"In order to aid in diffusing useful and practical information…": Boundary Organizations and Agricultural Extension

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Introduction

Agriculture is increasingly an information-dependent sector of the economy. It constantly experiences technological shifts, operates in markets embedded in a global economy, and is extremely sensitive to changes in natural systems (e.g., climatic, hydrological, soil, etc.). Making near- and long-term decisions in response to each of these factors requires an understanding of a wide range of scientific and technical information. This context in the U.S., combined with 150-year historical patterns and policy of expansion and development, has provided a crucible for the evolution of a government-supported system of research, education, and extension that has attempted to produce and diffuse scientific and technical information for agricultural decision-making.

Investigation of this system sheds light on emerging notions of how science and decision-making are linked, specifically probing the utility of the concept of *boundary organization*. Boundary organizations are conceived as institutions that "straddle the shifting divide between politics and science" (Guston 1999, p. 1), mediating between science and policy, and facilitating the interaction between actors on either side or who cross the boundary (Guston 1999). Emerging from the social studies of science literature, boundary organizations build on the idea that the boundary between science and policy is one that is socially constructed, and that what is "science" and what is "policy" is

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determined through *boundary work*: contestation and negotiation that delimit the boundary (and its associated institutions), and define what is on either side of it (Star and Griesemer 1989; Jasanoff 1990; Gieryn 1995; Jasanoff 1995)[3].

By exploring one aspect of agricultural decision-making – water management in the U.S. Great Plains – this research deepens the understanding of boundary organizations in two significant ways. First, this research provides a preliminary test of the hypothesis that "the presence of boundary organizations facilitates the transfer of relevant and usable knowledge between science and policy." (Guston 1999, p.1), finding that boundary organizations have been instrumental in creating and maintaining a system of assessment and decision-making which successfully addresses depletion the High Plains Aquifer in some parts of the region. Second, it extends the concept of boundary organization beyond the science-policy dimension to incorporate the dimension of levels of organization. Boundary organizations are thus characterized as not only helping bridge science and policy, but linking science and policy across different levels (e.g., from the local to state to national level).

This paper is comprised of: a brief history of agricultural education, research, and extension in the U.S.; an outline of the case and methodology of the research project; descriptive evidence is presented supporting a the framework of boundary organizations outlined by Guston (1999); arguments why this framework should be expanded to include an analysis of boundaries between levels of organization; preliminary findings supporting the hypothesis that boundary organizations facilitate the production and use of scientific and technical information; and summary and conclusions.

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A Brief History of Agricultural Education, Research, and Extension in the U.S.

With the passage of the Morrill Act of 1862, the U.S. Congress laid the foundation for a nationwide system of agricultural research, education, and extension[4] (U.S. Congress 1862). The act granted federal public lands to each state be sold and the proceeds used to create colleges of agriculture and mechanical arts – the land-grant colleges – in each state (National Research Council 1995). There were several rationales for such a system. First, at a time of rapid expansion of the American West, the establishment of distributed centers of agricultural education helped facilitate settlement and self-sufficiency on the frontier. Second, the creation of colleges that would be accessible to rural areas and the middle and lower classes had great political and ideological appeal. In the mid-1850's over 60% of the labor force worked in agriculture. Third, proponents of land-grant colleges anticipated assisting rural communication at a time when such communication was slow and costly (Rasmussen 1989).

Following the early implementation of the Morrill Act, it became apparent that there was an absence of organized scientific research that could form the backbone of curriculum at the newly established land-grant colleges (National Research Council 1995). In an effort to fill this gap, Congress passed legislation in 1887 that established and funded state agricultural experiment stations "to conduct original and other researches, investigations, and experiments bearing directly on and contributing to the

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[3] For a more complete treatment of boundary work and boundary organizations, see the [Guston paper] in this issue, [pp. x-y].

[4] "… agricultural extension work shall consist of the development of practical applications of research knowledge and giving of instruction and practical demonstrations of existing or improved practices or technologies in agriculture…to persons not attending or resident in [land-grant] colleges…" (Smith-Lever Act of 1914)

establishment and maintenance of a permanent and effective agricultural industry of the United States… having due regard to the varying conditions and needs of the respective States…" (U.S. Congress 1887). Building on the Morrill Act, each states' experiment station became associated with its land-grant college.

The third pillar upon which the production and diffusion of agricultural information rests is extension, embodied in the Smith-Lever Act of 1914 (U.S. Congress 1914). This legislation created the Cooperative Extension Service, a collaborative effort between the U.S. Department of Agriculture (USDA) and the land-grant colleges. The primary functions of the service were to disseminate information and make educational opportunities available to people not enrolled in the colleges. The general structure of the system enlisted the land-grant colleges to coordinate outreach and the dissemination of the research conducted at experiment stations through such media as workshops, demonstrations, and field-days (Rasmussen 1989).

Since 1914, this system of research, education, and extension system has evolved through numerous amendments to the three initial statutes, new federal legislation, and initiatives at the state and sub-state levels to tailor the system to local circumstances. In the last 85 years, for example, each county in the U.S. has created a county extension office with county extension agents specializing in such areas as crop production, home economics, and rural development. Each county agent is affiliated with the state's land-grant college. The most recent reorganization of USDA has consolidated the tri-partite system under one administration into the Cooperative State Research, Education, and Extension Service (CSREES) (U.S. Congress 1994). The system has become a partnership among federal, state, and local agencies and educational institutions with shared responsibilities and funding (Rasmussen 1989; National Research Council 1996).

Given its objectives of research and dissemination, and its presence throughout the U.S., CSREES provides an excellent case in which to explore the underlying conceptual foundation of boundary organizations and their functions.

The Case and Methods

Water Management of the High Plains Aquifer

The primary focus of this paper is on only one of the many issues that CSREES addresses: water management for irrigated agriculture. Irrigated agriculture is particularly well-suited to the High Plains region in the central United States, a semi-arid region with extremely variable precipitation, abundant and fertile soil, and moderately long growing season. Underlying parts of eight states is the High Plains (or Ogallala) Aquifer (See Figure1).

{Insert Figure 1 about here}

Acting as a purifying filter, the geology of the aquifer results in especially good quality water (Buchanan and Buddemeir 1993). Given the high quality of the water plus the climatic variability and semi-arid nature of the area, farmers attempted to secure a predictable source of water by pumping for irrigation as early as the late 1880s. Despite some advances in pumping and energy technology in the 1890s and early 1900s, the great increase in development of the aquifer did not begin until the 1930s when the dust-bowl drought and New Deal-era government programs provided incentives for farmers to exploit the groundwater (Green 1992). Further technological advances in drilling, pumping, and delivery, and the advent of inexpensive energy, favorable financing,

government subsidies and crop prices all contributed to steady increases in irrigated acreage from 1949 to the present (see Figure 2).

{Insert Figure 2 about here.}

Currently, approximately 95% of water withdrawn from the aquifer is used for agricultural purposes (McGuire and Sharpe 1997). Irrigated cropland accounts for 37% of the harvested cropland in the High Plains region, and for specific crops such as corn, 50% of the harvested cropland is attributed to irrigated acres (Kromm and White 1992). The region produces significant shares of the U.S. output of corn, wheat, sorghum, cotton, and cattle (fed on irrigated feed). Clearly, "[i]rrigated agriculture sustains the High Plains and is central to an integrated agribusiness economy..." (Kromm and White 1992).

With relatively low natural recharge rates and the dramatic increase in the use of groundwater throughout the region, the aquifer suffered declining water levels in parts of the region as early as the 1940s and 1950s (McGuire and Sharpe 1997). By the 1970s, farmers and officials at all levels of government were pressing to more closely examine aquifer depletion. In the mid-1970s the U.S. Congress authorized two assessments conducted in parallel. The first was a national effort, the Regional Aquifer-System Analysis, undertaken by the U.S. Geological Survey (USGS), which examined the hydrogeology of the nation's major aquifers. The second assessment process brought together federal, state, and local government agencies with private consultants within the High Plains region to analyze the potential economic and social impacts of aquifer depletion and management options (High Plains Associates 1982; Weeks, Gutentag et al. 1988; Kromm and White 1992). Motivation for these studies at the national level centered

on national food security issues. The local and state concerns focused on potential negative local and state economic and demographic impacts of partial or total depletion of the aquifer. At the time, concern for the aquifer rose on the public's agenda for two reasons: increased pumping costs, due to both the increasing depth to water and the energy price shocks of the mid- and late-1970s; and the potential social disruption due to the abandonment of irrigated farming in the region.

Another issue that focused state and local attention at this time was the common pool resource attributes of the aquifer. While pumping water in Nebraska will have no impact on water levels in Texas, at local levels (farms, counties, and immediately across jurisdictional lines), exploitation of the resource at one point decreases water availability at other points. By the mid-1980s, USGS, states, and multi-county water management districts[5] within the region had begun individual and collaborative monitoring, analysis, and modeling efforts to assist in the management of the resource, often facilitated CSREES (McGuire and Sharpe 1997). In addition, more recent research, management and legal concerns are focusing on the relationship between ground and surface water, particularly how depletion of the aquifer affects adjacent surface water levels and vice versa.

Given the national, state, and local concerns and the common pool characteristics of the resource, federal, state, and local actors have recognized aquifer depletion as a multi-level problem, requiring attention at many scales of organization.

Methods: Research sites

[5] Water management districts are multi-county jurisdictions given varying degrees of authority and autonomy depending on the state in which they reside.

A primary reason for this study's focus on this region is that it allows for a robust comparative analysis of the agriculture extension system. Within the High Plains region, there is variance in both natural conditions (e.g., precipitation, temperature, soil type, storm frequency, aquifer saturated thickness and recharge rates) and, more importantly, variance in educational, research, and extension institutions and their relation with other state and local entities. However, there is relatively little variance in overall socio-economic, industrial, and cultural makeup, within the region.

Ten counties in Kansas, Nebraska, and Texas were chosen as field sites for data collection (see Figure 3). These three states were chosen because: 1) they overly 75% of the aquifer (McGuire and Sharpe 1997); 2) they account for 89% of the irrigated acreage overlying the aquifer (Kromm and White 1992); 3) within each of the three states, the heterogeneity of the aquifer is represented, so variance of the natural resource itself can be controlled for; 4) agricultural production and irrigation development have taken similar paths in the three states, and thus a range of economic factors can be controlled for; and 5) there is useful institutional variance in water resource information and decision making - for example, all three states have evolved three different ways of managing the aquifer at the state and local levels and maintain different relationships with federal agencies such as USDA and USGS. The counties were chosen for this phase of the research because the level of risk of depletion, measured by saturated thickness, depth to thickness and historical rates of decline, faced by each is relatively similar, and thus controlled for. Thus, for this phase of the research, variables such as the characteristics of the aquifer, risk of water depletion, and general economic characteristics are held relatively constant, while specific institutional and management variables vary.

{Insert Figure 3 about here.}

Methods: Data collection

Two sources of evidence have been used in this investigation. The primary source of evidence derives from structured interviews completed in the states and through telephone interviews in Washington D.C., using a consistent interview protocol (Moser and Cash 1998). In particular, the interviews established what types of scientific information decision-makers need, which sources they turn to, why certain sources are preferred to others, what the characteristics of the decision-making process were, and what important links in information flow were. Over 80 interviewees in the three states and at the federal level were selected through an iterative process through: the pertinent literature; U.S.-wide and state-specific searches for non-governmental, governmental, academic and non-academic organizations involved in agricultural and water resource issues; and recommendations from interviewees themselves. Interviews were conducted with county and area agricultural research and extension personnel, scientists at land-grant colleges, USDA scientists, Natural Resource Conservation Service agents, private industry managers, state and local planners, representatives of non-governmental organizations, and elected officials on local resource management boards.

The second source of data complements the first and is comprised of a survey distributed to the 220 county agricultural agents in Kansas, Nebraska, and northern Texas. The survey probed questions similar to the interview but was more structured,

focusing on the county agents' involvement in collaborative efforts and multi-level linkages. The response rate was 74%[6].

The qualitative and quantitative data were analyzed to generate both a descriptive analysis of the extension system serving functions of a boundary organization, and a causal analysis to test the hypothesis that boundary organizations contribute to the effective transfer and use of scientific knowledge.

Results 1 - Support of the Guston Framework

Guston's (1999) initial framework presents three characteristics of boundary organizations: 1) they help negotiate the boundary between science and decision-making; 2) they exist between two distinct social worlds with definite responsibility and accountability to both sides of the boundary; 3) they provide a space to legitimize the use of boundary objects – items which are "both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain common identity across" boundaries (Star and Griesemer 1989, p. 393). While there is some variance in the samples analyzed, the agricultural research, education, and extension system in the High Plains region can generally be characterized by these attributes.

Negotiating between science and decision-making. Through legislative intent and mission statements of state land-grant colleges and state CSREES partners, it is clear that an intended role of the system is to serve as negotiator between scientific researchers and users (decision-makers) of scientific and technical information. For the most part, this intention has been realized. County agents, for example, mediate between farmers and

[6] A survey was sent to every county agent in the study area, with one follow up letter to those agents who did not

extension specialists at area research stations[7], and researchers at the land-grant college in a variety of ways. They facilitate dialogue between farmers and scientists to encourage research agendas that reflect the interests and needs of farmers. They translate scientific information produced at land-grant colleges, putting general findings into site-specific practical language and guidance. And they manage demonstration projects and field applications that integrate farmers into researchers' field experiments.

Accountability to both sides of the boundary. Sitting between the farmer, specialist, and land-grant scientist, the county agent is bound by institutionalized mechanisms that clarify responsibilities and accountability to principals on both side of the boundary (Guston 1996). The job of the county agent is essentially overseen by an elected committee from the county, which helps the agent set program priorities, design agendas to be communicated to scientists, and establish contacts with the farmer community. The agent is held accountable to the committee through the ability of the committee to make hiring and firing recommendations to the county agent's employer – the land-grant college. Thus, the agent is also held accountable to the land-grant college, and its scientists.

Use of boundary objects. The county extension office has evolved to be a site at which boundary objects can serve as meeting grounds between actors on either side of the science/decision-maker boundary. Boundary objects play a critical role at the boundary, allowing "members of different communities to work together around them, and yet maintain their disparate identities" (Guston 1999, p. XX). While needing to communicate across boundaries, scientists have an interest in maintaining independence

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respond within three weeks.

[7] Each state is divided into several *areas*, multi-county regions, each with its own research or experiment station where extension specialists conduct research appropriate to that area.

from the users of the information they produce. The balance they seek is to provide useful information, but maintain scientific credibility. Boundary objects help support this balance. In the High Plains, county agents (and area extension specialists) facilitate the production and use of a variety of different kinds of models (e.g., cropping models, hydrogeologic models, and economic models.) In Kansas, for example, county agents were integral in coordinating farmer input and involvement in the construction and use of a linked hydrogeological and socioeconomic model of aquifer management at Kansas State University. As one county agent described the process and his role in it:

> There was a question of a policy [regulatory] change from the Ground Water Management District, and the producers [farmers] were questioning whether the policy was going to affect them adversely or not. And so it was a producer driven need for an answer, to give them some credible knowledge to make a decision on whether or not they wanted that (New) policy in place
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> And so, as the agents, we contacted the university to find who was doing this study… [W]e got the department heads out here…the head of economics…and a couple of others, and a researcher that he brought. And we sat down with the members of the water board. …[W]e sent letters to producers and got a group of producers together, and all of us sat down and hashed out what we would like to see done here. And the university went back and set up the model, and started working on the model, and then we started putting the baseline data together... And it was a back and forth thing for several years getting it done because it was a rather involved model. (Interview March, 1999)

As this example demonstrates, models themselves can act as boundary objects, dependent on both the participation of farmers to get inputs that reflect reality and outputs that are useful, and scientists who incorporate basic research and understanding of the systems under study, and technical capacity to guide the endeavor. Moreover, actors on both sides of the boundary benefit. In the case outlined above farmers and water managers were able to test different management scenarios which they viewed as credible and scientists were able to produce scientific outputs that were policy-relevant, ground-truthed, and robust with respect to local data. Neither community could have produced a

model which was relevant and perceived as being scientifically sound without the other's participation. The county agent, in this case, acts as the facilitator across the boundary between these two groups.

Results 2 - Expanded notions of boundary organizations: Boundaries between levels of organization.

While the research and extension system has institutionalized the functions of boundary organizations in linking science to decision-making, this study has identified another function of boundary organizations: linking science and decision-making across different levels of organization. The original creation of the extension system and its subsequent evolution demonstrated awareness of the multi-level nature of the agriculture sector and different governments' interests in agriculture. The fact that interests of the federal government, state governments, county governments, and individual farmers differ has driven the architects of CSREES to build institutions that allow for sensitivities to diverse and geographically heterogeneous interests. The federal government might provide overall guidelines for a research program (e.g., water conservation), but how that research program is implemented might differ radically from state to state and county to county, depending on the needs of the end-users (e.g., focus on irrigation technologies, cropping patterns, or management techniques.)

In addition, the system (and how it relates to other entities) is flexible enough to define the level(s) of organization that are best suited to addressing an issue. For example, at what level aquifer management should be addressed is not a given, and in fact has evolved over time. Aquifer depletion was initially seen as a purely local issue,

only recently being viewed as a complex multi-level problem requiring participation by federal, state and local scientists and decision-makers. Exactly how this participation evolves and what it entails for which actors (i.e., who has responsibility for what) is still being negotiated, and the extension system is intimately involved with that debate.

Given this evolution, one question that this research attempted to ask was what function CSREES has played in the definition of water management as a multi-level problem, and in bridging across levels. In investigating this question, empirical evidence points to at least three additional hypothesized functions of boundary organizations: 1) they help negotiate the boundaries between levels (e.g., help define what the scale of a problem is); 2) they mediate multi-directional information flow across levels; and 3) they help capitalize on scale-dependent comparative advantages.

Negotiating the boundary between levels. The extension system has been integral in the negotiation of the level at which scientific research about the aquifer is produced. County agents, area specialists (scientists at area experiment stations representing multiple counties – the extent of which is itself negotiated within CSREES), and scientists at the land-grant colleges have articulated the need for information production integrated across levels, to address the problem of aquifer depletion. They have worked with colleagues in neighboring states, USGS and other federal agencies in defining depletion as a regional problem with implications from the local to federal level, and in defining who has what responsibilities for which scientific agendas, and at what level.

Mediating information flow across levels. One of the primary functions of CSREES has been to facilitate communication between the local, state, and federal levels. This is evidenced, above, in the discussion of county agents' role in linking farmers to state land-grant scientists (the science/decision dimension) in setting research agendas and

producing relevant research. It is also seen, however, in the objective of the extension system to link specialists at area experiment stations, research teams at state land-grant colleges, and federal research facilities. Evidence that confirms that this occurs draws on the results from the survey of county extension agents. If CSREES' objectives are being met, for example, one would expect to see communication between county agents and researchers at multiple levels. Figure 4 displays the frequency of communication between county extension agents and others at different levels. While county agents do not talk to *all* players at multiple layers (note the low frequency of communication with the Washington office of USDA or the Area Water Management District), they do communicate frequently with local farmers, scientists at area research stations, and scientists at the state land-grant colleges. Not surprisingly, the majority of communication happens within the extension system or with farmers.

{Insert Figure 4 about here.)

Network analysis, grounded in interview data, complements the survey results. Figure 5A displays a schematic diagram of possible connections among actors and organizations involved with water management and agriculture in the High Plains. Central to this network is the extension system, and for agricultural research and decision-making the most important actors and connections are highlighted in Figure 5B. Both the county extension office and area research/extension offices act as nodes, ultimately connecting individual farmers to researchers at land-grant colleges and USDA research facilities.

{Insert Figure 5 about here}

More important, however, is that county and area personnel actively help construct networks that bridge local-federal entities, and this has been evidenced in many places throughout the region in water management. As water management districts have come into being and evolved in the last several decades, the extension system has proven to be vital, as a pre-existing network with established trusted relationships, in helping link the managers and constituencies of local districts to higher level research entities. In so doing, county and area extension offices have provided another critical function as a boundary organization between different levels of organization:

Helping capitalize on scale-dependent comparative advantages. Both decision-makers and scientists are faced with the challenge of understanding a large-scale phenomenon (depletion of an aquifer which underlies eight states) with both causes and effects at numerous scales (e.g., individual farmers overpumping and/or noticing dry wells, interstate conflicts over water rights, etc.). Capturing how the large-scale phenomenon influences the local-scale, and *vice verse*, has traditionally been difficult (Easterling 1997; Lins, Wolock et al. 1997; Wilbanks and Kates 1999; Harvey 2000; Cash and Moser in press).

One way to address this challenge is to harness scale-dependent comparative advantages. Such comparative advantages can be thought of as unique knowledge, technical capacity, or scientific specialization characteristic of a specific level (Cash and Moser in press). Three examples in the High Plains highlight this dynamic: modeling; monitoring; and technology innovation.

Modeling: The computing and modeling resources of a federal agency like USGS complements the site-specific knowledge and data collection ability of a local water

management district, neither of which could individually undertake a regionally complete and locally relevant assessment effort of the status of the High Plains aquifer. In many places throughout the High Plains, county extension offices have been instrumental in coordinating and harnessing of scale-dependent comparative advantages by: 1) enlisting hydrogeologists at the state land-grant colleges or regional office of the USGS to produce models of the aquifer with high enough resolution to be useful to local decision makers; 2) coordinating local well-monitoring efforts that can be used as inputs into large-scale models; and 3) acting as liaison between these actors and the water management districts. The result of these efforts is the production of scientifically credible models of the aquifer, relevant to decision-makers on the ground.

This use of models can be seen as supporting the notion of boundary object described above. In this, case multiple actors with different perspectives and interests can agree on fundamental aspects of the model and use it as a meeting ground over which to share information. The model, however, might still be interpreted differently and, as described above, serve differing functions depending on whose lens is being used.

Monitoring: Scientists at the Amarillo Agricultural Research and Extension Center (an area research station), USDA's Agricultural Research Service (ARS), and county agents and farmers, have collaborated to establish a network of ten soil and weather monitoring stations throughout the Texas North Plains region. This network provides farmers with locally-specific potential evapotranspiration (PET) data, information about the water usage of different crops under different conditions of temperature, precipitation, wind, and soil type. This data, updated on a daily basis, helps farmers make decisions about irrigation management and water allocation. Facilitated by specialists at the area research station, the PET Network combines the computing and technical expertise of

scientists at Texas A & M University (the state land-grant college), ARS, and the area research station, tailoring the outputs and modes of dissemination to the needs of farmers as mediated through the county extension offices. As in the case of model building and use, the PET Network taps in to the unique abilities at different levels, constructing an information production and dissemination network that could not have succeeded without participation across levels facilitated by a boundary organization, in this case the area research station.

Technology innovation: Scientists at the Amarillo Agricultural Research and Extension Center have also been instrumental in the development of new technologies for water efficiency. One such innovation, for example, is highly efficient spray nozzles for Low Energy Precision Application (LEPA) irrigation systems (See Figure 6). With the program based at the Amarillo center, the innovation, testing, demonstration, and diffusion of this new technology depended on coordinated efforts of area and state land-grant scientists, private irrigation equipment manufacturers and distributors, county extension agents, and local farmers willing to be involved in demonstration projects.

{Insert Figure 6 (photo) about here}

Each of these nodes in the network undertook aspects of research, development and diffusion that took advantage of its unique strengths, coordinated through the area research and extension center. Tapping into the organizational expertise and local credibility of county extension agents, area specialists coordinated scientific field tests of different technologies on private land, while helping to communicate farmer concerns, ideas, and suggestions to teams of CSREES researchers and R&D scientists in the

irrigation equipment firms. The center acted as a bridge between state and area researchers, national irrigation equipment manufacturers, and local farmers, providing a channel for two-way communication. This two-way communication is highlighted in the following comment by an area irrigation extension specialist:

> Well a farmer may ask me a question [about irrigation management] that I can't answer, and we don't have the answer to. So we'll bring it back [to the researchers at the research center], and they may do some research on it and get us some more concrete numbers. At the same time, I may be working with the farmer, getting the same data, and we'll put it [the farmer's data and results from the research at the research center] in the same bucket and see what we've got. (Interview March, 1999)

In a multi-year iterative process characterized by these interwoven and complementary streams of research and field testing, new nozzle configurations were developed, tested, and demonstrated on farms. The process produced new technologies which achieved water efficiency savings of greater than 50% compared to existing technologies, and established a base of new users that were instrumental in diffusing the technologies.

Results 3 - Do boundary organizations facilitate transfer and use of information?

The novelty of the concept of boundary organization has spawned a variety of empirical work that has focused on identifying existing boundary organizations in a variety of different areas, and further refining the concept. This study also offers a preliminary test of the notion that boundary organizations matter. For water management in the High Plains, for example, are boundary organizations, and their attendant functions as outlined above, associated with more effective transfer and use of scientific information? To answer this question, county extension offices throughout the region were compared and evaluated on both the existence of the functions outlined above and their effectiveness in facilitating the transfer and use of information.

Coordinating modeling efforts. As noted above, county extension offices in parts of the region have played critical roles in coordinating modeling efforts that can assist local decision-makers in making decisions about management of the aquifer. Throughout the High Plains there is wide variance in the exhibition of this function. Several county agents in Kansas and Nebraska have successfully solidified long-term collaborative efforts among farmers, area specialists, managers in the local water management districts, scientists at the land-grant college and state geological service, and scientists at USGS. These collaborative efforts have produced models which have been instrumental in providing information to local management districts, local farmers, and state water agencies (e.g., depletion rates, predicted changes in the aquifer and farm income resulting from different management regimes, etc.). This information has been critical for decisions about regulating pumping quantities, experimenting with water transfers and pooling, and determining critical zones that require more stringent regulation.

By contrast, several county extension offices in Texas have not created such a network that links local constituencies to state or federal scientific agencies (e.g., the Texas Water Development Board or USGS) in the context of water management. The boundary has not been successfully bridged, and modeling efforts of the kind described above, which take advantage of different capabilities at different levels, do not exist in these areas. In one area in northern Texas, which like parts of Kansas and Nebraska is part of a multi-county water management district, the managers of a local water management district want to begin imposing pumping regulations on its constituents but do not have the scientific assessment in place to help guide them in defining specific limits. They have enough information to know that there is a depletion problem, but not enough to address it effectively . It is only recently that some county extension offices

are trying to create the kind of network that in parts of Kansas and Nebraska have resulted in coordinated assessment efforts characterized by capitalizing on strengths of different entities at different levels. Thus, where extension offices act as boundary organizations, and perform the function of coordination across levels, the effective integration of scientific expertise and knowledge at different levels helps produce useful and relevant scientific products that guide management decisions. Those areas without boundary organizations performing this function are not as successful in this regard.

Collaboration across levels and adaptive management. One measure of effectiveness in dealing with changing natural resources is a system's capacity to be adaptive (Holling 1978; Lee 1993). The above description of a system that institutionalizes linkages across levels suggests that such a system supports adaptability. The modeling exercises that are not one-time ventures, but sustained relationships that, in essence, created a platform from which scientists and decision-makers could assess various issues as they arose. For example, modeling efforts that were originally used to address only ground-water quantity issues are now being adapted to deal with ground-water quality issues and ground-water/surface-water interactions, two issues that have recently risen to the top of the agenda of local decision-makers.

In addition to these inferences about adaptability, the survey used in this research was designed to probe the relationship between collaboration across levels as performed by the boundary organization (the county extension office) and the level of adaptive management. Agents were asked questions about components of adaptive management, such as: management flexibility; ability to use new information to change existing management decisions; and policy experimentation. Answers to these questions were aggregated and categorized into terciles as indicating either low, medium, or high levels

of adaptive management. Through a series of independent questions, county agents also reported levels of collaboration with a variety of organizations at local, area, state, and federal levels. These answers were also aggregated into either low or high scores of collaboration across levels. Figure 7 displays an analysis of the conditional probability of high levels of adaptive management contingent on the amount of collaboration across levels. This analysis shows that those counties with higher measures of collaboration across levels tend to have a greater degree of adaptive management.

{Place Figure 7 about here}

While the surveys were not specific enough to discover whether or not the county extension office facilitated the collaboration (that is, other agencies such as the water management district might have taken the lead on facilitating multi-level collaboration), these findings are consistent with those from the interviews which provided similar, if not more nuanced, evidence.

Summary and Conclusions

As for many other issues in environment and natural resource policy, agricultural decision-making is characterized by two fundamental challenges: linking science to decision-making, and linking science and decision-making across multiple levels. Using the boundary organization framework has proved to be analytically fruitful in teasing apart the characteristics that contribute to effective performance of the Cooperative State Research, Education, and Extension Service. The concept of boundary organization is particularly helpful at illuminating the relationship of science and policy in the context of

multi-level natural resource problems. In the context of water management in the High Plains, this study supports existing concepts of boundary organizations linking science to decision-making, but also reveals a novel understanding of institutionalized but adaptive structures that link scientists and decision-makers across multiple levels. Moreover, this study provides preliminary evidence for the causal connection between boundary organizations and effective production and use of scientific and technical information.

In this case, the boundary organization provides an institutionalized space in which long-term relationships can develop and evolve, two-way communication is fostered, tools for management (such as models) are developed and utilized, and the boundary of the issue itself is negotiated. As such, the boundary organization is dynamic and changing, responding to the changing interests of actors on either side of the boundary.

While this paper has begun to ask empirical questions which can begin to address how boundary organizations matter (if at all), clearly this area of research is ripe for further exploration. In addition to following the line of research in this paper of asking whether the existence of boundary organizations contributes to effectiveness, other challenging questions to pursue include: What characteristics of boundary organizations are most important under what circumstances? What kinds of problems are most amenable to being mediated by boundary organizations? Under what conditions are boundary organizations constructed?

FIGURE 1: Extent of High Plains aquifer in the central United States (in dark gray). (Map derived from U.S. Geologic Survey.)

FIGURE 2: Increase in irrigated acres in the High Plains region, 1949-1990. Derived from McGuire and Sharp (1997), U.S. Geologic Survey.

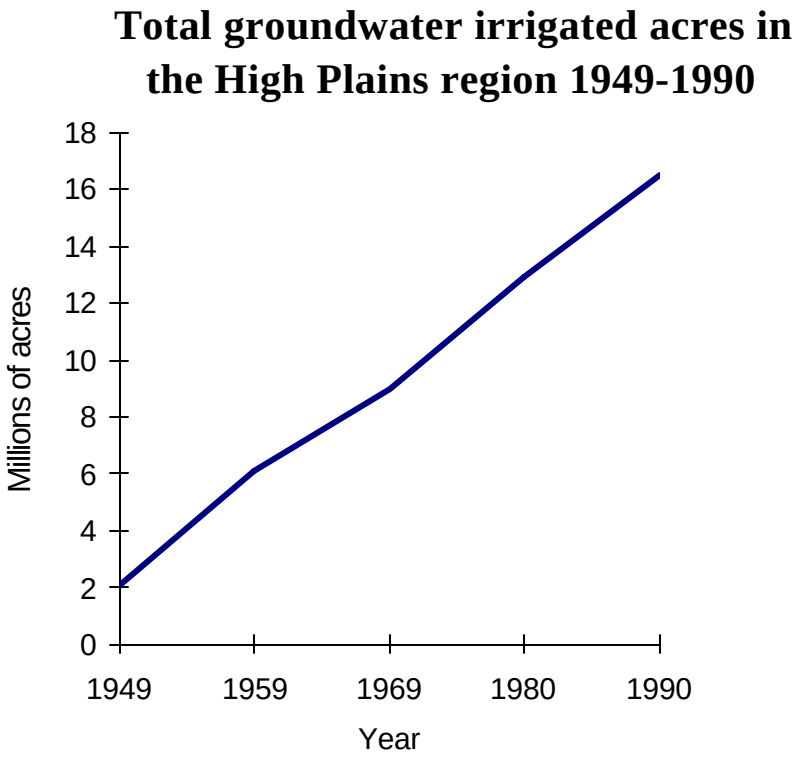


FIGURE 3: Study sites in Nebraska, Kansas, and Texas. (Map derived from U.S. Geologic Survey.)

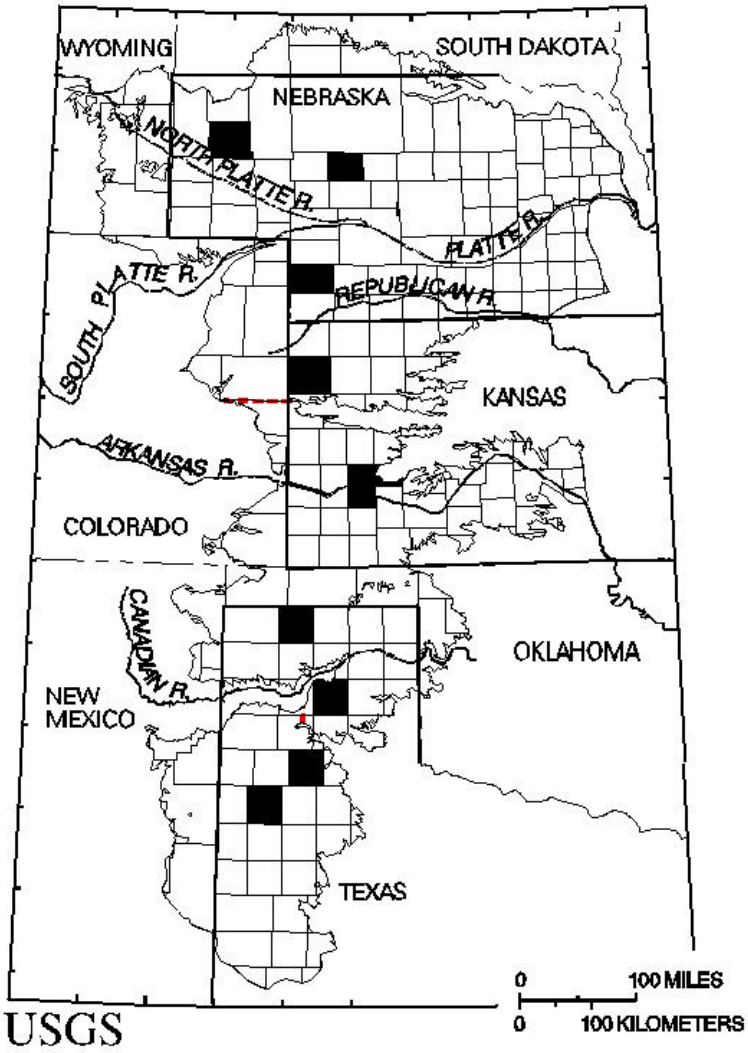


FIGURE 4: Plot of frequency of communication between county agents and other scientists and decision-makers at different levels. County agents communicate frequently from the local to state levels

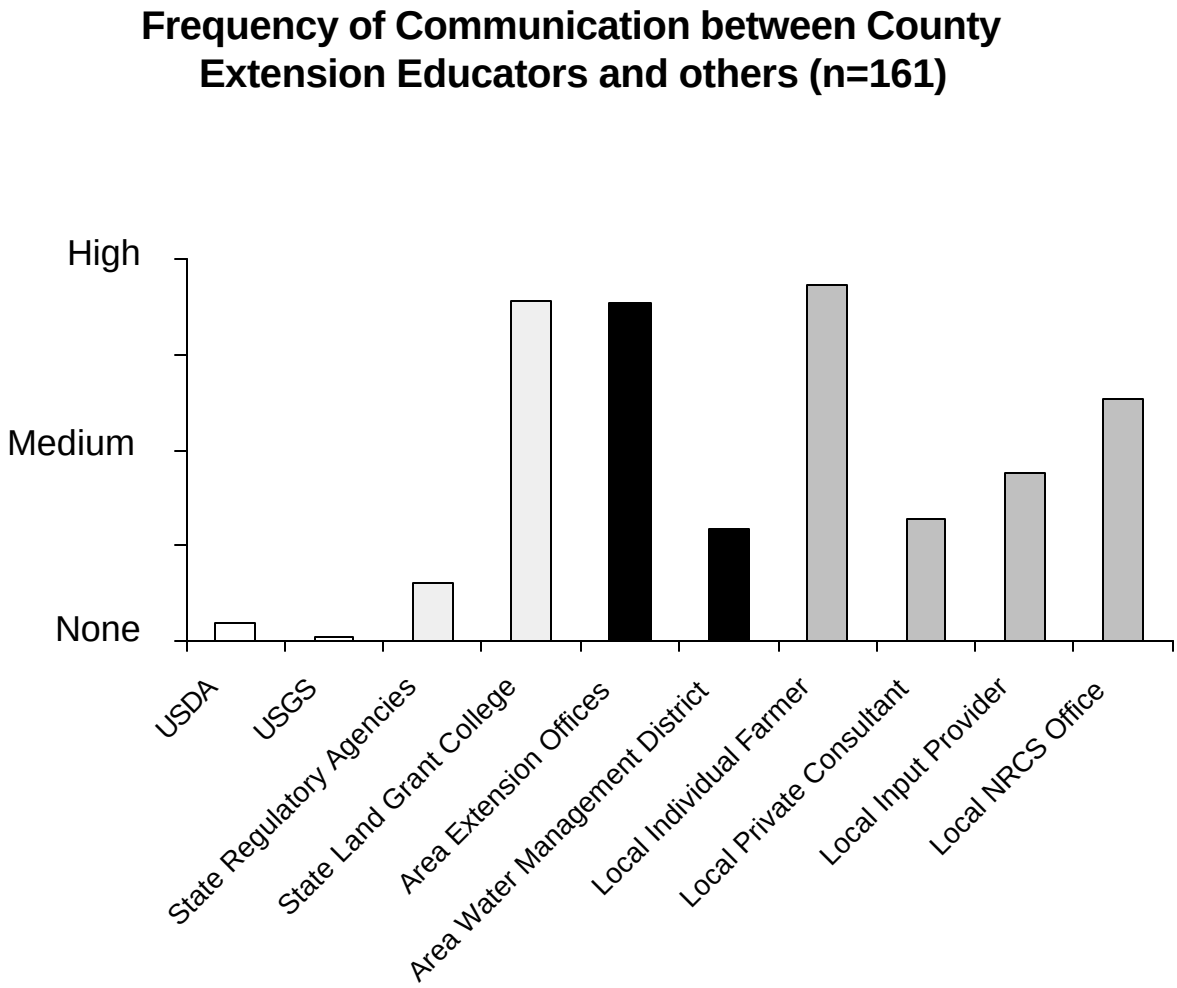
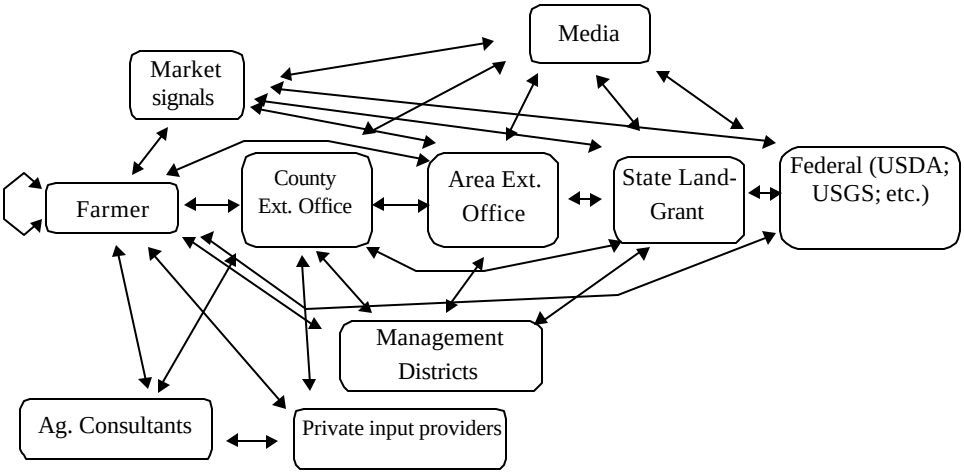


FIGURE 5: Network diagrams of possible nodes and connections for water management in the High Plains (Figure 5A), and revealed crucial nodes and connections (Figure 5B) showing the existence of multi-level linkages brokered by county and area extension offices.

5A:



5B:

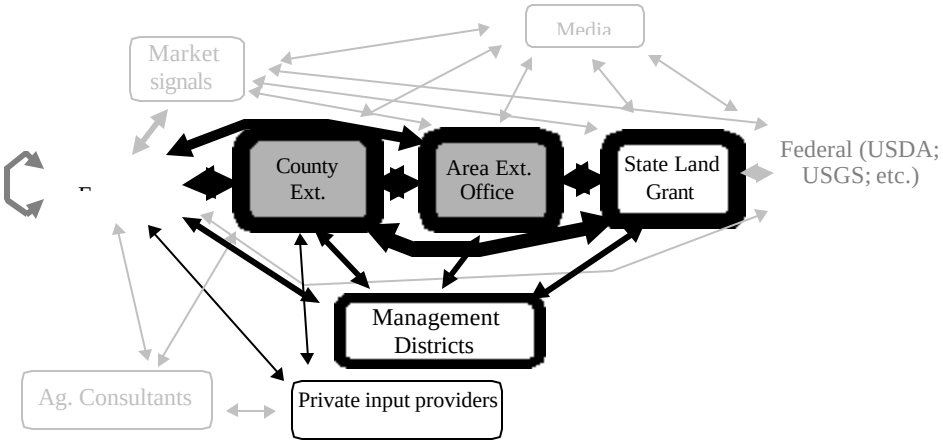
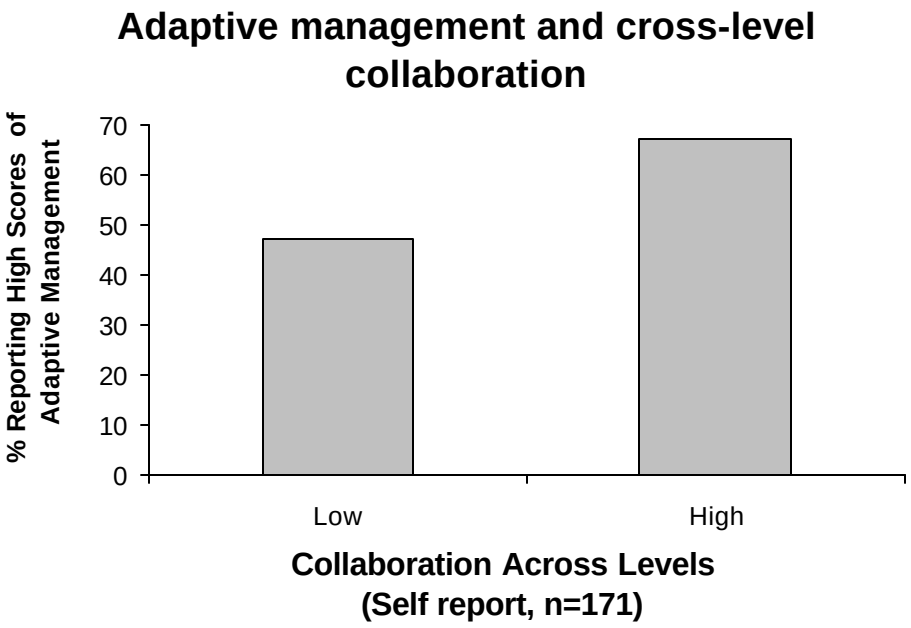


FIGURE 6: {Photo of Low Energy Precision Application irrigation system to be obtained through Texas Agricultural Research and Extension}

FIGURE 7: This graphs suggests an association between the amount of collaboration which crosses multiple levels and adaptive management – those counties with more cross-level collaboration tend to have a greater degree of adaptive management variables.



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