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Bridging Research and Environmental Regulatory Processes: The Role of Knowledge Brokers

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Abstract

Federal funding agencies increasingly require research investigators to ensure that federally-sponsored research demonstrates broader societal impact. Specifically, the National Institutes of Environmental Health Sciences (NIEHS) Superfund Research Program (SRP) requires research centers to include research translation and community engagement cores to achieve broader impacts, with special emphasis on improving environmental health policies through better scientific understanding. This paper draws on theoretical insights from the social sciences to show how incorporating knowledge brokers in research centers can facilitate translation of scientific expertise to influence regulatory processes and thus promote public health. Knowledge brokers connect academic researchers with decision-makers, to facilitate the translation of research findings into policies and programs. In this article, we describe the stages of the regulatory process and highlight the role of the knowledge broker and scientific expert at each stage. We illustrate the cooperation of knowledge brokers, scientific experts and policymakers using a case from the Brown University (Brown) SRP. We show how the Brown SRP incorporated knowledge brokers to engage scientific experts with regulatory officials around the emerging public health problem of vapor intrusion. In the Brown SRP, the knowledge broker brought regulatory officials into the research process, to help scientific experts understand the critical nature of this emerging public health threat, and helped scientific experts develop a research agenda that would inform the development of timely measures to protect public health. Our experience shows that knowledge brokers can enhance the impact of environmental research on public health by connecting policy decision-makers with scientific experts at critical points throughout the regulatory process.

Keywords

Regulations; Hazardous Waste Sites; Vapor Intrusion; Knowledge Brokers

INTRODUCTION

The National Institute of Environmental Health Sciences (NIEHS), like other funding agencies, requires that grantees demonstrate how their research will achieve “broad societal impacts.” Currently, NIEHS funds 18 multi-project, multi-disciplinary Superfund Research Program (SRP) centers that provide problem-based solutions through innovative approaches

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to improve risk assessment and management of hazardous waste sites. Unlike the United States Environmental Protection Agency's (USEPA's) task of assessing, listing, and cleaning up Superfund sites, NIEHS's Superfund Research Program provides research capacity to learn more about contaminants' health impacts, biological mechanisms, fate and transport, and potential remediation technologies. With a mandated collaboration of biomedical and non-biomedical research projects, each SRP focuses on a specific area of concern. While SRPs can interact with the USEPA around specific National Priority List ("Superfund") sites, this is not explicitly required, and generally SRPs are not site-specific in their research. Each center strives to make positive societal contributions not only through research projects, but also through research translation and community engagement activities. According to NIEHS, the objective of research translation is to communicate and facilitate the use of research findings emanating from the center in a manner most appropriate for the application and advancement of research objectives. This research translation involves sharing knowledge with multiple stakeholders, and is distinct from the commonly understood "translational research" conducted by Clinical and Translational Science Awards (CTSAs), which is more of a bench-to-bedside approach to clinical applications of basic research.[1] Community engagement enhances the multi-directional exchange of community-based knowledge and the science emanating from the center to support the needs of communities impacted by sites contaminated with hazardous substances. NIEHS encourages both the Research Translation Core (RTC) and Community Engagement Core (CEC) to form partnerships with government agencies and community groups to make knowledge sharing more efficient and their research more relevant. These broad definitions of research translation and community engagement allow each SRP grantee flexibility in tailoring approaches to make the scientific discoveries generated in their centers useful to their most suitable constituents. These constituents are typically seen as stakeholders, including health and environmental agencies at local, state and federal levels, professional groups such as environmental remediators and attorneys, and community-based organizations such as environmental justice groups. Yet because these definitions are so broad, there is some ambiguity about the best methods to integrate research translation and community engagement activities into center grants.

This paper demonstrates how RTC and CEC activities can be integrated with scientific projects and coordinated with one another to facilitate the timely translation of new scientific discoveries into policy and practice. Specifically, we illustrate how "knowledge brokers," or team members whose job it is to build bridges between academic researchers and key stakeholders, such as regulators, professionals, and legislators can play an important role in engaging scientific experts in the regulatory process. Knowledge brokers have long been used in a variety of settings to facilitate knowledge transfer among various scientific groups and public stakeholders.[2] Knowledge broker–like roles have also been shown to be important in establishing partnerships between communities and academic researchers.[3, 4] Further, the importance of knowledge-broker-like roles (e.g. opinion leaders) has been discussed in mass communications, especially in media-settings.[5]

Knowledge brokers serve as intermediaries and comfortably interact within and between the academic and regulatory realms. They need the ability to integrate contextual and scientific knowledge, and adapt quickly to new stakeholder relationships and needs. Additionally, they must be able to effectively communicate, engage and maintain long-term relationships with a variety of stakeholders. Knowledge brokers play an important role in every stage of the regulatory process in order to gauge when and what type of scientific expertise is warranted and which stakeholders could benefit from scientific discoveries.

To be effective, knowledge brokers must establish long-term, mutually beneficial partnerships, based on trust and mutual respect. Building these relationships takes time,

patience, regular personal interaction, mutual learning, and a collaborative agenda that addresses issues both parties have identified as important.[6] Scientific experts too infrequently nurture this type of relationship, because it is not always advantageous for them to do so and because they may be distracted by other priorities.[7] Regardless, research results can be used to inform decisions and priorities, assess problems, develop programs and policies, facilitate implementation, and measure outcomes.[8] For scientific knowledge to be usable, it must have adequacy, value, and legitimacy on a meaningful timescale.[9] However, scientific experts who are not trained to communicate directly with stakeholders such as residents and groups in contaminated communities, policymakers, health professionals, and industry representatives about their craft may feel uncomfortable doing so. As a result, scientific knowledge must often be synthesized and interpreted by a variety of intermediaries before it is applied.[10]

A knowledge broker is one such intermediary who considers the range of opportunities available for scientific experts to engage with during the regulatory political process. Because of the growing "scientization" of policy, community groups cannot always rely solely on moral suasion and political advocacy, but need to bolster their calls for regulatory action with scientific expertise, and hence scientists and engineers increasingly play a role in helping communities play a brokering role in environmental justice and other community-based contamination issues.[11] Further, the regulatory process at times unfolds in parallel with or is entwined with legislative initiatives or litigation, requiring scientific experts to serve as expert witnesses and provide scientific input for agencies.

We focus on the roles of the knowledge broker and the scientific expert within the regulatory process—especially insofar as they can facilitate discussion with regulatory officials as part of knowledge translation. We describe the stages of the regulatory process and highlight when interaction by the knowledge broker versus the scientific expert is most appropriate. Lastly, drawing on our experience with Brown University's SRP, we highlight research and knowledge brokering activities around vapor intrusion as an example, both because it has been a strength of our research projects, and because it is increasingly significant in environmental health. We focus on the interface between scientific experts and regulatory officials in knowledge translation as the key mechanism to facilitate research translation, to influence environmental health regulations, and to protect public health. Our methods for this paper are based on a self- reflective process by which the authors, as team members of the SRP, wrote down their experiences over the eight-year period to date, reviewed documents generated in the course of the SRP's work, and collectively discussed their findings with each other.

KNOWLEDGE BROKERS AND THE REGULATORY PROCESS

The dual and distinct roles for knowledge brokers and scientific experts are illustrated in Figure 1. Knowledge brokers serve as bridges for the multi-directional flow of information throughout all five stages of the regulatory process. However, their involvement is most significant (solid lines) during the policy formulation, decision-making and policy assessment stages. During each of these stages, the knowledge broker will likely be engaged in multi-directional communication with decision-makers and scientific experts. They will provide input to stakeholders about relevant scientific issues and will learn from stakeholders about agency progress on the issue. The exact nature of information seeking[12] and/or knowledge seeking[13] is complex and beyond the scope of this work; however, throughout the regulatory process there are clear and distinct opportunities for science to influence the process, and those opportunities are discussed subsequently.

Figure 1 depicts the five stages of the regulatory policy process, as described by Kropp and Wagner.[14] During the *agenda setting* stage an issue or problem is identified. Agenda setting is complicated and can be influenced by the media, and has been extensively researched,[15] perhaps most notably in context of presidential elections.[16] This is largely a political process and decision-makers do not commonly solicit scientific expertise directly from the experts themselves. However, scientific experts are at times engaged in this stage through their involvement with the legal community and advocacy groups. For example, scientific experts comfortable in the role of advocate can have substantial influence in the agenda-setting stage.[17] Similarly, advocacy groups with scientific expertise can also influence the process with their scientific knowledge. Once the issue has been identified as requiring regulatory action, *policy formulation* takes place. During this second stage, decision-makers seek information to increase their knowledge about this particular issue so that they can evaluate possible political responses before deciding on a particular policy. The influence of scientific expertise is especially significant during this stage. Here, scientific experts can provide a broad range of knowledge about a particular topic, although their task is made more difficult in explaining topics that are rapidly emerging or that are characterized by high uncertainty.[18]

New information is less frequently sought from experts during the next stage, *decision-making*; rather, decisions are made based on the knowledge previously gathered. Scientific experts may be asked to provide scientific support for the decision being selected, but scientific experts rarely (directly) influence the decision being made during this stage. However, experts can have considerable input, if they are engaged in a parallel litigation procedure. In this way, the scientific expert's knowledge is brokered within the legal system to influence the decision making stage. Once a policy decision has been made, *policy implementation* begins. During this stage, scientific experts lend science-based credibility to the regulations being developed to support or clarify policy decisions previously made. Once the regulations have been implemented, their intended and unintended consequences are evaluated during *policy assessment*. Here, scientific expertise can be instrumental in providing critical analyses.[14] While it is important that scientific experts are engaged during this stage, their input will become less significant as the process transitions and returns to agenda setting. As shown on Figure 1, the process continues forward and can serve as a feedback loop that informs and improves environmental policies.

It is important to note that the timeframe for each stage of this process is variable. For some issues, the *policy formulation* stage may last years, in other cases, only months. It is difficult for scientific experts to gauge when their input will be most useful and influential while they are also conducting research (which occurs on yet an entirely different timeframe). Because of these complexities, we have found that integrating a knowledge broker in RTC and CEC activities is key to managing relationships with government agencies. This ensures that scientific knowledge is most useful and that expertise evolves along with the real-world problems that regulatory officials confront in the field.

KNOWLEDGE BROKERS IN ACTION: BROWN'S SRP TACKLES VAPOR INTRUSION

Brown University's SRP focuses on complex environmental contaminants in Rhode Island with interdisciplinary perspectives related to environmental health risks. Rhode Island is a small and densely populated state with a proud industrial heritage that is unfortunately burdened by a toxic legacy. Over the past two centuries, mills and factories discharged contaminants into surface waterways, polluting the state's watersheds. The state has 12 sites on the United States Environmental Protection Agency's (USEPA's) National Priorities List and more than 300 active brownfields. The biomedical and engineering research projects

within Brown's SRP embrace the complexity of mixed exposures found at these sites and explore new technologies for characterizing hazards at and remediating these sites.

Brown's SRP established strong partnerships with the Rhode Island Department of Environmental Management (RIDEM) and Rhode Island Department of Health (RIDOH), including them as official SRP partners, i.e. they are written into the grant and part of the overall team. These agencies define many of the problems that Brown SRP researches; in turn, they are educated consumers of SRP research and key beneficiaries of our knowledge brokers' activities. Two individuals in state agency leadership positions, one each from RIDEM and RIDOH, are *key personnel* within the SRP serving as Co-Leaders (analogous to co-principal investigators) on the grant. These individuals have a broad view of their respective agency's activities and facilitate SRP access to appropriate personnel at these and other statewide organizations.

To facilitate interactions between Brown researchers and our state agency partners, Brown's SRP created the position of State Agency Liaison (SAL), who carries out the knowledge broker role. The SAL serves as the SRP's point of contact with the state agencies and is also responsible for establishing avenues of communication among academics, professional organizations and community groups. The SAL position was designed for an academic staff person with both doctoral-level training and experience in a regulatory setting. In order to have capacity to identify experts for consulting on diverse topics, the SAL knowledge broker is required to develop and maintain contact with scientific experts in varied specialties of interest to the SRP and its regulatory collaborators. These requirements ensure credibility with both academic researchers and regulatory/professional audiences, and competence in communicating with diverse audiences on either side of the science-policy interface. This familiarity with both the science and regulatory worlds also ensures that the knowledge broker is able to recognize knowledge gaps that arise in the field, and identify ways that researchers and regulatory officials could collaborate to bridge those gaps.

To enhance success of the overall project, Brown's SRP has consistently sought to engage high-ranking members of the academic and regulatory communities. While highly-positioned stakeholders within the university and at RIDEM and RIDOH have been able to commit resources to the SRP, they have many demands on their time, and academic researchers are at times not rewarded for the time-consuming work that goes into developing successful partnerships. The SAL is responsible for building and nurturing relationships among these important stakeholders.

The SAL has contact with a spectrum of stakeholders ranging from federal and regional agencies to local town officials. Over time, the SAL has developed relationships with individuals even beyond the formal partnerships at RIDEM and RIDOH, such as the USEPA Office of Solid Waste and Emergency Response (OSWER), USEPA Region 1, USEPA National Health and Environmental Effects Research Laboratory (NHEERL), Agency for Toxic Substances and Disease Registry (ATSDR), and various industry representatives and consultants. As the SAL's number of contacts has expanded, so has the sphere of SRP involvement in environment and environmental health-related issues in Rhode Island and beyond. The SAL has organized symposia for various professional audiences on technical topics such as manufactured gas plants, nanomaterial design and toxicology, epigenetics, and environmental health issues of concern in pediatric medicine. The SAL also engaged with state agency staff to build capacity in areas such as health impact assessments, and engaged with non-governmental groups, such as the RI Bar Association, the Metcalf Institute for Marine and Environmental Reporting, and real estate developers on issues related to contaminated land use. In addition, the SAL has facilitated stakeholder involvement to assist regulatory policy formulation and developed partnerships with

legislators and regulators to increase their awareness of SRP-related research. Brown's involvement in vapor intrusion research provides a unique vantage point for showing how the SAL facilitate communication between regulatory officials and scientific experts about an emerging public health issue.

Vapor Intrusion as a Research Topic

Shortly after Brown received initial funding for the SRP center, officials at RIDEM indicated vapor intrusion was an increasingly important problem at cleanup sites in Rhode Island. Because there was such a dearth of information about this environmental health problem, the SAL identified some activities that Brown's SRP could undertake to educate its state agency partners about this topic, while academic researchers began finding a way to integrate vapor intrusion as a topic in one of the Brown research projects. Figure 2 illustrates the vapor intrusion policy timeline and the role of the SAL.

Vapor intrusion involves the migration of volatile (and in some cases semi-volatile) organic compounds from contaminated soil and/or groundwater into indoor air spaces. The overall vapor intrusion process was first identified in association with radon in the 1970s. However, it wasn't until the early 1990s that vapor intrusion of organic chemicals gained wide regulatory attention.[19]

As shown on Figure 2, *agenda setting* (transitioning from policy assessment) for vapor intrusion on the national scale issue began in the early 1990s (and late 1980s) when the pathway was identified at several hazardous waste sites (e.g. Love Canal and later the "Redfield Site").[19] The agenda setting stage gained momentum and became intertwined with the policy assessment stage. Through regulatory documents issued by various offices,[*e.g.* 20] it became apparent that the vapor intrusion pathway was not being adequately addressed during hazardous waste investigations. For instance, in some cases non-potable groundwater clean-up standards had been derived to be protective of contaminant volatilization using occupational exposure limits based on equilibrium phase partitioning, but it was not clear if these standards were protective for residential settings (Figure 3).

Figure 3 is a simplistic representation of volatilization of groundwater contamination. In reality, advective and diffusive processes govern the transport of vapors into indoor air spaces from contamination sources, such as contaminated groundwater plumes. The indoor air concentration is not equal to the calculated value at the soil/water interface; however, it is not obvious that it would be sufficiently lower, such that vapor intrusion would not be a concern. This rationale, along with documented vapor intrusion at several hazardous waste sites, led to USEPA releasing the draft vapor intrusion guidance in 2002.[21]

From approximately 2002 until 2010, the vapor intrusion issue was situated within the policy formulation stage. USEPA and stage agencies actively solicited informal and formal input from experts about how best to address the vapor intrusion pathway. It became increasingly obvious that additional scientific evaluation was needed to better understand the vapor intrusion pathway.

For instance, interpretation of field data and the assessment of vapor intrusion risks are widely recognized as challenging because concentrations in neighboring structures can vary dramatically and inconsistencies between expected and measured results are commonly encountered.[22] The vapor intrusion issue is complicated by many factors and characterization of vapor intrusion risks is well-known to be challenging; however, instead of detailing the array of issues here, this paper discusses the process by which scientific experts and knowledge brokers (i.e. the SAL) engaged with decisions-makers around the topic of vapor intrusion.

Once RIDEM indicated vapor intrusion was an emerging topic of concern and requested input from the SRP, in late 2005, the SAL, acting as knowledge broker, began serving as the point of contact for RIDEM on vapor intrusion. The SAL established a Vapor Intrusion Working Group consisting of several Brown faculty and graduate students. The working group began studying characterization methods, knowledge gaps and modeling approaches for estimating health risks associated with vapor intrusion.

A few months later, in 2006, Brown submitted a research proposal for an ancillary project to NIEHS that focused on developing a vapor intrusion model. At first, a small-scale project was initiated, but later the research activities were expanded when Brown's SRP was awarded its renewal grant in 2009. As part of the renewal application, vapor intrusion was proposed as specific research topic within the SRP. Later, a supplemental project to conduct a field study was funded by NIEHS as part of the American Recovery and Reinvestment Act (ARRA). During all stages of Brown's SRPs activities (2005 until present), the SAL remained in regular contact with RIDEM, RIDOH, and USEPA on issues related to vapor intrusion. The SAL shared specific details of research findings, and the regulatory stakeholders provided feedback about current and emerging challenges for regulators and practitioners.

While Brown SRP's outreach and research translation activities did not meet formal qualifications of community-based participatory research, we were nonetheless motivated by some of those same principles in designing these programs. We were especially concerned about facilitating collaborative partnerships across sectors (academic-government-community) and helping those partners participate as equals in the identification of outreach projects and translational goals. We also found that the stated objectives of the research translation module were completely consonant with the expectations of CBPR to integrate knowledge and action for the benefit of all partners and to disseminate findings broadly.[23] Because we found this close correspondence between the design objectives of our research translation and outreach activities and the principles of CBPR, we considered several metrics of effectiveness from the CBPR literature[24] to qualitatively evaluate the efficacy of the SAL's role.

As an example of the SAL's effectiveness to engage and educate decision-makers, Brown's SRP collaborated with the Northeast Waste Management Officials Association (NEWMOA), whose membership includes state agencies throughout the northeast, to conduct two training events on vapor intrusion in 2007 and 2008. Over 100 regulators and practitioners from the New England area attended each of these training events. The SAL worked closely with NEWMOA and its membership to design workshops that were relevant and scientifically accurate.

Interactions with other stakeholders also took place on a regular basis. And, these interactions occasionally resulted in new opportunities for education. Brown SRP organized a workshop for the RI Bar Association on the topic of vapor intrusion for which approximately 200 attorneys attended. Subsequent training events on other topics relevant to Brown's SRP have also been conducted with the RI Bar Association. NEWMOA's and RI Bar Association's requests for additional trainings, as well as the large number of attendees at each event, provide evidence of the perceived value of the SAL in providing education and participation opportunities.

The SAL also had positive impacts on research directions and financial sustainability. As discussed previously, vapor intrusion research was not originally included in Brown's SRP. However, based on the perceived importance of this work by RIDEM and RIDOH, Brown's SRP proposed a formal research project during the SRP renewal. The project was funded

and is now included in the SRP. In addition, new research directions also resulted following the vapor intrusion training organized by the SAL and NEWMOA.

Specifically, during an SRP-sponsored training event, Massachusetts Department of Environmental Protection (MassDEP) approached the SAL to discuss challenges they were facing at a vapor intrusion site in the metro-Boston area. The SAL worked with other researchers at Brown and at Boston University's SRP to propose a field study at that site. The research was funded as a supplemental project by NIEHS (via ARRA). The field activities were initiated in 2010 and data analysis is ongoing. As part of the data-sharing plan for that research project, communication between the SAL, researchers, residences in the field study neighborhood and MassDEP takes place on a regular basis. The role of the SAL as knowledge broker has been critical in these communications. As an example, when results of the field study indicated a previously unrecognized background source of VOCs in indoor air, the SAL (along with researchers) communicated the findings and discussed possible implications for vapor intrusion regulations and guidance documents with MassDEP. Pennell et al. discuss the details of the field study and show that sewer gas acted as a source of tetrachlorethene for indoor air.[25]

In addition to the SAL's contributions to the financial sustainability of the SRP through receipt of supplemental funding, the SAL also contributed indirectly to the overall financial sustainability of Brown's SRP. The activities of the SAL add to the overall "richness" of Brown's SRP and repeated inclusion of the SAL position in SRP research proposals provides evidence that other SRP team members highly value the role of the SAL. In addition, student researchers also apparently value the role of the SAL. In 2011 when the former SAL stepped down, a recent PhD graduate who was trained within Brown's SRP successfully applied for and obtained the SAL position.

A final possible criterion to evaluate effectiveness is whether the SAL's role led to action. While conversations between the SAL and various federal and state agency staff indicate the results of the research have been taken under advisement and implications are being included in the forthcoming guidance, it is important to reference the regulatory political process timeline in Figure 2. The first research results from Brown's SRP on the topic of vapor intrusion were published in 2009 and continue.[e.g. 25–31] Around the time Brown's SRP began publishing on vapor intrusion, the regulatory policy timeline had transitioned to "decision-making," which does not provide significant opportunities for scientific experts to influence the regulatory process.[14]

In 2010, USEPA committed to finalizing the vapor intrusion guidance by November 2012;[32] however to date the finalized guidance has not been issued. With USEPA's 2010 announcement that the guidance would be finalized, multi-directional interest in vapor intrusion research slowed. Through continued attempts to collaborate and share research results, regulatory agency staff at both the state and federal levels indicated that they remain interested in research, but their focus is primarily, and appropriately, on finalizing (and then implementing) the guidance. However, just recently, NEWMOA requested that the SAL organize training on the topic of vapor intrusion because their constituencies are transitioning towards policy implementation. The training workshop is scheduled for September 2013 and 170 regulators and consultants are registered. Since the SAL (and now the scientific experts) has existing relationships with key decision-makers, we are able to ensure the timely and early communication of our research findings so that policymakers might have the benefit of the new information gained through the SRP projects. As the regulatory process evolves following the issuance of the final vapor intrusion guidance, Brown's SRP will continue to quickly engage with appropriate decision-makers regarding policy implementation and assessment activities.

A further regulatory success is the 2012 passage of the nation's first law to regulate school siting on contaminated land, with a prime focus on sites with vapor intrusion. The SRP's Community Engagement Core worked with partner organization Environmental Justice League of Rhode Island on this, as part of a broader coalition of local organizations. While the SAL did not focus on this legislation, the SAL's previous engagement with the DEM played an important role since the DEM had to provide expert testimony on that bill.[33]

Practical Considerations for Knowledge Brokering

Key qualifications for a knowledge broker include scientific or academic credentials (doctoral-level), as well as thorough understanding of political and practical environmental issues. Knowledge brokers exist on the periphery of two different worlds,[1] and therefore they should have credentials valued by both worlds. Further, knowledge brokers versed in some aspect of relevant science are likely, although not necessarily, well-qualified to develop connections between individuals who primarily investigate science, and those who apply it to regulatory policy. While it is likely that the knowledge broker is a scientific expert on a particular issue, the knowledge broker also develops and maintains contact with many scientific experts with deep, specific knowledge of different particular issues in order to readily identify which experts would be best suited to engage in a particular stage of the process at a particular time. The knowledge broker is responsible for recognizing knowledge gaps that arise in the field, and identifying opportunities for researchers and regulatory officials to work together productively to address those gaps.

While the knowledge broker and the scientific expert can exist as the same person, it may become inefficient, especially for tenure-track (or tenured) faculty to remain engaged in the political process throughout all five stages. In addition, it may become difficult for the individual to serve as a knowledge broker for a range of topics because of time limitations. For vapor intrusion research within Brown's SRP, the SAL served as both the knowledge broker and a scientific expert for several years (2005 – 2011). It was advantageous to exploit this dual role because building relationships and gaining credibility among stakeholders was enhanced by both the scientific knowledge and relationship building skills of the individual. The SAL identified many key scientific experts within the vapor intrusion community and also developed relationships with key regulatory and policy individuals leading vapor intrusion guidance efforts. This allowed Brown's SRP to expedite the development of scientific expertise in the area of vapor intrusion because the critical knowledge base for vapor intrusion was defined by knowledge brokering tasks. Ultimately the individual gained a broader research context, and established relationships with many other key scientific experts in the field.

However, balancing the knowledge broker and scientific expert roles can be challenging because as scientific expertise develops, the expectations on the expert in terms of research progress on that particular topic begins to compete with the important and time-consuming activities associated with her/his role as the knowledge broker. The knowledge broker moves from a peripheral position,[1] as shown on Figure 1, to a member of the scientific expert group. Unintentionally this may narrow the knowledge broker's focus, and the knowledge broker's effectiveness to engage with decision-makers on a *broad* range of topics will decrease. In this case, the individual may need to separate his/her role for the specific topic on which they are serving as both the scientific expert and the broker.

Additionally, when given a broad range of topics with which knowledge brokers must engage, the inclusion of multiple knowledge brokers may be necessary. Brown University's SRP, which initially began with a single knowledge broker in 2005, established a two-pronged knowledge broker system in 2011. The responsibilities of the two knowledge brokers are distinct, but complementary. One knowledge broker, the Engineering SAL,

maintains a strong relationship with RIDEM and is primarily involved with topics related to hazardous waste site clean-up and site characterization. The other knowledge broker, the Environmental Health SAL, maintains relationships with the RIDOH, and is primarily involved with environmental health issues and community engagement activities. The use of multiple SALs was motivated by the desire to have broader coverage of the full range of scientific questions of interest. Experts on characterization and remediation are not normally also experts on health aspects and risk, and it is too much to expect any one SAL to carry the full responsibility.

On issues of vapor intrusion, the division of labor between the two SALs is particularly appropriate. RIDEM is the agency that is primarily responsible for overseeing activities associated with vapor intrusion characterization and mitigations. RIDOH is engaged in vapor intrusion as it relates to radon, and when a community raises concerns about health risks at a particular site. The Environmental Health SAL can respond by engaging with appropriate scientific experts about health assessments, while the Engineering SAL can engage with appropriate scientific experts about vapor intrusion characterization and mitigation methods. The latter is the expertise that exists within Brown's SRP; however, it is not the only type of expertise that the knowledge brokers provide to the stakeholders. If expertise does not exist within the SRP, the knowledge broker would need to identify experts outside the organization to respond to the stakeholders' needs. For instance, the Environmental Health SAL is required to establish relationships with relevant environmental health experts (beyond the limits of Brown's SRP) on the issue of vapor intrusion. The knowledge brokers are both able to efficiently respond to the needs of various stakeholders by providing expertise from varying backgrounds. In addition, the knowledge brokers can share key information from the political process with the scientific experts, such that the process is bidirectional. Further, the knowledge brokers share information between each other to ensure they are both informed about the relevant political implications.

IMPLICATIONS

The contributions that Brown's SRP has made on the topic of vapor intrusion—both in basic research and in informing policy—are a direct outcome of the program's organizational structure and close partnerships with state agencies and community groups. Brown's SRP is committed to investigating environmental issues not only at the interfaces between different disciplines but also in response to requests from multiple stakeholders. This commitment has resulted in the production of cutting edge science that has broad impacts for diverse constituencies (e.g., academics, regulators, and community members), both locally and nationally. By mediating these relationships with scientific experts, regulatory officials, and communities, the SALs' roles as knowledge brokers, enables them to make the SRP's science uniquely responsive to local community needs. Brown's success with this structure indicates that a dedicated go-between person(s), i.e., a knowledge broker, is an essential element to research translation and community engagement. The highly visible commitment of resources to this research translation activity has shown the wisdom of this approach to our local partners at the state agencies and to our funders.

Formal assessments of the efficacy of knowledge brokers should consider the many ways knowledge brokers will interact with different constituents, and how these relationships will evolve over the life of a project. For the case study presented herein, the SAL (acting as a knowledge broker) effectively met the growing demand for information on vapor intrusion through multiple training events and workshops. Further, the SAL in connection with other researchers was able to establish a new research project to address unanswered questions by decision-makers. Through the timely provision of information to decision-makers and regulatory officials, the Brown SRP was able to have input into newly revised guidelines

that protect public health. When measuring the success of knowledge brokers in influencing science policy decisions, research funders and external reviewers need to be open to learning about program evaluation methods in multiple disciplines, including the social sciences.

Application of this knowledge broker model is a nontrivial and iterative process that is unique to each project and institution. Fostering and maintaining relationships with multiple stakeholders requires that significant resources (e.g., a full-time knowledge broker position(s)) be directed towards outreach and engagement. The regulatory process timeline (Figure 1) is complicated, and hence, gaining traction on a specific regulatory issue or project requires that a knowledge broker have accurate insight and foresight into stakeholders' unique agendas. Furthermore, it is important to note that not all ongoing scientific research projects will be of immediate concern/interest to stakeholders. Thus, successful outreach and engagement requires that knowledge brokers serve as patient, persistent, and creative multi-directional conduits of information.

Most knowledge brokers will face challenges that will likely include not fully understanding a particular subject. For example, even a highly educated knowledge broker may be well versed in one subject, but unfamiliar with another. In some cases, like that of the Brown SRP, it will make sense to divide the knowledge broker role into two closely linked, but distinct positions, based on background and stakeholders served. Another challenge faced is that of the apprehensive scientific expert. In other words, meaningfully engaging scientific experts can be difficult if those experts do not fully understand that their participation is vital to the knowledge broker model and that simply delegating outreach responsibilities does not necessarily result in a successful outcome.

The success of Brown's SAL model would not have been possible without adequate support from the NIEHS Superfund Research Program. Of course, not all institutions will have the funding or connections to support the SAL position or something similar. In such cases, researchers and institutions devoted to connecting research to regulatory processes will likely need to find others to serve as knowledge broker. For some projects, this individual might be the principal investigator, post-doctoral researcher, or graduate student for whom a certain agreed-upon segment of time has been designated as devoted to outreach. Physical and life scientists might also consider collaboration with social scientists (sociologists, economists, psychologists) for which research oftentimes involves outreach with various stakeholder groups. Lastly, investigators might consider working with public affairs and institutions' public relations staff who are regularly involved in transferring knowledge to and from a university or institution.

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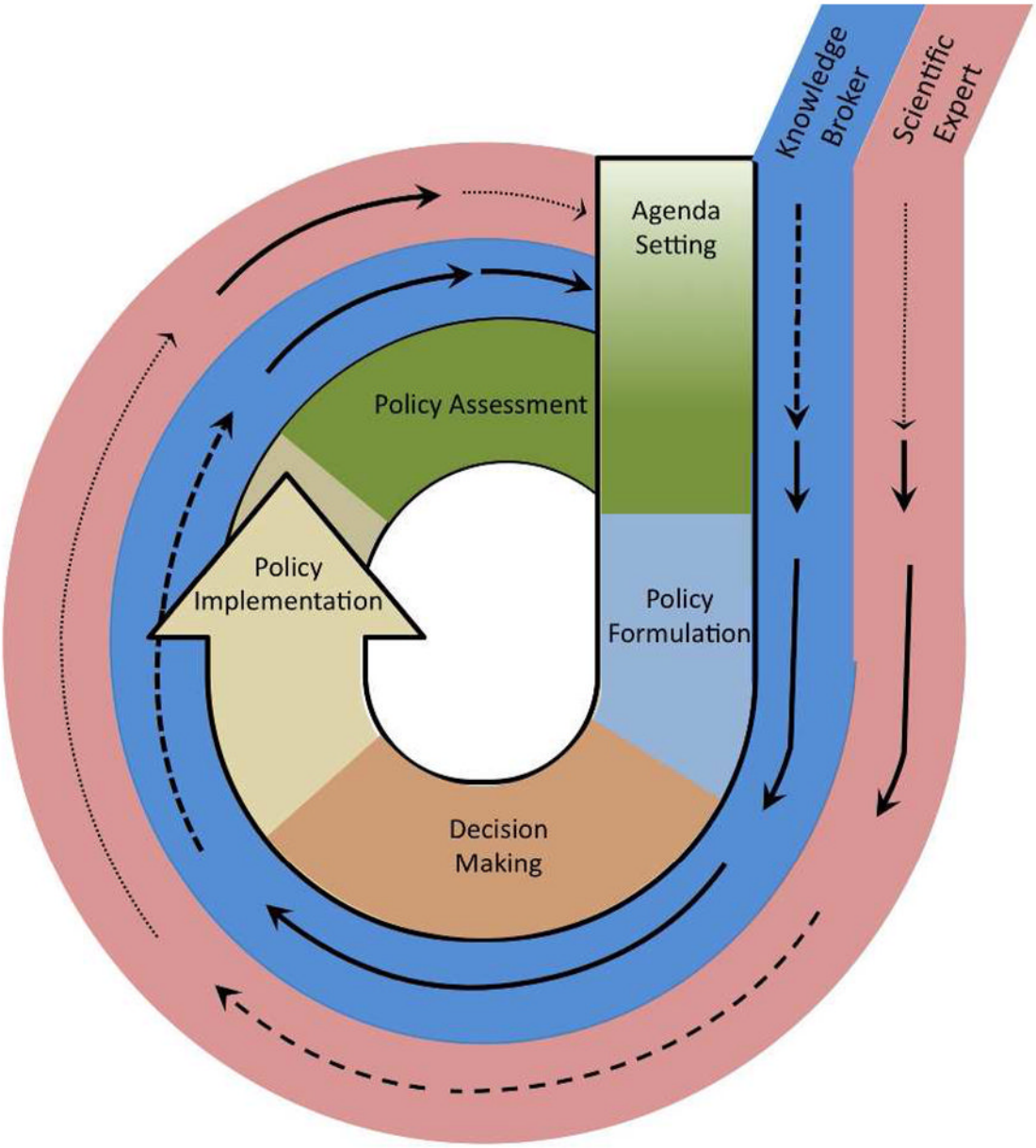

Figure 1. Regulatory Process: Types of Interaction for Knowledge Brokers and Scientific Experts

Notes: Solid lines indicate frequent interaction and a strong potential for multi-direction knowledge sharing. Dashed lines indicate periodic engagement with relevant policy stakeholders. Interactions will likely occur upon request of a policy stakeholder, but interactions should be periodically initiated by knowledge broker. Dotted lines indicate limited involvement with policy stakeholders. Interactions will likely occur upon the request of a policy stakeholder. Dashed lines indicate periodic engagement with relevant policy stakeholders.

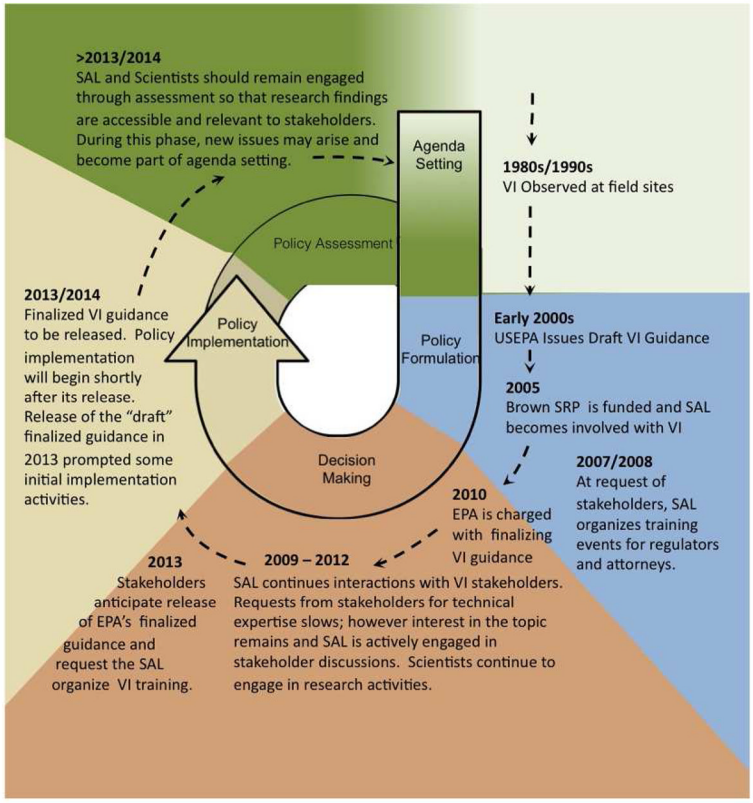

Figure 2.
Vapor Intrusion Timeline and Role of the SAL

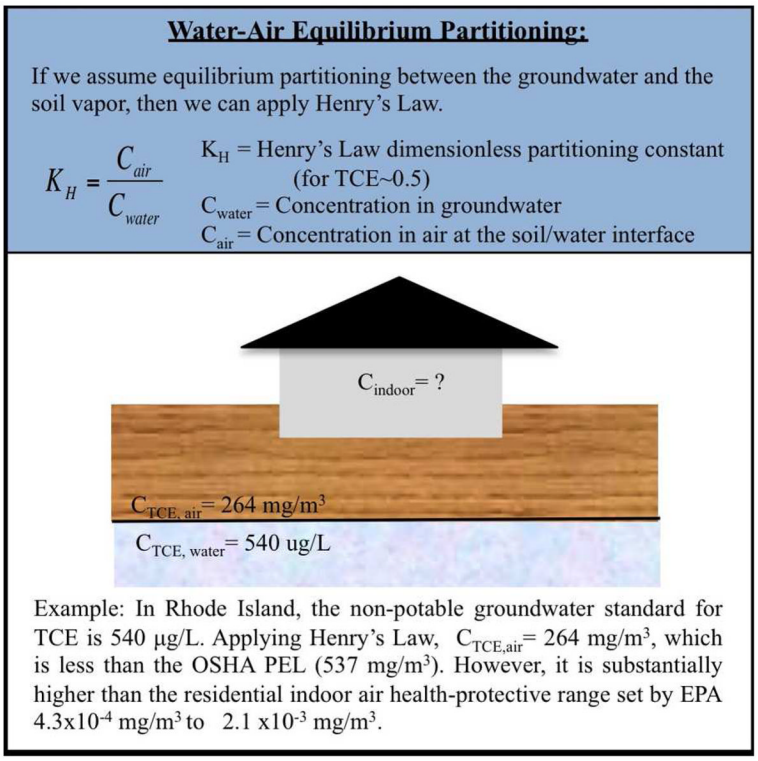

Figure 3. Groundwater Standards and Vapor Intrusion

Notes: Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL). Trichloroethylene (TCE).