scale *at the problem formulation stage* can ultimately determine the presence or absence of inequity.

Our research will apply recent advances in spatial ecological regressions to evidence of environmental inequities, which can be cast as a modifiable areal unit problem (MAUP) (Arbia 1989, Anselin forthcoming), a special case of the change of support problem (see Cressie 1996, Gotway and Young 2002). Yet only rarely has this problem been tackled directly (e.g., Siu 1999). The methodologies proposed here, which will include robust treatment of the MAUP problem, will be useful for much future environmental justice research. They will add a level of spatial sophistication in the problem formulation stage that makes explicit the consequences and robustness of modelers' choices. This research will use a detailed georeferenced dataset of hazardous sites across Illinois and Georgia and include detailed demographic data. Special attention will be paid to the presence of a spatial decay function, where declining disamenity effects over space allow for a weighting of proximate populations by estimated exposures. This can be used to inform the modelers' choice of spatial scale at the problem formulation stage.

Our research will investigate more deeply into issues of place. Standard hedonic price analyses, when combined with sophisticated spatial models, can provide rich information about the spatial scale and scope of people's values – yet there are limits to this quantification of the sense of place. Values associated with localities and spatial scale manifest in many ways outside of the housing market. Other empirical methods based on behavioral evidence will measure, indirectly, this sense of place. Residential location choices, especially when households relocate outside of an area, may be influenced by a sense of place. Using geocoded data from the National Longitudinal Survey of Youth, and the notion that location at birth is largely exogenous to the adult household, a regional migration model will examine the effects of location-specific features on migration decisions.

Special emphasis will be placed on the scale and bounds of location-specificity in modeling migration. Applications to the three case cities will indicate how the neighborhood, city, or other regional affects the propensity to move, and the destination of the move.

In addition, content and discourse analysis will be applied by Zia to recent on the issues of water management, urban growth, and environmental justice media reports in major newspapers in the three case cities. Discourse analysis methodologies are described in Titscher et al (2000) and Martin (2003). This research will also gather information from city council or similar proceedings to identify expressions of spatial sense of problem formulation used in practice and discussion. Finally, the spatial bounding of environmental problems can be revealed through the geographic scopes selected by various non-governmental organizations. Our research will identify the broadest set of organizations (e.g., environmental nonprofits, development associations, community-based organizations) and examine their geographic scope of operation in the three case cities. The groups will be selected based on their expressed interest in, or activities related to, issues of water management, urban growth, or environmental justice. Systematic variation in the groups' characteristics, contexts, and missions will be correlated with the spatial bounding of its operations. Altogether, these methods will expand the standard revealed, market-based approaches into new arenas of non-market behavior to address sense of place in discourse and practice.

4.C.3. Integration of Techniques

The qualitative mental models developed using direct elicitation will be compared with the quantitative spatial analysis of empirical data to augment the limitations of each method in isolation. While the quantitative analysis enables a broader swath of case area population to be considered, the qualitative interviews enable "ground-truthing" of specific stakeholders relevant to the cases in question. The proposed research will identify the simultaneous areas of insight and blindness uncovered through such comparison of the direct and indirect methods, and will experiment with new methods as appropriate.

With some grounding of sense of place as reflected in both broader patterns and in stakeholder mental models, such social information can be incorporated with geophysical knowledge of the problem at hand in an agent-based GIS framework. With such a framework, utilizing the Java-based simulation software AnyLogic in conjunction with relevant extensions (e.g., Dibble and Feldman 2004), individual agent perceptions and activities can explicitly be modeled on a landscape.

Researcher Metcalf has been involved with early development and instruction of modeling with AnyLogic, and both Hannon and Metcalf will apply expertise developed with spatial dynamic modeling of urban sprawl, brownfield redevelopment, and hydrological systems. While many complex models have been developed to investigate land-use change over a range of spatial and temporal scales, few have emphasized decision-making in adequate spatio-temporal detail (Agarwal et al 2002).

Social and geophysical modeling using agent-based GIS techniques willl be used to integrate other techniques that will be developed and employed to garner insights about how individual perceptions evolve in the social context and impact ecological problem formulation. These techniques, described above, include meta-analysis techniques to review prior empirical studies, discourse and text analysis, secondary data sources, surveys, and interviews. The application of these techniques will depend directly on the limitations of articulated methods in eliciting the information needed for analysis of ecological boundary setting.

5. Expected Project Significance

Authors in several disciplines—geography, environmental ethics, planning, anthropology and sociology) have recently called for more attention to locally based values and for more study of place-based values (See Norton and Hannon 1997; 1998 for examples and discussion). Environmental equity researchers continue to struggle with wicked spatial modeling problems. Recent research (e.g., Bowen et al 2002) highlights contradictory findings and the methodological challenges. Early research by Anderton et al (1994) emphasizes the problem of choosing the appropriate spatial scale of analysis, and this problem still plagues environmental justice research (e.g., Davidson et al. 2000, Taquino et al. 2002).

Similarly, there has been increasing attention to matters of scale in ecological research and modeling. The proposed research draws attention to a key focal point of this cross-disciplinary research—the point where geophysical modeling, social scientific study of citizen perception and values, and policy decision-making intersect—that must be better understood if disciplinary work on localism and sense of place values is to be integrated into normative decision analysis and used to improve decision processes.

Another merit of the proposed research is that it addresses, using techniques of several social scientific disciplines, the way spatio-temporal scale and boundary setting decisions interact with problem formulation issues, which will allow the team to illuminate the interaction of values, place-connection, and place identification with implicit or explicit "boundings" of the system associated with a given set of environmental concerns. Because this area of research is so new, perhaps the greatest merit of the proposal will be to examine, adapt and refine available techniques for doing social scientific research with special attention to spatio-temporal scale, and to explore the possibilities of using GIS modeling to integrate multi-scalar information about systems and communities.

The broader impact of this proposed project will be an enhanced ability to integrate diverse perspectives of the ecological problems at hand as exhibited by the chosen case studies. This impact crosses the constituent disciplines of geography, environmental ethics, planning, and public policy, as well as the myriad of stakeholder domains in addressing ecological problems. This trend of embedding science and policy analysis within an ongoing, collaborative dialogue by embedding spatial analysis within decision process is in keeping with the recommendations of NRC (1996; EPA Science Advisory Board, 2000; Norton and Steinemann, 2001). The proposed research contributes to this trend by showing that improving process—bringing the insights of decision science and analysis to bear on actual decision-making—is more important in addressing problem formulation of wicked problems than are decision algorithms and optimizing programs.

Finally, this research will open new frontiers in social science by developing new methods and techniques to emphasize spatiality. Pioneering this new frontier, where locally based values interplay with spatial modeling perspectives, requires research on the wicked spatial bounding problems facing society in the search for better environmental policies. We propose to take the first step.

The team will disseminate its results by publishing no less than five co-authored and single-authored journal articles in refereed journals, and the team will publish a monograph on the role of values in spatio-temporal modeling of environmental problems. Two students (Metcalf and Hirsch) will incorporate research from this project into their dissertations, and important results from the project will be presented at one or more conferences per year for the duration of the grant.

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