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Managing Uncertainties in Radioactive Site Clean-ups

Clark University

Robert Goble
Clark University

Abel Russ
Clark University

Octavia Taylor
Clark University

Seth Tuler
Clark University

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by

Robert Goble
Abel Russ
Octavia Taylor
Seth Tuler

George Perkins Marsh Institute
for the Study of Human-Environment Interactions

Clark University
950 Main Street
Worcester, MA 01610

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Introduction – Uncertainty is a challenge for management; it is not solely a limitation to assessment.

In the environmental and public health arena, uncertainty is like the weather: people talk about it, but no one seems to do much about it. In this paper we suggest that, in the difficult and often contentious situations involving cleanups at radioactive sites, good discussions of uncertainty among stakeholders can prove helpful; even more significantly, however, we also suggest that addressing issues posed by uncertainties should be an integral part of planning, of implementation, and of follow-up.

We develop these suggestions through a sequence of observations: uncertainty can be usefully examined and addressed only in a context that recognizes the particular technical difficulties posed by radioactive materials, that recognizes as well that diverse stakeholders hold diverse perspectives and concerns, and that explicitly acknowledges the legacy of distrust attached to most of these sites; cooperation among the stakeholders at particular sites should lead to clear objectives for plans to address the challenges posed by uncertainties; such objectives and planning are not usually found in standard practice for radioactive site cleanup; while every site has its particular challenges, we can identify some key elements that will serve as a basis for planning.

Our goals in this discussion derive from our belief that effective cleanups that meet broad public health and social welfare objectives are most likely to occur when there is real cooperation between the parties responsible for cleanup and the affected communities. Such cooperation at most radioactive sites of concern is extremely difficult to achieve. The technical nature and complexity of the issues is a serious barrier to communication: faced with lengthy and incomprehensible technical documents that set forth apparently arbitrary goals for cleanup, community people may well feel that the responsible parties are not addressing their principal concerns, and often enough this perception is correct (Goble 1993; Goble and Thompson 1994; Goble 1998). Furthermore, at many sites there has been a long history of mishandling of radioactive materials, of secrecy and concealment, and of exclusion of the public from decision-making processes. The legacy of fear and distrust extends in both directions: the public does not trust the technical community to protect it or even to give adequate warning of problems; the technical community expects irrational fear and unreasonable demands from the public.

In such unpromising settings, the inevitable presence of large uncertainties can very well exacerbate failures in communication and understanding. However, this challenge to cooperation is also an opportunity for the different parties with their different perspectives to make the effort to develop shared understandings and to cooperate on appropriate plans for addressing uncertainty. Our intent is to offer pointers toward cooperation that will be useful both to members of the technical communities involved in cleanup planning and implementation and to concerned members of the public.

Uncertainties must be considered in a context that recognizes the many technical and managerial difficulties posed by radioactive materials, that recognizes as well that diverse stakeholders hold diverse perspectives and concerns, and that explicitly acknowledges the legacy of distrust attached to most of these sites

The many difficulties that confront plans and programs for cleaning up the legacy of radioactive sites across the country are by now familiar. These include the persistence of the radioactive contaminants, the fear-provoking health effects of delayed cancers and genetic damage, the associations with nuclear weapons, the long periods of operations when only limited and unsystematic attention was paid to monitoring for potential exposures and risks, the large scale of many operations and the difficulty of reconstructing what actually occurred, the lack of agreement or even predictability on cleanup objectives and on future uses of the sites, a lack of knowledge and experience about the full consequences of various cleanup choices, the irregular flow of resources to the cleanup efforts, and the often contentious attempts at organizing public participation in planning oversight. The difficulties have inspired much innovative work technically in developing new engineering approaches to isolating radioactive materials, and in better monitoring and modeling capabilities, and managerially in providing opportunities for public and other stakeholder involvement. Nevertheless, the difficulties and the contention are still very far from being resolved, and there are very few completed cleanups that are widely accepted as successful.

Of course it is also widely known that there are very substantial uncertainties associated with these difficulties. We consider it useful, however, to distinguish different types of uncertain situations that pose a challenge to management. The following categories are based on a preliminary classification that we created a few years ago (Goble and Hattis 2001); while we are presently updating that classification, we consider these examples to be useful in their present form for considering characteristic challenges to management.

1) Uncertainties in general knowledge relevant to risks from radioactivity about which there is already a considerable amount of information and debate and for which there is little reason to expect that new information will substantially reduce uncertainty or quiet the debate. The principle example here is health effects of ionizing radiation, particularly at relatively low doses. There is a majority position based on a linear extrapolation of risks from the study of Japanese survivors of atomic bombs; it is reflected for example in the BEIR VII report (BEIR VII, 2005). That position already assumes considerable uncertainty; but in addition there are significant minorities who either believe that low-dose radiation is more dangerous than the linear extrapolation, or who believe that low doses of radiation are substantially less dangerous or even protective. There is little prospect that this debate will be resolved soon. Indeed an emerging perspective is that low dose radiation causes a more complex set of effects than is traditionally expressed in the debate and this perspective will most likely increase uncertainty rather than decrease it.
2) Uncertainties in site-specific information for which new information is now largely inaccessible. An example might be information about early releases of

short-lived radioactivity for which there are limited records and monitoring data and there is no obvious way to collect more information.

3) Uncertainties in site-specific information for which there is the potential of acquiring new information. Here we can distinguish examples of new information that could be obtained in the present, new monitoring information that would reduce uncertainties in the distribution of contamination at a site, for instance, and examples of new information that could only be obtained in the future. We may be uncertain about the prospects for releases from a site or about the amount of residual contamination left after implementing a particular decontamination process, but we could minimize uncertainty in these characterizations with more thoughtful preliminary monitoring planning, provided that we made monitoring arrangements to track future releases or to test the effectiveness of decontamination.
4) Uncertainties that arise because of complexities in the compilation, analysis, and presentation of information. Here good examples are from the use of elaborate computer models to describe radiation exposures; while these generally involve some validation with monitoring data, much still must be done to properly characterize the attendant uncertainties and proper characterizations are rarely presented in the model results. Increasingly Geographical Information Systems are now used to provide maps characterizing relevant features of sites for planning purposes, yet the underlying information sources for such maps vary considerably in quality and reliability and there has been to date little attempt to communicate information about map reliability in GIS presentation. And cleanup plans are sometimes so complex that implications about difficulties and possible failures in implementation are hard to infer.
5) Unknown possibilities are an extreme form of information that appears inaccessible, but they require a different management approach. These may include unexpected sources or types of contamination, unfamiliar pathways for exposure, etc.
6) There are substantial uncertainties in ascribing social risks both direct and perception-based (Tuler 2006) to a site cleanup plan. One can expect a potential for a wide range of social impacts associated with radioactive sites. These presumably would be affected by cleanup plans and implementation, but attributing particular effects to particular choices appears difficult in itself. Very little has been done to characterize uncertainty for such attributions and there is certainly no general agreement on approaches to making such characterizations.
7) Beyond the direct implications of a particular cleanup choice for a site are numerous possibilities for indirect impacts; these are associated with considerable uncertainty. Some uncertainty is more or less analyzable depending on the accessibility of information and the familiarity of the effect as in some of the cases above; but further uncertainty results from management considerations: secondary effects generally fall outside the responsibilities of the entities making choices about the site. Information accessibility may require special consideration, and relevant management choices will be made independent of the local site planning. An example might be the impacts associated with transporting contaminated waste and storing it on another site.

8) And there will be substantial uncertainty about management at the site. What resources will be available for cleanup and how long will they be available. How committed are the entities to completing the job; what are the possibilities for mismanagement or failures in implementation?

Each of these eight uncertainty configurations poses a different sort of challenge and, in the next section, we will identify appropriate management responses. Before doing so, however, it will be helpful to consider some key differences in stakeholder perspectives.

Of course the group of interested and affected parties (National Research Council 1996) at any site will be quite heterogeneous. For the purposes of this paper, which is to reflect on the context for considering uncertainties, it may be sufficient to consider two simple categories – responsible parties those responsible (and generally performing the planning and implementation) for cleanup and affected nearby public those concerned members of nearby communities who consider themselves affected by the site and its cleanup. Although neither category is homogenous, we can try ascribing goals and beliefs to them in order to explore potentially important differences in perspective. The following highly simplified descriptions make the principal points.

The responsible parties and their technical entourage want to focus on the cleanup. They want to work with clear definitions of what will count as clean enough so they know how much they have to do and can try to match those needs to the resources available. They don't want to be distracted by questions about past activities and they don't want to be blamed for them (and they certainly don't want to encourage lawsuits), although they may be driven to point out that the there was limited knowledge in the past regarding what had to be done to protect people and that the facility was performing work in the public interest. They accept the idea that the cleanup is for the benefit of the public and that public involvement in the process is appropriate, but they may be skeptical about how helpful the public can be, and they believe that the public is apt to be overly fearful and to slow down unnecessarily the process of cleanup. The responsible parties and especially their technical practitioners are caught in the competence/honesty trap that is familiar from the psychometric literature. People judge how competent a person is, in part, by how confidently the person addresses problems. Acknowledging uncertainties may win points for honesty, but it threatens to lose points for the assessment of competence.

The affected nearby public are worried about the past. They are likely to believe that they are still at risk from exposures that occurred long ago; they are angry that little concern was shown for protecting them and that they were not well-informed about the dangers. At a minimum they would like some sort of acknowledgement that they were put at risk, and in some settings, lawsuits may have been filed. The public also would like cleanup done immediately; often they don't see why the responsible parties can't get on with the job and get it done instead of going through some complicated technical rigmarole. Without recognizing a contradiction, they also demand extensive assurances that the cleanup will be done right and that they will no longer be at risk.

Clouding the affected public perspective is a legacy of distrust. Some of it comes from the secrecy and lack of care that produced past exposures; some comes from a suspicion that technical analysis is being used to hide some of the remaining hazards and to minimize the efforts needed for cleanup. And some of that distrust is reciprocated. The technical community involved with cleanup is likely to believe that the public is prone to panic and silly fear, that it is not really interested in and can not understand the technical issues that are critical to cleanup plans, that it makes unreasonable and obstructive demands that impede progress, and that it is changeable so that agreements on technical standards might not stick.

With such divergence in concerns and perspective, discussions between the parties are very often tense and unproductive. The large uncertainties about health impacts, about technical capabilities, and about institutional commitment typically exacerbate the problem, as does the competence/honesty dilemma. However, both parties genuinely want an effective cleanup and their cooperation is essential. It is to everyone's interest to find subject matter and a structure so that discussion and cooperative efforts can be productive. It is our view that the exacerbating uncertainties provide just such subject matter, that it is better to deal explicitly with these issues than to try to avoid them.

Practical approaches should be sought that explicitly address uncertainty and that respect diversity of concerns

The challenges in addressing uncertainty in cleanup planning are first to find suitable ways of describing the uncertainties, and second to have management approaches that are both realistic relative to the current state of knowledge and have provisions for dealing with possible new knowledge. Needed are agreed upon goals and constraints (with diverse concerns and objectives), pathways toward the goals, and opportunities for assessment and correction – including reevaluating the goals. Many key issues for describing uncertainty and for creating suitable management approaches apply pretty much across the eight configurations described above, so we begin with some general observations.

Fundamental to any collaborative approach to site cleanup that recognizes that different parties have different concerns and different values and approaches to making choices is to view risk assessments and the characterizations of uncertainty within them as tools for informing risk management decisions, not as decision tools themselves. Therefore, the objective should be to provide information about what is known and not known about unproved and uncertain possibilities, and about the management opportunities available to address such possibilities. This view that the task of risk assessment is to provide the best available scientific information in a form useful to all concerned parties has implications for how assessments are conducted. By now there is considerable, though not perfect, consensus on the implications. They are discussed (with some variation) in numerous reports such as the NAS report *Understanding Risk* (NRC 1996) and the British Department of Health report *Communicating about Risks to Public Health* (Department of Health 1998). Risk assessment from this perspective requires (Goble and Hattis 2001):

- Consultation with concerned and affected parties
- A deliberative process involving both the assessors and the parties
- Consideration of a broad range of management possibilities as part of the assessment
- In depth description of uncertainties and controversies
- Qualitative characterization of risks as well as quantification

The last item – qualitative characterization - is not yet part of the consensus; but in our view it should be, and we can observe the field gradually assimilating the need for qualitative characterizations. There are three linked reasons. The first is that there is little agreement for some of the uncertainty configurations on how one would quantify the particular type of uncertainty. The second is that many people do not naturally think in terms of probabilities or numbers generally, yet they want and deserve to learn what science can say about the risk. The third is that important aspects of every person's thought about risk are necessarily non-quantitative. For example, Paul Slovic (Slovic 2000) distinguishes between "experiential" thinking about risk and "analytic" thinking about risk. Some information exists which can only be conveyed in qualitative terms.

We have developed a set of tools to assist in the analysis and communication of uncertainties (Goble, Hattis et al. 1998). Among these are recommendations that the presentation and discussion of uncertainty should include discussion of the arguments for and against alternative possibilities, qualitative characterizations and, where appropriate, quantitative characterizations, and an assessment of the likelihood of relevant new information plus opportunities for obtaining new information.

The demand that management strategies for site cleanup be realistic about the state of knowledge and provide for dealing effectively with new knowledge has important implications. For instance a management approach that is based on a set of standards for cleanup would be vulnerable to controversy over the state of knowledge that serves as a basis for the standards and uncertainty over how well the standards will be met. A strategy that combines an ALARA (as low as reasonably achievable) principle with standards – the general framework that is most commonly used in the nuclear arena – is less vulnerable to such controversies and to the possible appearance of new knowledge. However, substantially more can be done to create a more robust and adaptive management approach and to create and facilitate the use of new information. The main innovation would be to institute check-points that go well beyond the current practice of assessing progress toward implementation. The specific agenda for check-points should be negotiated among the parties, but it should include an assessment of progress toward target goals, a review and evaluation of new information including new information collected as part of the management plan, a reevaluation of overall cleanup goals and of targets for subsequent check-points, and an explicit assessment of state of the institutional commitment and pursuit of cleanup. Because radioactive site cleanup is very much a long term problem (Department of Energy speaks of "environmental stewardship," DOE, 2001) explicit consideration of maintaining a secure institutional commitment to the site should be part of the management strategy; it would be desirable as well to include

explicitly plans for maintaining communication and coherence with the management of cleanup at other sites to assure that best practices are widely known and that problems are simply moved from one site to another.

Within such a general management framework, there is opportunity to address the specific problems posed by the eight uncertainty configurations.

1) Because the issues in this category are both general and unlikely to be substantially altered, it would be counter-productive to have them addressed at every site separately. What is needed is an informative site-specific distillation of those aspects of general knowledge including the characterization of uncertainty that apply to the particular site. This should provide a clear enough basis for an informed discussion of standards and of ALARA considerations. The distillation can be updated infrequently in the context of the check-points.
2) Inaccessible site-specific information can be treated in much the same way, providing a statement of what is known and what isn't suitable for informing the management discussion. However, the reasons for inaccessibility are an important aspect of site history and of importance to many stakeholders, so these should be clearly documented in the assessment.
3) Monitoring and evaluation of potentially accessible information will be an important component of planning. Information needs should be developed in the light of specific management concerns such as assessing implementation, ALARA compliance, better understanding of residual risks, etc. and should be targeted to checkpoints. New opportunities for acquiring information should be assessed periodically as well.
4) Making complex information accessible to all interested parties and improving confidence in it should be viewed as a long term challenge. Goals should be set that correspond to check-points.
5) It is, of course, difficult to look for information when you don't know what it is or where it will be found. However, there should be ongoing surveillance both of the site and information from elsewhere that prepares for possible surprises and can report on its observations at check-points.
6) So little systematic work has been done in assessing social risks that there is little basis for addressing uncertainties. The appropriate recommendation at this time is that such risks be an explicit part of the agenda; and we can hope that we will develop usable experience.
7) Here again the critical challenge is to make both the possibility of indirect impacts and the institutional issues raised part of the agenda. Assessment of what is known and known should be done for each check point.
8) The stability of the resource base and institutional commitment is a major concern of parties expecting cleanup to be successful over the long term, and one for which there is substantial uncertainty. As with 6) and 7) we believe that requiring periodic assessment of how secure these are will be an important aspect to strengthening stewardship capabilities.

Existing assessment and planning at radioactive site fall short in addressing uncertainties

Current practice in the risk assessment used to support radioactive site cleanups (and most contemporary applications of risk assessment) is to treat uncertainty as an unfortunate aspect of the assessment. The pattern is that assessments are produced usually to justify a particular management choice such as the setting of a cleanup level or to determine a level of further intervention. Very often the assessment will have only a limited discussion of uncertainty, an enumeration perhaps of the main sources of uncertainty. Detailed treatment of uncertainty usually occurs in the context of model calculations where Monte Carlo methods or sensitivity analysis will establish how large an impact (within the context of the model) a specified uncertainty in model parameters can have. This information is placed in the hands of risk managers and concerned members of the public with no guidance about the implications of the uncertainties to the extent they are discussed and no guidance concerning what has been left out. This might be acceptable if it were the case that uncertainties were small and had little impact: but even the well characterized uncertainties are quite large and have direct implications for management choices. Furthermore, as the list of uncertainty configurations shows, there is a great deal of uncertainty that is not at present well characterized and that should strongly influence people's judgments about management choices.

Some examples point to various kinds of problems that are not being addressed. For instance in the familiar case of radiation health effects, much of the assessment effort at radiological sites recently has been performed by an office at ATSDR. Contrary to the recommendation in the previous section, ATSDR has been preparing a number of site specific analyses of the information on radiation-induced health effects and used their determinations to define management criteria such as "below public health concern". We conducted a detailed review of one such assessment that considered tritium releases at Lawrence Livermore Laboratories (Russ and Goble 2003).

Our primary findings were as follows:

- **Process problems.** The health assessment process has been marked by a lack of responsiveness to community concerns, a series of contradictory documents, and very limited attention to establishing a record of what happened in the accidents and to informing the public in a detailed and understandable way about what happened. ATSDR has lost its opportunity to serve as an honest broker on these issues, and thus departed from its defined public health mission.

- **Treatment of uncertainties**. These calculations involve a large degree of uncertainty, in part due to the unfortunate lack of information about the conditions around the accidents. ATSDR has made no evaluation of the reliability of the information derived from LLNL records on the release. Other key factors for which uncertainty was underestimated include meteorological conditions and the rate of tritium deposition. The treatment of uncertainty in the retention time of tritium in the human body is incoherent. There has been no attempt to explain in

ordinary language the reasons for and the implications of the uncertainties in the modeling effort.

- **Calculation and presentation of dose estimates**. The health assessment makes mistakes in presenting its results. In particular, the models predict higher rather than lower doses for the 1965 accident contrary to assertions in the text. A significant factor in calculating dose, the dose and dose-rate effect factor, was misused. We present revised dose estimates that correct these errors; our estimates are 3-4 times higher than those presented in the health assessment. Population dose estimates should have been made and we make a rough attempt at doing so here.

- **Discussion of health risks.** In its treatment of risks from radiation exposure the authors of the health assessment contradict standard practice as described in the National Academy of Sciences BEIR V report (1990), in international commissions (ICRP 1991, UNSCEAR 2000), and the ATSDR Toxicological Profile for Ionizing Radiation (ATSDR 1999). The authors give no indication that their assumption of a threshold for radiation induced cancer is at variance with standard risk assessment practice or that there has been a very substantial scientific and policy debate on the issue. In contrast, using standard methods we find that within the range of uncertainty there was potential for cancer mortality risks that are considered 'significant' in common regulatory practice- that is, the risks using both ATSDR's and our estimates for a maximally exposed individual are in the vicinity of 1 in 10,000; in some uncertainty ranges, the risks exceed 1 in 1,000.

- **Irresponsible conclusions.** The assessment and the consultations use the term "below levels of public health concern" in a number of places, including in its conclusions about potential risks. There are serious problems with this usage. The term is nowhere defined, nor is there any indication of what the authors would consider to be a level of public health concern. Risks calculated using standard practice from the radiation doses presented in the assessment are at levels that are generally taken to be significant by the agencies supervising Superfund cleanups. Most disturbingly, the inferences drawn by ATSDR directly subvert the ALARA principle (as low as reasonably achievable), a cornerstone of the social compact for managing radiological hazards. The impression left by the ATSDR documents is indifference to releases of 300,000 Ci of tritium (in the form of hydrogen, or 10,000Ci in the form of water vapor) in a highly populated area.

The most egregious faults in the assessment can be traced to its departure from the duty to inform an audience of stakeholders in a complete and balanced way about the state of knowledge concerning potential health impacts at the site. The choice to use the analysis to pursue a particular management goal rather than to help the discussion of management and the choice to use a minority approach to estimating health effects without discussing alternatives represent an exploitation of uncertainty to limit the consideration of

management possibilities, rather than using the uncertainty to gain better understanding and better collaboration for management planning.

The Risk Based End State analysis for the Idaho National Engineering and Environmental Laboratory (INEEL) (DOE 2004) contains implicitly a minimal treatment of health risk uncertainty in the setting of radiation levels for cleanup; however, there is no detailed characterization of this (limited) aspect of the uncertainty, nor is it integrated with other uncertainties about exposure. The report itself presents a vision of site use that involves continued use as a DOE laboratory indefinitely, yet it deliberately does not address possible future contamination and risks that might arise from those activities, nor does it consider the potential interaction between those activities and the present contamination. The vision, instead, seems primarily designed to avoid considering cleanup levels that would apply to residential use. A series of management choices are made, including setting check-points for observing the effectiveness of cleanup in meeting target contamination levels, but there are no provisions for redirecting the program. It is important to observe that the plans promise land use controls for 400 years or more, but there is no discussion of the associated uncertainty or the institutional arrangements for maintaining such controls. Another interesting aspect of this example is that the vision reflects a very complicated engineering management plan described in a large number of tables and maps. It is not readily understandable by interested and affected parties nor is it possible to assess the relative quality of the underlying information which derives from many sources. It certainly does not serve as a convenient starting point for a discussion among interested and affected parties. Most significantly, no guidance is provided to what might go wrong within the many pieces of the plan, what the available alternatives were, or what the contingency plans are in case things do go wrong.

The modeling of the Cerro Grande fire discussed by one of us (Russ 2005) is a different example of uncertainty associated with complexity. Here there is a complex model and some very limited monitoring information. The model provides detailed predictions, whereas the monitoring was too limited to be used for interpolation. However, the model predictions are incompatible with even the limited amount of data. This is clearly a situation of high uncertainty and the RAC modelers discuss prospects for obtaining more monitoring information that could be used to adjust the model. The most significant aspects of the review, however, are the observations on the implications for site management. Clearly models are not sufficient to answer the questions that arise when an unexpected event such as the Cerro Grande wildfire occur. A more carefully prepared surveillance program, coupled perhaps with some modeling capability, and addressed to a range of possible public health concerns, should be considered part of site management.

The paper on Social Risks of Radioactive Waste Transport by one of the authors (Tuler 2006) also offers useful illustrations. It is a reminder that export of radioactive materials implies further hazard in transport and in subsequent handling and storage. Such concerns are among the bases for a recently filed lawsuit by the Governors of Oregon and Washington, the Yakima Nation and the Nez Perce Tribe against the U.S. Government demanding participation in the management of the Hanford Site. We also learn from the

paper and the National Academy's study (NRC 2006) that forms its basis that, to date, there is not available an agreed on framework for considering the uncertainty in social risks, either direct risks or perception-based risks, and that only recently are they starting to receive detailed consideration in the nuclear risk arena.

Explicit management of uncertainties along with attention to the diverse perspectives and concerns of stakeholders offers significant opportunities to improve clean-up planning

The message of this paper is that a revised approach to cleanup planning could secure the collaboration needed to get the job done. Key opportunities for revision include:

1) Addressing the concerns about site history felt by many affected people. It is better for many practical reasons that cleanup planning not be held hostage to people's concerns about previous exposures. But the concerns represent a legitimate demand for knowledge and cleanup planning should also not be an impediment to obtaining such knowledge. This means that cleanup efforts should be as transparent as possible, that all information about past, present, and future operations should be publicly available (except for genuine concerns about individual privacy and genuine national security concerns); the government has no legitimate interest in concealing publicly funded information. On that basis, it should be possible to maintain a focused planning effort.
2) And transparency is essential also both for maintaining public confidence in the cleanup efforts and for making use of the contributions that interested and affected parties can bring to the process.
3) Critical to an adaptive approach that can generate needed new information and respond to new findings and new concerns is the establishment of check-points. These must go beyond measuring compliance with previously established goals, and allow for the interpretation of new information that may suggest rethinking goals and approaches; monitoring, surveillance, and analysis should be directed toward gathering information that will be useful in making management choices, not just verifying progress.
4) Ongoing attention to the institutional needs to maintain a long term stewardship role is very important. We have only limited experience with maintaining such institutions and maintaining their effectiveness and credibility and it would be sensible not to be too complacent about the potential difficulties.

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