Mitigating the Impacts of Reactive Nitrogen through Federal Scientific Research and Policy: The Application of a Science Knowledge-Agreement Framework

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Abstract

In the past 100 years humans have doubled, mainly due to agriculture, the amount of available nitrogen on Earth. Excess reactive nitrogen (Nr) in the environment is associated with many large-scale environmental concerns, including: toxic algae blooms, hypoxia, air pollution, drinking water contamination, and global warming. In an effort to mitigate the cascading effects of excess nitrogen in the environment, the EPA, USDA and other federal agencies have implemented programs to reduce the risks posed by excessive reactive nitrogen. The purpose of the Joint Agency Science and Management Action Plan on Nitrogen and Co-pollutants (SMAP) is to develop a collaborative research and management partnership between EPA, USDA, and USGS to promote sustainable management of reactive nitrogen and co-pollutants (e.g. phosphorus, sulfur). There are many hurdles to overcome in science driven policy development, and an important focus of SMAP is to understand what kinds of scientific research are required to provide policy makers the information they need to design effective policies. Typically, this question is not well addressed in scientific research, but is fundamental to translating scientific research to science-based policy. A component of this question is designing policies that capitalize on low-hanging fruit. To better evaluate what nitrogen policies might be low-hanging fruits for implementation, we explore a variety of science-policy options. Using a science-policy-agreement framework (DecisionScape), we assess the level of scientific understanding and political agreement surrounding individual policies by placing policies into unitary, contested, collaborative, or adversarial subsystems. Potential policy options analyzed with the science-policy framework (DecisionScape) range from outreach and technical assistance, water quality trading, regulatory nutrient management planning, and fertilizer tax incentives. Each policy has multiple scientific and technical tools which span low to high degrees of knowledge, with varying agreement in the federal scientific community for use in science-based policies decisions. This work is intended to help measure the level of scientific consensus, and provide a more systematic approach to understanding nitrogen policies that would be likely candidates for federal agencies to work on together.

1. Introduction to the Wicked Nitrogen Problem, a Knowledge-Agreement Framework, and Federal Nitrogen Research

Excess reactive nitrogen (Nr) compounds in the environment are associated with many large-scale environmental concerns, including eutrophication of surface waters, toxic algae blooms, hypoxia, air pollution, nitrogen deposition in forests, drinking water contamination, and global warming (Sutton et al. 2011, Davidson et al. 2012). The EPA, USDA and other federal and state agencies have implemented programs to reduce the risks posed by excessive Nr, but a more comprehensive and integrated approach is needed to manage the use of Nr in a way to achieve its benefits, such as fertilizer for food production, and mitigate its damages as it is introduced to and cycles repeatedly through the environment in different nitrogen forms and media.

The basic goals of the U.S. Environmental Protection Agency (EPA) and U.S. Department of Agriculture (USDA) include improving food production, protecting the environment and enhancing the quality of human life. For complex problems, the research mandates of these government agencies may be inadvertently at odds. In an effort to further build collaborative interagency efforts, we developed a means to map policy solutions based on agreement among agency policy mandates and a research database from three agencies (USDA, USGS, & EPA).

In the paper, we propose the modification and use of the science policy framework set forward by Stehr (2012) (See Figure 1), as a means of evaluating and developing policy solutions inside the policy subsystem of reactive nitrogen loss to the environment, emphasizing the degree of scientific/technical knowledge and political agreement. Our work takes place within the confined bounds of an interagency working group between the USDA, EPA, and USGS; called, the Joint Agency Science and Management Action Plan on Nitrogen and Co-pollutants (SMAP). Joint agency knowledge, in the form of an interagency database, provided levels of scientific understanding, and the overall agency mandates of the USDA and EPA served as a means of assessing agreement between agencies. It is hoped that the practical application of a framework addressing the nexus between science and policy will yield beneficial results in creating a map for future progress and achievements made by the interagency working group.

1.1 The Wicked Nitrogen Problem

In order to understand the relevance and placement of this work, a basic description of the reactive nitrogen loss is useful, as well as a basic understanding of the concept of complex social dilemmas such as wicked problems. The concept of the wicked problem formally laid out in Rittel and Webber (1973) has been used to describe a variety of environmental and social dilemmas. Rittel and Webber (1973) identify ten key factors that are characteristic of wicked problems. Whether real or legendary the term, *wicked problem*, has come to be used about several environmental and social dilemmas that are particularly convoluted. The socio-environmental problem of specific concern addressed here is that of reactive nitrogen (Nr) lost to the environment.

> "Reactive N is considered to be a wicked problem for a variety of reasons: there is no agreement between stakeholders on what the problem is; there is no defined solution or endpoint; the problem changes over time and there is high uncertainty in the measurement of nitrogen throughout the environment; and values and goals are not necessarily shared by all parties involved." (Cadmus 2014)

The problem of Nr can be couched as over population, malnutrition, environmental degradation, nutrient loading, unsafe drinking water, infertile soils, and greenhouse gas emissions (Smil 2002, Smil 1999, Galloway et al 2003). The disagreement about the problem stems from the location of the stakeholder, the time in which the stakeholder is in, and the values to which the stakeholder adheres (Doering, 2002). A particularly relevant instance of this is that of the upstream farmer and the downstream fisherman. We will assume for this example the farmer and fisherman have the same values in regards to protecting their own interests, protecting their profits, and reducing risks. A farmer in the Midwest applies fertilizer to grow a crop, and as a safety net against the frightening uncertainties of farming, such as: weather, pests, weeds, and volatile commodity markets—the farmer usually adds more fertilizer then needed. Some of the nitrogen the farmer applies to the field travels downstream through the Mississippi River and into the Gulf of Mexico. In this case the practices which the upstream farmer is using are negatively affecting the economic outlook of the fisherman whose fisheries are dwindling due to the growing hypoxic zone (lack of oxygen in the water) caused by excess algae blooms coming from the excess nitrogen fertilizer leached from the farmers field. Because there is no defined problem from stakeholders the endpoint goals can be different: 1) the endpoint goal of the fisherman may be no fertilizer nitrogen entering the fishery from upstream, and 2) the endpoint goal for the farmer may be to apply as much nitrogen as needed to ensure a good crop year after year.

The effect of any environmental policy put into play can have multiple effects that can vary depending on your location and timeframe. In examples from the European Union, it can be seen that it can take years for a positive environmental goal to come to fruition (Bechmann et al. 2008, Dodds et al. 2012). The technical and scientific uncertainty surrounding the issue of reactive nitrogen is tied up in time and space quite similarly to the issue of a competing problem formation. Because the physical processes related to Nr is quite dynamic in time and space it is problematic to generalize and model, or to move models between scales which lead to high uncertainties that lend themselves toward the status quo (Dodds et al. 2012). Because the whole human race is involved in the Nr issue, the goals and values are as varied as the human race's opinion on any one thing. Although Nr to the environment may not strictly be classified as a wicked problem, it is certainly a convoluted social and environmental dilemma, which for the sake of brevity we will refer to as a wicked problem.

1.2 A Knowledge-Agreement Framework

Wicked problems require a significant amount of technical knowledge about a variety of fields. The inherent physical, economic, and sociological complexities mean that 'scientific certainty' will not be easily achieved. Diverse stakeholder goals add difficulty to the process of public policy formation—making a high level of certainty desirable prior to the formation of policy solutions. These factors mean that interactions between scientific knowledge and policy formation surrounding a wicked problem will not be straightforward, but convoluted. The general theory regarding the relationship between science and policy has been debated over for many years. In 2012, Stehr discussed different ways in which science has been seen to influence policy, categorizing a number of environmental issues and policies into policy subsystems. In Stehr's paper, others make the claim of the linear model of science transfer to policy, but newer models of the relationship between science and society call for a different view, such as "Use Inspired Research" (Stokes, 1997), and "Actionable Research" (Palmer, 2012). Stehr's (2012) work focuses on policy subsystems (Weiss, 1979), and presented are 4 ideal types of policy subsystems: 1) Unitary, 2) Collaborative, 3) Contested, and 4) Adversarial (Weible 2008). Unitary Subsystems have agreement on core policy goals and high consensus on technical knowledge, while Collaborative Subsystem still have agreement on core policy goals and there is a lack of agreement on the degree of technical knowledge, alternatively a Contested Subsystem is one with disagreement on core policy goals but has consensus on the amount of technical knowledge, and Adversarial Subsystems would have disagreement on core policy goals and a lack of technical knowledge (Stehr 2012, Weible 2008, Weiss 1979). In Stehr's (2012) policy subsystem typology space (See Figure 1) there are two variables to determine the policy subsystem classification of environmental policies: 1) the degree of agreement on preferences regarding core policy goals, and 2) the level of technical knowledge. The complexities and uncertainties surrounding the amount of technical knowledge about Nr lost to the environment, and the diverse focus/agreement of stakeholders point toward the overall Nr problem as being a likely candidate for fitting into the Adversarial Subsystem described in Stehr's framework for understanding the science-policy-knowledge interface (See Figure 1). To reduce uncertainties about technical aspects of Nr research and to reduce siloing between USDA and EPA, a 2011 EPA Science Advisory Board report suggested that:

> "Successful Nr management will require changes in the way EPA interacts with other agencies. Coordinated federal programs could better address Nr concerns and help ensure clear responsibilities for monitoring, modeling, researching and managing Nr in the environment. Thus, the Committee recommends that EPA convene an inter-agency Nr management task force." (EPA SAB, 2011)

1.3 SMAP (Federal Nitrogen Research)

The Joint Agency Science and Management Action Plan on Nitrogen and Co-pollutants (SMAP) was formed with the express purpose "[of] develop[ing] a collaborative research and management partnership between EPA, USDA, and the U.S. Geological Survey (USGS), to promote sustainable management of Nr and co-pollutants (e.g., phosphorus, sediment, and sulfur)" (Cadmus 2014). The origin of the SMAP working group can be roughly traced back a report on Nr conducted by the EPA's Science Advisory Board (SAB). In the SAB report the EPA was encouraged to form a multi-agency working group with the purpose of collaborating on research and Nr management (SAB 2011). The SMAP working group consisted of four working groups focused on environmental monitoring, policy solutions, technical solutions, and database analysis and formation. The database analysis and formation group assembled research projects funded by the USDA and the EPA regarding Nr loss to the environment. The policy solutions group assembled potential policy solutions grouping them by the policy tool and actual existing policies being used (See Figure 2).

The SMAP group provided the initial boundaries inside which the DecisionScape framework would be tested. Because research gaps and Nr management plans are core goals of the SMAP group, it is hoped that this work will be exploratory in assessing and addressing wicked problems as well as providing a useful tool for synthesis inside the SMAP group. In addition to this the work done by the policy sub-working group and the data working group can be used as potential policies with which to frame the knowledge-agreement framework and the database assembled can serve effectively as a primary set of knowledge to query about the individual knowledge understandings of a group. Potential goal conflicts between the EPA and the USDA mandates can serve as a source for agreement or disagreement for populating the level of agreement metric. The EPA is mandated with ensuring a clean, healthy, and safe environment for the United States (Cadmus 2014). The USDA is mandated with the protection of U.S. Agriculture and the insurance of a safe economical food supply (Cadmus 2014). Although, these goals are not by definition competitive in the realities of the biophysical world, they may often be found at odds. Even though the mandates of the two agencies potentially conflict, the obvious desire for collaboration can be seen through the formation of the SMAP group.

In this paper, we explore how the SMAP group can work to hone their expert-based knowledge and information to find fruitful places in federal nutrient research and policies that are amicable between USDA and EPA agency mandates and cultures. Our means of doing this is by entering different scenarios into the knowledge-agreement framework (DecisionScape) with the goals of: 1) providing a useful framework for agency collaboration through policy scenarios, and 2) exploring the benefits of reducing wicked problems into 'bite-sized' policy solutions in order to further analyze the problem and move towards meaningful synthesis.

2. Methodology: Fitting the SMAP to DecisionScape

In order to accurately place policy scenarios in the knowledge-agreement framework, methods for developing metrics for the level of scientific/technical knowledge and level of agreement had to be developed. In order to determine an agency's stance on a particular policy, the level of agreement for a policy scenario was evaluated based on a set of simple questions. The first question from both the EPA and the USDA, in the context of the SMAP working group, was: Does this policy adequately protect the people in the environment from negative economic, health, or aesthetic damage? The second question was: what are the impacts of this policy on agriculture and food production? To answer this the suggested policy solution was broken down into the policy tools being used and the related technologies attached to the specific policy. This lead into asking sub-questions: 1) Is the policy tool being used effectively implementing the attached technologies? 2) Are the attached technologies appropriate a meaningful reduction of Nr loss to the environment? 3) Do the technologies being used negatively impact the productivity of U.S. Agriculture? 4) Do the policy tools involved negatively impact the productivity of U.S. Agriculture? Based on the answers to these questions the USDA and the EPA were scored as fully supporting (=1) or fully opposing (=0) a policy solution. The difference between the USDA and EPA's level of support/opposition were used to characterize the level of agreement, which means if the EPA and the USDA fully agree, a policy solution will be rated as 0, and if the USDA and EPA fully disagree, a policy will be rated as 1. A case in which questions 1 & 2 have a positive answer, the EPA will be supportive of a policy. If questions 3 & 4 are answered positively then the USDA will be supportive of a policy. If both the USDA and EPA oppose a policy solution there will be a high level of disagreement. In this manner individual policy solutions were marked for agreement or disagreement between the USDA and the EPA.

To determine the scientific knowledge aspect of a particular policy, and the associated technologies, a database assembled by SMAP was used. This database consists of as much relevant research projects from the USDA, USGS, and EPA as have been assembled—to date there are over 20,000 projects in this database (See Figure 2 for a Topic Model view of this database). Queries for this database are then developed from the policies described in the SMAP policy tools table (See Figure 3). The query results are then used to determine the amount of technical knowledge available surrounding a particular policy solution. In this way the data efforts of two separate working groups in the SMAP working group are synthesized and combined in a visual means to facilitate the understanding of so called golden zones where policy progress may be made.

Four trials were made of specific policies suggested by the SMAP working groups. The first these trials was the regulatory implementation of nutrient management planning with the real-world example of Maryland Nutrient Management Law, the second trail was voluntary education and extension programs, the third was on water quality trading credits, and the fourth was incentivized technology upgrades for farmers embodied in the Virginia Fertilizer Tax Law.

3. DecisionScape: Policy Solution Case Studies

3.1. Mandatory Nutrient Management Planning: The Maryland Nutrient Management Law

The policy here will be modeled after the Maryland Nutrient Management Law. The Maryland Nutrient Management Law is a mandatory policy tool requiring that commercial fertilizers and manure be applied as a part of a nutrient management plan. The nutrient management plans were developed considering: 1) available N and P in the soil, 2) available N and P in the fertilizer, 3) crop nutrient requirements (based on the fields previous yields), 4) soil erodibility and nutrient retention capacity, 5) the best scientific data from the Department of Agriculture, 6) existing BMPs, and 7) flexibility for conditions beyond the ability of the farmer (Maryland 2002). This law requires that if you are applying fertilizer you be a nutrient management specialist. In summary this policy is regulatory, but and specific as to the application of nutrient planning as a specific technology. However, under the realm of nutrient planning there maybe a fair bit of variation, and many technologies may be used. In answer to question 1 this policy is regulatory and depending on the effort given to enforcement all farmers in Maryland will adopt the technologies. In answer to question 2: the range of technologies is broad being incorporated under the title of ‘nutrient planning’, however because this is attached to a detailed handbook laid out by UMD and focuses on not over applying for specific crops in specific areas it is likely that the technologies used will lead to reductions in nutrient loss.

Because the policy tool being used here is regulatory it has a higher likely hood to be successful which would lead to a high level of support from the EPA (EPA assigned 1.00 level of support) (See Figure 4). The law does add an additional burden to growers through increasing either the time required to authorize the application of nutrients or through mandatory hiring of a nutrient planner, which could lead the USDA to be wary of the law. The support level assigned for the USDA was 0.5. The overall level of agreement would therefore be 0.5. In order to position this policy on the knowledge axis, keywords associated with testing for available nutrients, crop nutrient requirements or yield potential, nutrient retention capacity, and best management practices were included as pertinent key words. In addition, terms relating to soil type and texture were added in. 21 related topics were found ranging from 68-671 occurrences. The average was 206 occurrences, which served as the rating on the knowledge index.

3.2. Water Quality Trading: The Nitrogen Credit Exchange Program

Water quality trading is an innovative way to reduce the amount of a pollutant being emitted into a watershed to meet water quality goals. Water quality trading allows those participating in the program to mediate high pollution costs by buying environmentally comparable reduction credits from a central water quality authority. To examine the policy of water quality trading, the example of the Long Island Sound Nitrogen Program will be used. The portion of Long Island Sound that is in Connecticut includes 79 public wastewater treatment plants (EPA, 2009). Wastewater treatment plants can contribute a large amount of nitrogen from human waste to urban watersheds. In this case, the wastewater treatment plants in the Long Island Sound watershed were contributing enough excess nitrogen in effluent discharge to cause hypoxia (very low levels of dissolved oxygen) in the Sound waters during the summer. Excess nitrogen in water can stimulate algae blooms, when the algae decays, this process leads to depleted oxygen levels and causes fish kills and harm to other aquatic organisms (Davidson et al. 2012). In 2001, the Connecticut Department of Energy and Environmental Protection (CDEEP) and the New York Department of Environmental Conservation, along with the EPA completed plans for a regulation to limit nitrogen coming from human activities in the Long Island Sound watershed (CDEEP 2005). The overarching goal of the water quality trading program in the Long Island Sound was to reduce the amount of nitrogen discharged from urban and rural activity by 58.5 percent from 2002 to 2014 (EPA, 2009).

To determine the amount of nitrogen reduction needed and the extend of hypoxia in the Long Island Sound, a three-dimensional, time-variable model was developed based on long-term monitoring that started in 1988 (EPA, 2009). This water quality model was used to help determine the amount of nitrogen reduction that needed to be reached in the water quality criteria outlined in a Total Daily Maximum Load (TMDL) regulation for the Long

Island Sound (Stacey and Tedesco 2004). 12 localize management zones were created within the Connecticut and New York portions of the watershed. To reduce the amount of nitrogen being loaded into the Long Island Sound by 58.5 percent, the State of Connecticut determined that 10 percent of the reduction would come from urban and agricultural non-point sources, and 65 percent would come from public wastewater treatment plants for a combined 58.8 percent reduction (CDEEP 2014). To regulate and incentivize compliance with the Nitrogen Exchange Program, each wastewater treatment plant is required to monitor water flow and total nitrogen concentrations of the effluent being discharged on a weekly or bimonthly basis, which is reported each month to the state of Connecticut. Each wastewater treatment plant is subjected to annual inspections, and if a plant exceeds the amount of nitrogen discharge allotted to them they must purchase Nitrogen Exchange Program credits. If a wastewater treatment plants annual discharge of nitrogen is lower then allowed they are awarded program trading credits which they will receive money for at the end of each year.

Accomplishments of the Nitrogen Exchange Program have been: 1) a cost savings of $300-400 million through implementation of the TMDL, 2) 53 wastewater treatment plants have received infrastructure upgrades to further remove more nitrogen before effluent is discharged into waterways, 3) Complete compliance with the TMDL was meet in 2013, and 4) the Long Island Sound Hypoxic zone has been reduced from ~200 sq. miles to ~150 sq. miles. Overall, the water quality trading program has been successful. Next steps for the trading program are to continue to maintain TMDL compliance. In 2014, the Nitrogen Exchange Program meet the 65 percent nitrogen reduction goal set in 2002 (CDEEP, 2014). Due to the success of the program the projections for 2018 show the state of Connecticut to pay over $5 million in subsidies to wastewater treatment plants for positive trading credits. Because of this result the Nitrogen Credit Advisory Board voted to move the trading program to a self-sustaining model (CDEEP, 2014).

What are some solutions gleaned from the water quality trading program? The success of this program, and the example it leaves is mainly applicable to point-sources of nitrogen pollution, such as other wastewater treatment plants and industrial effluent in the U.S. There are many watersheds in the U.S. where this policy could be implemented to reduce a lot of nutrient pollution from entering waterways (streams and rivers, and lakes, to the ocean). There is a relatively high degree of technical knowledge about water quality trading, but we would find there to be some opposition on the policy between USDA and EPA (See Figure 4). The EPA has played in instrumental role in developing water quality trading programs, and given that they are a mandatory regulation there would be some reluctancy from the USDA to co-develop any trading program that would require farmers, growers, and others involved in the agricultural sector.

3.3. Public Outreach and Technical Assistance Policy

The USDA and EPA have invested a lot of resources into research pertaining to nitrogen and other nutrients in the environment. With combined agency efforts of over 20,000 research projects on the subject, there exists a wealth of federal and academic knowledge on nitrogen and co-pollutants (Cadmus, 2014). In order to further communicate the importance of reducing nitrogen and co-pollutants in the environment there will need to be collaboration between USDA and EPA on how to better distribute and publicize the knowledge that has been assimilated. Here, we look at a couple of current examples and models of how agency knowledge has been spread to the general public and to specific groups, chiefly the American farmer and grower.

USDA Extension has played a central part in research, synthesis of research, and education dissemination in U.S. agriculture for over 100 years (USDA-NIFA, 2014). Extension has been the face of agricultural research at the national, state, and local level. For many years USDA Extension offices across the U.S. have been where most farmers received much of their farming information. Much of the physical presence of USDA Extension has changed, and there has been a shift to e-Extension. The extension.org web page has become a good source of information for farmers. The e-Extension service is a place where farmers or anyone from the general public can ask questions they have about agriculture, it provides access to weekly webinars, and a wide range of resources; from information about community planning to marine aquaculture.

Looking at the extension.org web page through the lens of nutrient education, there is a lack of information on the topic. Currently, there is information about animal manure management, where there could be a lot more on nutrient reduction and management education. Other examples of voluntary educational programs include an EPA Education and Outreach program on Stormwater Impacts (www.water.epa.gov/polwaste/npdes/stormwater), EPA's information about climate change (www.epa.gov/climatechange), a USDA radio station, and the USDA's Conservation Technical Assistance program – which provides farmers with information and training to plan and develop grower practices.

A potential goal for USDA and EPA could be to co-develop effective ways to teach people about the environmental issues of excess nutrients, and how people can reduce nutrient losses from human activities. Collaborative outreach, extension, and technical assistance has a high degree of consensus about the technical knowledge; what is needed is a way to agree on how to transfer that knowledge, in other words, there may or may not be agreement on the goals of multiagency education programs. Depending on what is incorporated into the educational material this policy could fit into a Unitary or Contested

Subsystem, where there is a high degree of agreement about the knowledge being disseminated, and there could be agreement or disagreement about the core policy goals (See Figure 4). Agency mandates and institutional cultures differ between USDA and EPA. The USDA is a voluntary agency that provides assistance to farmers, food for the U.S., and an economic basis for the country. The EPA is a regulatory agency with an emphasis on the monitoring and wellbeing of the environment. The differences in agency cultures do not exclude the two agencies from working with each other, there are many instances of collaboration, but it may prove to be a hurdle to the co-development of nutrient education programs. A co-developed nitrogen communication strategy maybe a strong start to further outreach by the EPA and USDA on the growing issue of reactive nitrogen in the environment.

3.4. Tax Incentives: The Virginia Fertilizer Tax Credit

The Virginia Tax credit (Code 58.1-337) is for the purchase of specific pieces of more precise fertilizer or chemical application equipment along with the implementation of a nutrient management plan (Virginia 1996). The equipment that is to be supported is spelled out in specific categories and to be verified by the Virginia Soil and Water Conservation Board. The categories of technologies can be roughly classified under the 4Rs of nutrient management right time (starter fertilizers), right rate (Sprayers, Computer Regulators, and Height adjustable booms), right place (Monitors), and right type (liquid fertilizer applicators). This form of legislation incentivizes increased technology purchases and nutrient planning, but is still essentially voluntary in nature. Answer to question 1: Due to the incentives the technologies associated with this policy are more likely to be adopted than simply information sharing. In Answer to question 2: The associated technologies could broadly be described as precision agriculture which has potential to mitigate nutrient loss, but is not the strongest set of technologies provided for reducing nutrient loss. Because the answers to questions 1 & 2 are not strong the EPA would likely want to caveat them with the need for more being done at a later date the overall EPA support for this policy would be rated at 0.75. The answers to questions 3&4 would both be strongly affirmative as this policy actively supports increased sophistication of agriculture through tax breaks making the USDA's support for this policy solution 1.00. The level of disagreement between the USDA and the EPA would be 0.25 meaning that when put into the DecisionScape it would fit into either the Unitary or the Collaborative subsystem depending on the level of knowledge surrounding the technologies (See Figure 4). The technologies encouraged and listed in the laws associated with this are roughly focused on precision agriculture. Terms such as site specific, geographic information system, yield monitor, and prescription maps were used as key terms. Results from the topics list showed a total of 9 related terms ranging from 77-211 occurrences with an average of 137 occurrences.

4. Evaluation, Conclusions, and Uses:

The use of a science-policy agreement scape such as DecisionScape could prove useful as a map for forward progress in assessing different policy solutions. Policy solutions landing in the lower left corner of the knowledge agreement framework are in an ideal space for more research funding, or at a minimum as an interest for the agencies to look into funding reviews or pushing forward with the assembly of specialist panels. Policies landing in the upper left are prime for implementation and should continue business as usual in progressing toward becoming co-agency developed programs. The left side of the framework is the zone in which there can be immediate action, which might yield positive progress as the USDA and EPA align with both agency mandates. Policy solutions landing in the right hand side of the typology should not be seen as unapproachable, but rather longer-term political solutions requiring more political care and delicacy than policies on the left side of the framework. Those policies in the upper right of DecisionScape would require a lot of co-agency discussion and resolution of opposing views, but could still be potential areas of policy development if the right factors come together. Policies that fall in the bottom right of DecisionScape will require additional agency research given that there is a low amount of scientific/technical knowledge on the subject, and is a policy that would need supplementary co-agency agreement. Policies that are located in the lower right would need a lot of development before they would move toward the upper left or even the lower left of DecisionScape.

Ample opportunities exist for the further development and refinement of this tool. Foremost being the fine-tuning of rating the knowledge and agreement metrics. The accuracy of the agreement metric could be increased through surveys of agency personal or surveys from the respective agencies or comments by agency leaders rather than a generalized comparison of mandates. A survey-based method would take into consideration the diversity of the cultures of both agencies and may change where different policy solutions are located in DecisionScape.

By drawing on the potential disagreement in a system and estimating the amount of scientific knowledge that has been gathered about a particular policy solution and the attached technologies—this work demonstrates a practical sense in which the gap between policy and science can be bridged at an interagency level. It is our sincere hope that this framework will aid in the joint venture of the SMAP working group, effectively tying existing knowledge to future policy solutions.

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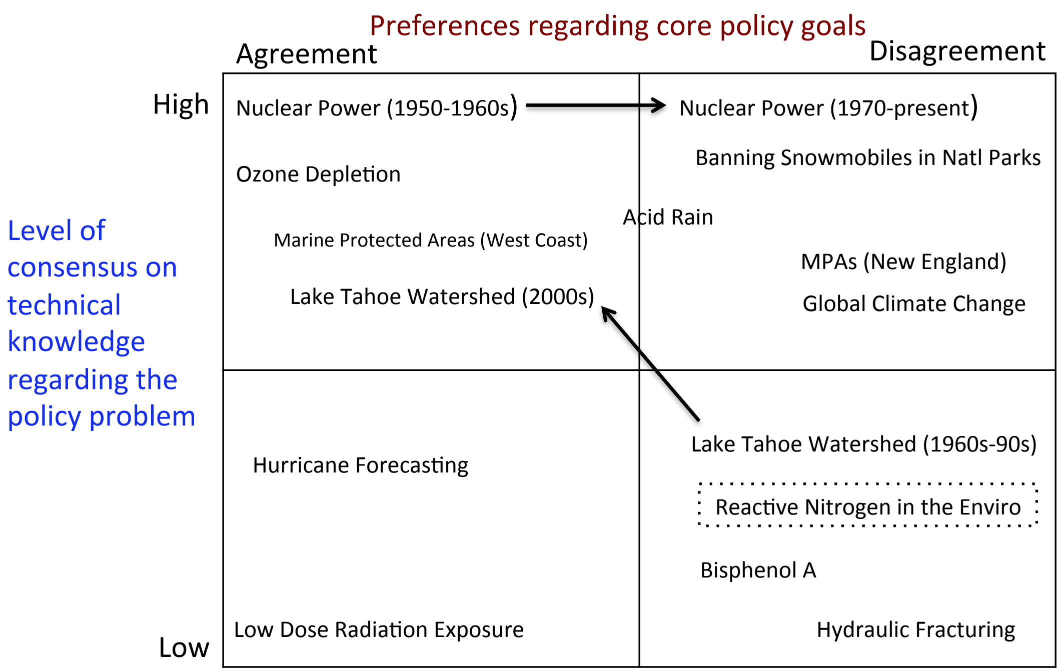
Figure 1:

Types of Policy Subsystems: Applications to Selected Environmental Policy Areas

❖ Toward understanding how scientific knowledge influences the policymaking process



(Adapted from Stehr, 2012)

Figure 2:

Topic Model (themes of research) of the SMAP database from over 20,000 research projects on nitrogen and phosphorus

EPA, USGS, and USDA Nutrient Research Topic Model

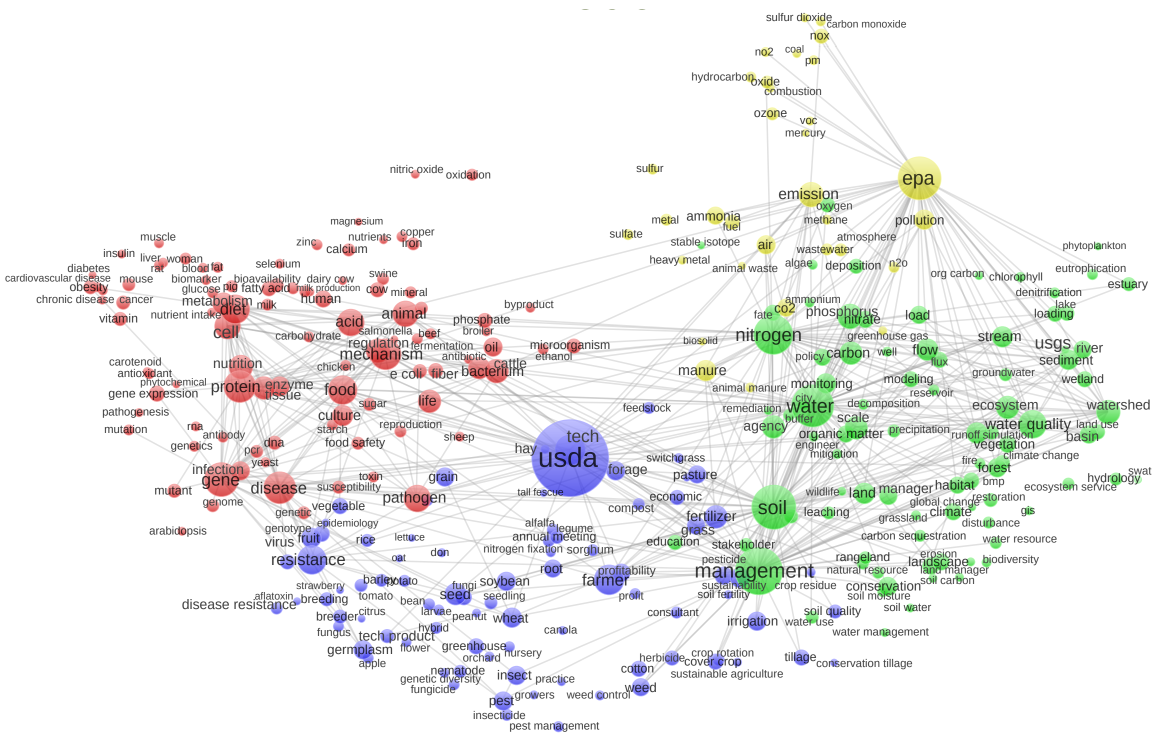
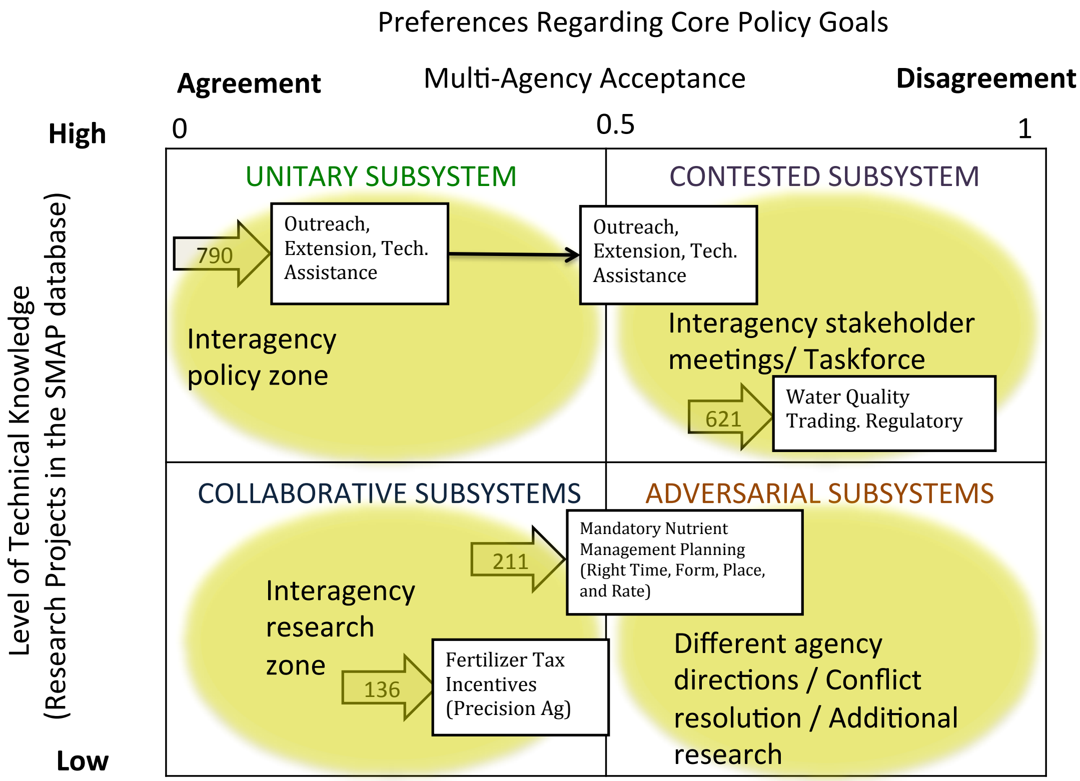


Figure 3:

A survey of public policy tools for addressing environmental effects of agriculture (Cadmus, 2014)			
Policy tool	**Participation**	**Description**	**Selected U.S. programs**
Educational/ Technical Assistance/outreach	Voluntary	Provide farmers with information and training to plan and implement practices Seek out farmers for participation	Conservation Technical Assistance Cooperative Extension Program
Long-term contracts (easements)	Voluntary	Payments for retiring land from crop production from 10 years to permanent easements. Use of auctions enhances efficiency.	Conservation Reserve Program—General Signup Agricultural Conservation Easement Program
		Payments for partial-field practices, e.g., grass waterways, filter strips	Conservation Reserve Program—Continuous Signup
Financial assistance on working lands	Voluntary	Payments to offset the cost of adopting nutrient management (cost-shares) or to purchase emissions reductions (pay for performance). Use of auctions enhances efficiency.	Environmental Quality Incentives Program; Conservation Stewardship Program Nonpoint Source Control Program
		Loans	State Revolving Loan Fund REAP
Taxes	Involuntary, but payment/credit amount depends on behavior	Implement tax on polluting inputs or on emissions Raise money for programs Tax credit/rebate for	None at the Federal level Fertilizer taxes at state level

		conservation equipment purchases environmental goal	Virginia Tax credit/rebate for meeting Florida
Compliance Mechanisms	Involuntary, after opt-in to Farm Programs	Sets standards for environmental performance and determines whether requirements are met before releasing payments. One approach for addressing perverse incentives from commodity programs	Highly Erodible Land Conservation (Conservation Compliance and Sodbuster) Wetlands Conservation (Swampbuster) Sodsaver
Regulatory Requirements	Involuntary	Permit limits on emissions (also known as performance standards)	Clean Water Act – NPDES Clean Air Act
		Practice requirements	MD nutrient management laws NE groundwater law
Trading	Voluntary, but driven by regulatory cap	Polluters allowed to trade allowances to meet permits and reduce costs	Clean Air Act Clean Water Act
Certification	Voluntary	Requirements to meet certification standard	Certified Crop Adviser Program LA Master Farmers Program MI Agriculture Environmental Assurance Program
Labels	Voluntary	Producers who adopt environmental practices can distinguish their products and receive a higher price or participate in a market	Organic program
Performance contracts	Voluntary	Conditions placed on suppliers by purchasers – private sector	

Figure 4:


Preferences Regarding Core Policy Goals
Agreement
Multi-Agency Acceptance
Disagreement
High
0
0.5
1
Level of Technical Knowledge
(Research Projects in the SMAP database)
Low
UNITARY SUBSYSTEM
790
Outreach, Extension, Tech. Assistance
Interagency policy zone
CONTESTED SUBSYSTEM
Outreach, Extension, Tech. Assistance
Interagency stakeholder meetings/ Taskforce
621
Water Quality Trading. Regulatory
COLLABORATIVE SUBSYSTEMS
Interagency research zone
211
136
Fertilizer Tax Incentives (Precision Ag)
ADVERSARIAL SUBSYSTEMS
Mandatory Nutrient Management Planning (Right Time, Form, Place, and Rate)
Different agency directions / Conflict resolution / Additional research