# Resolving Disputes over Science in Natural Resource Agency Decisionmaking

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# Acronyms

| | |
|---|---|
| ADR | Alternative Dispute Resolution |
| APA | Administrative Procedures Act |
| CAA | Clean Air Act |
| CEQ | Council on Environmental Quality |
| CFR | Code of Federal Regulations |
| DOI | U.S. Department of the Interior |
| EDR | Environmental Dispute Resolution |
| EPA | U.S. Environmental Protection Agency |
| NEPA | National Environmental Policy Act |
| NIH | National Institutes of Health |
| NEJM | New England Journal of Medicine |
| NRC | National Research Council |
| NSTC | National Science and Technology Council |
| OIRA | Office of Information and Regulatory Affairs |
| OMB | Office of Management and Budget |
| SVP | Shared Vision Planning |

# Contents

# Background

Natural resource agencies make decisions involving public resources in which the public, by definition, have a stake. These resources are often finite. Thus, different viewpoints, interests, or beliefs may conflict when parties are perceived to be interdependent or one party is perceived to block or oppose other parties' use of a scarce resource. These conflicts may occur regardless of whether there are any real differences between the parties or whether one party's actions actually affect the other (Thomas 1992; Robbins 1994; Appelbaum et al. 1999). Conflicts are defined here as "a process of social interaction involving a struggle over claims to resources, power and status, beliefs, and other preferences and desires" (Appelbaum et al. 1999, 63). Such conflicts can occur at multiple stages or levels of decisionmaking and can be embedded within other conflicts.

Conflicts have been labeled "wicked" when they involve parties with incompatible values or interests, and agency decisions that must have a scientific and technical basis but are not easily resolved by scientific and technical problem solving (Rittel and Webber 1973; Ozawa 1998; Schmidtz 2000; Nie 2003). This leads to or exacerbates disputes between the parties involved over what and how information is used to inform a decision (Brooks 1984; Sabatier et al. 2005; Scholz and Stiftel 2005). Disputes are defined here as "vocalized or articulated disagreements over what ought to be done" (Ozawa 1996, 220). Disputes over science can occur at multiple points in a decision process, from the inception of a planning process to the adoption of a decision or course of action. As resources become or are perceived to be increasingly scarce, disputes over the use of science in agency decisionmaking are also increasing (Nie 2003; Sabatier et al. 2005). Because disputes over the use of science are often nested within larger conflicts of values and interests, disagreements among parties often continue after disputes over science have been resolved (Ozawa and Susskind 1985).

In recent years, natural resource agencies have dealt with a growing number of constituencies that compete for the use of finite resources, while scientific studies provide uncertain or competing recommendations to guide resource management (Nie 2003; Natural Resource Council [NRC] 2004b; Sabatier et al. 2005). In this decision context, multiple stakeholders may represent diverging views, and they are likely to use science to support their preferences. At some level, the conflict represents social preferences and cannot be resolved by scientific means. Thus, the resolution of disputes over science will assist decisionmakers reduce confusion and incorporate the best scientific judgment in natural resource management (Mazur 1973; Ozawa and Susskind 1985). However, current approaches to resolving disputes have demonstrated limitations, which have prevented their broad application, or have not yet proven their success or feasibility for long-term use (Abrams and Berry 1977; Roberts et al. 1984; Coglianese 1999; Ehrmann and Stinson 1999; Koontz et al. 2004; Ozawa 2005;

Sabatier 2005; Quirk 2005; Koontz and Thomas 2006; Langfeldt 2006; Lori and Cardwell 2006; van de Wetering and McKinney 2006; Wagenet and Pfeffer 2007). This indicates that managers need a system to identify which approaches are more likely to succeed—and which are more likely to fail—at resolving disputes over science that differ in composition and underlying drivers.

The objectives of this review are to identify, evaluate, and compare approaches that have been proposed or used to resolve disputes over science in natural resource decisionmaking processes. First, we highlight the inherent difficulties in using science to inform decisionmaking. Next, we emphasize the importance of identifying the underlying drivers behind disputes over science in decision-making, because these determine whether resolving disputes over science can resolve conflicts overall. We then outline several dimensions along which disputes can vary in their composition and scope. Following this, we discuss how scholars define "resolution," and by what characteristics resolution is identified. Finally, we review what scholars have identified as the strengths and weaknesses of currently used and proposed approaches to resolve disputes over science in decisionmaking processes, particularly over water management and allocation. We conclude by identifying gaps in current understanding and make preliminary recommendations for further study on the performance of these approaches for resolving a diverse array of disputes over science.

# Difficulties in Using Science to Inform Decisionmaking

## Conducting Science versus Natural Resource Decisionmaking

There are several inherent difficulties in applying scientific information to management decisions that likely contribute to disputes between parties over how and what information is used to inform agency decisions. These difficulties stem from important differences between the way that science is conducted and the way that decisionmakers use and weigh scientific information. Scientific information is often difficult to utilize in management decisions, because scientific norms, processes, and limitations can result in scientific information that does not clearly support any particular alternative over any other. Further, as more scientific information is obtained, the weight of support may shift from one alternative to another. These shifts result from science having different priorities and practices than management decisionmaking processes (Bradshaw and Borchers 2000; Dowie 2005; Ozawa 2005; Patt 2007).

Science is discovery-oriented and focuses on anomalies that do not follow expectations—with the goal of reducing what we do not understand or are uncertain about (Kuhn 1970; Brandshaw and Borchers 2000; Sarewitz 2004). Scientists do not accept theories as fact even when they are accompanied by substantial amounts of supporting evidence (Kuhn 1970; Dowie 2005). Instead, science is an ongoing, "revolutionary process by which an older theory is rejected and replaced by an incompatible new one" (Kuhn 1970, 2; Shapiro and Guston 2006). Consequently, scientists accept uncertainty as the norm rather than the exception (Bradshaw and Borchers 2000; Ozawa 2005). Sarewitz (2004) argued that scientific uncertainty "can be understood not as a lack of scientific understanding but as the lack of coherence among competing scientific understandings" (385). However, scientific uncertainty can also occur when scientists are unable to identify what factors are important, which is a lack of understanding (Roberts et al. 1984). Areas of scientific uncertainty are expanding as scientists increasingly recognize that "a great many factors, biophysical, social, economic and political, interact in processes that are only partially path-dependent and usually unpredictable" (Ison et al. 2007, 502).

In contrast to the way that science is conducted, natural resource decisionmaking is usually mission-oriented and seeks certainty in order to minimize the risk of unexpected and undesirable outcomes (Bradshaw and Borchers 2000; Ozawa 2005; Scholz and Stiftel 2005). Natural resource decisionmakers are often non-scientists who must make and justify management decisions even when science does not clearly point to one alternative or another. However, policymakers and the public also often do not understand and are not skilled at applying scientific information to the context of a policy decision (Scholz and Stiftel 2005; Graffy 2008).

Shifts in scientific knowledge are initially viewed with distrust, and scientific uncertainty is a reason to view science as suspect (Ozawa 1996; Shackley and Wynne 1996; Bradshaw and Borchers 2000). As a result, scientific uncertainty is "one of the most difficult aspects of translating science into policy" (Bradshaw and Borchers 2000, 7; Ozawa and Susskind 1985). Moreover, the scales at which management decisions occur often do not align with the scales at which scientific questions are pursued (Ozawa 2005; Folke et al. 2007). Application of scientific knowledge to scales other than those from which it was produced results in even greater levels of uncertainty. Scientists may view uncertainty and communicating uncertainty as a technical challenge and not recognize the importance of specifying the nature of the uncertainty for decisionmakers, stakeholders, and the public (Patt 2007). However, even when scientific consensus occurs, managers, policymakers, and the public may not be provided with the level of certainty and deterministic solutions that they desire (Bradshaw and Borchers 2000; Adler et al. 2001; Scholz and Stiftel 2005; Boykoff 2008).

Complicating things further, despite the popular notion that science is an independent, logical, and politically neutral endeavor, many scholars argue that scientists often cannot help but inter-mix scientific inference with their own personal values and that their selection of subjects, hypotheses, assumptions, and other discretionary decisions are often made based on their personal preferences for social action (Roberts et al. 1984; Lamb et al. 1996; Ozawa 1996; Sarewitz 2004). Everything from deciding what research should be funded to engaging in scientific debates has political influences, because humans "inevitably mix factual and value judgments" (Andrews 2002, 8; Sabatier 2005; Stiftel and Scholz 2005). Furthermore, Brooks (1984) argued that "the more an issue is in the public eye, the more expert judgments are likely to be influenced unconsciously by pre-existing policy preferences or by supposedly unrelated factors such as media presentations, the opinions of colleagues or friends, or even the emotional overtones of certain words used in debate" (40). Then, scientists may go beyond the presentation of scientific information, which is the legitimate role of a scientist, to actually making policy recommendations to decisionmakers based on their preferences, which is no longer a scientific endeavor, but instead a political endeavor (Brooks 1984; Roberts et al. 1984; Ozawa and Susskind 1985; Jasanoff 1990; Lamb et al. 1996; Ozawa 1996).

Thus, it is not surprising that even though scientists and decisionmakers are working on different scales and with different goals, stakeholders and the public view them as politically biased (Susskind 1981; Roberts et al. 1984; Andrews 2002; Sabatier 2005; Stiftel and Scholz 2005). To some extent, this view may be correct. The most politically neutral parties are then the independent parties that are brought into a particular policy situation from outside to run the negotiations or to conduct further study after the goals have been predefined (Sabatier 2005).

However, because public agencies are the main targets in litigation surrounding natural resource decisions, managers do try to pursue the best scientific and technical information throughout the decisionmaking process so that decisions are not overturned and consensus is lost (Adler et al. 2001). Given that decision-making processes are frequently under the microscope and questioned by affected interests, Henry and Conrad (2008) argue that the science used in regulatory decisions, "in many cases is actually likely to be more reliable than science conducted outside the regulatory arena" (136). In accordance with this, the courts generally defer to the judgments of government scientists during reviews unless there is concrete evidence that they were arbitrary or capricious (Roberts et al. 1984; O'Leary 2006).

## Framing Science for Decisionmakers

Another difficulty in using science to inform decisionmaking processes is that it requires 1) the selection of relevant information from reputable sources, 2) organization of that information, and 3) presentation of that information to non-scientists in a format that they can understand and use (Dewulf et al. 2007; Patt 2007). This process is called "framing," which is "the inevitable act of describing a decision and the relevant background information to make it understandable and interesting to decisionmakers" (Patt 2007, 40; Kühberger 1998). In other words, frames are "sense-making devices" (Weick 1995; Dewulf et al. 2007). Graffy (2008) argued that framing is a legitimate component of scientific activity, particularly in natural resource agencies, but that scientists are sometimes reluctant to put scientific information into perspective for policy makers. Other scholars have argued that framing scientific information for a policy decision can be risky for natural resource agencies, because the selection and presentation of science is increasingly viewed by stakeholders as politically motivated and agencies can be accused of misrepresentation (Lakoff 2004; Patt 2007). To remain credible, agencies must appropriately incorporate how people evaluate and use scientific information in order to present information to decisionmakers and the public in a format that allows them to use science effectively (Graffy 2008).

Although there is no consensus on how humans make decisions, all scholarly perspectives describe people as sensitive to framing (Patt 2007). Insights gained from the field of social psychology demonstrate that framing is important because of the way that people evaluate and use scientific information. For example, the context in which scientific information is gained affects whether people consider it valid. People are more likely to trust expert opinion when they fully understand it and when it is perceived to come from a source that is obliged to be honest (Birnbaum and Stegner 1979; Birnbaum and Mellers 1983; Sniezek et al. 2004; Patt et al. 2006). Therefore, obtaining information from fairly neutral sources (e.g., university scientists) may be required to ensure that all parties will consider the conclusions valid (Sabatier 2005). Additionally, decisionmakers and stakeholders have more trust in scientific information when they are involved in obtaining or processing it, because people weigh information they personally acquire differently from information gained from third parties (Griffin and Tversky 1992; Edgell et al. 2004; Patt 2007). However, people also often suffer from source amnesia, which occurs when people forget where a statement came from (Wang and Aamodt 2008). Often, they also forget whether that statement was true or false, which is exacerbated by repetition of that information—even if that repetition includes disclaimers (Wang and Aamodt 2008).

Another important aspect of decisionmaking is that people often try to avoid or discredit information that is incompatible with their current beliefs (Festinger 1957; Cockerill et al. 2004; Wang and Aamodt 2008). New information that conflicts with peoples' existing beliefs and behaviors creates "cognitive dissonance" or psychological discomfort, which people can reduce by changing their beliefs and behaviors (Festinger 1957). Most often, however, people prevent cognitive dissonance by rejecting or avoiding conflicting information or by biasing their interpretation of such information (Festinger 1957; Adams 1973; Yaffee 1994; Patt 2007). Furthermore, people will continue to believe that they do not know much about a subject even after they have received a great deal of information about it, likely in order to protect their social identity (Michael 1996). In evidence of this, scholars have noted that decisionmakers and stakeholders will give inordinate credence to scientific interpretations that support their preferred outcome, and largely disregard those that do not (Ozawa and Susskind 1985; Cockerill et al. 2004).

Finally, because people often give incorrect relative mental weights to probabilities, they may misjudge the significance of scientific predictions for specific situations and issues (Patt 2007). For example, people usually over-react to very small probabilities and under-react to very large probabilities (Kahneman and Tversky 1979; Lee 1993; Patt 2007). When there are two potential outcomes, people will perceive each outcome as having a 50 percent chance of occurring regardless of the actual probability of either outcome (de Bruin et al. 2000; Patt 2007). Also, people remember probabilities as different than those provided based on whether they consider them plausible (Windschitl and Weber 1999). Memorable events or events that generate strong emotional responses are also considered to be more likely than others and are more likely to be remembered (Tversky and Kahneman 1973; Covello 1990; Patt 2007; Wang and Aamodt 2008).

In order for agencies to avoid accusations of scientific distortion, the National Research Council (NRC 2006) and Patt (2007) recommend that agencies tell a complete story of scientific information that takes into account the different types of scientific uncertainty, and to recognize that decisionmakers' and the public's response to uncertainty are affected by numerous social and context-specific factors. Adler et al. (2001) recommend that agencies use the following categories when framing science to facilitate public understanding of scientific information and uncertainty:

1. **Descriptive:** Generate accurate inventories, map land use types, natural features, and critical areas, and depict natural processes.

2. **Causal Analysis/Diagnosis:** Explicate the causes and consequences of public health or ecological disturbances.

3. **Prediction and Modeling:** Identify probable ecological effects of specific land, water, or public health decisions.

4. **Prescriptive Design:** Provide advice in formulating performance standards, emission standards, etc.

5. **Valuing:** Place social, ecological, or economic values on resources or impacts (internalized vs. externalized costs). Create cost comparison of various activities and decisions so that stakeholders can see their relative impacts (28).

However, even when managers carefully frame scientific information to educate stakeholders, policymakers, and the public, it may not be enough to resolve disputes between parties that were caused by unawareness or misunderstanding of the science, particularly when agencies are not considered politically neutral by one or more of the parties (Susskind 1981; Sabatier 2005). Disputes may remain due to gaps in scientific information, the information available may have high levels of uncertainty, or parties may refuse to accept the validity or importance of certain types of information.

In some cases, parties may disagree about how issues are framed and conflict will not be reduced. Adler et.al (2001) recommend that framing include a step where the probable causes and consequences of public health or ecological disturbances are diagnosed. If parties disagree about the causes of a disturbance, for example, they would likely disagree about the perspective produced by the frame. In cases like this, competing frames are created and conflict over the use of science may be one of the ways this conflict is manifested.

# Underlying Drivers of Disputes over the Use of Science

Drivers are beliefs, emotions, actions, events, or situations that cause parties to actively oppose others. The underlying drivers of disputes over the use of science in management decisions likely determine whether disagreements between parties will continue after disputes over science are resolved (Roberts et al. 1984; Ozawa and Susskind 1985; Ozawa 1996). If disputes over science are caused solely by disagreement about what is the best scientific information or the appropriate interpretation of that information, then conflicts between parties should not continue after these specific disputes are resolved (Roberts et al. 1984).

Disagreement between scientists on what is the best scientific information or interpretation of that information may be the only driver of such disputes (Mazur 1973; Dewulf et al. 2007). Despite having expert status, scientists often behave in the same manner as other people when they engage in disputes, (e.g., protecting their egos against threats to the importance of their training or research, forming coalitions with similarly minded parties, and polarizing their positions relative to the opposing party, regardless of how much uncertainty exists) (Mazur 1973; Burkardt et al. 1995; Sabatier 2005).

Disputes between scientists can arise from the biases that all scientists carry, which are created by their educational background, discipline, affiliation, and experience (Brooks 1984; U.S. Environmental Protection Agency [EPA] 2000; Sarewitz 2004; Dewulf et al. 2007; Henry and Conrad 2008). Scientists from different disciplines also ask different questions (which places emphasis on different components of a system) and use and understand scientific terms and concepts in different ways (Brooks 1984; Roberts et al. 1984; Ozawa and Susskind 1985; Sarewitz 2004; Boswell 2005; Stiftel and Scholz 2005; Dewulf et al. 2007). As a result, scientists from different agencies or organizations can provide different results for measurements or tests of the same thing (Roberts et al. 1984; Ozawa and Susskind 1985; Adler et al. 2001; Patt 2007). Alternately, the use of competing or fragmentary theoretical frameworks or set of assumptions can result in different findings or increased uncertainty (Roberts et al. 1984;

Ozawa and Susskind 1985; Adler et al. 2001; Patt 2007; Dewulf et al. 2007). Finally, scientists may disagree on standards of scientific proof (Andrew 2005; Stiftel and Scholz 2005).

In contrast, if competing values and interests are driving disputes over science, conflicts between parties will likely continue after disputes over science are resolved because the parties are primarily concerned with the distribution of losses and gains from a decision (Roberts et al. 1984; Ozawa and Susskind 1985; Burkardt et al. 1995; Cockerill et al. 2004). Values, which are defined here as: "the goals and obligations that policy aims to promote as desirable in their own right, not just as means to some other objective," determine what scientific information is considered and how it is weighted in decisions (Thatcher and Rein 2004, 460; Dowie 2005). Scholars have argued that disputes over science are usually value and interest-based political conflicts that involve scientific information rather than real disagreements between scientific methodologies (Roberts et al. 1984; Ozawa and Susskind 1985; Nie 2003; Lorie and Cardwell 2006). The issues around which parties disagree "are in their essence not scientific but political," because parties are not actually interested in finding and using the best scientific information but rather seek to highlight scientific information that best supports their positions (Ozawa 2005, 193; Sarewitz 2004).

When there are competing values or goals in policy decisionmaking processes, parties seek to use science to support their position or undermine another (Burkardt et al. 1995; Ozawa 1996; Adler et al. 2001). Policymakers or stakeholders often attempt to counter or refute the strength or validity of existing scientific information if they disagree with the supported policy decisions (Burkardt et al. 1995; Adler et al. 2001; Sabatier 2005; Gearheard and Shirley 2007). There may also be arguments over whom should bear the burden of proof rather than real disagreements over the validity of existing information (Brooks 1984; Roberts et al. 1984). Scientific information can become politicized when it is difficult to apply to policy decisions and is disputed by non-scientists (Shapiro and Guston 2006; Boden and Ozonoff 2008).

Often these disputes involve "non-contradictory argumentation," where scientific information does not directly conflict, but rather focuses on different components of the issue (Baumgartner and Jones 1993; Pralle 2006). As discussed above, scientists from different disciplines frequently predict available resources, costs, or benefits for a particular action for different parts of the system (von Meier 1999; Adler et al. 2001; Dowie 2005; Patt 2007). Different but not contradicting types of scientific information are then used to justify each competing interests' position, because the parties have different ideas of which experts are the most relevant (von Meier 1999; Sabatier 2005). As a result, for every scientific finding, competitive processes can create the misperception of equal evidence in support of the opposite finding (Sarewitz 2004; Boykoff 2008).

The intransigence of parties in disputes involving science largely depends on what types of values, beliefs, and interests are in conflict or competition with others, because they affect how the parties weigh existing information and react to new scientific findings (Lord et al. 1979; Sabatier 2005). Studies have demonstrated that all individuals (including scientists), "perceive the world through a set of preexisting beliefs," which vary in their resistance to change (Sabatier 2005,197). Highly normative "deep core" values or beliefs (e.g. political ideology) are acquired early in life, influence individuals' perceptions in all policy arenas, and are highly resistant to modification (Sabatier 2005). Beliefs specific to a policy arena, like valuing increased water quality over cost-efficiency, are individuals' basic policy positions and are also very resistant to change (Sabatier 2005). Beliefs about specific circumstances within a policy arena, like the importance of a specific species of fish in a specific body of water, are the easiest to change (Sabatier 2005).

Parties involved in disputes may have many or very few common interests upon which they can reach an agreement. If parties have many common interests, disagreements may be resolved very quickly once they are identified. These resolutions are commonly called "win-win" situations (Fisher et al. 1991; Rothenberg 2005). Some scholars have argued that because adversarial politics has led to polarization of groups and ideas, there are undiscovered "win-win" solutions to conflicts over resources that can be revealed through communication, education, and trust (Porter and van der Linde 1995). However, other scholars have shown and argued that these situations are probably rarer than advertised, particularly for wicked natural resource problems with zero-sum characteristics (Loucks 2003; Quirk 2005; Rothenberg 2005).

Parties are much less likely to work together when there are few or no common interests between parties and will likely focus their attention on battling over the distribution of resources rather than reaching an agreement (Ozawa and Susskind 1985; Quirk 2005). In other words, when situations are "win-lose," parties will mainly focus on resource gains and losses, and distributional politics are the underlying concern (Ozawa and Susskind 1985).

Disputes can also involve actors with different attitudes toward the status quo. When one or more parties are advantaged by the status quo, they have little incentive to reach an agreement that reduces their advantage (Quirk 2005; Rothenberg 2005). Instead, "the actor whom the status quo favors fights change and contrives instances of seeming governance failures," because they have made investments under the existing policies that would be adversely affected (Gunderson 1999; Rothenberg 2005, 217).

# Varying Scope and Composition of Disputes over Science

Disputes over the use of science in decisionmaking can vary widely in composition, and different types of disputes likely require different approaches for resolution (Roberts et al. 1984). In order to evaluate and identify the utility of different approaches to disputes over science, we classified disputes by their composition and scope (modified and expanded upon from Robert et al. [1984]).

## Number and variety of parties involved

Processes for effectively resolving disputes over the use of science may depend on the number and types (e.g. perspectives, beliefs, ideologies, groups, organizations, disciplines, communities, or cultures) of competing parties involved in the dispute. Different dynamics between parties can operate at a variety of levels, from policymaking to decisions on specific projects or activities. Larger numbers and variety of parties involved in a dispute greatly increase the difficulty of organizing negotiations, particularly with ad-hoc processes that do not have stable legal and administrative precedents (Quirk 2005). The number and types of parties involved in a dispute may change over time, which can greatly complicate attempts to incorporate ever-changing and frequently non-representative groups of stakeholders in decisionmaking processes, particularly for time-consuming dispute resolution processes (Burkardt et al. 1995; Koontz et al. 2004; Quirk 2005; Koehler and Koontz 2008). There may also be sub-groups or sub-cultures within organizational groups or cultures, which view the same scientific or technical information in very different lights (von Meier 1999).

Some parties represent larger organizations or the "public interest," while others only represent their own interests (van de Wetering and McKinney 2006). Some parties are paid to be involved, while others must invest their own time and resources (van de Wetering and McKinney 2006). Some parties are willing and able to be flexible and/or modify their preferences when offered an acceptable alternative, while others are unwilling or unable to be flexible, because they or their members have a fixed position, leaving no room for compromise (Roberts et al. 1984).

## Distribution of Political Power and Resources

In addition to having unequal access to participation, stakeholders may have unequal access to and understanding of scientific and technical information (Ozawa 1998). Some may use imperfect or outdated scientific information to support their positions (Ozawa 1998; Adler et al. 2001; Ozawa 2005; Gearheard and Shirley 2007). Others have high levels of expertise at their disposal with which they can "wield greater influence throughout the decision process by virtue of their ability to cite technical and scientific arguments in support of their preferred decision alternative" (Ozawa 1998, 104). Additional power disparities include unequal skills and experience in debate and negotiation, time and financial resources, and social capital, which is broadly defined as "the set of norms, networks, and organizations through which people can access power and resources, and through which decisionmaking and policy formulation occur" (Groortaert 1998, 2; Appelbaum et al. 1999; Ozawa 2005). Long-term dispute resolution processes may benefit parties with greater resources, because they can afford to stick it out (Brooks 1984). These parties have been labeled the "public participation elite" (Brooks 1984, 48). Public participation elites may also be better equipped to act or implement a decision than those with little political power or resources (Roberts et al. 1984).

## Agency Resources

Agencies vary in the amount of resources they have at their disposal to resolve disputes. These resources include managerial and leadership skills, multi-disciplinary experts, financial resources, time before a decision has to be made, and the public and stakeholder trust (Susskind 1981; Lee 1993; Walters 1997; Cockerill et al. 2004; Cockerill et al. 2006; Richter 2006). Given that some approaches to disputes over science may require significant agency resources for success, agencies should evaluate whether they have or should try to obtain resources prior to initiation of any dispute resolution processes (Lamb et al. 1996; Walters 1997; Cockerill et al. 2006).

## Types of Information Considered

In disputes over science, the type of information used or challenged by parties in disputes can vary from anecdotal information to observational studies to peer-reviewed scientific experiments. Traditional and local knowledge comes from non-scientists (indigenous peoples and local resource users) in the form of observations and anecdotal information (Ozawa 2005). This information "does not owe its origin, testing, degree of verification, truth, status, or currency to distinctive professional techniques, but rather to common sense, casual empiricism, or thoughtful speculation and analysis" (Lindblom and Cohen 1979). Information can also consist primarily of the informed opinions of experts, particularly when there are no other types of information available (Ruckelshaus et al. 2002). Alternately, science can be loosely defined as "the collection of biological information and translation of that information into useful forms" (Ruckelshaus et al. 2002, 666). For example, the "best available" scientific information pertaining to endangered and threatened species is often sparse and filled with scientific uncertainty (Ruckelshaus et al. 2002; Carden 2006). At the other end of the spectrum are controlled experiments that have been published in a peer-refereed scientific journal or validated by an independent panel of experts that deliberate in a public forum (Henry and Conrad 2008).

## Scientific and Technical Clarity

Scientific and technical clarity is the degree to which disputing parties acknowledge and agree on the validity of existing information (Burkardt et al. 1995). This does not mean, however, that they interpret or weigh that information in the same way. However, if there is scientific and technical clarity, then certain types of approaches that primarily serve to facilitate technical clarity may not be needed.

## Attitudes Toward the Use of Science

Regardless of their level of understanding of scientific and technical information, parties in disputes may have different attitudes about how science should be used in decisionmaking. Some parties may prefer that science is not required to justify an action or policy, while others may prefer to make a management decision or develop a policy based primarily on science (Roeder 2005; Stiftel and Scholz 2005). Some parties may be comfortable with technically complex issues while others are intimidated (Burkardt et al. 1995; Ozawa 1998). Attitudes may also differ depending on the specific nature of the decision and the stage in the process (Graffy 2008).

## Nature of the Natural Resource or System

Disputes over science pertaining to resources with unlimited to highly limited availability can arise. However, disputes over science may be less likely to arise when resources are unlimited and may be relatively easy to resolve even when they do arise. In contrast, when a resource is finite and/or when agencies may limit or regulate public or private use of the resource, disagreements frequently arise over the validity of the science behind decisions (Quirk 2005).

Disputes can also involve systems that are well studied and understood or large, complex social and ecological systems where scientific uncertainty is high (Johnson 1999). Complex systems usually do not have straightforward technological solutions for improving management (Johnson 1999; Schmidtz 2000; Nie 2003).

Common pool resources are a special case, because it may be impossible to exclude or regulate users. Ostrom et al. (2003) and Adams et al. (2003) argue that indigenous knowledge of local stakeholders is central to sustainable management of common pool resources. Whether this knowledge is accepted by all those who share in the use and management of these resources becomes a critical component of the success or failure of these undertakings. For example, a local water user may be very knowledgeable about the cultural importance of traditional water uses, but not well-versed in state water law and policy. Each body of knowledge provides a framework for water management, but if participants focus on only their own level of expertise, then conflict may ensue. Thus, in some common pool resource systems, disputes may be focused on which component of the system is the appropriate focus for decisions.

## Scope of the Dispute

Disputes may differ in temporal and geographic scope. Disputes may be relatively new and between two parties that had not conflicted prior to the current dispute (Lorie and Cardwell 2006). Alternately, disputes may be continuations of older disagreements where parties have clear and relatively entrenched positions against each other (Lorie and Cardwell 2006). Disputes may also involve site-specific issues within small geographic areas or large geographic areas covering multiple jurisdictions (Lee 1993; Burkardt et al. 1995; Loucks 2003; Cockerill et al. 2006). For example, a management decision could involve the selection of an effective method for the restoration of a specific section of a stream or involve a decision concerning an entire multi-county or multi-state watershed.

## Legislative Constraints

Beyond resource constraints and political infeasibility issues, managers may decide to use or not use a particular approach to disputes over the use of science because they lack statutory authority to negotiate or may be required by law to prioritize some needs over others (e.g. the requirements of endangered species) (Rothenberg 2005; Jacobson et al. 2006). Ozawa (2005) cautioned, "any attempt to modify the dynamics of relationships and interaction among competitors for scarce resources must take seriously existing legal rights and protections" (188). Agency decisions must comply with laws, rules, and procedural requirements or else they can be overturned (Ozawa 1998). For example, the Administrative Procedures Act (APA) of 1946 (5 U.S.C. 1001–1011), mandates that agencies follow specific procedures during decisionmaking to ensure that decisions are based on non-partisan expertise and not on political values—the courts have generally required agencies to be consistent with these procedures (Ozawa 1996).

Existing legislation and administrative rules and policies create and ensure institutional stability that allows individuals to make decisions about private investments and actions (Ozawa 2005; Rothenberg 2005). Thus, the predominance of incremental change in public policy that preserves stability will inhibit approaches whose effectiveness relies on broad administrative reforms, which managers must consider before initiating dispute resolution processes (Rothenberg 2005; Stiftel and Scholz 2005).

# Defining "Resolution" of Disputes

Clearly, natural resource agencies must find ways to effectively deal with different types of disputes over the use of science in decisionmaking processes. Managers must be able to recognize the underlying drivers and composition of the dispute that they are dealing with in order to choose the most appropriate dispute management approach (Appelbaum et al. 1999).

However, before any approach to resolving disputes can be systematically evaluated, there must be a common understanding of the meaning of the overlapping concepts of "resolution" or "success" or "effectiveness" in relation to the outcomes of disputes over science (Roberts et al. 1984; Ury et al. 1988; Andrew 2001; Todd 2001). Scholars agree that there is no single factor or outcome that can be measured to determine when the end goal of a dispute resolution process has been reached, which has likely contributed to the lack of empirical evidence on the rates that different approaches resolve disputes over science (Roberts et al. 1984; O'Leary 1995; Andrew 2001; Todd 2001). However, there does appear to be general agreement among scholars that a suite of outcomes should be considered to evaluate the relative collective costs and benefits of different dispute resolution processes (Roberts et al. 1984; Ury et al. 1988; van de Wetering and McKinney 2006).

One of the likely beneficial outcomes of resolving disputes over science is an advancement of knowledge across stakeholders and the public (Roberts et al. 1984). For example, the use of a dispute resolution process may increase stakeholders' and the public's understanding of the scientific information used in the decisionmaking process (Roberts et al. 1984). However, this may be difficult to judge if disagreement over interpretation of the science remains (Roberts et al. 1984). Dispute resolution processes may also improve stakeholders' and the public's broader understanding of the scientific method and scientific uncertainty (Roberts et al. 1984). However, the public's access to and appreciation and understanding of science is largely gained through the mass media, so this is difficult to attribute solely to any dispute resolution process (Roberts et al. 1984; Pew 2003; Boykoff 2008).

Other potentially beneficial or negative outcomes involve the social, political, and economic consequences of the dispute resolution process (Roberts et al. 1984). For these, managers may be able to estimate the time, monetary, and emotional costs and gains of the process (Ury et al. 1988). It may also be important to consider how dispute resolution processes affect the credibility and capacity of the institutions involved to resolve future disputes over science (Roberts et al. 1984). Institutions that fail to resolve disputes or exacerbate rather than resolve conflicts may be less likely to attract participation or gain the cooperation of parties in the future (Roberts et al. 1984).

Finally, an outcome of dispute resolution processes that has often been considered important, particularly in reducing costly and time-consuming litigation, is whether the parties can reach an agreement (Roberts et al. 1984). Agreements have been argued to "improve rather than exacerbate the relationships among the parties" (Susskind 1981, 18; Ury et al. 1988; Adler et al. 2001). Better relationships between parties may reduce the probability of further disagreement (Ury et al. 1988). A related outcome is whether the agreement between parties is durable, which likely depends on whether the agreement is actually implemented (Roberts et al. 1984). Many agreements that have satisfied all of the parties involved were never implemented due to various political factors (Burkardt et al. 1995; Loucks 2003; Koontz et al. 2004; Cockerill et al. 2006). Thus, the before-mentioned benefits of reaching agreements may also not be durable if agreements are never implemented.

# Approaches for Resolving Disputes Over the Use of Science in Decisionmaking

Ury et al. (1988) argued that there are three primary avenues by which disputes are resolved: 1) determining who is right, 2) determining who is more powerful, or 3) reconciling the disputants' underlying interests. The "best" or most preferable resolution to any particular dispute is often considered to be the one that incurs the least aggregate costs (van de Wetering and McKinney 2006). However, as demonstrated above, evaluating different dispute resolution approaches is often a difficult task for managers, because disputes can vary widely in composition, underlying drivers, and the costs and benefits of different approaches are difficult to identify and predict.

The courts have usually been used to resolve disputes by determining who is right, but it has been argued that they have also resolved disputes based on which party was the most powerful (McKinney et al. 2008). However, the use of legal proceedings to resolve disputes over science is often seen as less desirable than other approaches, because the courts lack scientific and technical expertise and court proceedings are usually costly adversarial processes that increase the antagonism between parties (Susskind 1981; Roberts et al. 1984; Ozawa and Susskind 1985; Kubasek and Silverman 1988; van de Wetering and McKinney 2006). Furthermore, because not all parties can afford to litigate due to the time and financial resources required, this system favors power inequalities among affected interests (Kubasek and Silverman 1988). Scholars have also questioned whether the courts, which were primarily designed to resolve disputes between two parties, can adequately deal with environmental disputes involving multiple parties (Kubasek and Silverman 1988).

Alternate processes to the courts that reconcile disputes over underlying interests are, therefore, argued to provide more benefits and be less costly in the long-term than determining who is right and much less costly than determining who is the most powerful (Kubasek and Silverman 1988; van de Wetering and McKinney 2006; McKinney et al. 2008). Numerous alternative types of approaches have been attempted or proposed to resolve the increasing number and scope of disputes over the use of science in natural resource decisions (Nie 2003; Sabatier et al. 2005). These approaches vary from those that handle these disputes as technical challenges for the experts to approaches that allow equal participation of non-scientists (Roberts et al. 1984). They can be used alone or combined with other approaches (Ozawa and Susskind 1985; McKinney et al. 2008).

Scholars have identified some of the strengths and weaknesses of applied and proposed approaches to resolving disputes over the use of science in natural resource management decisions. However, there appears to be no standard approach or set of approaches that work well in every situation, and yet scholars have advised that best practices be established (National Science and Technology Council [NSTC] 2007; McKinney et al. 2008; Werick and Palmer 2008). Given this, it is important that managers be able to identify which approaches have the most potential to resolve the different types of disputes they are dealing with. To facilitate this, scholars have advocated and attempted to create "dispute resolution systems" that are "comprehensive systems for dealing not with just a single dispute, but with the stream of disputes that arises in nearly all relationships, communities, and institutions" (van de Wetering and McKinney 2006, 31; McKinney et al. 2008). Although there has been substantial theoretical development of approaches for resolving disputes, there has been very little empirical evaluation of how specific approaches perform in a variety of conditions and contexts (Clary and Hornney 1995; O'Leary 1995; Sipe and Stiftel 1995; Sipe 1998; Andrew 2001; Beierle and Konisky 2000; Beierle 2002; McKinney et al. 2008). We attempt to review that theoretical and empirical work here.

## Pursuit of More Science

Prescribing additional scientific studies is a common approach that agencies use when scientific and technical clarity is lacking or the existing science does not provide clear solutions to problems (Moir and Block 2001; Kiker et al. 2006). Advancing or validating scientific information may be the most fruitful approach for conflicts between scientists, which can result from contradictory measurements of the same thing or from the use of different models or assumptions, because it may correct mistakes in poorly conducted studies or reveal obsolete methodologies (Boden and Ozonoff 2008). The additional data obtained from these studies may also allow more sensitive analyses to be conducted that reveal trends or patterns that were previously undetected due to low statistical power.

However, caution is warranted, because "targeted research may clear up disagreements or lack of data, but cannot resolve policy disputes beyond the current abilities of science" (Stiftel and Scholz 2005, 230). Scientists frequently have different points of view on issues and will interpret information differently (Sabatier 2005). Thus, this approach may not provide resolution for other types of scientific conflict that result from varying yet equally reasonable models or assumptions or from different types of questions asked by different scientific or professional disciplines (Sarewitz 2004). Scientific progress does not necessarily end scientific disputes, because science is "an ongoing activity and a changeable body of knowledge" and progress may instead increase the degree of uncertainty and thus, conflicts (Shapiro and Guston 2006, 536).

Thus, the pursuit of scientific consensus may result in delays in decisionmaking processes (Bradshaw and Borchers 2000; Ozawa 2005). Incentives for inaction may exist, because agency decisions and actions can have immediate costs to managers while there are few or deferred costs of inaction (Roberts et al. 1984; Walters 1997). Also, parties benefiting from the status quo will often advocate the need for more study in order to delay change (Ozawa 2005). Consequently, there may never be enough scientific certainty to satisfy those who use "wait and see" strategies (Bradshaw and Borchers 2000).

## Technical Forums

In technical forums, scientists from multiple disciplines and/or agencies work together to identify data needs and data gaps, develop common data management protocols, create models, monitor common resources or ecological systems, combine datasets, and create common data analyses protocols (van Eeten et al. 2002). Technical forums can be used to coordinate multi-disciplinary and multiple agencies' efforts in the pursuit of scientific knowledge. Because multiple agencies with different mandates and missions are charged with different aspects of water planning and management, decisionmaking requires the coordination of agency expertise and resources—despite the fact that agency missions often conflict (van Eeten et al. 2002; Loucks 2003). More and more frequently, water planning and management requires a broad range of scientific and technical expertise, which can be difficult to coordinate and integrate (Dewulf et al. 2007).

The benefits of technical forums are that trends are detected more quickly in larger datasets, agencies' performances relative to each other are revealed and standardized protocols and common databases are created.

Technical forums do require substantial coordination and communication efforts between agencies. Agencies must be able to agree on the data products needed and how they will be used. In order to facilitate this, oversight committees can be created from personnel from all of the agencies involved that will provide an infrastructure for agency cooperation.

## Professional Forums

Competing parties in disputes often retain scientific experts they trust and who support their values, beliefs, and interests, because scientific support can strengthen a party's position (Sabatier and Zafonte 2001; Sabatier 2005). However, not surprisingly, competing parties often do not consider these scientists to be neutral and do not trust the scientific information they provide (Sabatier 2005). Stakeholders may not trust agency scientists when the scientists are perceived to side with a competing party (Sabatier 2005; Weible 2007).

Professional forums are designed so that scientists associated with competing parties work together with scientists who are more likely to be considered neutral to reach a scientific consensus on the relevant issues, using professional norms (Sabatier and Zafonte 2001; Sabatier 2005). This promotes scientific learning by all competing parties because scientists may view science conducted using the forum's pre-defined professional norms as credible and legitimate, even when that science does not support their position (Sabatier 2005). Sabatier and Zafonte (2001) argued that professional forums are most useful when a fair amount of information on a system already exists, but there is disagreement among parties about how it should be interpreted. Sabatier (2005) also argued that in order to succeed, professional forums must be funded by a neutral source (a politically neutral organization or jointly, by multiple agencies), have a balanced composition of scientists clearly associated with each position and neutral scientists, make decisions on norms and issues by consensus, and meet many times over a sufficiently long period of time so that scientists can thoroughly evaluate the information and gain respect and trust for one another. If any of these conditions are not met, a disgruntled party "almost always can find some decisionmaking venue in which they can circumvent or obstruct the committee's recommendations" (Sabatier 2005, 199). Sabatier (2005) also cautioned that professional forums will likely not be able to reach a compromise or gain representative participation if any of the parties wish to maintain the status quo.

In conclusion, approaches that seek technical clarity using scientists and scientific review processes may provide some help in resolving disputes among scientists within agencies and between agency and outside scientists. However, additional studies may have limited usefulness in resolving conflicts overall if results are still inconclusive and uncertainty remains high. This approach should be taken only after carefully considering the nature of the resource or ecological system, because little may be gained from obtaining more science, and more science may actually increase scientific uncertainty and areas of disagreement. Furthermore, obtaining more science can favor some scientists over others, which can increase scientific biases (Langfeldt 2006). Additional study may also favor parties that prefer the status quo and/or benefit from delays (Gunderson 1999; Quirk 2005; Rothenberg 2005).

## Scientific Peer Review Processes

Peer review processes can give credibility to scientific conclusions and information, which can facilitate scientific and technical clarity (Adler et al. 2001). Peer review processes are commonly employed during regulatory and political processes. These processes are usually less time consuming than pursuing additional scientific studies and can help determine whether the existing scientific information is valid. Thus, obtaining outside peer review of existing scientific information is an attempt to identify the most reliable information from what is available.

Peer review was defined by NRC as an "in-depth critique of assumptions, calculations, extrapolations, alternate interpretations, methodology, and acceptance criteria employed and conclusions drawn in the original work" (NRC 1998, 28) conducted by independent, "established working scientists or engineers from diverse research institutions who are deeply knowledgeable about the field of study and who provide disinterested technical judgments as to the competence of the researchers, the scientific significance of the proposed work, the soundness of the research plan, and the likelihood of success" (NRC 1995, 69). An independent reviewer is one that: "a) was not involved as a participant, supervisor, technical reviewer, or advisor in the work being reviewed and b) to the extent practical, has sufficient freedom from funding considerations to assure the work is impartially reviewed" (NRC 1998, 28).

Since January 2005, Federal agencies have been required to use outside peer review for any "highly influential scientific assessments" used in support of a regulatory action (Office of Management and Budget [OMB] 2005; Shapiro and Guston 2006). A scientific assessment is categorized as "highly influential" if "the agency or the OIRA [Office of Information and Regulatory Affairs] Administrator determines that the dissemination could have a potential impact of more than $500 million in any one year on either the public or private sector or that the dissemination is novel, controversial, or precedent-setting, or has significant interagency interest"(OMB 2005, 2671). The scientific community at large relies on peer review to ensure quality research standards, in defining and judging what is good or bad research when allocating funding, in book or journal publication, or when informing agency decisionmaking (Langfeldt 2006; Shapiro and Guston 2006).

The use of third-party scientists to review and disseminate available peer-reviewed studies and the current state of knowledge on an issue can also resolve conflicts between scientists (Adler et al. 2001). Third-party peer review has multiple terms, such as blue-ribbon panels, special juries, technical advisory groups, and expert commissions, which all generally involve obtaining scientific review that is independent from decisionmakers. Third-party peer review examines the available information and may even conduct additional research before providing recommendations to decisionmakers. Sometimes the findings and recommendations of independent scientific review conflict with scientists within the agency with jurisdiction (Freudenburg and Gramling 2002). For example, in 1989, an independent scientific panel from the National Academy of Sciences disproved the consensus opinion of scientists within the Minerals Management Service on the environmental impacts of offshore oil and gas industry activities, which led to a Presidential moratorium on Federal lease sales outside of the Gulf of Mexico (Freudenburg and Gramling 2002).

However, there has been evidence of biases and problems associated with peer review processes (Ernst 1994; Stehbens 1999; Langfeldt 2006). Peer review processes have also been criticized as inconsistent and vulnerable to bias despite guidelines and practices for avoiding conflicts of interest (Roy 1985; Ernst 1994; Holden 2000; van Kolfschooten 2002; Langfeldt 2006). Investigations have found that peer review often does not detect poor quality analyses, inadvertent mistakes, or even fraud and is often not corrected when these problems are identified (Stehbens 1999; Smith 2006; Boden and Ozonoff 2008). For example, scientists and journal editors are reluctant to publish corrections, critical papers, and negative results (Stehbens 1999; van Kolfschooten 2002). In addition, multiple peer reviews of the same research have been shown to vary considerably (Cole et al. 1981; Stehbens 1999). Thus, the influence of scholarly bias may depend on the types and number of scientists that have different scholarly traditions included in peer review processes (Langfeldt 2006).

Outside expert review may also be problematic when members of the selected review panel or committee are not balanced and experts have conflicts of interest (Stehbens 1999; Shapiro and Guston 2006). Reviewers with conflicts of interest may be difficult to avoid because scientific peers are often chosen from the same discipline as the reviewed research and as a result, may unfairly judge a competitor's work (Stehbens 1999). Thorough peer review processes may favor traditional research methods and existing paradigms and discourage innovative, non-conventional research (Stehbens 1999; Frey 2003; Langfeldt 2006). As a result, peer review can result in cumulative advantages and disadvantages for individual scientists or scientific viewpoints (Ernst 1994; Langfeldt 2006). Although not well studied, Shapiro and Guston (2006) argue that outside expert review is an increasingly used instrument of political control of the bureaucracy.

Despite these problems, peer review processes can be improved. For example, in response to thousands of comments and criticisms in 2007-2008 on the National Institutes of Health (NIH) peer review process, the NIH Director commissioned two peer review working groups and came up with the following four implementation priorities (NIH News 2008), to improve peer review processes:

1. Engage the best reviewers by standardizing their training and compensating them for their time and effort.

2. Improve the quality and transparency of reviews by improving the application process for better matches between applications to reviewers, specifying and standardizing review criteria. Clarify the rating system.

3. Create systems that ensure a balanced and fair review of applications across disciplines and career stages by supporting a minimum number of applications from new investigators and encouraging new innovative research.

4. Develop a monitoring and review process of the peer review process.

## Science Court

A Science Court is a highly qualified panel of experts who hear arguments from opposing scientists and make a ruling based on the quality of the data and inferences made from it, which they judged from their own expertise (Mazur 1977; Ozawa and Susskind 1985). Within the Science Court, the underlying purpose is not to settle disputes between scientists over scientific "truth," but rather to settle the matter for decisionmakers (Abrams and Berry 1977). Disputes are conducted in an adversarial legalistic-feeling process where one side becomes the winner and the other the loser (Abrams and Berry 1977). The basic premise behind the Science Court is that questions of "fact" can be separated from questions of "values" and that the Science Court can adjudicate questions over these facts, which leaves decisionmakers to address issues involving values (Mazur 1977; Ozawa and Susskind 1985).

However, many scholars have criticized the Science Court as an inappropriate way to resolve disputes over scientific and technical information (Abrams and Berry 1977). They argue that the Science Court might further polarize issues and encourage parties to emphasize information that supports their position and withhold information that does not (Abrams and Berry 1977). The precedent set by a Science Court judgment may be hard to overcome even if new information emerges that refutes the decision (Abrams and Berry 1977). In addition, many scholars have questioned whether questions over facts can be cleanly separated from questions over values in decisionmaking, because value preferences affect how all parties, including scientists, select and interpret scientific evidence (Brooks 1984; Roberts et al. 1984; Ozawa and Susskind 1985; Ozawa 1996).

In conclusion, while peer-review has become a valuable quality check on science used during decisionmaking processes, these processes can have serious shortcomings. In addition, expert reviews often do not prevent further litigation, because they "are unlikely to have the legitimacy to resolve disputes so intense that they have already overwhelmed the political and legal mechanisms normally used to deal with policy questions" (Roberts et al. 1984, 118; Ozawa 1998). Thus, in many circumstances, peer review has potential limitations for resolving disputes over science, which managers should consider before using peer review as the primary tool for resolving disputes over science.

## Adaptive Management Approaches

In many instances, scientific uncertainty is unavoidable due to time or financial constraints or the complexity of the system (Bradshaw and Borchers 2000; Patt 2007). As scientific uncertainty increases, so do levels of conflict during decisionmaking processes, particularly over limited resources (Bradshaw and Borchers 2000). Thus, resolving such conflicts likely requires that decisionmaking processes learn to operate and act despite scientific uncertainty, but in a flexible manner (Walters 1986; Holling 1995). In general, experts have agreed that "the greater the uncertainty, the more 'adaptive and heuristic' the resulting agreement should be" (Adler et al. 2001, 16; Williams et al. 2009). Being adaptive requires an ongoing evaluation process to decide whether to change courses of action based on performance measures (van der Brugge and van Raak 2007). Ongoing learning and decision processes allow action, but require re-assessment and revision to actions at specific future points, so that decisions can be refined (Adler et al. 2001; Ozawa 2005). Instead of focusing strictly on stability, institutions favor experimentation, innovation, and discovery and flexible management approaches (Carpenter et al. 2001, Berkes 2007).

Performance-based adaptive decisionmaking or the structured process of "learning by doing" is commonly labeled adaptive management and was first developed by C. S. Holling in 1978 (Holling 1978; Walters 1997). Adaptive management approaches acknowledge that there will never be complete understanding of complex social-ecological system dynamics (van der Brugge and van Raak 2007). When implemented appropriately, adaptive management approaches can have the best environmental outcomes, because they are the most holistic and long-term (Walters 1986; Holling 1995; van der Brugge and van Raak 2007). Furthermore, adaptive management can potentially find or create win-win outcomes for all involved (Walters 1997; Moir and Block 2001).

The U.S. Department of the Interior (DOI) (Williams et al. 2009) adopted the following definition of adaptive management used by the NRC (2004a, 1-2):

> "Adaptive management [is a decision process that] promotes flexible decisionmaking that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions

> and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders."

However, there has been a very low rate of implementation of adaptive management approaches by agencies thus far (Walters 1997; Moir and Block 2001; Meffe et al. 2002; Jacobson et al. 2006). There are several key factors that may discourage managers from adopting adaptive management approaches (Jacobson et al. 2006):

- Barriers to adaptive management approaches may arise within agencies.
- Adaptive management requires continuous experimentation and monitoring, which managers frequently perceive as relatively expensive and risky compared to traditional approaches (Walters 1997; Johnson 1999; Moir and Block 2001; Jacobson et al. 2006; Williams et al. 2009).
- Substantial and continuous funding is often required to develop and implement monitoring programs, which usually have short-term scales that may not be able to detect slower ecosystem responses or distinguish noise from real patterns (Walters 1997; Moir and Block 2001).
- Monitoring may end up only highlighting management mistakes, particularly when situations are lose-lose because the resource is already irreparably damaged prior to monitoring (Moir and Block 2001).
- Agency scientists may act to protect their own discipline-specific process research programs, which may be affected by adaptive management approaches (Walters 1997; Johnson 1999; Jacobson et al. 2006).
- Managers may feel that decisions must have the "pretense of certainty" (the appearance of expert decisiveness) to maintain agency credibility with the public and policymakers (Walters 1997).

Outside forces may also present obstacles to adaptive management approaches. Experimentation may be considered too risky if the resilience of the ecological system is low or perceived to be low (Gunderson 1999). There are increasingly deep value conflicts between environmental interest groups that can lead to opposition to experimentation and that may increase environmental risks due to potential management mistakes (Walters 1997; Gunderson 1999; Williams et al. 2009). For example, populations of endangered species may not be resilient enough to survive a flawed management experiment and thus, an adaptive management approach may be considered by some groups to violate the Endangered Species Act (ESA; Walters 1997).

Inflexible power relationships among stakeholders can also derail adaptive management efforts when powerful stakeholders resist changes to policy (Gunderson 1999). Even when restructuring is possible, adaptive management studies require protection from short-term political forces, because management experiments may take a long time to complete (Kiker et al. 2001). Stakeholders may dislike the uncertain nature of decisions (Adler et al. 2001). For example, "defendants and respondents usually require closure and release so that they do not have on-going liability or adverse publicity. Plaintiffs and complainants are often unwilling to concede closure because of scientific uncertainties" (Adler et al. 2001, 31). Thus, managers may feel that decisions must have some degree of finality to resolve conflicts. Potential options to mitigate such issues include: contingent agreements with future negotiation based on further research, capping future liabilities by purchasing insurance for future unexpected costs, agreement to revisit decisions within a certain amount of time, and compensation for losses (Johnson 1999; Adler et al. 2001). However, these may not be within the legal jurisdiction of agencies (Ozawa 1998; Ozawa 2005; Rothenberg 2005).

Another disincentive to adaptive management is that some stakeholders are likely to support the management policies that are in place, and they may resist change. If the original agreement was difficult to develop, the thought of re-opening issues may be resisted by those who are satisfied with the current situation or who are not convinced that reconsideration will improve conditions.

As of February 1, 2008, DOI's official policy is "to encourage the use of adaptive management as appropriate as a tool in managing lands and resources" under the jurisdiction of the DOI (DOI 2008, 1). Recognizing that there are barriers to successful implementation, DOI's Technical Guide for adaptive management advises that the approach is only appropriate when all of the following conditions are met (Williams et al. 2009):

1. A management decision must be made
2. Stakeholders can be engaged
3. Management objectives can be stated explicitly
4. Uncertainty exists about potential management impacts
5. Resource relationships and management impacts can be represented in models
6. Monitoring can be designed so that it informs decisionmaking
7. Progress in achieving management objectives can be measured
8. Management actions can then be adjusted in response to what has been learned

9. The whole process is in full compliance with relevant laws, regulations, and authorities

In addition to the criteria listed above, adaptive management approaches are likely to be most useful for disputes where disagreement is not about policy goals but about the best way to achieve them (Scholz and Stiftel 2005). Simultaneously, politically feasible adaptive management approaches may require known ecological resilience and flexible power relationships among stakeholders (Gunderson 1999). Finally, adaptive management approaches may be best suited for smaller scale systems that encounter fewer political obstacles and require fewer financial resources (Walters 1997; Gunderson 1999; Kiker et al. 2001; Moir and Block 2001). Johnson (1999) recommends applying adaptive management to a suite of similar small-scale systems in order to address problems that managers collectively face. The even more holistic focus is then "on a general class of problems that require similar types of decisions in different situations and locations" (Johnson 1999, 11).

In conclusion, adaptive management approaches have the potential to improve management of increasing complex systems where scientific uncertainty is increasingly the norm, rather than the exception (Lee 1993; Williams et al. 2009). However, such approaches may be infeasible for many to most disputes over science (Williams et al. 2009).

## Public Management Approaches

Public management approaches are those where agencies attempt to diffuse potential disputes with the public, stakeholders, and/or policymakers by promoting and facilitating communication, discussion, and understanding on the use of science in management decisions (scientific and technical clarity) while retaining all decisionmaking authority. Some scholars have argued that allowing the public to participate confers greater political legitimacy to decisions, because decisionmaking processes become more democratic (Brooks 1984; McKinney 1988; Weber 2000). This, in turn, may make the implementation of decisions more broadly acceptable (Brooks 1984).

### Scoping and Public Commenting

Agencies can include the public in decisionmaking processes by using scoping and providing public comment opportunities on proposed decisions, usually while implementing the National Environmental Policy Act (NEPA) of 1969 (42 USC § 4321) (Wagenet and Pfeffer 2007). Scoping, as required by the Council of Environmental Quality's (CEQ) 1978 Regulations, is "an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to a proposed action," where the public may express concerns over the proposed action (40 Code of Federal Regulations [CFR] 1501.7). Federal agencies must also provide a public comment period after posting a Notice of Availability in the Federal Register for Findings of No Significant Impact, Environmental Assessments, and draft and final Environmental Impact Statements for all proposed actions, and then consider and address each comment (40 CFR 1501.4(e)(2); 40 CFR 1506.10(b),(c),(d)).

However, public scoping and commenting processes have been criticized as not allowing meaningful participation by the public (McKinney 1988; Wagenet and Pfeffer 2007). Because stakeholders are also only allowed a limited role in agency decisionmaking, they are often unclear about the grounds on which final decisions are made and how their concerns were incorporated (McKinney 1988). As a result, affected interests may accuse agencies of not truly incorporating public comments in decisions but rather of only complying with legislative requirements while effectively making decisions prior to public comment periods and sessions (Wagenet and Pfeffer 2007). Agencies have countered that the quality of comments are generally poor and unsupported, which reduces their applicability (Wagenet and Pfeffer 2007). Decisionmakers are then forced to guess at the validity of these concerns and the appropriate weight they should have relative to other concerns (McKinney 1988). Consequently, widespread dissatisfaction has led to public opposition to many agency decisions and increased costly litigation (McKinney 1988; Wagenet and Pfeffer 2007).

### Educational Efforts

In order for the public to provide useful input for agency decisionmaking, the public must have sufficient understanding of the scientific information and uncertainty that is used to inform decisions (Lee 1993; Ozawa 2005). Educational efforts, such as public statements, workshops, educational presentations, and the dissemination of technically complicated information, promote the sharing of information among agencies, stakeholders, and the general public (Ozawa 2005). However, if educational efforts do not demonstrate to stakeholders that their concerns are incorporated in final decisions or show the logic behind decisions, then disputes over science and broader conflicts are unlikely to be diffused (McKinney 1988; McKinney 1990).

## Environmental Dispute Resolution (EDR) Approaches

EDR, alternately labeled "Alternative Dispute Resolution (ADR)," refers to a group of approaches that facilitate stakeholder communication and negotiation to reach mutually acceptable agreements (Bingham 1986; McKinney 1988; McKinney 1990; Brock 1991; Walker-Coffey 2004). These negotiations are a means to distribute costs and benefits, which can sometimes be quantified using technical and scientific information (Burkardt et al. 1995). These processes are considered successful when an agreement between the parties is reached, clear implementation and monitoring procedures are put into place, and the parties agree to future negotiations if necessary (Lee 1982; Kubasek and Silverman 1988; Burkardt et al. 1995). EDR may facilitate participation that is more satisfactory to stakeholders than previously discussed approaches, because they are given more influence over decisions and EDR processes focus on the issues and interests that concern them (McKinney 1988; Lowry et al. 1997).

EDR efforts are usually voluntary, flexible, ad-hoc processes designed to fit the particular circumstances of each dispute (Bingham 1986; McKinney 1988). However, there have been some attempts to mandate that parties make "a good faith effort at resolving differences before resorting to unilateral decisions by an administrative agency, to litigation, or to other means of making decisions and resolving disputes" (van de Wetering and McKinney 2006, 25-26). For example, section 164(e) of the Clean Air Act (CAA) requires that the Environmental Protection Agency (EPA) use EDR processes to resolve certain types of disputes between Indian tribes, states, and the EPA (Public Law Number 95-95, 91 Stat. 685; van de Wetering and McKinney 2006). Several states have also passed legislation encouraging the use of dispute resolution processes prior to court proceedings (McKinney et al. 2008). However, these statutes are not accompanied by funding support or are not assigned to a responsible program or agency, and as a result, are largely unfruitful (McKinney et al. 2008).

Other scholars, however, caution that a greater understanding about the effects of mandating mediation and specifying rules of conduct and procedures is needed, because the effects of these requirements on the incentive structures of parties are unclear (Bingham 1986; van de Wetering and McKinney 2006). In addition, creating an institutionalized framework for EDR has proven to be difficult, because EDR approaches are not always feasible, must be crafted to each situation, and require the cooperation of all parties (Brock 1991). The following subsections describe the major types of EDR processes.

### Convening

Convening is often used first to bring parties and issues to the table (Walker-Coffey 2004). This is generally an assessment process to identify which issues and parties are involved and what if any EDR processes may be best suited (Walker-Coffey 2004).

### Negotiation

Negotiation generally occurs directly between an agency and the stakeholders that are regulated by that agency or that have some stake in the issue (Ozawa 1998; Walker-Coffey 2004). Stakeholder knowledge can be used by the agency to create solutions that are more acceptable to regulated parties and which the agency would not necessarily have been able to craft on its own (Walker-Coffey 2004). Using stakeholder input may also reduce court challenges (Walker-Coffey 2004). In addition, negotiations can lead to greater scientific and technical understanding among stakeholders (Burkardt et al. 1995).

However, direct negotiations between agencies and stakeholders may not be productive if the agency is resented or distrusted by stakeholders or the public (Walker-Coffey 2004; van de Wetering and McKinney 2006). Furthermore, parties may have unrealistic expectations of possible outcomes (van de Wetering and McKinney 2006). Resentment may be exacerbated by the fact that the agencies ultimately make the final decision and generally have the advantage in court proceedings (Walker-Coffey 2004; van de Wetering and McKinney 2006). When agreements are not implemented, stakeholders may be reluctant to participate in time- and resource-intensive negotiation processes in the future (Burkardt et al. 1995).

But perhaps the greatest disadvantage to negotiations is that the "public interest" or "common good" may not be adequately considered when some parties cannot or choose not to participate (Ozawa 1998). Ozawa (1998) argued, "it is easy to imagine how interest-group bargaining may result in the sacrifice of the interests of parties not represented at the negotiating table" (116).

### Facilitation and Mediation

Facilitation and mediation are voluntary processes in which stakeholders communicate with each other to try to reach agreement over disputes with the guidance of a third-party neutral. These processes have been used to settle environmental disputes in the U.S. since the early 1970s (Kubasek and Silverman 1988; Walker-Coffey 2004). Third-party neutrals are independent, impartial individuals whose primary concern is to facilitate productive negotiations between disputing parties (Walker-Coffey 2004; Sabatier 2005). Because agency officials and scientists are often not viewed as independent or impartial by stakeholders or the public, facilitators and mediators must be perceived as independent of both (Ozawa 1998; Adler et al. 2001; Weible and Sabatier 2005; Weible 2007). They may be able to establish process ground rules, by which all parties agree to abide, in order to ensure a neutral negotiation process (Stiftel and Scholz 2005). Facilitators usually play the role of process manager by organizing negotiations between parties, scheduling meetings, and keeping meeting notes (Ozawa and Susskind 1985; Dewulf et al. 2007). Mediators, sometimes called "policy brokers," additionally work for technical clarity among parties and suggest potential alternatives for compromise (Ozawa and Susskind 1985; Kubasek and Silverman 1988; Ozawa 1998; Walker-Coffey 2004; Sabatier 2005).

Mediators vary in style and strategy and typically use an ad hoc approach to each mediation process (Kubasek and Silverman 1988; Ozawa 1998). Mediators may choose to force parties to repeatedly meet face to face or may allow disputing parties to communicate through the mediator only (Susskind 1981; Ozawa 1998). Another strategy that mediators may choose is to require that each party in a dispute explains how scientific information supports their position until the opposite party agrees that they fully understand where their positions differ from each other (Abrams and Berry 1977). With this understanding, parties may also be able to better recognize perceived from real differences and when those real differences are overcome (Abrams and Berry 1977).

A potential benefit of using mediation is that mediators may be able to build bridges between scientists and non-scientists by developing their understanding of each others' concerns, values, and knowledge (Adler et al. 2001). They can encourage and train scientists in presenting technical information to non-experts without technical jargon (Ozawa 1998; Adler et al. 2001). Thus, mediation can be educational for stakeholders and to members of the public that did not have access to scientific information prior to the process (Abrams and Berry 1977; Ozawa 1998). Perhaps most importantly, because mediators are objective they can determine whether calls for more science are legitimate or simply stalling tactics (Adler et al. 2001).

However, scholars have identified some critical requirements associated with successful mediation (Ozawa 1998; McKinney 1990; Walker-Coffey 2004). The first element is representation (Susskind 1981; McKinney 1990). Without adequate representation, any agreement made is unlikely to satisfy parties that abstained or were unaware of the process (Susskind 1981; Ozawa and Susskind 1985). Because negotiated agreements tend to only include the interests of the groups involved, unrepresented groups will be disadvantaged or present later challenges (Susskind 1981).

Second, each party at the table representing a group, business, or organization must have the willing participation and commitment of their senior leadership; otherwise the agreement may not be implemented (Susskind 1981; Ozawa and Susskind 1985; Walker-Coffey 2004; van de Wetering and McKinney 2006). Often, lawyers that represent parties in negotiations do not have the authorization to commit their clients to an agreement, and yet they are the only representative for that party in attendance (van de Wetering and McKinney 2006). When they do make commitments or compromises, parties or groups must be able to retain their support base or they will no longer be able to negotiate or represent those interests (Susskind 1981). It is difficult to hold parties to their agreements if they are unable or choose not to honor them (Susskind 1981; Roberts et al. 1984; McKinney 1990).

The third requirement is that there are no substantial power disparities among parties (Susskind 1981; McKinney 1990). There is some controversy among experts on whether and how mediators should neutralize such power disparities (Ozawa 1998). Some scholars argue that ignoring differences in technical and scientific resources will increase power disparities and that agreements will eventually unravel if resource-poor parties discover that other parties used their power to withhold technical expertise (Susskind 1981; Ozawa 1998). Other scholars and practitioners argue that such attempts compromise the mediators' neutrality (Amy 1987; Ozawa 1998).

The fourth requirement is that all parties have equal incentive to reach an agreement (Roberts et al. 1984; Ozawa 1998). If any party benefits from the status quo, they may encourage delays in the negotiation process or undermine potential agreements (Susskind 1981; Roberts et al. 1984; Ozawa 1998).

The fifth requirement is that an agreement must be confined within legal and financial limits (Susskind 1981). If it is not, the agreement will be difficult, if not impossible, for agencies to implement and disputes between parties may recur (McKinney et al. 2008). Furthermore, the blame for the failure may be placed on the agency and lead to increasing public and stakeholder distrust of that agency (McKinney et al. 2008).

There also appears to be some disagreement among scholars and mediators over the appropriate level of transparency in mediation processes (Abrams and Berry 1977; Walker-Coffey 2004). Some scholars argue that mediation sessions must be private because only then, "the underlying causes of a dispute can be brought out without fear of compromising one's ultimate position or giving something away" (Abrams and Berry 1977, 53). They argue that stakeholders will not choose to present important information unless they can be assured that it will not be used against them in future litigation or arbitration processes (Walker-Coffey 2004). However, other scholars and mediators argue that negotiations must be transparent for the process to be acceptable to the public, and for the participants to be held accountable to their agreements and to the law (Abrams and Berry 1977; Walker-Coffey 2004).

Attempts at mediation have had mixed results (Susskind 1981; van de Wetering and McKinney 2006). Mediators have often been successful at getting the parties involved to reach mutually acceptable agreements (Susskind 1981; van de Wetering and McKinney 2006). However, implementation of these agreements has been less successful, because new political actors altered the terms, the agreements did not comply with legal requirements, or non-represented parties challenged agreements in court (Susskind 1981). Some of these cases may not have been appropriate for mediation (van de Wetering and McKinney 2006).

## Arbitration

Arbitration is similar to the Science Court, where both sides of a dispute are submitted to one or a panel of neutral parties for a final decision (McCrory 1981; Walker-Coffey 2004). In contrast to the Science Court, panel members are not necessarily scientific or technical experts (McCrory 1981; Walker-Coffey 2004). Prior to arbitration, the parties involved in the dispute decide whether the ruling will be binding or not (Walker-Coffey 2004). However, this approach may not always be feasible, because agencies are legally charged with making the final decision and must be the final arbitrators in decisionmaking (McCrory 1981; van de Wetering and McKinney 2006).

### Mediation-arbitration

This process, known as "med-arb," occurs when the mediator serves as the arbitrator if the parties fail to reach an agreement (Ury et al. 1988; van de Wetering and McKinney 2006). This process has the advantage that parties are given the incentive to reach an agreement on their own, but as a result may perceive the agreement as an imposed one (van de Wetering and McKinney 2006). Furthermore, "because the parties know that the neutral may decide the dispute, they may withhold information that would be useful in reaching a mediated settlement" (van de Wetering and McKinney 2006, 27).

## Collaborative Approaches

Many scholars and politicians strongly advocate collaborative approaches for resolving disputes over the science used to inform decisions (Kemmis 1990; Cortner and Moote 1999; Snow 2001; Koehler and Koontz 2008). These approaches aim to incorporate a diverse and representative group of stakeholders in decisionmaking, thereby reducing conflict through the development and advancement of common goals (Gray 1989). Scholars have argued that greater participation leads to more types of information being taken under consideration (ranging from peer-reviewed scientific information to traditional and local knowledge), which may improve decisions (Doak 1998; Fischer 2000; Ozawa 2005).

Collaborative participation necessitates that agencies share some control and power over the decisionmaking process (Appelbaum et al. 1999). In fact, many agency decisionmaking processes include a legal requirement to incorporate some degree of participation by the public, interest groups, other agencies, and state and local governments (e.g., the National Environmental Policy Act [NEPA]). Natural resource agencies may play varying roles in participatory and collaborative approaches, which can range from the dominant actor with the final say to equal-footing participants (Koontz et al. 2004). However, agencies are often restricted or perceive that they are restricted from fully implementing collaborative approaches by legislative constraints such as sections of the Administrative Procedure Act that state that all agency adjudications are subject to judicial review based on procedural error, poor reasoning, inadequate justification for final decisions, or misinterpretation of a statute (Kubasek and Silverman 1988).

### Joint Fact-finding

Joint Fact-finding, alternately called "Joint Inquiry," is very similar to a professional forum, except that all parties, not just scientists, participate. In a Joint Fact-finding process, agency officials, stakeholders, and scientists jointly decide what and how scientific information is to be obtained and used at the beginning of decisionmaking processes. This is thought to improve scientific and technical clarity and to build consensus prior to discussions about decision alternatives (Ozawa and Susskind 1985; Ehrmann and Stinson 1999; Adler et al. 2001; Ozawa 2005). Generally, Joint Fact-finding is used when there is conflict over a situation or issue for which there is inadequate or incorrect scientific information (Appelbaum et al. 1999; Ehrmann and Stinson 1999). Joint Fact-finding may also be useful when parties interpret scientific data in incompatible ways (Ehrmann and Stinson 1999).

In the earliest stages, all parties and stakeholders agree on what constitutes "adequate" scientific information and the ground rules for acquiring that information (Ehrmann and Stinson 1999; Adler et al. 2001). They "should jointly determine the issues of concern that require technical analysis, the questions that the experts ought to ask (and who those experts should be), the best process for gathering information and answering questions, the limitations of the various analytical methods that will be used, and the best way of proceeding once a scientific or technical analysis is completed" ( Ehrmann and Stinson 1999, 377). In order to be successful, participants must be able to isolate areas of disagreement from other issues and identify which issues do and do not need to be resolved by the process (Adler et al. 2001). However, the process does not assume that parties will interpret the information in the same manner (Ehrmann and Stinson 1999; Adler et al. 2001).

All discretionary decisions (i.e., those in which "choosing the analysis more appropriate to the situation is a matter of judgment and values") are made by the group as a whole (Ozawa 2005, 190). Consequently, the use of scientific information to inform decisions is, "socially constructed by the parties and gain[s] legitimacy as a matter of course" (Ozawa 2005, 189). Joint Fact-finding also has the benefit of increasing participants' understanding of scientific information and uncertainty, which may allow them to negotiate with more skill (Ehrmann and Stinson 1999; Ozawa 2005).

Potential roadblocks to Joint Fact-finding are differences in technical understanding between parties and the substantial effort required by those lacking a technical background (Ehrmann and Stinson 1999). This can make Joint Fact-finding very time consuming and difficult (Ehrmann and Stinson 1999). Also, even when technical problems and methodologies are understood by all parties, they may be unable to reach an agreement on which experts to select or how to interpret the results of the process (Ehrmann and Stinson 1999). Finally, parties that benefit from the status quo or delays in the decisionmaking process may not accept the results of the process and may ask that more science be conducted (Ehrmann and Stinson 1999).

### Multi-attribute Trade-off Analyses

Multi-attribute trade-off analyses attempt to identify, if possible, alternatives that all parties will find acceptable. "Whether or not any such alternatives exist might be discovered in an iterative process in which parties explore the impacts of various decisions and begin to understand the tradeoffs among these impacts"

(Thiessen and Loucks 1992, 163). These attributes can include direct and indirect economic, social, and environmental costs and benefits (Connors 2007). Numerous computer programs have been designed to support multi-party negotiation processes by evaluating the trade-offs for a variety of alternatives (for a review of a variety of these programs see Thiessen and Loucks [1992]). However, the real costs and benefits of some of the factors and attributes are difficult or impossible to calculate in comparable units, such as social welfare and ecosystem services (Thiessen and Loucks 1992; Lee 1993; Connors 2007). Scholars claim that these analyses can be used to facilitate stakeholder communication, identify complementary versus competing sets of options, and determine which alternative is the "optimal" one out of multiple feasible options (Thiessen and Loucks 1992; Connors 2007).

### Collaborative Modeling

Collaborative modeling is similar to joint fact-finding but focuses strictly on resolving disputes over technically difficult problems by involving the public and stakeholders in developing computer simulation models (Lorie and Cardwell 2006). Collaborative modeling involves stakeholders and decisionmakers in deciding how computer models will be used in management decisions and in the actual design and construction stages of computer models (Cockerill et al. 2006; Lorie and Cardwell 2006). Because modeling frequently requires that some discretionary and potentially value-laden assumptions be made, "if the parties to a technical dispute can develop a model that incorporates key assumptions acceptable to all of them, they are more likely to produce a prediction that none can easily dismiss" (Ozawa and Susskind 1985, 33). When collaborative modeling is successful, stakeholders and the public become exposed to and educated on the complexity of water planning and management (Cockerill et al. 2004; Cockerill et al. 2006; Richter 2006).

Computer modeling has the advantage of requiring parties to propose and formalize quantitative performance objectives and measures (Lund and Palmer 1997). A wide range of alternatives can be created and evaluated against each other so that the best set of alternatives can be identified relatively easily and quickly compared to experimental studies (Lund and Palmer 1997). Thus, collaborative modeling processes may provide a structured and informed "forum for negotiations" that could lead to cooperation between parties (Lund and Palmer 1997, 71).

Another potential benefit of collaborative modeling approaches is that they may allow managers to identify whether conflicts are truly differences over the use of science or are instead value conflicts disguised as scientific disputes (Lorie and Cardwell 2006). If disputes between parties are solely factual disputes, this approach appears useful for technically complicated problems and projects. However, collaborative modeling approaches are unlikely to resolve value conflicts between parties, because "computer models do not resolve conflicts; people do" (Lund and Palmer 1997; Cockerill et al. 2006).

Some members of the public, stakeholders, and decisionmakers may be unfamiliar with computer modeling and find the outputs difficult to understand (Lund and Palmer 1997; Cockerill et al. 2004; Lorie and Cardwell 2006). As a result, they may distrust the information gained from models into which they had no input, particularly from agencies they do not trust, and they may challenge decisions made using these models (Saunders-Newton and Scott 2001; Cockerill et al. 2004; Lorie and Cardwell 2006).

Collaborative modeling also requires that all stakeholders have incentives to participate, because these processes can be very time-consuming and easily delayed or derailed by a single party (Lund and Palmer 1997; Cockerill et al. 2006; Richter 2006). Thus, consensus over a model may occur only when parties feel that they have no other option and may require that all other approaches, save litigation, have failed to produce a desirable result (i.e., a "lose-lose" situation) (Lund and Palmer 1997). Given the importance of stakeholder cooperation, Lund and Palmer (1997) suggest that collaborative modeling is the most promising for "relatively new or low intensity conflicts before legal or political alternatives have been considered or for higher-intensity conflicts where agreements have been made or incentives have been imposed to maintain broad dedication to the process" (Lund and Palmer 1997, 78).

An example of collaborative modeling is the U.S. Army Corps of Engineers' approach called Shared Vision Planning (SVP) developed by W. J. Werrick and R. N. Palmer (Lorie and Cardwell 2006; Werick and Palmer 2008). SVP processes involve stakeholders early in the planning and development of technical systems models, which represent a "shared vision" and "serve as the primary tools for plan formulation and evaluation, and are designed to be transparent and easy to use" (Lorie and Cardwell 2006, 26; Lund and Palmer 1997). Following this, a traditional water resources management planning process is used to define objectives and evaluate and select among reasonable alternatives (Lorie and Cardwell 2006).

Although SVP processes are increasingly being used, results of attempted SVP processes have been mixed (Lorie and Cardwell 2006; Werick and Palmer 2008), with some partial successes and at least one failure (Lorie and Cardwell 2006). As Lund and Palmer (1997) anticipated, the likely causes behind these SVP failures were the stakeholders that were unwilling to participate or attempted to undermine the process and insufficient managerial skills (Werick and Palmer 2004). Like many other approaches that involve stakeholders, collaborative modeling approaches depend on managers with both technical and public mediation skills (Werick and Palmer 2004; Lorie and Cardwell 2006).

On a positive note, Cockerill et al. (2004) found that the majority of participants involved in water planning in the Middle Rio Grande Region, New Mexico, believed that models are appropriate to use in agency decisionmaking and had trust in a model if they trusted the model's developers. However, they were more inclined to question the validity of a model than their own beliefs if that model produced results that were incompatible with commonly held beliefs (Cockerill et al. 2004). Thus, Cockerill et al. (2004) caution that a high degree of trust in agencies and/or model developers may be necessary for participants to accept model outputs.

### Collaborative Management

Collaborative management approaches provide stakeholders with the authority to make recommendations to agencies, and sometimes even to make management decisions, rather than simply providing agencies feedback (Weber 2000; Koontz et al. 2004; Pralle 2006). Increasingly, collaborative management has been promoted and initiated, due to increasing public distrust in the ability of government agencies to appropriately address environmental issues and legislative efforts to increase public participation in policy making (Cortner and Moote 1999; Koontz and Thomas 2006; Koehler and Koontz 2008). Proponents argue that because collaborative management usually requires widespread agreement to arrive at decisions, it can lead to more stakeholder and citizen cooperation and thus, better outcomes (Weber 2003; Layzer 2006; Koehler and Koontz 2008). Additionally, allowing interest groups more influence in decisions may prevent bureaucratic stalemates by reducing litigation (Ozawa and Susskind 1985; Koontz and Thomas 2006; Pralle 2006). Proponents of collaborative management also argue that decisions are more democratic because of increased equity and accountability (Fung and Wright 2001; Weber 2003; Koontz and Thomas 2006; Wagenet and Pfeffer 2007).

Collaborative management approaches may not be effective in every circumstance, and disputes may not be resolved in a socially or ecologically appropriate way (Kubasek and Silverman 1988; Ozawa 1998; van de Wetering and McKinney 2006; McKinney et al. 2008). Some collaborative approaches may create additional disputes. Appelbaum et al. (1999) argue that conflict is inherent to groups and organizations, including collaborative groups, and will arise when people with different backgrounds, values, and interests work together as a team. Thus, the collaborative approaches themselves will create conflicts among participants, regardless of whether conflicts already existed. Potentially beneficial outcomes of these conflicts include the development of solidarity among members, more in-depth discussion of issues, new creative policies and processes, and a heightened sense of purpose among members. Realizing these benefits requires that conflicts are appropriately managed within collaborative groups (Appelbaum et al. 1999; Beierle and Konisky 2000; Beierle 2002). Attaining the potential beneficial outcomes of collaborative management likely depends on the active and lasting participation of an informed citizenry; neutralization of power disparities among stakeholders; and the commitment of participants to create effective, scientifically informed solutions to resource problems (Appelbaum et al. 1999; Scheffer et al. 2000; Koontz et al. 2004; Bidwell and Ryan 2006; Koontz and Thomas 2006). There must also be the capacity and commitment to reward compliance and punish violators of agreements (Rothenberg 2005).

Critics argue that collaborative approaches frequently fail to achieve or sustain these characteristics. Collaborative efforts have often been unable to attract and maintain a representative group of participants, particularly among the general population and local governments (Beierle and Konisky 2000; Koontz et al. 2004; Dedekorkut 2005; Quirk 2005; Koehler and Koontz 2008). Many stakeholders' primary incentive to participate in collaborative efforts is to avoid traditional agency regulation (Koontz et al. 2004; Dedekorkut 2005; Rothenberg 2005). Of those that participate, collaborative management may favor some interests over others, thus undermining the more equitable premise of such approaches (Koontz and Thomas 2006). For example, some collaborative efforts have advantaged local stakeholders and disenfranchised broader public interests that were late to join or discouraged from participating (McCloskey 1996; Koontz and Thomas 2006; Pralle 2006). Collaborative management can also reinforce existing power disparities among stakeholders (Bidwell and Ryan 2006; Koontz and Thomas 2006). Decisionmaking processes that have unequal distributions of social capital among stakeholders can result in policy outcomes that benefit stakeholders with strong social capital and disadvantage those with weak social capital (Scheffer et al. 2000). Instead, collaborative processes may increase distrust, hostility, and antagonism among parties (Appelbaum et al. 1999; Koontz et al. 2004; Rothenberg 2005). Thus, collaborative management may overly rely on what Quirk (2005) labeled "extraordinary feats of negotiation" (204).

Currently, very little is known about the effectiveness of collaborative management processes for making decisions that have positive social and environmental outcomes (Beierle 2002; Koontz and Thomas 2006). As a result, Koontz and Thomas (2006) make the argument that "collaboration is not a panacea; it is a choice that policy makers and public managers should make based on evidence about expected outcomes" (111). While the outputs of collaborative efforts, which include plans, projects, and recommendations, are well documented, the outcomes (which are the effects of outputs on social and environmental conditions) are much less studied (Koontz et al. 2004; Koontz and Thomas 2006).

Only recently have studies shown that some successful collaborative efforts have led to advantageous social outcomes, such as increased trust and social capital among participants and increased levels of scientific knowledge among participants (Beierle and Konisky 2000; Lubell 2002; Koontz et al. 2004; Leach and Sabatier 2005; Scholz and Stiftel 2005; Koontz and Thomas 2006). However, collaborative efforts have also led to increased fractionalization and distrust in other case studies (Beierle and Konisky 2000; Koontz et al. 2004; Scholz and Stiftel 2005). Furthermore, Weible (2007) showed that collaborative management did not increase some stakeholder's trust in scientists or willingness to use scientific information. In the end, the participants and non-participants that disagree with collaborative decisions often resort to litigation to achieve their objectives and conflicts are resumed (Koontz et al. 2004; Dedekorkut 2005; Pralle 2006).

To date, very little is known about environmental outcomes of collaborative approaches (Koontz and Thomas 2006). Environmental outcomes have not been well studied to this point, because 1) variables that describe environmental outcomes are difficult to measure, 2) there may be long time horizons between the implementation of collaborative outputs and environmental change, and 3) it is difficult to design research protocols that untangle the effects of multiple interacting variables that influence environmental change (Koontz and Thomas 2006). Thus far, the success of collaborative approaches has been judged largely on the perceptions of participants (Sabatier 2005). However, Leach and Sabatier (2003) demonstrated that participants' perceptions are skewed by social outcomes and are not valid indicators of environmental outcomes. Until environmental outcomes are known, collaborative approaches must be undertaken with considerable caution. It is quite possible that collaborative approaches actually lead to worse environmental outcomes than traditional command and control approaches, because collaborative decisions (especially those requiring consensus decisionmaking) are often the "lowest common denominator" in that they are the easiest to achieve, not necessarily the best decisions (Coglianese 1999; Koontz et al. 2004).

A major criticism made by several scholars is that collaborative decisions have disregarded scientific recommendations to obtain the policy goals of environmental mandates when economic interests were adversely affected (Hamilton and Viscusi 1999; EPA 2001; Layzer 2006). However, this argument is difficult to evaluate empirically (Beierle 2002). Through a meta-analysis of 239 published case studies, Beierle (2002) demonstrated that collaborative processes have generally had sufficient access to technical and scientific expertise and incorporated more technical and scientific information than traditional decisionmaking processes. However, Beierle (2002) did not measure whether the recommendations and decisions of collaborative efforts actually used the scientific and technical information to further the policy goals of environmental mandates.

If collaborative decisions do not consistently lead to both positive social and environmental outcomes, then collaborative approaches are inappropriate for resolving conflicts and will lead to future conflicts.

## New Holistic Hybrid Approaches

A number of very similar approaches and frameworks have been developed that advocate the need for combining adaptive management approaches with participatory and collaborative approaches in order to solve complex and recurring natural resource conflicts. Some of these frameworks place more focus on specific components of one approach than others. For example, the adaptive ecosystem management approach emphasizes the importance of learning over time from evolving scientific and technical knowledge (Kiker et al. 2006). Another approach, which stems from the Adaptation Policy Framework, emphasizes the importance of incorporating stakeholders in decisions and argues that adaptation is impossible without their cooperation (Conde and Lonsdale 2005). Because their holistic characteristics make these approaches highly similar in nature, we describe only two of them, adaptive co-management and adaptive governance, which come from the fields of sustainability and resilience research and water policy research, respectively.

## Adaptive Co-Management

Adaptive co-management is defined as ". . . an emerging approach for governance of social-ecological systems. Novelty of adaptive co-management comes from combining the iterative learning dimension of adaptive management and the linkage dimension of collaborative management in which rights and responsibilities are jointly shared. Complementarities among concepts of collaboration and adaptive management encourage an approach to governance that encompasses complexity and cross-scale linkages and the process of dynamic learning" (The Resilience Alliance 2009). Adaptive co-management is proposed as a new approach to sustainable management of complex social-ecological systems, which are inextricably linked social and ecological systems at multiple interacting scales (Anderies et al. 2004; Folke et al. 2007). Adaptive co-management is "a process by which institutional arrangements and ecological knowledge are tested and revised in a dynamic, ongoing, self-organized process of trial-and-error" (Folke et al. 2002, 8). The goals of adaptive co-management are to avoid the loss of ecological system components or "1) [functions that] cannot be substituted for by other functions (whether environmental or technological); 2) functions whose loss would be irreversible; and 3) functions whose loss would risk or actually involve losses that are too significant to be acceptable" (Plummer and Armitage 2007, 67).

For adaptive co-management to succeed, institutions must facilitate experimentation, innovation, and discovery, which are prerequisites for adaptation (Carpenter et al. 2001). Adaptive co-management incorporates social and policy learning across scales, which are "relatively enduring alterations of thought or behavioral intentions that result from experience and/or the assessment of new information involving the precepts of beliefs" (Sabatier 2005, 98; Heclo 1974). Adaptive management also involves shared management across organizational levels, cooperation across organizations, and collaboration among stakeholders (Olsson et al. 2004; Walker et al. 2006; Plummer and Armitage 2007).

Benefits to adaptive co-management may include legitimacy of decisionmaking at a broader scale, greater equity and efficiency in decisionmaking and greater local capacity for decisionmaking (Plummer and Armitage 2007). However, adaptive co-management approaches are limited by the same political difficulties as adaptive management approaches. Also, like all collaborative approaches, adaptive co-management requires increased capacity for local-level monitoring and enforcement and corrections to imbalances in power among stakeholders to avoid reinforcing existing inequalities and catering to narrow interests (Nelson et al. 2007; Plummer and Armitage 2007).

## Adaptive Governance

Adaptive governance is defined as "a new generation of governance institutions for resolving collective actions problems that occur between different types of resource users" (Scholz and Stiftel 2005, 1). Adaptive governance is very similar to adaptive co-management, in that it 1) calls for the creation of new governance institutions that use adaptive management approaches to account for uncertainty in ecological systems and 2) takes into account uncertainty in social systems to create long-term sustainable solutions (Scholz and Stiftel 2005). Proponents of adaptive governance argue that wicked natural resource conflicts require that governance systems coordinate the efforts of independent and fragmented systems of users, interests, institutions, and information (Scholz and Stiftel 2005).

Scholz and Stiftel (2005) argue that five critical components of adaptive governance efforts determine their outcomes. Each of these five components of adaptive governance can be difficult to achieve (Stiftel and Scholz 2005):

1. **Representation** is the extent to which all users and interests are represented in decisionmaking processes, particularly those interests that are subject to collective action problems that limit their participation (Scholz and Stiftel 2005).

2. **Process design** is the mechanism and process for making decisions (Scholz and Stiftel 2005). The appropriate role for representatives and degree of transparency needed in adaptive governance decisionmaking processes is unclear (Conde and Lonsdale 2005; Scholz and Stiftel 2005). Participation that has little impact on final decisions may alienate users and interests and, at the other end, consensus solutions frequently do not last and may constrain future flexibility if there are limited common points of agreement (Coglianese 1999; Koontz et al. 2004; Scholz and Stiftel 2005). Transparency of processes is important for building trust and accountability, but it may also limit compromise and creativity, which are important for adaptability (Scholz and Stiftel 2005).

3. **Scientific learning** is largely limited to attempts to better understand natural processes and is critical for effective environmental policy and adaptive management (Sabatier 2005: Scholz and Stiftel 2005; Kiker et al. 2006). However, what kinds of information should be used, from what sources, and the relative weight given to different kinds of information has not been resolved (Scholz and Stiftel 2005).

4. **Public learning** combines social and policy learning (Olsson et al. 2004; Scholz and Stiftel 2005; Walker et al. 2006; Plummer and Armitage 2007). Public learning occurs when "users learn about the broader consequences of their actions, the reasons for restricting particularly

harmful actions, and the available alternative policies that reduce harms and enhance benefits" (Scholz and Stiftel 2005, 9). Without public learning, adapting to changing circumstances and knowledge over the long-term is impossible (Scholz and Stiftel 2005). However, achieving an adequate level of public learning is likely to be a formidable task because people avoid or resist information that conflicts with their core beliefs and values (Sabatier 2005).

5. **Problem responsiveness** is how equitably, efficiently, and sustainably policy decisions and implementation respond to emerging problems and sources of conflict (Scholz and Stiftel 2005). However, there are often difficult tradeoffs within and between the goals of equity, efficiency, and sustainability—which makes the appropriate balance difficult to identify (Scholz and Stiftel 2005). Problem responsiveness could alternately be defined as the resilience of the governance system to changes in the system.

In conclusion, public management approaches, EDR approaches, collaborative approaches, and hybrid approaches face considerable challenges in reducing natural resource conflicts due to the perceived zero-sum nature of water resources in the West and the competitive behaviors and strategies of stakeholders. For any approach that requires participation by the public and/or stakeholders, there are serious difficulties in identifying, recruiting, and maintaining a representative group of parties to participate in dispute resolution processes, particularly a representative public (Burkardt et al. 1995; Ozawa 1998; Beierle and Konisky 2000; Koontz et al. 2004; Quirk 2005; Koehler and Koontz 2008). Approaches that involve stakeholders and the public can be very long and time-consuming, leading to disinterest, meeting fatigue, and large drops in attendance over time (Cockerill et al. 2006; Richter 2006). It is also unclear when broader representation actually leads to or creates greater acceptance of decisions (Meyer 2001; Conde and Lonsdale 2005) and when it simply complicates or prolongs negotiation processes—risking participant burnout (Scholz and Stiftel 2005).

Scholars have suggested that participatory approaches are more likely to be successful when conflicts have most or all of the following characteristics: no strong clashes of values and interests among the representative group of participants, a relatively equal distribution of political power and technical expertise among participants, all participants desire an alternative to the status quo, and there are potential "win-win" issues (Appelbaum et al. 1999; Scheffer et al. 2000; Koontz et al. 2004; Quirk 2005; Sabatier 2005). Thus, disputes that involve smaller numbers of uniformly committed parties may be the most likely to maintain adequate levels of representation during dispute resolution processes. Disputes involving large and changing numbers of parties with unequal degrees of commitment to the process may be much less likely to succeed, because any disaffected party can thwart an alternate dispute resolution process using the courts or other political venues (Susskind 1981; Roberts et al. 1984; Ozawa 1998). Brooks (1984) pointed out that "in a democracy, the public must be the ultimate arbiter of decisions which affect it, but it is unrealistic and impractical to appeal every issue—especially complex, technically oriented issues—to a public process" (49).

# Conclusion

Before managers judge all disputes, disagreements, and conflicts as undesirable and as a result, feel that disputes must be resolved as quickly as possible, they must recognize that "bounded conflict is politics" (Lee 1993, 8) and "a stubborn fact of organizational life"(Appelbaum et al. 1999, 74). Furthermore, any dispute resolution system must recognize that not all disputes over science can be resolved outside of traditional venues such as the courts (Roberts et al. 1984; van de Wetering and McKinney 2006). Some resolution processes are rights-based and may not involve compromise or reconciling interests, because it is not in the public interest, which agencies are charged to protect by many environmental statutes (Kubasek and Silverman 1988; Ozawa 1998; van de Wetering and McKinney 2006; McKinney et al. 2008). Some environmental disputes may require a yes or no decision and no compromise is possible (Kubasek and Silverman 1988). In addition, alternate dispute resolution processes will not satisfy parties who are trying to set a new legal precedent or judicial interpretation of a statute, which are only achieved through a lawsuit (Kubasek and Silverman 1988).

Nonetheless, scholars agree that there should not be a one-size-fits all approach to natural resource conflict, particularly those designated as wicked (Koontz et al. 2004; Conde and Lonsdale 2005; Scholz and Stiftel 2005; Stiftel and Scholz 2005). There are times when it is likely more desirable to resolve disputes outside of the courts (Susskind 1981; Roberts et al. 1984; Ozawa and Susskind 1985; Kubasek and Silverman 1988; van de Wetering and McKinney 2006). However, before implementing any alternate approach, managers need to ensure that all participants involved understand the strengths, limitations, and rules of the process, such as whether the resulting agreements are binding or non-binding (Lamb et al. 1996; McKinney et al. 2008). Managers and participants should work to develop realistic expectations, because "dissatisfaction with outcomes may lead to the recurrence of disputes," which can be costly, reduce the credibility of the institutions involved, and put off parties from participating in subsequent resolution processes (Roberts et al. 1984; Loucks 1992; McKinney et al. 2008). Finally, all of these approaches require significant agency resources to increase their likelihood of success (Susskind 1981; Lee 1993; Lamb et al. 1996; Walters 1997; Cockerill et al. 2004; Cockerill et al. 2006; Richter 2006).

Perhaps most importantly, managers must be cautioned that conflicts among parties will not always be resolved once disputes over scientific and technical issues are resolved (Roberts et al. 1984; Ozawa and Susskind 1985; Cockerill et al. 2004). Furthermore, any process that narrows discussion to only technical and scientific concerns can prevent parties from reaching agreement if other concerns or issues are paramount (van de Wetering and McKinney 2006). In other situations, disputes over science may not be resolved because there is too much uncertainty and "ignorance raises rather than lowers the heat of the arguments, in which divergent values are reinforced by causal beliefs of dubious validity" (Lee 1993, 146). Finally, reconciling interests may simply be impossible if there is no common ground among parties and, thus, no potential "win-win" situation (Quirk 2005; Rothenberg 2005; Cockerill et al. 2006). Currently, very little is known about which types of disputes over science managers most frequently face, what managers consider when choosing a dispute resolution approach, and the outcomes of those choices. Each of the approaches discussed above are likely to be useful only for a limited set of situations (Stiftel and Scholz 2005). Thus, the development of a screening process seems appropriate to select the approaches that are most likely to succeed for each type of dispute (McKinney et al. 2008). Continued research and hypotheses development and testing (particularly comparative case studies and large n, empirical studies) are needed to understand the real strengths, limitations, and applicability of each dispute resolution approach in order to effectively assist managers to appropriately cope with disputes over science.

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