RECLAMATION

Managing Water in the West

Manual for Managing Disputes over Science

Research and Development Office
Science and Technology Program
(Final Report) ST-202014-021380
& Manuals and Standards Project G6095

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U.S. Department of the Interior
Bureau of Reclamation
Research and Development Office

June 2016

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

REPORT DOCUMENTATION PAGE		*Form Approved OMB No. 0704-0188*
T1. REPORT DATE MONTH YEAR	**T2. REPORT TYPE** Research	**T3. DATES COVERED**
T4. TITLE AND SUBTITLE: Manual for Managing Disputes over Science		**5a. CONTRACT NUMBER** 156R5065C6-RX596898701120095 (8)
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER 1541 (S&T)
6. AUTHOR(S): Douglas R. Clark		**5d. PROJECT NUMBER** ST-202014-021380
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER 86-68260
7. PERFORMING ORGANIZATION NAME(S) Douglas R. Clark, 86-68260		**8. PERFORMING ORGANIZATION REPORT NUMBER** ST-202014-021380
9. Research and Development Office & Manuals and Standards U.S. Department of the Interior, Bureau of Reclamation, PO Box 25007, Denver CO 80225-0007		**10. USBR R&D/ Manuals and Stnds**
		11. SPONSOR/MONITOR'S REPORT NUMBER(S) ST-202014-021380

12. DISTRIBUTION / AVAILABILITY STATEMENT
Final report can be downloaded from Reclamation's website: https://www.usbr.gov/research/

13. SUPPLEMENTARY NOTES

14. ABSTRACT ***Focus groups on the genesis of water conflict found that disputes over science occurred repeatedly and consumed a substantial time and money to resolve. A subsequent survey of Reclamation showed that these disputes occurred in distinct domains: the biosphere, lithosphere, hydrosphere, water supply and demand, agriculture, and cultural resources. In addition, specific aspects of the science were disputed: management of scientific enterprises, scientific competency, classification, measurement, standards, data, analytic methods, modeling and interpretation.***

Reclamation water managers need tools for managing disputes over science and forums where they may be used. It was observed that the various domains listed above could benefit from comprehensive mapping and geospatial analysis. A set of geospatial tools, including geographic information systems and geospatial modeling, is described. In addition, a list of tools for addressing the scientific disputes are proposed including, among others: collaborative planning, collaborative modeling, making use of international standards, and development of project management and data management plans.

Finally, six forums for the management of disputes are briefly described: direct discussions among disputing scientists, independent expert peer review, conducting additional science, collaborative learning, public education, and adaptive management.

15. SUBJECT TERMS: disputes over science, collaborative learning, adaptive management

16. SECURITY CLASSIFICATION OF: U			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON: Douglas Clark**
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	**U**		**19b. TELEPHONE NUMBER 303-445-2271**

S Standard Form 298 (Rev. 8/98)
P Prescribed by ANSI Std. 239-18

PEER REVIEW DOCUMENTATION

Project and Document Information

Project Name: Manual for Water Managers WOID: G6095

Document: Manual for Managing Disputes over Science

Document Author(s) Douglas Clark Date: June 2016

Peer Reviewer: Karri Jan Oliver

Review Certification

Peer Reviewer: I have reviewed the assigned items/sections(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer Karri J. Oliver Date reviewed 6/20/2016
(Signature)

Executive Summary

Focus groups examining the causes of water conflict found that disputes over science occurred repeatedly and consumed substantial time and money to resolve. A subsequent survey of Reclamation managers, engineers, and scientists showed that these disputes occurred in distinct domains affected by Reclamation operations: endangered species, invasive species, human health, infrastructure, risks to facilities, water science, supply and demand for water resources, agriculture, and cultural resources. In addition, specific aspects of the science related to these domains emerged over which disputes were generated: management of scientific enterprises, scientific competency, classification, measurement, standards, data, analytic methods, modeling and interpretation.

Reclamation water managers need tools for managing disputes over science and forums where they may be used. Various domains listed above could benefit from comprehensive mapping and geospatial analysis. A set of geospatial tools, including, most prominently, geographic information systems and geospatial modeling, is described herein. Solutions to identified scientific problems included:

- Management of science: a peer-reviewed project management plan
- Competency: outside peer-review
- Classification: investigation of the scientific literature, existing classification systems, methods for creating new systems, peer-review, and/or laboratory analysis, peer-review.
- Standards: investigation of the scientific literature, investigation of existing standards provided by standards organizations, peer-review.
- Data: development of a peer-reviewed data management plan.
- Analytic methods: interviews with disputing scientists, causal analysis, inductive and deductive reasoning, consultation with statistical experts, peer review.
- Modeling: collaborative modeling and peer-review.
- Interpretation: consultation with the disputing scientists, peer-review.

Broadly speaking, six forums are available for the management of disputes over science: direct discussions among scientists, outside peer-review, conducting more science, public outreach and education, collaborative research, and adaptive management. Direct discussions work best when differences are minor. Outside peer review offers a means of bringing a new set of eyes to the problem in order to clear up gray areas and offer new direction. When gaps in the science are determined to be present, Reclamation often can often make personnel and expertise available to conduct additional science. Public outreach can be used when confusion exists amongst various segments of the body politics over technical data or methods. Collaborative learning allows for scientists, stakeholders, the public, and managers to jointly tackle a problem, identify

solutions that benefit from a diversity of understandings, and potentially add new institutional capacity for managing future problems. Adaptive management is particularly useful for disputes over science characterized by sizable uncertainties. It offers a way for scientists, managers, stakeholders, and the public to develop alternative management approaches, implement one, monitor the results, and make adjustments at new data are added to the collective knowledge base.

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Background and Scope

Reclamation makes numerous water management decisions to fulfill its mission. Science and technical data are often the bases for these decisions. Sometimes disagreements arise between agencies, stakeholder organizations, or the public over these technical data, methods, or findings, which are sufficiently serious to impede a water resource management decision. These disputes over science are the focus of this manual. The aim of the manual is to describe these disputes and provide a set of tools for managing them.

The Bureau of Reclamation delivers fresh water to the 17 Western states. Nearly all water basins are over-allocated, so conflicts over water are rampant. A few years ago, a Reclamation research team conducted focus groups on the manifold causes of water conflict. Prominent among these were *conflicts over science*. For example, Scientist A would assert that an endangered fish needs X amount of water to survive and thrive and Scientist B would assert that, no, it required Y amount of water. One water manager told the research team that she wished that the fish could "just talk". Another observed that the only point scientists could seem to agree on was that the fish did, in fact, need water, but nobody could say for sure how much or at what time in their lifecycle.

This manual will do something a little unorthodox. It will describe the problem of disputes over science by way of summarizing the results of a Reclamation-wide survey that was conducted to identify the exact nature of those disputes. It will then proceed to offer some tools for managing the types of disputes that the survey uncovered. And then it will finish by describing various forums in which those disputes might be addressed.

Survey of Disputes over Science

With funding from the Reclamation Research and Development Office, a research team surveyed 2799 Reclamation scientists, engineers, and managers. About 1 in 4 of those individuals who responded (438 of 1745) said that they had been faced with managing a dispute over science. The research team asked respondents to characterize particular scientific disputes they had confronted. The responses the team received were extraordinarily varied and yielded a complex picture of just how broad and pervasive disputes over science were in the agency.

For the purposes of the survey, a dispute over science was defined as a disagreement with other agencies or stakeholder organizations over technical data, methods, or findings, which were sufficiently serious to impede a water resource management.

The research investigated the following issues:

1. In what broad subject domains or thematic areas do disputes over science occur?   Examples would include agriculture, endangered species, and cultural resources.

2. Within these domains or themes, what specific scientific questions or issues emerge? What issues are addressed in the scientific enterprise itself?   Examples would include classification, measurement, modeling, standards, etc.

3. What forums exist for handling disputes over science?

Broad Subject Domains for Disputes over Science

To repeat, respondents were asked if they had been involved in a dispute over science. Those who had answered 'yes' were subsequently asked to briefly describe what types of issues were involved in the most recent dispute. A database of the open-ended responses was prepared. The following is a list of subject/thematic classifications of types of dispute types that were derived from the database.

- Agriculture/Consumptive Use: This category included disputes related to agriculture and related consumptive water use. Examples of these sorts of disputes included the need (or not) for drainage on irrigation projects, the accuracy of evapotranspiration (ET) estimates, methods to be used to calculate ET estimates, and the amount of water crops are consuming.

- Cultural Resources: Cultural resource issues or disputes concerned management of archeological sites and artifacts of historical interest. Examples included managing access to sensitive sites, gauging the spatial extents of culturally sensitive sites, the effects of Reclamation water operations on sensitive sites, planning of mitigation efforts concerning at risk sensitive sites, and developing plans as to how historic preservation processes should be conducted.

- Engineering/Risk: The engineering/risk subject area included disputes related to water infrastructure such as dams, canals, canal linings, pipelines, tunnels, storage tanks, and the like. In addition, there were scientific issues related to the threats that seismic events, floods, landslides, problem soils, vegetation, mining exploration, and other phenomenon presented to the structural integrity of water infrastructure. Examples of this type of dispute included the management of issues surrounding the remediation of underground storage tanks, the potential threats canal liners presented to human and animal health, differences over the development of flood-risk metrics for operational responsibilities, and disputes over tunnel stability.

- Environment/Biology/Human Health: Environmental, biological, and human health related disputes revolved around water quality, ecosystem services, fisheries, habitat, non-native species, and wetlands. Generally speaking, these issues were concerned with the effects of water operations on the environment and the reverse, *exclusive of those issues related to the Endangered Species Act (ESA)***.** (There were so many ESA issues that the research team decided to designate a special separate category for them.) Examples of this category of dispute included non-native species issues such as the effects and management of quagga mussel infestations in the West; management of downstream operations to support fish migration (for instance, are survival benefits linearly related to flow increases?); erosion control impacts on water quality; water use by native and non-native species; the effects of a desalting plant operations on wetlands; and the risks and consequences of biological invasions resulting from inter-basin water transfers.

- Endangered Species Act: These disputes, obviously, concerned issues related to the ESA. Examples of these disputes included the extent of the risks of river drying on endangered fish habitat; the effects of selenium on endangered fish; the design of new fish screens; reservoir release impacts on aquatic communities; how to model fish behavior; the effects of power line construction on water resources and endangered vegetation; and processes for removal of non-native fish encroach on Threatened and Endangers (T&E) species.

- Water Science: The Water Science category related generally to hydrology and geomorphology-- surface flow, ground water, sedimentation, erosion, landslides, channel morphology, and the extent of climate impacts on water systems. Examples of disputes in this category included: the effects (or not) of ground water depletion on surface water; the existence or non-existence of links between ground and surface water; the role of sediment in maintaining the geomorphology of a river system; the status of beaches; the probabilities associated with possible river channel migration; and the spatial extent of aquifers.

- Water Supply/Demand/Legal: This category concerned disputes related to water rights, supply, and demand. A few samples include: how best to estimate future water demand; examination of the depletion of water resources in a certain area and determining who exactly was responsible for them; canal seepage losses; and the degree to which ground water use influences surface water availability-- and associated water rights.

The rank order frequency of the responses within these thematic domains was as follows:

Endangered Species	30.7%
Environment/Biology/Human Health	25.0%
Engineering/Risk	14.8%
Water Science	8.4%
Water Supply/Demand/Legal	5.1%
Agriculture/Consumptive Use	2.4%
Cultural Resources	1.2%

Endangered Species and Environment/Biology/Human Health disputes comprised 55.7% of the total. This was consistent with previous investigations into the causes of water disputes. Clark (2005), for instance, found that ESA issues were the most mentioned cause of water conflict in a 2002 West-wide survey of Reclamation water managers. The ecological impacts of water projects have been well documented elsewhere (see, for example, Reisner, 1986; Freeman, 2010; Graf, 1985; McCool, 2012).

Scientific disputes over engineering issues and related hazards, especially those that could affect Reclamation's infrastructure, represented nearly 1 in 7 responses in the survey. This factor had also figured prominently in the earlier research by Clark (2005). The research team was surprised that disputes over hydrology, geomorphology, sediment, and the like would be as important as they turned out to be. It was also surprising that Water Supply/Demand showed such a low frequency, given that over-allocated river basins were thought to be at the root of all Western water conflicts. Finally, given that Reclamation is the largest provider of water to irrigated agriculture in the U.S. West, it was surprising to see that this issue played such a limited role in the survey responses.

As the team examined the various categories where disputed science occurred, it became evident that each would benefit from spatial analysis, or, more specifically, from a geographic information system application. In other words, understanding the underlying geography of these disputes over science could play an integral part in understanding the science. Pairing the geography with the science held the potential of clarifying context and providing crucial insights. More will be said on this score later.

Scientific Issues within the Thematic Domains

The researchers also wanted to identify the *scientific* disputes that were associated within the previously identified thematic domains. Again categories were derived from the database of open-ended narrative responses. They are listed below.

<u>Management of Science:</u> These were disputes that concerned the design and administration of a scientific project or enterprise such as a river restoration

program. Examples included the disputes surrounding the scientific culture of an agency; the effects on and involvement of stakeholders in a scientific endeavor; or how best to coordinate with multiple agencies and stakeholders in enterprises such as river restoration programs or dam removal projects. Other examples included: determining which methodology was best for calculating consumptive water use; how to choose a common map projection for studies encompassing many jurisdictions; or developing regional monitoring standards.

Competence: These disputes concerned the qualifications (or lack thereof) of the scientists conducting a technical study and/or the adequacy of a scientific study itself. In one example, the stability of a mine tunnel under Reclamation's jurisdiction was questioned by another agency. Reclamation conducted a study that found that the tunnel was stable. Reclamation scientists submitted their results to be peer-reviewed by a university. Agency findings were validated. Other examples included: disputes concerning the competence of biological opinions, or how best to manage conclusions made by non-scientist lay-persons making assertions about, say, the relationships between channel conditions and river operations. Other examples included the disputes concerning the reality of human-induced climate change.

Classification: These were issues related to the definition or categorization of data and information. They were disputes over whether a phenomenon was an instance of one defined category or some other. Examples included classification of wetlands, animal species, a plant species, etc. In one instance, at a river restoration site, there was concern that a commercially available tree species might not be suitable to plant in the restoration area, because it might be a hybrid and not the original species. In another instance, there was a dispute over whether a wetland was an irrigation-induced wetland or a naturally occurring wetland. In the realm of economics, a Reclamation scientist was criticized for characterizing Reclamation Project farmers as "rational utility maximizers." Or in a cost benefit analysis, there was a dispute over "what really constitutes actual water project benefits."

Measurement: These disputes over science concerned the appropriate way to quantify an entity or a phenomenon. It involved determining the precision and accuracy of an observation or an estimate. These disputes also revolved around how measurements are taken and with what instrumentation. Examples included disputes over the accuracy of flow measurements using specific flow devices, how to measure juvenile fish habitat, how to properly measure water quantity and quality, or what constitutes appropriate flood risk metrics.

Standards: These were disputes concerning the existence, construction, appropriateness, or adequacy of standards or guidelines. They almost exclusively pertained to water quality standards, i.e. what the standards should be and/or whether the standards were being met. For example, there were challenges in coming to agreement at to how much of a particular pollutant a body of water could receive, while still meeting the water quality standard. There were also disputes over the setting of unrealistic standards. One respondent wrote that "instream fishery temperature targets set by lab studies are infeasible with local/physical reservoir capabilities."

Data: These were disputes related to the proper collection of data, or the adequacy, quality, integrity, currency, or appropriateness of the data for a particular scientific objective or decision requirement. Examples included disputes concerning the adequacy of survey data to establish the presence or absence of non-native or of T&E species. There were disputes over sampling results obtained from devices provided by competing manufacturers. There were disputes over determining how much data is too much or too little to reach a decision point. Finally, disputes arose over the proper or improper use of data to make operational decisions.

Analysis: Every scientific enterprise seeks to answer some question. Two specific types of questions were present in this survey, however: first, questions devoted to establishing causality, i.e. establishing a connection between phenomena and second, answering some question that was devoted to fact-finding, i.e. "getting to the bottom of some issue". Examples of the causality question were "examining the effects of dam operations on fish habitat and wetlands, or examining the risks posed to health and the environment of selenium in agricultural drainage. Examples of the fact-finding questions were: determining the presence or absence of trace elements in lake-bottom substrate; how best to design new fish screens; and determining the life histories of T&E species.

Modeling: These were disputes surrounding the adequacy, reliability, or appropriateness of various models. They included issues concerning what inputs to incorporate into a model or how best to interpret model results. One example had to do with the credibility of output generated from climate change models. Another example involved a fish biologist disputing how to properly model fish behavior. There were also disagreements over the merits of flow models such as Riverware and Modflow. Disagreements also surrounded how to manage the uncertainties inherent in ground water modeling.

Interpretation: These were issues related to the implications of scientific findings. Could the science support certain findings, for example? And there were disagreements over how to apply findings in a credible manner. One example concerned salt cedar. Certain scientists questioned whether the existing science would support the claim that salt cedar removal did not result in water gain. Scientists wrestled with the question of whether water operations at some distinct point in time should be changed based upon new science. Others disputed whether paleo-hydrologic studies were relevant to flood risk analyses? There were disagreements over the health risks of polyacrylamide for reducing canal seepage. Finally, there were also disputes over the interpretation of biological opinions.

The rank order of frequency of categorical responses are listed below:

Analysis:	40.7%
Management of Science	16.0%
Modeling	7.8%
Measurement	6.6%
Data	3.6%
Interpretation	3.6%
Classification	3.3%
Competence	1.8%
Standards	1.2%

Disputes over Analysis were by far the most cited. Of these responses, about 37% of the disputes concerned the downstream effects of Reclamation operations, 31% were concerned with the amelioration of potential adverse downstream effects, 16% with the assessment of various risks such as floods, 7% with the effects of natural systems or events such as landslides on Reclamation operations, 7% on how to improve technology, 2% on the effects of irrigation operations, and 1% on meeting regulatory requirements.

Management of Science was the second highest category. Disputes in this category generally involved how multiple parties could collaborate to reach consensus on scientific methods, often for large projects that covered multiple jurisdictions.

Summary

Conventional wisdom asserts that water conflict arises “where existing supplies are not adequate to meet water demands.” Results from this survey though, indicate that, at least in the realm of water conflicts over science, many more issues are in play than supply versus demand. The survey revealed disputes over a range of topics, for example, seismic risk analyses, the accuracy of flow devices, the effects of erosion control on water quality, model accuracy, the effects of canal lining on humans and animals, among many others.

To this point we have uncovered distinct thematic domains and scientific issues within them to further analyze disputes over science. These analyses have served to describe range of the problem for the agency regarding disputes over science both in terms of related thematic domains (agriculture, cultural resources, ESA, etc.) and in terms of the associated scientific issues (classification, analysis, interpretation, etc.). The next questions to address are:

- “What tools exist to manage disputes over science?”
- “What forums exist for implementing these tools?”

Tools for Managing Disputes over Science

Basic Tools

The first phase of this research uncovered the previously identified dispute domains: Endangered Species, Environment/Biology/Human Health, Engineering/Risk, Water Science, Water Supply/Demand, Agriculture/Consumptive Use, and Cultural Resources. Tools are required to manage data and analysis in these domains. As noted before, maps of the study area could be beneficial in each of the domains. The research team proposes that the review of the science in dispute should be, at least in part, conducted using geospatial analytic processes. A useful first step would be to determine what physical and human geographic variables impinge upon the dispute over science. The parties can accomplish this by collaboratively developing a conceptual model of the salient relationships (Gross, 2003).

A conceptual model (Figure 1) is "a visual representation of theoretical constructs (and variables) of interest" (Stanford Center for Postsecondary Improvement; Gross, 2006). It is developed from a review of relevant literature and from discussions with subject matter experts and stakeholders who know the landscape in question. This model portrays the various systems that impinge upon the science in dispute. Arrows connect the dependent and independent variables. The model gives a picture of the various elements or entities in the scientific dispute and their relationships. A conceptual model is essential to inform the hypotheses related to the scientific question in dispute. It also provides a basis for development of criteria for addressing the natural resource problem, for example, "more habitat", "fewer non-natives", etc.

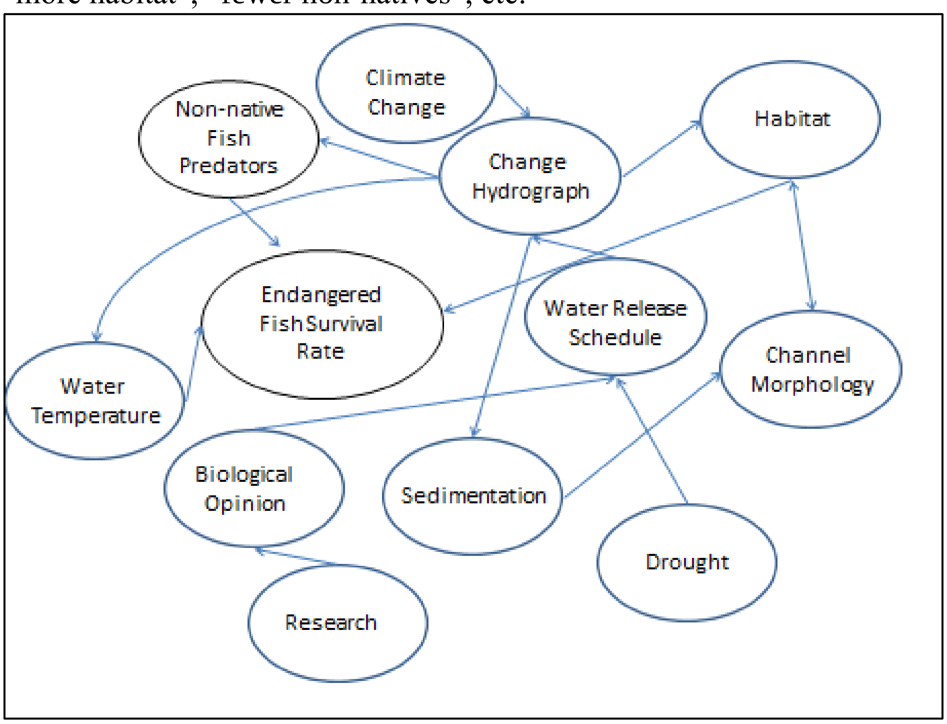

Figure 1: Hypothetical Conceptual Model for Endangered Fish Recovery.

After development of a conceptual model, resolving a dispute over science can then proceed with a study of the physical and/or human geography of the study area. In disputes involving the Bureau of Reclamation, the study area will usually encompass one or more watersheds. A geographic information system (GIS) application should be developed for the study area (Berry, 1993; Berry, 1995; Mitchell, 1999; Malczewski, 1999; Scally, 2006; Morain, 1999). Based upon the conceptual model, the GIS application will contain data and information about the climate, geology, soils, hydrology, topography, and the biosphere. These data are readily available from a variety of sources: GIS Geography, ESRI, the USDA Geospatial Data Gateway, the USBR DataSpace Console, the USGS, DATA.GOV, and many others. State and local agencies can often provide detailed data for immediate regions.

Additional map elements, again, as required by the conceptual model, might include land use and land cover feature classes: wilderness, agriculture, water, industry, commerce, recreation, roads, residences, etc. In some cases, it is also critical to map the social geography of the watersheds, i.e. the elements comprising the composition of the basin's human population: age, race, sex, ethnicity, income, birth rate, death rate, educational attainment, fertility rate, migration rate, crime rate, etc. This information can be obtained from US Census materials, state vital statistics records, local assessor office records, council of government records, criminal justice office records, etc. It is also often important to develop a map of jurisdictional boundaries pertinent to the study area. Clearly, each study is unique and will require consideration of a different set of variables.

Why is a geographic information system application essential? It is because some subset of disputes over science concern what is actually present on the landscape. Disputing scientists and stakeholders must first come to agreement as to what is actually physically present in the study area. Building a GIS application, replete with aerial photographs, current maps, and accurate data can help to alleviate such disputes. It is recommended that the disputing scientists and parties act jointly in this venture. Doing so can build confidence that the data have not been compromised in some way.

Another reason for populating a GIS database is that it helps to operationalize the variables in the conceptual model in terms of project objectives.

> "An *objective* is a statement of the desired state of the geographical system under consideration. It indicates the directions of improvement of one or more attributes. In the context of decision analysis, the attributes can be thought of as indicators of future outcomes (outcome measures)… For any given objective, several different attributes might be necessary to provide a complete assessment of the degree to which the objective might be achieved. For example, if we have the objective "minimize loss of pine forest, "we may use the attribute "acres of pine forest lost" to measure the degree to which the objective is to be achieved. Similarly, if the objective

under consideration is "maximize forest habitat preservation," attributes associated with this objective might be "populations of different animal and bird species," "quality of water in streams," and "acreage of different tree species in the forest." The specific objectives represent the direction of improvement in the forest." (Malczewski, 1999).

In other words, GIS provides a way of quantifying objectives, namely, for example, "the more of X, the better, the less of Y the better".

The GIS application also offers a venue for discussions. For instance, if there were a dispute over wetlands, one of the parties might offer up, "If you will let me build at a higher density here on the map, I will double your wetland over there." (Berry, 1995). Finally, GIS also offers opportunities for spatial modeling of the impacts that various management decisions will have on the study area (Morain, 1999).

In addition to a map of the landscape in question, it is important to ask what *external* forces impinge upon this landscape. For instance, one might observe that climate change, changes in technology like fracking, or political changes such as a change in administration may impinge upon the landscape. The likely impacts of these should become part of the GIS application.

Once agreement has been reached about the inventory of climate, geology, soils, hydrology, ecology, and human factors, next, it is necessary to re-examine, broadly at first, the interactions amongst these factors as they impinge upon the scientific question at hand. To this end, the conceptual model should be revisited and adjusted as necessary, once the GIS application has been developed.

Having reached agreement both on the geography and the conceptual model, other specifics surrounding the science can be investigated to determine where differences may exist. This discussion should begin with an analysis of the degree of concurrence between the parties with respect to key definitions. There may be disagreement, for instance, over what constitutes "habitat" for an endangered species. Does the term refer to just enough resources for species subsistence or, rather, enough resources for the species to thrive and even expand its population? Similarly, classification schemes must be clearly defined. For instance, what constitutes a wetland? What are salient characteristics distinguish a zebra mussel from a quagga mussel? Such issues of classification and definition, which may indeed be a part of the dispute, must be resolved before the scientific dispute resolution process can proceed and the dispute over science resolved.

At this point, the parties must reach agreement regarding the hypotheses. Given the conceptual model, were the hypotheses generated by the previous science, over which there is now a dispute, appropriate? Are new hypotheses needed? And do new data collections and analyses also need to be undertaken?

Whether the old hypotheses still pertain or new ones are required, the parties must come to agreement as to the appropriate data that are required to answer the scientific questions. What levels of accuracy and precision are required? What data attributes must be collected and how should they be measured? Without clear directions, scientists will likely go off independently and collect the data they *think* are required, which may or may not accord with what is actually needed to answer the scientific question. In addition, questions of the protocols for sampling, data acquisition (with associated audits), data validation and quality assessment, laboratory procedures, data documentation, and custody protocols must be settled. This is a critical step. Data protocols must be compared amongst the parties who collected data in the previous scientific endeavors to determine whether these account for the differences over science in dispute. Agreement must certainly be reached if further science is to be conducted.

It is also important to come to agreement concerning the analytic procedures. First, it must be asked, "were the analytic methods used appropriate for evaluating the specific questions and related hypotheses in question?" Would they be characterized as best scientific practice for the type of inquiry at hand? Put another way were the analyses being used recognized as appropriate in the scientific literature? What were the statistical error bars?

It is also essential to scour the data collection and analytic processes for bias. Were the samples truly representative? Were accuracy assessments conducted? Likewise, were analyses conducted in an impartial and objective manner? If different methodologies were used or planned amongst the parties, what are the strengths and limitations of each according to the scientific literature and/or expert opinion? Obviously, if new science must be conducted, the parties must come to agreement as to what analytic procedures will be followed.

Finally, conflicts over scientific findings can also occur. To begin to address these concerns, it must be asked, "Can the science be replicated using the same data or data sampled from the same area?" If not, then it is possible that measurement error has occurred at some point or that the data collection was flawed in some other way? In some cases, differences in instrumentation can cause differences in measurement. Failure to achieve replication brings into doubt the entire scientific enterprise and may require that the parties start from the beginning and conduct new science or at a minimum conduct additional science.

Schumm's Tools

In his widely used book *To Interpret the Earth: Ten Ways to be Wrong*, Stanley Schumm recommends examination of the following items or questions when evaluating or reviewing earth science research. In the research team's view, these may also be fundamental to discussions in disputes over science (Schumm, 1999).

Problems of Time and Space
There are two types of problems regarding time and space. One has to do with the time expended in data collection, which is commonly too little to accomplish what needs to be done. The period of record must be adequate to describe the phenomena of concern. For instance, change can occur in the short term or the long term. A single field season may be an inadequate amount of time to detect change. In addition, as scale increases, so does complexity and the number of variables impinging upon the scientific problem. It is important to examine questions of scale when addressing disputes over science.

Problems of Location
Have the inferences drawn from one location been extrapolated to apply to all parts of the system? For instance, geological processes in one part of a river basin may differ from those in other parts because different parent materials are present or different erosions factors exist. Or one portion of the system may be exposed to a higher energy environment than another. An example of this phenomenon might be erosion rates on south versus north facing slopes.

Problems of Process and Cause, Convergence
Different causes can produce similar effects. For example, channel incision can result from a variety of causes: baselevel lowering, climate change, tectonics, and land use or land cover change.

Problems of Process and Cause, Divergence
Similar causes and processes can produce different effects. “For example, a climate change may trigger massive landslides in one area, gullying in another, and a limited response elsewhere.”

In addition, it is important to ascertain how “work” is being accomplished in the system? What sorts of events (floods, landslides, lightning strikes, infestations, solar flares, human impacts, etc.) occur and how do they then interact to create different system states? It “becomes clear that an understanding of the processes operating and the material being affected by the process is necessary for a confident extrapolation.”

Problems of Multiplicity
The interaction of several causes may converge to create a particular phenomenon. Related questions might be:

- What variables acting together can account for the phenomena in question?
- Have all the relevant variables been specified and accounted for?
- Is there only a partial explanation at present? Must other variables be included for a full explanation?

Problems of Singularity
Singularity is the unexplained variation of the individual case. Generalizations about the population can be made based upon a random sample, but each individual case will contain some residual variation or singularity. Related questions might be, "How does the particular part of the system or particular case in question differ from what might be predicted using the norm? What explains this singularity?"

Problems of Sensitivity
The problem of sensitivity relates to the proneness of a system to respond to minor changes. Related questions might be:

- "At what thresholds do the changes in question occur within the system?" For example, "How much water does the endangered fish require to thrive?"
- "Where are the trigger points or thresholds in the system?" For example, it may be important to determine the point at which a slope fails, the point at which a species has insufficient habitat to survive, the point at which wind mobilizes soil particles, etc.

Problems of Complexity
Problems of complexity refer to the multifaceted, mobile-like response to perturbation. This requires a system-wide understanding. Are there a predictable set of responses to perturbations within the system? Or do they vary? If so, why?

Schumm's questions should be broached to determine if they might be at the bottom of the disputed science. Again, a fully developed GIS application will facilitate discussions of most of these.

Tools for Addressing Specific Disputes over Science

Having addressed geospatial tools useful for managing disputes in the various domains such as biology, ESA, supply and demand, etc., let us now turn to some tools that may be useful for managing specific scientific issues.

Management of Science
Management of science disputes are related to the design and administration of a scientific project or enterprise. Disputes of this sort often result from the lack of a *written project plan* and/or science plan. (Ideally, the plan would have been developed collaboratively with subject matter experts and stakeholders). Those undertaking to review and resolve management of science disputes should ask to see these plans to determine if they addressed the critical scientific issues and adequately spelled out the responsibilities for its implementation. The Strategic Science Plan: Salton Sea Restoration Project is a good example. Critical questions related to the project plan include:

- Was a scoping meeting held to develop the plan? Were any relevant scientific disciplines excluded, that should have been included? Were essential stakeholders excluded, who should have been invited?
- Does the science set forth in the plan adequately address the scientific need, including decision-maker requirements?
- Are there gaps in the science? If so, what additional science is required?
- Have responsibilities for the scientific enterprise been spelled out in sufficient detail? Do new ones need to be added?
- Was a data management plan included in the project plan? If not, one should be added.
- Were provisions made for how measurements were to be taken and how disputes over differing measures would be handled?
- Was the project plan peer-reviewed and was the conducted-science peer-reviewed at significant junctures during the implementation of the plan?
- Did the plan contain provisions for periodic communications with the end user? Were communications adequate tracked and documented?
- Did the plan contain adequate provisions for quality assurance and control?
- Did the plan contain an adequate assessment of risks to the project?
- Was the plan revisited on a periodic basis to ensure that it still reflected the project goals? Were changes is scope, methods, and design adequately tracked and documented?
- If the plan appears to be adequate to meet the original scientific requirement, were other factors involved in the failure of the scientific enterprise such as funding, change of management, change of personnel, change in the law?

If no plan exists, then one should be drawn up. It should peer-reviewed by subject matter experts and reviewed by stakeholders, managers, and end users. This will require a scoping meeting or series of scoping meetings that will include key scientists and stakeholders. Please see Reclamation documentation on project management planning.

Competence

Disputes over competence concerned the qualifications of the scientists conducting a scientific study or the adequacy of a study itself. Relevant questions include:

- What were the educational credentials of the scientists conducting the project? What research credentials qualified them to work on this project?
- Did the expertise of the scientists conducting the project match the project end requirements?
- Were there additional areas of expertise that the project should have included?

- Did the scientists working on the project have substantial experience with this sort of project?
- Were junior scientists adequately supervised by senior scientists?
- Was peer-review included at key milestone junctures?
- Was peer-review of the finished project conducted?
- Is there any reason to suppose that the peer-review was compromised or biased?
- Did the project staff have adequate time and funding to satisfactorily complete the project?
- Were there any other issues or external factors that could adversely affect the competent completion of the project such as a natural disaster, change in political culture, institutional change, or change in technology?
- Is further outside peer-review of the project required, such as by the National Academy of Sciences to ensure that it is competently completed?

Classification

Classification disputes concern the definition or categorization of data and information. Those listed in the survey were disputes over whether a phenomenon or entity was categorized correctly. Classification disputes focused on of wetlands, animal species, a plant species, economic taxonomies, etc. Classification issues can also arise in remote sensing or mapping applications, especially where vegetation categories must be assigned for the purpose of map production and spatial analysis. Relevant questions to manage such disputes include:

- What procedures were followed to select the classification system for this project? What system was adopted, for example, the U.S. National Vegetation Classification System or the Anderson Classification Scheme?
- Why were others excluded?
- Was the classification system developed "from scratch"? Was it peer-reviewed?
- Did the classification system meet the scientific requirements of the project? Were additional classes required? Were there unneeded classes?
- Were the classes assigned both mutually exclusive and exhaustive? Were the defining characteristics of the classes appropriate to this project?
- Were the various classes based upon similar and different properties the elements possess, or were they agglomerative? For example, a land cover of "Forest" (first order agglomeration) may be divided into "deciduous" and "evergreen" trees (second order), then "deciduous" subdivided into "maple" , "beech" and "birch" (third order), etc. (See: Abler, 1971)
- Were the classes adequately defined? Are new elements or defining characteristics required in the class definitions?
- Is the classification system viewed as the best one to use for this type of project in the scientific literature?

- Was the classification system that was chosen too coarse or too fine grained for the project requirements?
- Was the classification system that was chosen reviewed and approved by subject matter experts? Was stakeholder input sought?
- In disputes over biological classification, was genetic testing conducted to determine the correct classification?
- Do Reclamation Directives and Standards pertinent to the classification under scrutiny exist?
- What were the strengths and limitations of the classification system that was chosen?
- Was a competent accuracy assessment of the assigned classifications conducted?

Measurement

Measurement disputes concerned the appropriate way to quantify an entity or a phenomenon. The American Measuring Tool Manufacturer's Association (AMTMA) recommends four possible tools to manage disputes over measurement:

1. The parties could agree beforehand on a method that will be used to settle differences in measurement. This should be a part of the project plan.
2. The parties might agree to use the mean of the various measurements that were taken. A variation would be to calculate the mean from three or more outside parties along with the parties involved with the project.
3. The parties could agree to accept the measurement that has the least uncertainty.
4. The disputants could agree on a third party who will provide a referee measurement which will be viewed as the actual value.

Questions relevant to disputes over measurement include:

- What levels of accuracy and precision are required for this work?
- In addition, what was the level of measurement: categorical, ordinal, interval-ratio? Were these appropriate for answering the scientific question?
- Were the statistics that were used appropriate to the level of measurement? For example, was product moment regression analysis used to process ordinal data?
- Did the instrumentation that was used rise to this level?
- How were differences over measurement resolved?
- Will the methods outlined by the AMTMA serve to resolve the current dispute over measurement?

Standards

These disputes concern the construction, appropriateness, or adequacy of standards or guidelines. There are numerous national and international organizations that produce scientific standards such as the American National Standards Institute and the International Organization for Standardization. In addition, there are governmental organization such as The National Institute of Standards and Technology, the Environmental Protection Agency, and the Bureau of Reclamation that produce and maintain standards. Finally, the peer-reviewed literature pertaining to each recognized scientific discipline regularly discusses standards and best practices for conducting science. For disputes of this type, relevant questions might include:

- What standards were adopted for this project? Are they officially recognized standards? Were they adequate to meet the scientific requirement?
- Was adequate training provided to meet standards requirements?
- Were the standards used required by law, i.e. *de jure* standards?
- Were the standards used *de facto* standards? If so, are they recognized as best practice within the discipline?
- Were the standards deployed in keeping with best practice in the scientific literature?
- Are there Reclamation directives and standards pertinent to the current dispute?
- Were the adopted standards peer-reviewed by subject matter experts?

Data

Some scientific disputes are concerned with the proper collection of the project data. Or they dispute the adequacy, quality, integrity, currency, or appropriateness of the data for a particular scientific or decision requirement. Every scientific endeavor should have an associated data management plan. Those managing a dispute over data should ask to review the project's *data management plan*. (The U.S. Geological Survey has developed best practices for the management of data and for the development of a data management plan.)

The plan should be examined to determine if it adequately addresses the areas of acquisition protocols, data quality, data maintenance, data access, data analysis, data reporting, and data archival. In addition, the reviewers should ask to see if the plan was provided to partners and contractors. Relevant questions for disputes over data would include:

- Was a written data management plan prepared and reviewed on a periodic basis?
- Was the plan peer-reviewed?
- What data management elements were included in the data management planning process, for example, data acquisition, evaluation, maintenance, access, analysis, reporting, and archival?
- Were the individuals handling the data associated with this project trained on the plan and required to gather, quality check, process, and maintain the data in accordance with its provisions?

- What quality assurance measures were in place? Was a quality assurance plan prepared?
- What plans were made for the integration of data from the various parties collecting data: Reclamation personnel, partners, contractors, etc.?
- How were the data documented? What metadata process was followed?

If a data management plan was not prepared, then a plan must be prepared as the dispute resolution process proceeds.

Analysis
Disputes over analysis were concerned either with the establishment of causality between one phenomenon and another or with "getting to the bottom" of some issue. Though causality can be indicated, it is very difficult to infer. Relevant questions related to causality include (Trochim, 2008):

- Can it be established that the purported cause preceded the effect?
- Can it be established that where and when the purported cause is not present the effect is not present on the landscape? In other words is there a spatial correlation?
- Can it be shown that there is temporal and/or spatial co-variation between the purported cause and effect?
- Can alternative explanations for the effect in question be ruled out?
- Is it possible that multiple-causality is at work? Were multiple hypotheses tested as to possible contributing causes to the effect in question?
- Can the proposed cause be classified as a necessary, but not sufficient cause of the effect? Can it be considered a sufficient cause of the effect?
- Is there a mechanism evident, which would plausibly drive the cause to create the purported effect? An example might be the forcing mechanisms that latitude, land or water surface, and the percent carbon dioxide in the atmosphere have in driving climate.

Agreement must be reached ahead of time as to what level of correlation is sufficient to state that a relationship is strong enough that a causal relationship can be inferred or indicated—acknowledging in advance that while causality will nearly always infer correlation, correlation cannot always be said to infer causality. Sometimes, it will be useful to involve one or more subject matter experts and statisticians in the process of inferring causality. In extreme cases expert peer-review processes can be called in to sort out questions of causality.

The second type of analytic question was concerned with "getting to the bottom" of something, such as answering a question. For example, scientists might try to determine the presence or absence of certain trace elements in a lake substrate. Disputes of this type should begin with interviewing the *scientists who questioned the previous science*. The following questions may be asked in the interviews:

- What do you specifically question in the previous scientific endeavor: axioms, assumptions, definitions, problem statements, hypotheses, data, sampling, measurements, analytic methods, interpretation, reporting, peer-review, reproducibility, etc.? Please prepare a specific and detailed analysis.
- What would you change in the analyses to improve the science?
- What do you see as the gaps in the present science? How can they be addressed?

A report should be prepared of the deficiencies that were alleged. This critique should then be evaluated by competent subject matter experts and a judgment rendered as to the adequacy of the analysis.

Modeling

Disputes over modeling encompassed issues such as the adequacy of the model for the scientific problem, the appropriateness of the data inputs, model calibration, the area and temporal extent of the data, model uncertainty, and determinations as to what decisions to make or actions to undertake based upon model results.

The Army Corps of Engineers has developed an approach to modeling that it contends will avoid many of these problems. This approach is variously called Collaborative Modeling, Computer Aided Dispute Resolution, and Shared Vision Planning (Cardwell, et al, 2009).

This approach combines scientific analysis, including modeling, with facilitated collaborative processes to assist in the management of scientific and other types of disputes. Participation from stakeholders, the public, scientists, and governmental agencies is viewed as key to successful modeling. Collaborative construction of models builds relationships and trust among scientists and stakeholders and promotes group learning. In addition, the participatory process enhances the acceptability or credibility of the model output.

Collaborative modeling begins with an identification of stakeholders and their needs. Advocates for the sustainability of the natural resource in question must also be identified. Conceptual models of the problem are built. A set of mutually beneficial alternatives is selected. Modelers are hired and, in facilitated group meetings, a systems model is constructed to address the collective requirements of the participants and the natural resource. (In the case of a dispute over science, the model would be selected or modified to meet the technical requirements of the scientific problem). A variety of interacting models may ultimately be required: groundwater models, econometric models, demographic models, etc.

In the collaborative process just outlined, team members learn about one another. Their vision of the problem begins to encompass other scientific disciplines.

Economists learn from biologists who learn from geologists who learn from civil engineers. In scientific disputes over modeling, one or more of the following questions could be asked:

- Was the scientific problem completely defined using a conceptual model, such that the model would encompass all germane aspects of the problem? Did the conceptual model leave out any important elements or relationships? Were the temporal and spatial limits of the problem the right ones?
- What role did the scientists, stakeholders, and partners have in construction of the model? Did the parties agree that the model would yield scientifically credible results?
- Was the model selected appropriate for the class problem? For example, should a probabilistic model have been used instead of a deterministic model? Were additional models such as meteorological, hydraulic, demographic, etc., needed?
- Were the model inputs variables spatially and temporally compatible? For instance were the same spatial extents or units (30 meter pixels, hydrologic units, census blocks, township and range, etc.) used for each of the variables? For example, were the areas from which temperature data was drawn comparable to the resolution of the remote sensing data that were used? Were time steps equivalent, for instance, were the time steps of one variable in hours and another in days?
- If historic data were used, was the period of record sufficiently long enough to give a representative sample?
- If data on historic conditions were used as inputs, were they being compared to current conditions, which could be very different?
- How was the model calibrated? Were the calibrations and parameterizations appropriate?
- Was the model peer-reviewed by independent experts to ensure its scientific integrity?
- Did the parties agree in advance how the results would be interpreted and used to make decisions?
- What alternative(s) that would be beneficial to the stakeholders and the sustainability of the natural resource were used to guide model construction?

Interpretation

Differences in inferences can also occur and it is important to identify these differences. At the most basic level, inference is simply the determination that the stated hypotheses have been validated or invalidated. A remedy for disputes over interpretation or inference is to ask the parties to lay out in detailed terms their reasoning for the interpretations and inferences they have made. These can then be discussed and evaluated at length by the dispute resolution team. In some cases expert independent reviewers will be required to validate or invalidate the various interpretations of the findings. Relevant discussion questions might include:

- Was the validation or invalidation of the hypotheses straightforward or did ambiguities exist? Could steps be taken to remove these ambiguities, such as collecting more data?
- Were the interpretations of the findings objective? Was there evidence of bias in the interpretations? If so, where did evidence of bias exist and how can it be rectified?
- For inductive conclusions, identify the premises and the conclusions of the disputed science. How strong are the inferential links between the premises and the conclusions? Given the strength of the premises, are the conclusions of the research in dispute more probable than improbable? In other words, given that the premises are true, does the probability that the conclusions are true rise to greater than 50%? Has contradictory evidence been thoroughly investigated and ruled out? (Hurley, 2006)
- For deductive conclusions, it must be determined that both the premises are true and the argument is valid, meaning that, if the premises are true, that the conclusion must be true. Therefore, both the premises and argument must be examined. (Hurley, 2006).
- Were the interpretations and conclusions peer-reviewed by competent, independent scientists?
- Have the scientific findings been replicated?
- Have alternative hypotheses been disproven?

Summary

The Reclamation-wide electronic survey disclosed that scientific disputes emerged regarding the management of the scientific enterprise, classification, competence, measurement, data, standards, analysis, modeling, and interpretation. This section provided a set of tools that may be useful for managing disputes of this type. Peer review and thoughtful planning from the beginning appeared frequently among these. Detailed scrutiny of the disputed scientific enterprise and its implementation also played an integral role in resolving the dispute over science. Disputants of the existing science are asked to specify completely the nature of their concern. Above all, collaboration between and among the scientists, the public, and stakeholders was considered essential to managing disputes over science.

Forums for Managing Disputes over Science

There are six broad categories of forum for managing disputes over science: direct discussions between scientists, independent expert review, undertaking additional science and analysis, collaborative research, public education, and adaptive management. Survey respondents were asked to indicate which of these forums they had used and then comment upon the forum's effectiveness.

What follows is a description of each of the various forums for managing disputes over science. Any of these might make use of the various tools that have been outlined thus far. It is believed, however, that making use of geographic information technology could be of benefit in nearly all, if not all of them.

Direct Discussions between Scientists

"Direct discussions among scientists" are just that. They are forums that bring technical experts involved in a scientific dispute together to identify areas of agreement and disagreement, data needs and gaps, appropriate scientific protocols, and potential approaches to resolving technical disputes. A few years before the survey, the research team conducted focus groups in Reclamation Area Offices to investigate the causes of conflict over natural resources. The team learned that it was not uncommon for scientists involved in one or more facets of an ongoing scientific investigation to reach what appeared to be inconsistent results, conclusions, interpretations, etc. In such cases, the first alternative was nearly always to invite the disputing scientists to hold discussions to ascertain where differences arose with respect to assumptions, hypotheses, data collection methods, analytic methods/procedures, classification systems, etc.-- and if the differences were minimal, to resolve them.

Generally speaking, the direct discussions approach assumes that differences in the science are fairly minor and can be cleared up by identifying and then explaining differences in assumptions, definitions, theoretical perspectives, methods, and conclusions. Questions to ask of the scientists to determine if differences are major or minor include:

- Have you reviewed the scientific work of the scientists with whom you disagree and who are also conducting work in this domain? If you have, can you pin-point where the differences in science exist? Can you provide a detailed account of the differences?
- If so, do you view your differences as easily resolvable, moderately difficult to resolve, or very difficult to resolve?
- What do you view as the time-line for resolving the scientific differences you have: days, weeks, months, years?
- Do you believe that conducting additional science will be necessary to resolve your differences? If 'yes', how much?
- Would it be helpful to have a facilitated discussion to resolve your differences?
- Do you believe that an expert neutral party or expert panel will be necessary to resolve your differences?
- Do you believe that this ostensible dispute over science is really a dispute over something else such as values, politics, personalities, etc.? Are these

differences easily resolved, moderately difficult to resolve, or very difficult to resolve?
- Have you been hired to represent one of the parties in this dispute?

Direct discussions generally require the following conditions to be successful:

- The disputing scientists are able to converse in a mutually respectful and collegial manner.
- The differences in the science can be pin-pointed and easily resolved. For example, the differences can be traced to minor differences in terminology, classification, or theoretical perspective.
- Little, if any, additional science must be conducted to resolve outstanding differences.

If the scientists are conversant about each other's work, able to pin-point differences, consider them to be easily resolvable in a short span of time, believe that little if any additional science needs to be conducted, think there is no need for neutral third party review, and do not see the dispute as anything but a dispute over science, then direct discussions between them may be the tool of choice to use.

Direct discussions amongst scientists can result in quick resolution of differences according to those working in the Area offices. However, if necessary, the Basic Tools (including GIS) listed early on in this document can be used to help pin-point differences in conceptual maps, assumptions, nomenclature, theoretical perspectives, protocols, data, analytics, etc.

At each step in the Basic Tools checklist, the scientists should ask themselves, "Are these differences easily resolvable in terms of effort, money, and time? Is more science required? If more science will be required, what level of effort will be required?

Obviously, to be successful, this approach requires that the scientists involved willingly and openly share the particulars of their research questions and associated hypotheses, methods, results, and inferences. If the purported differences in science are, in fact, a cover for differences in value or politics, direct discussions by themselves may not be productive. The discussions may have to be conducted in tandem with other conflict management approaches. In cases where one or more parties will not disclose their hypotheses regarding the scientific issue at hand, the dispute resolution professional may reasonably consider the possibility that the dispute over science is a red herring. Other dispute resolution techniques such as facilitation, mediation, or arbitration may be required.

Direct discussions are primarily successful where disputes over science are neither deep nor complex. The strength of this method is that it can succeed in a fairly short span of time and with very little effort compared with other methods. This results in savings in time and money. Direct discussions will not be successful where scientists are unwilling or unable to communicate with one another. It will not be successful where they are unwilling or unable to discuss or even reveal their hypotheses or methods.

Independent Expert Review

Independent Expert review recruits one or more outside experts to review the disputed science and reach conclusions regarding the weight of the evidence and the adequacy of the science. Peer-review has been defined by The National Research Council (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 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).

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).

Independent Expert Review involves obtaining scientific review that is independent from decisions makers. A National Institutes of Health (NIH) peer-review working group developed some peer-review implementation priorities (NIH News 2008). First of all, reviewers should be thoroughly trained and should be compensated for their work. Seek assurance from the prospective reviewers that they have the time to commit to the work, that they have no conflict of interest, and that they can be objective. It is important to carefully match the expertise of the reviewers with the science they are to review. The rating system should be worked out and agreed upon in advance. Ideally, peer-reviewers will themselves be monitored and reviewed over time.

Meetings should be held with the scientists, stakeholders, managers, and peer-reviewers to brainstorm exactly where the disputes in the science reside. The reviewers should ask to see both the project and the data management plans, along with the final reports. Review should consist of, but not be limited to the following questions:

Questions of Study Management

- Do the scientific questions accurately reflect the study objectives? Was a conceptual model of the problem prepared? Has the problem been

adequately defined? Are any important variables missing from the analyses?
- Have all the relevant questions been asked to meet the study objectives?
- Do the scientific questions address the needs of Reclamation decision makers and the sustainability of the resource?
- Was a project plan prepared? Was a data management plan prepared? Were the data adequately documented and managed?

Questions of Expertise
- Were the appropriate scientific disciplines incorporated into the study? Should others be included?
- Was the literature review adequate?
- Are the scientific assumptions sound?
- Are there flaws in the experimental design?
- Are all of the potential hypotheses relevant to the original question being addressed? Are there any that have not been addressed?
- Were best practice protocols used to collect, manage, and process the data?
- Have the results and findings been replicated elsewhere? Overall was the science competently executed?
- Were the data adequately evaluated for integrity, appropriateness or relevance for the scientific question, and currency?

Questions of Data Analysis
- Were the inferences drawn from the results objective and valid? Could others be drawn just as validly? Was contrary evidence tracked down and taken into account when the inferences were drawn?
- In using existing science was the suitability and compatibility valid? Are there possible or likely implications that could make it valid?
- Were all the potential hypotheses relevant to the original question addressed? Are there any that have not been addressed?
- Were the scientific assumptions sound. Were inferences about cause and effect sound?
- Were there flaws in the experimental design? Was the sampling design adequate? Were sound statistical analyses conducted?

Questions about Data Quality
- Were measurements correctly made?
- Were classification schemes adequate and valid?
- Were prepared models adequate to address the scientific question(s)?
- Were sound scientific standards observed?
- Were there gaps in the science? What further steps need to be taken to address the gaps?

In addition to these questions, it is recommended that Schumm's questions, listed previously, also be examined at length in any peer-review.

Recruiting third-party scientists to review studies can help to resolve conflicts between scientists (Adler et al. 2001). Third-party peer-reviewers not only examine the previous science and other relevant available information, but may even conduct additional research before providing recommendations to decision-makers.

Undertake More Science and Analysis

In certain cases where a dispute over science exists, independent of other parties, Reclamation may undertake additional studies or analyses in an effort to resolve concerns or conflicts. Reclamation maintains nationally and internationally recognized expertise in water resource management. It regularly provides both engineering (hydrologic, hydraulic, civil, agricultural, mechanical, electric, etc.) and environmental science expertise to Federal agencies, states, localities, stakeholders, and the public. When disputes over science occur, Reclamation has the personnel and equipment to conduct the science required to answer the germane questions. The agency has a rigorous internal peer-review process and, where prudent or necessary, willingly submits its work for outside peer-review.

Active Collaboration in Research and Analysis

Collaborative Research or Learning "is a framework and set of techniques intended for multiparty decision situations. It is a deliberative process, which involves designing and implementing a series of events (meetings, field trips, joint fact-finding, cooperative modeling efforts, etc.) with scientists, stakeholders, managers, etc. to promote creative thought, constructive debate, and the effective implementation of proposals that the stakeholders generate." (Daniels, et al, 2001). It is a blend of several fields: conflict management, learning theory, and systems theory. It seeks to create shared learning as people meet and collaboratively investigate the issues before them. It actively recruits scientists, stakeholders, agencies, and the public into a joint learning experience designed to make improvement to the existing state of affairs. Conducted appropriately, collaborative learning can put the dispute over science into a larger context and make the results more satisfactory for all parties. (Analysis of survey responses indicated that this forum showed superior outcomes as compared to the other five forums).

Practitioners of this approach to problem solving, believe that policy decisions should respect ideas and knowledge gleaned from a variety of disciplines including physical science, social science, traditional knowledge, and local knowledge. They assert that cultural differences and differing world views among the parties must be understood and respected. This approach further asserts that decision quality is a positively related to knowledge development or learning. In short, better decision processes result from better learning (Daniels, et al 2001). Learning itself, then, becomes the foundation upon which to base collaboration. This involves conduct of inclusive meetings, field trips, joint-fact-finding, workshops, experiential exercises, etc. designed to promote mutual learning, innovation, constructive debate, and decision-making.

Collaborative learning takes a *systems* approach to understanding the issues. It looks for interrelationships rather than linear cause and effect chains, and examines processes of change rather than "snapshots" (Daniels, et al, 2001). This technique has been used for community level planning, organizational learning, and natural resources management. For communities, systems learning might examine politics, laws, infrastructure, organizations, kinship groups, social networks, etc. In a like manner, for natural resources management, this approach looks at the matrix of atmosphere, geology, biology, hydrology, anthrosphere, and the like. Collaborative learning emphasizes that these are interacting systems and asks participants to recognize that learning about these systems will have to occur before workable solutions can be reached. (See: Walker and Daniels). (As mentioned previously, GIS applications can be built to facilitate system understanding). Systems contain:

- *Elements*, i.e. the tangible items that constitute the system such as soil, trees, formation, mammals, humans, minerals, and water.
- *Relationships*, which are the dynamic connections between the elements. These would include transportation, communication, predation, symbiosis, constraint, etc.
- *Boundaries*, or system edges, which distinguish between what is included in the system and what is external to it.
- *Inputs*, which are the things that flow from the environment into the system such as money, political authority, sunlight, rain, pollution, etc.
- *Outputs*, or the things that flow from the system into the surrounding environment such as drainage, pollen dispersal, radiation, evaporation, crops, and the like. (Daniels, et. al., p. 105)

Systems mapping can be a valuable tool for understanding the current dispute and its underlying processes. A systems map is a collaboratively constructed graphic, composed of boxes, lines, and arrows that is used to gain a shared understanding of the problem. The boxes are "elements," the lines between them contain verbs to convey the dynamic relations. Bounding the systems in time and space takes place early on. Ideas are generated collaboratively without critique during the mapping process. The objective is to portray the fundamental forces that drive, reinforce, and constrain the system and to come to a shared vision amongst the participants. This does not mean that all participants agree with its contents, but do, at least, acknowledge the views of others. (See Daniels, et al, 2001).

Collaborative mapping, modeling, and analyzing these constituent parts, their interactions, and feedbacks can provide powerful insights into system dynamics and illuminate the impacts various parties to the conflict have on the system.

Several steps are involved in coming to grips with internal and external forces that impinge upon the system. The first is to collaboratively gather information, i.e. people's accounts of the situation. Semi-structured interviews and focus groups are often used for this purpose. The goal should be to gather the fullest range of perspectives possible. The purpose of these communications is to arrive at a shared understanding of the facts surrounding the issues at hand.
The next step is to summarize or amalgamate the multiple perspectives into a single representation of the situation. What follows is the development of a vision for an improved system, state, or scenario (Daniels, et al, 2001). Both the existing system and proposed system are collaboratively modeled. As modeling proceeds, visions of future states and related statements are refined. In addition subsystems are uncovered and maps, inputs and outputs are defined, boundary issues are resolved, and measures of performance are developed. Decision processes are agreed upon, and environmental effects on the system at hand are clarified. Model outputs are scrutinized in an effort to find a convergence scenario that addresses the problematic dimensions of the status quo. The final step is to develop and put into place an implementation plan (Daniels, et al, 2001).

Collaborative learning has a variety of strengths. It is less competitive than other approaches and more accepting of new parties because they are viewed as contributors. It is based on joint learning and fact-finding; the learning is an ongoing process. The forum acts to integrate scientific and traditional knowledge about the problem/situation and thereby develops an improved understanding of the specific problem situation. It fosters a clearly articulated systems-based perspective concerning the problem situation (Walker and Daniels, http://oregonstate.edu/instruct/comm440-540/CL2pager.htm). Conclusions are generated by participants during the course of their deliberations. It, therefore, has the potential to build individual and ongoing community capacity in such areas as conflict management, leadership, decision-making, and communication (Daniels, p. 63). Since stakeholders are part and parcel of the decision process, the bases for the ultimate decisions that are made are transparent. Finally, it allocates the responsibility for implementation across many participants.

Public Education, Data Sharing, and Results Dissemination

Nearly all of the forums discussed in this document involve some form of public education or outreach. Public outreach activities are designed to inform the public and stakeholders about technical issues, existing data and science, and Reclamation's analysis of the information. CMP P03 of the Reclamation Manual states that:

> …whenever Reclamation actions may significantly affect individuals or groups, Reclamation will systematically provide opportunities for affected individuals, groups, and communities to be informed about the issues; as appropriate, participate in the definition of the problem, objectives, and possible solutions; and have their views documented and considered in Reclamation's decision-making processes.

Reclamation policy requires public outreach and education under certain conditions. If these conditions pertain, Reclamation must inform the public and gather feedback when a dispute over science is in question. Every effort should be made to identify and invite anyone who may have a stake in the outcome of the dispute over science. These efforts can take many forms: brochures, websites, public meetings, social media, newspapers, visitor centers, and broadcast media.

In public forums, Reclamation presenters must be adept at making technical information intelligible to lay persons, without distorting the substance of the science. It is beneficial if a trusted member of the local community will help explain both the nature of the dispute over science and the technical issues inolved. Local scientists should be invited to the meeting to ensure that someone in the community has understood the technical content of the agency presentation—someone who can explain it to others, as well as raise technical questions with Reclamation representatives.

Room set-up for public meetings is critical. While the presenters or facilitators may need to be in the front, they should not be elevated above the audience and must not appear to "talk down" to those present. It is best that they do not appear in uniforms. In addition, presenters should consistently be open, fair, and honest. This fosters legitimacy, credibility, and a spirit of collaboration. The public may not fully agree with the final decision. Nevertheless, they may more likely accept or support an action when their voice has been heard (Doerman, et al 2012).

Additional benefits of the public forum include (see Reclamation Manual, CMP 04-01):

- Offering the public opportunities to participate in the decision-making process,
- Providing information about issues and decisions under consideration
- Developing documentation on how public and stakeholder input is being considered

Consulting and coordinating with the public can help to identify potential conflicts and issues, foster the development of supportable solutions, and build agency credibility.

Adaptive Management

Adaptive management is a systematic approach to natural resource management. It is particularly useful when:

- There is substantial scientific *uncertainty* regarding the most appropriate strategy for managing natural resources,
- There is good collaboration with cooperators/stakeholders,
- And criteria and stipulations can be developed to allow for effective planning.

This forum identifies alternative approaches for managing a natural resource, implements one or more of these approaches based upon the best current science, enacts a monitoring program, and then uses what has been learned to adjust future management actions as required (Williams, et al, 2009). For disputes over science where several avenues of resolution exist, Adaptive Management offers a good potential solution.

Successful use of Adaptive Management requires real-time learning and knowledge creation to effectively change operational plans and processes as the accumulating data require. Stakeholders and managers must be committed not only to the stated management objectives, but also to the complementary monitoring phase with its associated metrics/indicators. Data gathered during the monitoring phase is an integral and essential component of the evolving knowledge base. The data are pertinent to intelligent management actions within the natural system. Adaptive management plan architects must develop identifiable thresholds that will identify when a management response is required.

Flexibility in management/decision-making must exist to provide a nimble level of control in the system. Managers must be able to adapt readily to the changes the natural and human induced changes that occur. They must also skillfully address system uncertainty and any issues that arise that foster it. There must also be a certain amount of tolerance for risk among the parties and decision-makers, owing to the fact that, by definition, system uncertainties can and will "spring surprises". Finally, the adaptive management plan must be implemented in a manner consistent with applicable laws. (Williams, et al 2009)

Figure 2 diagrams the Adaptive Management approach: assess the problem, design one or more management approaches, implement one of the management approaches, monitor the system response, evaluate the management approach's effectiveness, and, when required, adjust the approach to better address the original problem.

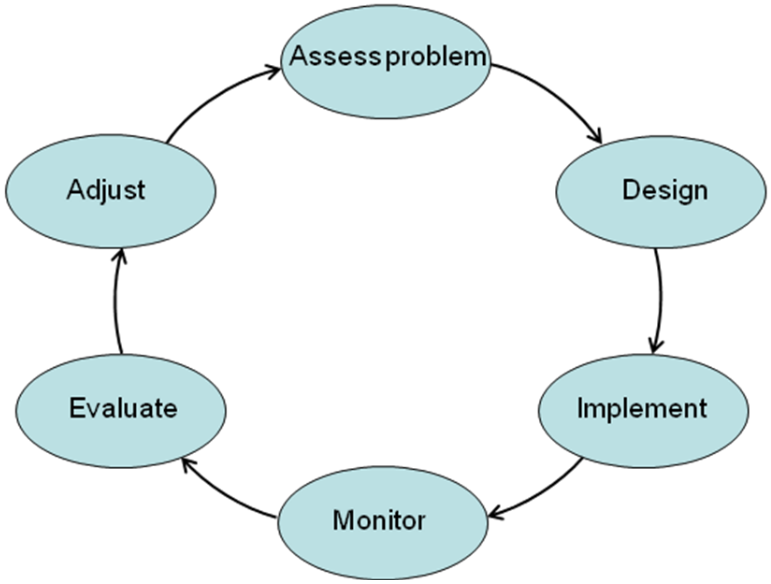

Figure 2. A diagrammatic framework for the adaptive management process of learning by doing (Nyberg 1999).

The process begins with capturing stakeholder commitments to use the adaptive management framework to address the natural resource dispute. (When this is a dispute over science, adaptive management is particularly useful for sorting out workable and unworkable alternatives for the management of the resource). The next step is to collaboratively identify clear and measurable objectives to guide decisions about the resource's management. After this is done, management actions in pursuit of these objectives must be developed. Models that characterize various hypotheses about how the natural and human systems in question work should be developed next. One of the management actions should be implemented and, at the same time, a monitoring plan should be initiated to determine how the natural and human systems respond. Monitoring will provide data to determine whether selected management alternative was indeed viable. Results should be carefully evaluated, adjustments made, and further monitoring instituted. As Figure 2 indicates, adaptive management is an iterative process. Continued assessments and adjustments can be made through time. (Williams, et al 2009, Williams et al 2012).

Adaptive management is applicable for small-scale local resource projects as well as large-scale conservation programs. Legal constraints may impinge on planning processes. Adaptive management reduces the uncertainties that limit effective management of natural resource systems and produces a practical management operation that promotes sustainability. According to Williams et al, 2009:

- Adaptive Management is inherently democratic, requiring, as it does, that stakeholders stay involved and committed to resource objectives.
- It promotes adaptive learning. The adaptive process is based on science designed to understand the resource better and, thus, to make increasingly intelligent management decisions in its behalf.

- It is risk tolerant. Plans for uncertainty are part of the adaptive management fabric.
- It is re-iterative and the management plan is flexible so it can adapt to unexpected or unintended consequences of a selected management strategy. Since it is guided by targeted monitoring of the impacts of management on the resource, Adaptive Management allows for addressing system variability.
- Knowledge gained at one site can often be applied to other sites.

Williams et al point out that limitations are inherent to the adaptive management process. It is neither short-term nor inexpensive. A considerable amount of upfront planning is required to make progress in achieving project objectives and for creating a framework for sustainability. Adaptive management requires patience, flexibility, careful planning, and evaluation. If surety is required, such as knowing exactly what outcome, response, or control must happen – and there is only uncertainty; then developing an adaptive management strategy to comply in a NEPA situation requires a lot of detail to address the environmental consequences of that management plan before implementation.

Adaptive management will fail when (Williams et al, 2009; Williams et al, 2012):

- Stakeholder collaboration or agreement cannot be reached about resource management objectives, adequate funding is not available, and/or technical expertise is not available;
- There is insufficient time to allow the iterative process to work and management actions or policy to be adjusted;
- When the parties are risk averse or certainty is a requirement;
- A monitoring program cannot be put in place to guide management decisions;
- There exists no flexibility in the decision-making or policy/legal processes to achieve management alternatives.

Summary

Broadly speaking, six forums are available for the management of disputes over science: direct discussions among scientists, outside peer-review, conducting more science, public outreach and education, collaborative research, and adaptive management. Direct discussions work best when differences are minor. Outside peer review offers a means of bringing a new set of eyes to the problem in order to clear up gray areas and offer new direction. When gaps in the science are determined to be present, Reclamation often can often make personnel and expertise available to conduct additional science. Public outreach can be used when confusion exists amongst various segments of the body politics over technical data or methods. Collaborative learning allows for scientists, stakeholders, the public, and managers to jointly tackle a problem, identify solutions that benefit from a diversity of understandings, and potentially add new institutional capacity for managing future problems. Adaptive management is particularly useful for disputes over science characterized by sizable uncertainties. It offers a way for scientists, managers, stakeholders, and the public to develop alternative management approaches, implement one, monitor the results, and make adjustments at new data are added to the collective knowledge base.

Discussion

Disputes over science exist in Reclamation offices and in every aspect of water management that the agency touches: agriculture, infrastructure, the biosphere, water supply, the hydrosphere, etc. The disputes exist in many facets of the related science: project planning, categorization, data, analysis, interpretation, and so on. These differences are aggravated when discussions fail to include significant parties: stakeholders, the public, public or private agencies, and scientists.

There are six broad categories of forums for managing disputes over science: direct discussions among scientists, independent expert review, Reclamation undertakes more science, public outreach and education, collaborative learning, adaptive management. According to previous research, collaborative learning processes were considered to be the most efficacious, followed in order by a tie between direct discussion and adaptive management in second place, followed then by a tie between public outreach and education, then Reclamation conducts more science, and, last of all independent expert review (Clark, 2014). The predominance of collaborative efforts seems to underscore the words of Herman Karl, former chair of the Massachusetts Institute of Technology-USGS Science Impact Collaborative (MUSIC):

> What we advocate is that scientists need to be engaged, be at the table for discussions, instead of jumping into the process at the final stages. Scientists should be part of the stakeholder group (Karl, 2006).

Collaborative processes whether in the form of joint fact-finding, public outreach, cooperative modeling, or adaptive management, appear to pay significant dividends.

Geographic information systems provide a set of mapping, modeling, and analytic tools that can help the parties to visualize both the problem and possible future states.

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Data Sets that support the final report

If there are any data sets with your research, please note:

Share Drive folder name and path where data are stored:

This project was an anonymous survey conducted with the assistance of the U.S. Geological survey. The data are confidential and not available for circulation.

Point of Contact: name, email and phone: Douglas Clark, drclark@usbr.gov, 303-445-2271

Short description of the data: (types of information, principal locations collected, general time period of collection, predominant files types, unusual file types.)

This project was an anonymous survey conducted with the assistance of the U.S. Geological survey. The data are confidential and not available for circulation. The data exist as tabular spreadsheets. The survey was conducted across Reclamation in the year 2011.

Keywords: Disputes over science. Conflict management.

Approximate total size of all files: 150 megabytes.