A Literature Guide Supporting the Planning and Implementation of a Risk-based End State Program

Prepared for the Department of Energy
Environmental Management Corporate Project:
"A Cleanup Program Driven by Risk-based End States Project"

DRAFT
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ABSTRACT

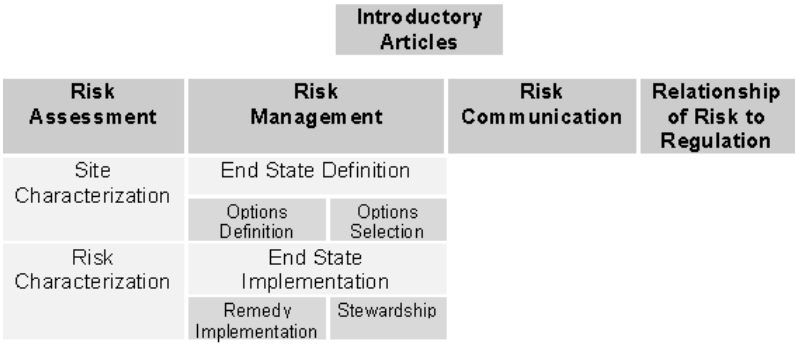
This guide is intended to present the reader with a set of quality peer reviewed literature that will aid the reader's understanding of human and ecological risk involved in DOE's cleanup efforts in "achieving clearly defined, risk-based end states" as stated in the EM's Cleanup Driven by Risk Based End States Policy.

The science basis for risk-based end states, as considered in the Department of Energy, encompasses a variety of concepts from multiple disciplines. The compendium thus provides a useful risk-related reference tool for the ongoing support of Department personnel and its stakeholders.

In this compendium a whole-risk paradigm or framework is described that is specifically relevant to contaminated sites. A set of key articles are identified from the peer-reviewed literature that relate to each element of the paradigm. The paradigm was derived from a 1997 governmental report, the Presidential/Congressional Commission of Risk Assessment and Risk Management. **Risk Assessment** components of a site include **Site** and **Risk Characterization. Risk Management** considerations encompass **End State Definition** (including **Options Definition** and **Selection**) and **End State Implementation** (including **Remedy Implementation** and **Stewardship**). All of the above components interact with **Risk Communication** and, in order to have meaningful impact, include the **Relationship of Risk to Regulation**.

A literature base relevant to each component (and to a general overview) was developed through a structured computer search of large, relevant reference databases, such as the Environmental Sciences and Pollution Management Index and the ISI Web of Science. CRESP Science Center Chairs and other key scientists added further article recommendations based on their own expertise and experience dealing with hazardous waste site issues at DOE and elsewhere. The literature base was pruned through a preliminary CRESP review of journal article titles and abstracts, and a further consolidation resulted from assessment of the actual texts of the residual articles. The final articles were sorted into "preferred reading" (with full text provided in Appendix 3), "other key articles" (with abstracts given), and other useful articles (full reference noted).

The compendium was designed to be an easy to use reference tool. Over 200 articles are listed in this resource, out of which 16 articles, because of their accessibility to a general



audience, relevance to DOE risk issues or the topical nature of the paper, have been selected for complete text presentation. The list of such articles is in Appendix 2 and the complete text is in Appendix 3 (available upon request). This priority list of full-text articles is meant only as a starting point and should be critiqued, updated and shaped to meet the informational needs of the Department and its stakeholders. The abstracts of several other directly relevant articles have also been provided. A complete listing of articles selected through this process is noted in Section E (where they are sorted by risk-related category) or Appendix 2, an entire alphabetic listing.

It should be noted that the references were selected based on their relevance to one or more aspects of risk as applied to understanding the implications of contaminated site assessment and management. Nearly all of the chosen articles should be understandable to the generally- informed reader. Articles requiring high levels of technical (e.g., toxicology, medicine, epidemiology, etc.) or mathematical knowledge were generally not included in this compendium. While the compendium will likely be of substantial value to those with less extensive experience in risk-related issues, its scope is such that even seasoned risk managers should find the framework and the set of interrelated references, abstracts and the 16 full publications (Appendix 3) quite useful.

The compendium editors were requested to limit the number of full text articles, in order to provide the reader with a practical, manageable set of information to read. Of course many other fine publications could have been included in full text, had the number of articles not been a factor. The reader is encouraged to look at the other listed article abstracts and to scan the complete bibliography to potentially identify other references of interest that might supplement the given complete text list to better serve one’s own informational needs.

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A. INTRODUCTION

The Environmental Management Office in the Department of Energy (DOE-EM) has recently increased its emphasis on the application of risk concepts as a guide to waste site clean up efforts that as early as possible define end states and evaluate progress in that effort. To foster that effort, DOE-EM created A Cleanup Program Driven by Risk-based End States Project as one of its new corporate projects designed to focus on problems identified to the Department in EM's Top to Bottom Review Report (February, 2002). One important aspect of this project is to identify tools it considers of high priority to assist understanding and implementation of the risk concepts as they inform risk based end state processes. The goal of this report is to provide a significant start to the development of one of those tools: a literature reference base of peer-reviewed journal publications by recognized experts that describe key concepts of human and ecological health risk and provide examples of the application of such concepts to environmental clean up issues.

Of particular interest to the Project is a relatively small subset of articles (including review articles) that would be particularly suitable for a broadly educated readership and yet would be directly relevant to the major health and environmental risk issues (particularly including risk-based end state development) confronting the Department. This smaller subset might be useful to help support continuing understanding of non-scientific staff and others, and could foster a more informed and open dialogue regarding risk-related topics confronting the Department among the Department, its regulators and other stakeholders. CRESP (Consortium of Risk Evaluation with Stakeholder Participation) was asked to develop the initial literature reference base. It was also charged to develop a more comprehensive listing of relevant risk-related articles that could be used for more technical backup or additional reading. This draft report seeks to meet that request.

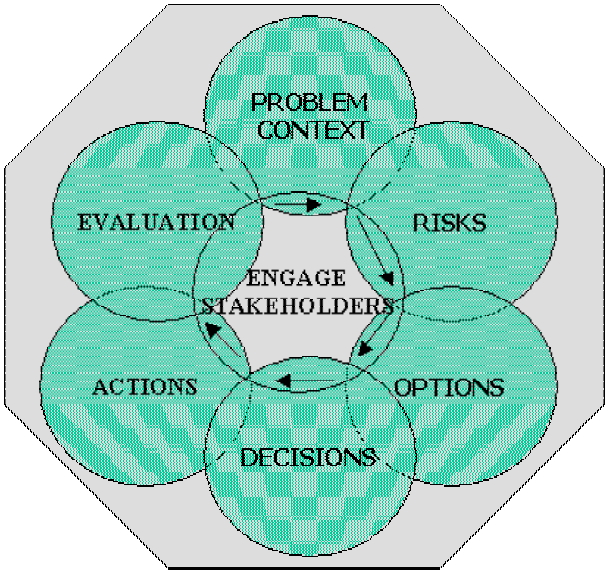
If this report serves its purpose, it will enable its readers quickly to link the risk-related questions and implementation concerns they have to key articles in the literature that directly address those issues. Achieving that purpose is no simple challenge. The Compendium that has emerged here is the result of many attempts to find both graphic and conceptual ways to help the reader make that linkage efficiently. We believe the result is a unique way of arraying the literature and, we hope, of making it more readily available to readers with very diverse levels of prior experience with risk ideas and with very diverse questions about how risk could be applied to the clarification and resolution of the issues that confound them at contaminated sites.

B. ORGANIZING CONCEPTS

1. INTRODUCTION

The literature base on risk is immense. There are thousands of articles on a wide range of risk-related topics. In order to assemble literature specifically designed to the goals of this project, CRESP developed a framework to depict the relevant health and environmental risk issues associated with the environmental management of hazardous waste sites. Given the framework, the effort focused on categorizing some of the most lucid “best in class” peer-reviewed literature relevant to steps in the risk sequence applied to the end state planning of hazardous waste sites. We reviewed and discussed the attributes and intended purpose of the general framework of the risk decision-model (figure 1) developed by the Presidential/ Congressional Commission on Risk Assessment and Risk Management (PCC, 1997). That report (the full text is included in the attached CD) is considered an excellent introduction to a decision-making process using key risk concepts, many of which were described in an earlier milestone report by the National Academy of Sciences and the National Research Council (NAS/NRC, 1983). While the Commission model was not written for specific application to risk-based end states and potential land use options, it did format a useful decision pathway from recognition to the control of risk. Thus, it furnishes a process foundation for many of the considerations that must be made in risk-based end state planning and implementation. With some added specificity, the general Commission model can be transformed into a Risk Paradigm that can be applied to contaminated sites and their end states (figure 2).

FIGURE 1. Risk Paradigm (The Presidential/ Congressional Commission on Risk Assessment and Risk Management. 1997. Framework for environmental health risk management.)



The Commission risk decision model consists of six sequential steps, each engaging stakeholder communication throughout the process. The general steps include: a) defining the problem and understanding its context, b) assessing risks associated with problem, c) looking at options, d) coming to a decision on the options, e) performing actions on the decisions to address the risks, and f) evaluating the effectiveness of the actions taken.

This process, which in retrospect seems almost too simple and self-evident, is a very useful risk decision framework and many of its components are reflected in our extended adaptation of it as summarized in the series of interlocking circles on the right side of figure 2. Starting from the top of the series and moving clockwise, the following specifications have been adapted to the Commission cycle: Site Characterization, Risk Characterization, Definition of available Options, Option Selection, Remedy Implementation, and Stewardship/End state Achievement for Evaluation. These steps rotate around and interact with stakeholders, through ongoing communications of a two-way nature. Each step has, to be sure, a number of components. A more comprehensive view of the components is noted in figure 3 titled “The Whole Risk Paradigm Applied to Contaminated Sites”. (For more details of the paradigm, see Appendix 1.) The current report will identify relevant research and summary literature important to the steps in figure 2 and for several of its key components. First, however, we will briefly describe the major steps in the risk-related processes included under Risk Assessment and Risk Management, as well as Risk Communication activities that are applicable to several parts of the paradigm.

FIGURE 2. Risk Paradigm: CRESP Application of the President’s and Congressional Commission Model Applied to Contaminated Sites

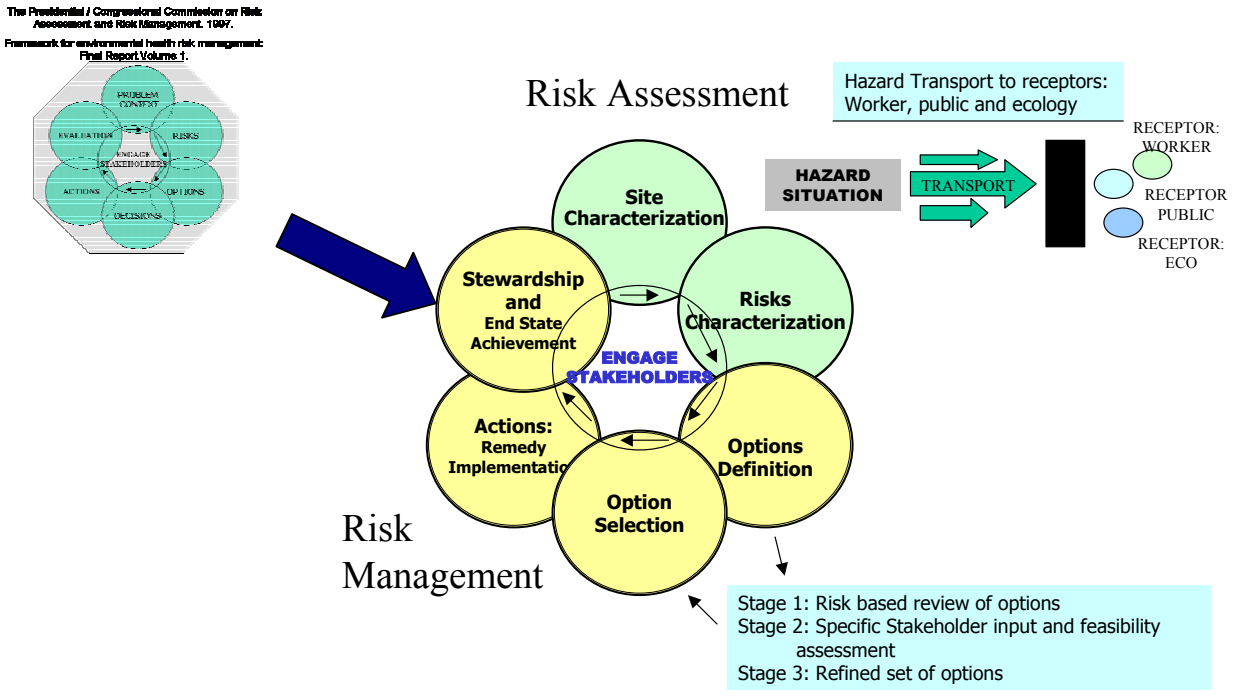
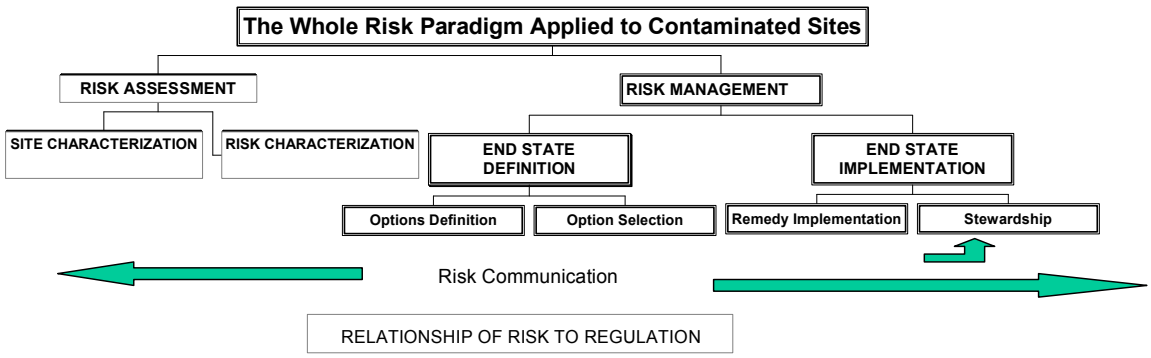


FIGURE 3. Whole Risk Paradigm

Outline of Key Articles to Guide Planning and Implementation of Risk-based End States



2. RISK ASSESSMENT

For the purposes of this report, Risk Assessment will include the phases necessary to characterize a site and the risks the site can present to biologic receptors (including human and ecologic) on and off site. Risk Management will start with the definition of potential options, the process by which an option is selected, the remedy implemented, and stewardship of the site.

Site characterization defines the site and its geological attributes, its contents (structures, contaminants, etc.), its occupants (including non-human), its function, and its relevance to the area and region. Contamination is often a key issue at sites, and the extent and hazardous nature of contaminants, and their pathway to receiving populations/ecologies can influence potential risks, land use options, methods and degree of risk management, and the realistic nature of envisioned end states linked to anticipated land use scenarios.

One element of the current literature search will be to identify published articles (peer reviewed, if available) that provide a working *definition of contamination* on a site, and discuss methods of determining the distribution and concentration of contaminants in various site media (i.e., surface, vadose zone, groundwater, etc.). Some recent work has been accomplished to develop methods and concepts needed to distinguish contaminants from "*background*" exposures, that is, materials present on a site that are not generated or concentrated by site activity and would exist at the site without such activity.[1]

[1] This distinction is important, since any rational proposed cleanup goal must take into consideration existing background concentrations across a site.

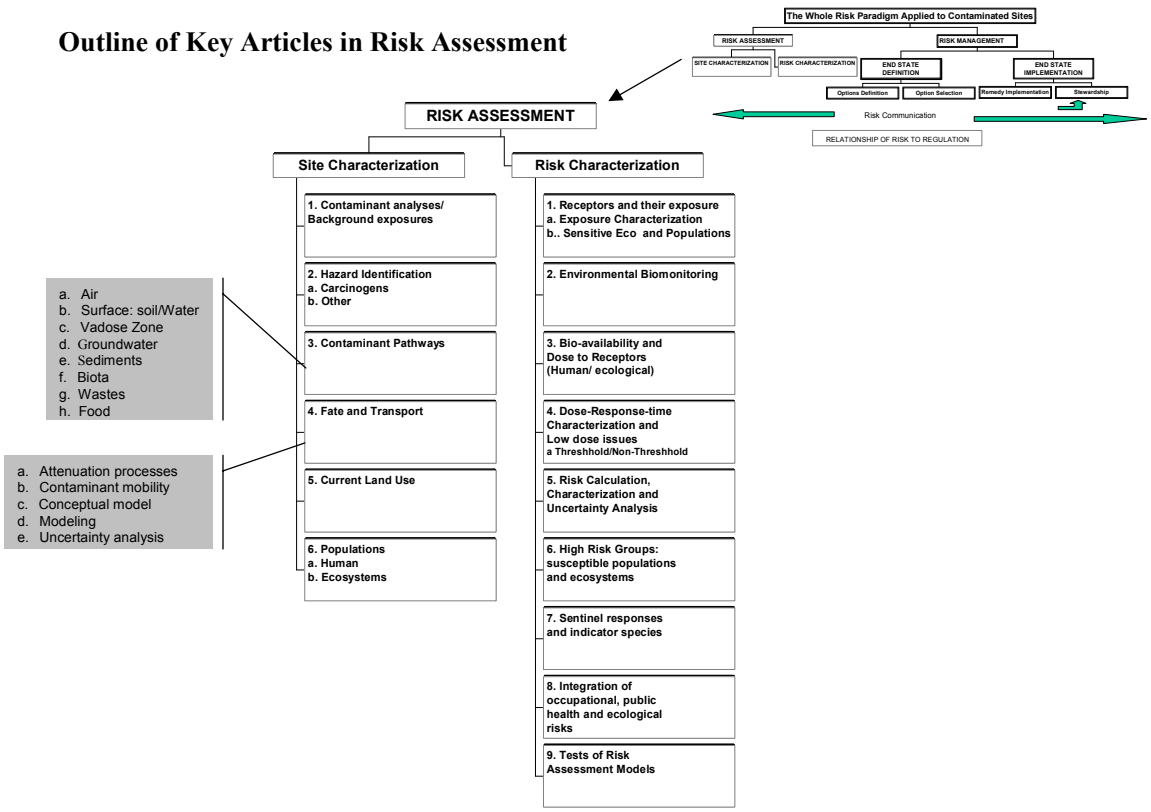


FIGURE 4:Risk Assessment

Several other aspects of Site Characterization are also noted above in figure 4 and include the identification of known *hazards* (carcinogen, neurotoxin, reproductive toxin, etc.) associated with the known contaminants, the potential *pathways* of contaminant movement from its source or current location to human populations or to ecologic receptors – on site or off site, as well as the *fate, half life and transport* features of the contaminant. In addition, a Site Characterization would include a description of the receptors (current workforce, surrounding neighborhood, and local ecology) and their relationship to current site use and activities. These and other features might be taken into consideration during the eventual comprehensive assessment of risk and the plan to manage it. Contamination on a site could presents little or no concern to current workers but still might have ecologically-mediated public health importance, i.e., biological systems could be contaminated and enter humans through food, recreational or agricultural pathways (i.e., through contaminated fish, hunted wildlife or farm crop).

Once the relevant details and more regional view of a site have been described, it is usually possible to develop a *Risk Characterization.* This step includes the consideration of whether the toxicants are in a form that is available to enter the receptor (human or ecologic) and be biologically absorbed and active. The type

of toxicologic (and epidemiologic) response that is known to occur as a function of the dose received is characterized to describe, as best possible, the degree of risk that might exist for different exposure scenarios. While risks for certain outcomes can be estimated for different exposures, the degree of uncertainty associated with the dose-response estimate also needs to be understood. Other considerations in the Risk Characterization stage include the identification of groups or populations that could be at highest risk – either because of predispositions (genetic, prior disorders, lifestyles, etc.) or because of greater exposures (dietary patterns, etc.). Ecological issues also must be considered, and the issues of endangered species can be important both ecologically and politically. Sentinel responses are either specific biological changes that are characteristic or unique responses to a particular exposure or are early indicators of responses to that exposure. There is a growing interest regarding these types of responses and their role in surveillance and monitoring systems. Finally, there are always issues regarding low (and high) doses – specific for the substance – and whether measurements and estimates of dose and response can be verified and are relevant.

3. RISK MANAGEMENT

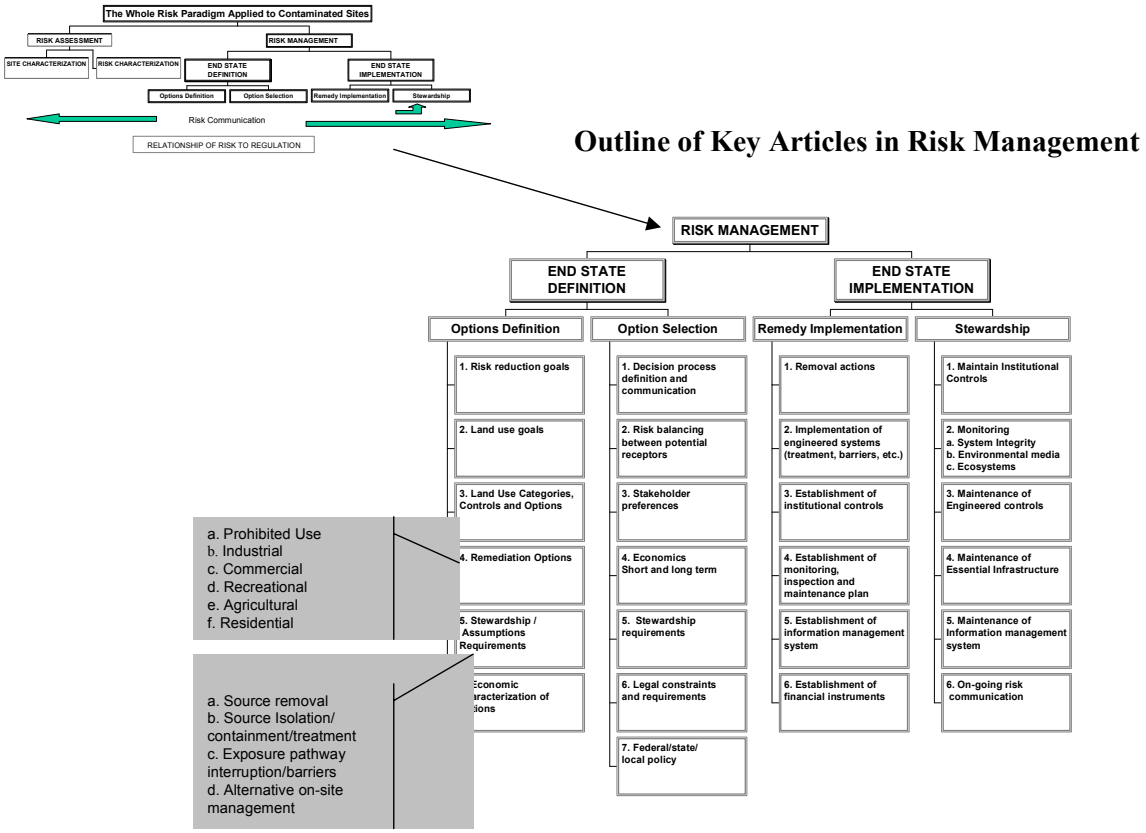


FIGURE 5: Risk Management

The steps of defining and selecting options, putting in place a remedy, and maintaining stewardship after remedy all fit under this phase. (figure 5). Land use decisions are often influenced by the initial state of risk, realistic land use options, the feasibility of risk reduction remedial goals and remediation options, and the relationship of these factors to both stewardship requirements (and negotiated agreements) and economics. The option selection process includes a balancing of risks that might exist for different groups (workers, public health, ecology) and at different times (present, during remediation, residual risk). An interplay of the noted variables (and others) will influence both land use and remedial option selection. The literature relevant to some aspects of this process is not as robust it is for other steps, since only recently has serious scholarship been focused on this process. Remedy implementation may include activities aimed at removal of waste, may implement a range of engineering systems, often includes a set of institutional controls, and establishes a plan for needed monitoring, inspections and maintenance. The documentation and subsequent tracking of actions and results requires the establishment of information management systems – which could include mapping to picture changing status of sites and foster communication with stakeholders. Of course, the provision and maintenance of

resources requires the establishment of appropriate financial instruments. Adequate stewardship includes the maintenance of institutional and engineering controls as well as adequate information management, monitoring to assess the long term effectiveness of the remedy, and on going risk communication.

4. RISK COMMUNICATION

All of the above steps are linked to risk communication with stakeholders. Effective risk communication requires not only a sharing of relevant information with key stakeholders throughout the risk assessment and management process, but an environment in which trust exists across the communicating groups (Slovic, 2001). While trust "must be earned", it certainly is encouraged when, through the risk communication process, information is clearly shared with those who may be affected by it and when it can serve as an informed basis of rational options – including the gathering and sharing of additional information addressing concerns - for those potentially affected. Published concepts and practical examples displaying exposure scenarios with stakeholder participation in the risk assessment and management process – including the content, timing and process used – all would be relevant reading for those working to develop and implement an risk-based end state driven cleanup program.

5. RELATIONSHIP OF RISK TO REGULATION

Literature that relates to the development of a solid risk assessment is, by itself, of potential value for planning purposes. However, the use of risk concepts and information by the public and by the regulatory community is critical to its eventual role in risk management and in the viability of an end state planning model. Therefore, a final, but important, section of the literature search was to identify publications that have addressed the evolving role of risk and risk methods in regulatory policies and applications.

C. REFERENCE IDENTIFICATION/ SELECTION PROCESS

There is an enormous risk-related literature, and an even larger reference pool when one considers the different aspects considered in the Paradigm as it is applied to the assessment and decision-making process of hazardous waste cleanup. In order pare the workload to a manageable scope, and at the same time take advantage of CRESP's senior science leadership's experience, a three pronged attack was developed for the project.

Each CRESP Chairperson (Exposure, Human and Ecological Health, Remediation and Mitigation, Social and Economic Impact, and Public Policy and Communications) was asked to select from the literature a small set of articles that could help explain their science topic (as relevant to risk-based end states) to educated readerships from other disciplines. It was expected that each Chair, through current research/teaching efforts, review committee participation and journal editorial responsibilities, would have timely information on developments in their respective fields, and would have a scholarly overview of the work of its key practitioners and theorists. Furthermore, the Chairs would have more than a degree of perception as to what is important to convey to DOE personnel and stakeholders, since the Chairs are all experienced in addressing several key DOE issues and in working with DOE and its communities. Therefore, this seemed to be a useful initial step for gathering key literature relevant to the DOE request.

The second step involved a more standard approach for computer-driven literature search strategies – a scan of publications by applying selection criteria against relevant reference databases. The search covered the Environmental Sciences and Pollution Management Index (ESPMI), as well as the ISI Web of Science. The ESPMI comprehensively covers 6095 serials from 1984 to the present, including (among others) the abstract service systems noted in table 1.

Table 1: Abstract Service Coverage of the ESPMR

Agricultural and Environmental Biotechnology Abstracts
Aquatic Pollution and Environmental Quality
Ecology Abstracts
Digests of Environmental Impact Statements
Environmental Engineering Abstracts
Health and Safety Science Abstracts
Industrial and Applied Microbiology Abstracts
Pollution Abstracts
Risk Abstracts
Toxicology Abstracts
Water Resources Abstracts

The ISI Web of Science includes Science Citation Index Expanded (SCI-Expanded) and the Social Sciences Citation Index (SSCI). These indexes have substantial coverage. SCI indexes more than 5,700 journals and has a total of over 17 million records in its system. It cites over 350,000 new references each week. The SSCI comprehensively indexes over 1,700 journals and, in addition, selects further articles from another 3,300 journals. It has holdings of over 3 million records and cites over 50,000 new references each week. It covers such areas as law, political science, social issues and public health.

The initial search criteria limited articles to those that were published in English, were published in a journal, and were published by March, 2003. The second level of criteria included categories that included individual or combined occurrences of such terms as risk assessment, radionuclides, risk management, land use, hazards, stakeholders, communication, cleanup, risk-based, decision making, and other terms and synonyms. The search query was partly iterative, with subsequent searches being keyed off of the yields from prior, related searches.

The application of these two levels of search criteria resulted in master list of over 1,000 journal articles. As a third step, the list was narrowed by a manual review undertaken by CRESP technical and policy staff, which reviewed both the titles and available abstracts of the articles and identified those that seemed most relevant. In addition to selecting the articles, an additional level of assessment placed each selected article, as best possible, into the most appropriate Whole Risk Paradigm category. After the articles were sorted into the Paradigm categories (table 2), a further review was undertaken to identify (through article summaries, a review of the complete articles, and dialogues with CRESP senior researchers, etc.) a subset of articles highlighted as priority initial reading material for those interested in exploring risk-based end state related concepts and examples. *This initial reading material is listed in Appendix 2 and has been printed in full text in Appendix 3.*

Table 2: The Whole Risk Paradigm Applied to Contaminated Sites:

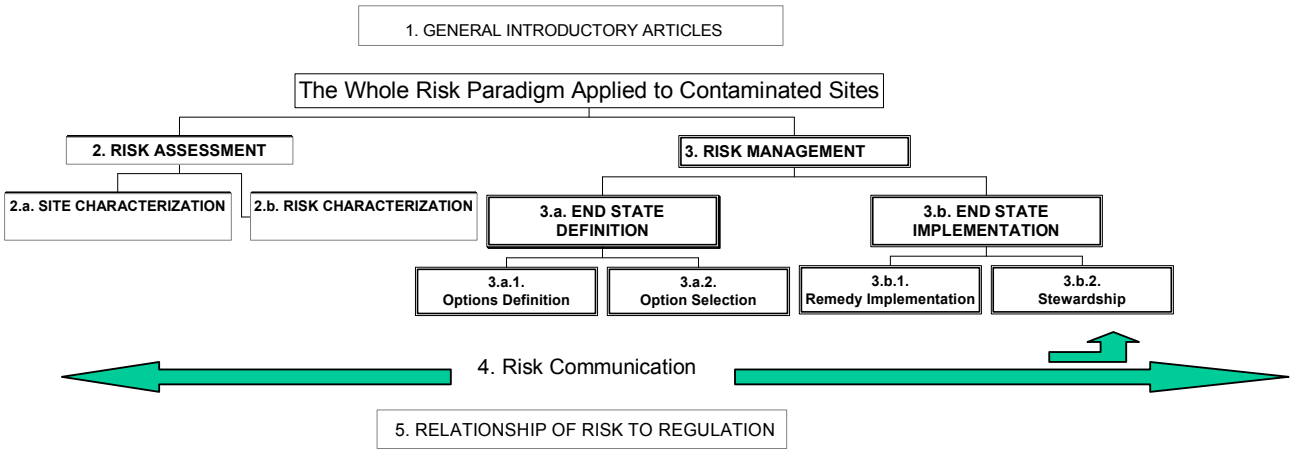
1. General Introduction
2. Risk Assessment
    - 2.a. Site Characterization
    - 2. b. Risk Characterization
3. Risk Management
    - 3.a. End State Definition
        - 3.a.1 Options Definition
        - 3.a.2 Option Selection
    - 3.b. End State Implementation
        - 3.b.1 Remedy Implementation
        - 3.b.2.Stewardship
4. Risk Communication
5. Relationship of Risk to Regulation

D. REFERENCES BY PARADIGM CATEGORY

Each reference was placed into a single risk paradigm category (i.e., 1 through 6), for the purposes of cataloguing and facilitating the retrieval of articles from the data set (see figure 6). For example, articles on Risk Communication are placed under category 4. By their very nature, however, some articles clearly cut across more than one paradigm category. In such cases where multiple categories could be associated with a single article, the reviewer selected a "best fit". It may be useful to scan the contents of closely-related reference categories.

Articles thought to be particularly useful as introductions to the topic are identified and presented in abstract form within the appropriate section, are listed in Appendix 2, and are printed as complete articles in Appendix 3. Copyright requirements have been addressed, with copyright copying fees paid to journals for all articles provided in Appendix 3. Additional abstracts are provided for other articles within each section. A more comprehensive reference list is shown, by category, in Section E and is listed alphabetically in its entirety in Appendix 2.

FIGURE 6: A Numbered Outline of Key Articles to Guide Planning and Implementation of Risk-based End States



1. GENERAL INTRODUCTORY ARTICLES

The following introductory references are highlighted because of their wide scope, their relevance to Risk Assessment and Risk Management, and their technical level of writing being accessible to a broadly educated audience. An abstract and the complete text (see Appendix 3) are provided for the first two references listed in this section and discussed below.

The National Research Council and the Presidential/Congressional Commission references are basic to many of today's regulatory policies, and offer comprehensive overviews of the risk process.

The McClellan publication places in historical perspective default assumption options used in regulatory risk models and how scientific data may replace such defaults. This topic is of considerable importance since the replacement of default options (which can be highly conservative) with site-specific data can have substantial impacts on risk assessments and subsequent risk management options. Furthermore, such issues can be considered in negotiated health and safety compliance agreements.

The Presidential / Congressional Commission on Risk Assessment and Risk Management. "Framework for environmental health risk management: Final Report Volume 1." (1997). Available from World Wide Web: (http://www.riskworld.com/Nreports/1997/risk-rpt/pdf/EPAJAN.PDF)

[Available in Full Text in Appendix 3]

The Commission's Framework defines a clear, six-stage process for risk management that can be scaled to the importance of a public health or environmental problem and that:

• Enables risk managers to address multiple relevant contaminants, sources, and pathways of exposure, so that threats to public health and the environment can be evaluated more comprehensively than is possible when only single chemicals in single environmental media are addressed.

• Engages stakeholders as active partners so that different technical perspectives, public values, perceptions, and ethics are considered.

• Allows for incorporation of important new information that may emerge at any stage of the risk management process.

McClellan, R.O. “Risk assessment: Replacing default options with specific science. *Human and Ecological Risk Assessment* 9, no. 1 (2003): 421-438.

[Available in Full Text in Appendix 3]

The history of approaches to evaluating the hazards and risks of chemicals is briefly reviewed. The role of default options (generic approaches based on general knowledge in the absence of specific knowledge to the contrary) is discussed as a part of the risk assessment paradigm advanced by the National Academy of Science/ National Research Council in 1983 and 1994. Examples are given of the impact of acquiring specific science to replace default options. An argument is made for developing specific science that would reduce uncertainty in risk assessments. Research on specific science would be guided by identified sources of uncertainty in the risk assessment process. The importance of using a research strategy that builds on human data is emphasized for validating new molecular and cellular biological assessment methods. The paper closes with a discussion of the tension between a hazard-based approach versus quantitative risk assessment in guiding risk management decisions. The former requires limited data, is qualitative, and easy to communicate, while the latter requires substantial data and is difficult to communicate. However, quantitative risk assessment provides a more rational basis for decisions on the allocation of both public and private resources for actions that will effectively minimize overall health risks to the public.

Additional Key Selected Articles

Omenn, G. S., “The New Millennium: Values, Perceptions Of Risk And The Key Roles Of Science And Technology”, *Health Physics* 80, no.4 (2001): 328-332.

Radiation protection and management of radioactive waste streams and products are certain to be important areas of public policy, worker education, and technology development in the new millennium. Overriding values of freedom, sustainability, transparency, and public participation in decision making about technology's benefits and risks will shape the public policy agenda. Early engagement of stakeholders in the identification and assessment of risks and in communications about risk management will be beneficial in most cases. Putting specific environmental problems into broader public health and ecologic context will be helpful to all parties and will improve decisions about how best to utilize precious resources and enhance public confidence in the process and the outcomes.

Eduljee, G. H. Trends in Risk Assessment and Risk Management. *Science of the Total Environment* 249 (2000): 1-3.

Environmental risk assessment has matured into a powerful analytical tool, which is finding ever-wider applications in the arena of policy making and regulation. However, the principal focus of its development to date has been on the technical challenges of characterizing and modeling the environmental behaviour and biological action of chemicals, whereas issues concerning its broader socio-political context have been generally neglected. Problem definition, risk analysis and decision making have, therefore, tended to be dominated by experts and by expert opinion. Fresh insights from the social sciences advocate a pluralistic, inclusive approach, with experts participating alongside other stakeholders in a consensual decision making process. Adoption of this paradigm has far reaching consequences for the form and conduct of risk assessment and risk management.

Goldstein, B. D. "If Risk Management Is Broke, Why Fix Risk Assessment?" *EPA Journal* 19, no. 1 (1993): 37-38.

Those who argue that risk assessment and risk management should not be independent say that risk assessors--scientists--have values and therefore risk assessment cannot be an apolitical effort. The deconstructionist approach, which argues that there is not absolute truth, may hold for the policy world but not for science. There is a knowable law of nature that describes the risk of dioxin or benzene, but no immutable law as to the best management approach to deal with these risks. At the very least, risk management is contextual, with the best decision being related to time and place, while risk assessment inherently embraces the concept that there is a single right assessment for all time.

Jurczyk, N., C. Marcussen, and W. Tucker. “Risk Assessment: A Tiered Approach.” *Natl. Environ. J.* 5, no. 5 (1995): 20-26.

For many years, risk assessment has been used as a valuable interpretive tool to determine the relative significance of contamination in food, soil, water, and air. The technologies of risk assessment, like many other technologies, have undergone significant changes and refinements since the first Superfund requirements more than a decade ago. Under Superfund, a risk assessment is required to assess the health risks associated with potential exposures to site contaminants; in addition, it plays a crucial role in the development of cleanup objectives for the site. Although risk assessment was once reserved only for costly Superfund sites, today this remedial decision making tool is increasingly being used for sites of all sizes and complexities as a cost-effective approach for setting cleanup objectives. Underground storage tank (UST) sites are an excellent example of where a risk assessment often is not required by regulatory agencies, but is rapidly becoming a cost-effective approach for setting cleanup objectives for these sites. Due to the financial constraints by state-funded programs to remediate all UST sites to pristine conditions, regardless of current and reasonable future land use, regulators and industry are recognizing the need to base cleanups on health risks rather than overly stringent uniform standards.

2. RISK ASSESSMENT

2.a. SITE CHARACTERIZATION

Each site can be described in terms of its contaminants (concentrations, media and fate/pathways), its background level of radiation and other agents, its current use or stage of decontamination, its related human populations (workers, neighbors, recreational users), and its ecology (including endangered or threatened species).

Site Characterization references of Kosson et al and Regens et al have been noted for initial reading (full text in Appendix 3), but a larger list of additional publications relevant to other aspects of site characterization is provided in this section as well as in section E1. Understanding contaminants, their sources and the local geophysical attributes that influence their potential to move through pathways relevant to receptors are central to site characterization. The paper by Kosson et al provides an important new tiered framework to assess how contaminants leach or can be predicted to leach under field management scenarios. A recent article by Regens et al reviews several common multimedia models that are used in assessing or predicting the potential for contaminants to move through pathways. Other abstracted articles cover an additional set of characterization issues.

Concepts in Site Characterization

1) Contaminant analyses/ Background exposures
2) Hazard Identification
   a) Carcinogens
   b) Other
3) Contaminant Pathways
   a) Air
   b) Surface: Soil/Water
   c) Vadose Zone
   d) Groundwater
   e) Sediments
   f) Biota
   g) Wastes
   h) Food
4) Fate and Transport
   a) Attenuation processes
   b) Contaminant mobility
   c) Conceptual model
   d) Modeling
   e) Uncertainty analysis
5) Current Land Use
6) Populations
   a) Human
   b) Ecosystems

Kosson, D.S., H.A. vander Sloot, F. Sanchez and A.C. Garrabrants. “An integrated Framework for Evaluating Leaching in Waste Management and

Utilization of Secondary Materials." *Environmental Engineering Science* 19, no. 3: (2002): 159-204.

[Available in Full Text in Appendix 3]

A framework for the evaluation of constituent leaching from wastes and secondary materials is presented. The framework is based on the measurement of intrinsic leaching properties of the material and use of mathematical modeling to extrapolate from laboratory testing to estimates of release under field management scenarios. Site specific and default scenarios are considered, which may be selected based on the evaluation context. A tiered approach is provided to allow the end-user to balance between the specificity of the release estimate, the amount of testing knowledge required, a priori knowledge, and resources required to complete an evaluation. Detailed test methodologies are provided for a suite of laboratory leaching tests.

Regens, J. L., K. R. Obenshain, C. Travis, abd C. Whipple. "Conceptual site models and multimedia modeling: Comparing MEPAS, MMSOILS, and RESRAD." *Human and Ecological Risk Assessment* 8, no. 2: (2002): 391-403.

[Available in Full Text in Appendix 3]

The use of multimedia models to assess current and future human and ecological exposure to contamination at hazardous waste sites has become common practice in recent years. The U.S. Environmental Protection Agency has identified development of a conceptual site model as a critical part of the risk assessment process. This paper investigates the relationship between the choice of conceptual site models and application of multimedia models and the variation in risk estimates obtained when using data and default parameter values suggested by the individual model developers.

Additional Key Selected Articles

Cox, L.A.,Jr. "Adaptive Spatial Sampling of Contaminated Soil." Risk Analysis 19, no. 16 (1999): 1059-1069.

Suppose that a residential neighborhood may have been contaminated by a nearby abandoned hazardous waste site. The suspected contamination consists of elevated soil concentrations of chemicals that are also found in the absence of site-related contamination. How should a risk manager decide which residential properties to sample and which ones to clean? This paper introduces an *adaptive spatial sampling* approach which uses initial observations to guide subsequent search. Unlike some recent model-based spatial data analysis methods, it does not require any specific statistical model for the spatial distribution of hazards, but instead constructs an increasingly accurate nonparametric approximation to it as sampling proceeds. Possible cost-effective sampling and cleanup decision rules are described by decision parameters such as the number of randomly selected locations used to initialize the process, the number of highest-concentration locations searched around, the number of samples taken at each location, a stopping rule, and a remediation action threshold. These decision parameters are optimized by simulating the performance of each decision rule. The simulation is performed using the data collected so far to impute multiple probable values of unknown soil concentration distributions during each simulation run. This optimized adaptive spatial sampling technique has been applied to real data using error probabilities for wrongly cleaning or wrongly failing to clean each location (compared to the action that would be taken if perfect information were available) as evaluation criteria. It provides a practical approach for quantifying trade-offs between these

different types of errors and expected cost. It also identifies strategies that are undominated with respect to all of these criteria.

Breckenridge, R. P., J. F. Keck, et al. "Characterizing soils for hazardous waste site assessments." *Environmental Monitoring and Assessment* 30, no. 2 (1994): 113-138.

The data needed to characterize soils for hazardous waste site assessments and to comply with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) are reviewed in this paper. Scientists and managers within the regulatory agency and the liable party need to know what are the important soil characteristics needed to make decisions about risk assessment, what areas need remediation and what options of remedy are available. Data can be collected more efficiently and less costly, if those involved in characterizing a hazardous waste site can agree on the required soil data set before commencing an investigation. Having the data needed will help in deciding how to address concerns at and close-out, hazardous waste.

Cushman, D. J., K. S. Driver, and S. D. Ball. "Risk Assessment for Environmental Contamination: An Overview of the Fundamentals and Application of Risk Assessment at Contaminated Sites." *Canadian Journal of Civil Engineering* 28 (2001): 155-62.

Many jurisdictions throughout Canada and the United States allow the decision to proceed with an active site cleanup, an evaluation or monitoring program, or site closure to be determined from the results of a risk assessment. Risk assessment can protect both human health and the environment while providing significant savings to industry and government by reducing unnecessary environmental expenditures and allowing for the more efficient allocation of resources. Risk assessment is a dynamic process which is evolving as new methods for contaminant fate and transport modeling, more complete toxicological data, and more standardized statistical methods become available. Principal methodologies for conducting risk assessments are provided by the United States Environmental Protection Agency (USEPA), the American Society for Testing and Materials (ASTM), and the Canadian Council of Ministers of the Environment (CCME). Risk assessment methodologies include both "forward" risk calculations and "reverse" risk calculations. Uncertainties inherent in risk assessment methodologies can be difficult to quantify and are dealt with by incorporating conservative assumptions throughout the risk assessment process. Institutional controls may be required to ensure the continued validity of assumptions. There is a trend toward the increased application and acceptance of risk assessment, although Canada remains well behind the United States. To ensure the expanded use of risk assessment in Canada, more training for both regulators and environmental professionals, increased public awareness, and the adaptation of the risk assessment methodologies being applied in the United States to reflect the environmental policies and technical concerns of interest across Canada will be required.

Byrnes, M. E., R. W. Nelson, et al, "Complementary investigative techniques for site assessment with low-level contaminants*." Ground Water Monit. Rev*. 10, no. 4: (1990). 90-95.

A remedial investigation (RI) was performed in an area down gradient from an abandoned missile silo at Vandenberg Air Force Base, California, as part of the United States Air Force Installation Restoration Program (IRP). A number of complementary investigative techniques were used to assure a reliable assessment of site contamination. These included the review of aerial photographs, the use of an organic vapor analyzer (OVA) and carbon adsorption/mass spectrometer (MS) method to conduct a soil-gas survey; magnetic and electromagnetic geophysical surveys; bedrock permeability testing; and the chemical analysis of soil, sediment, surface water, and ground water samples.

Burger, J. and Gochfeld, M. “On developing bioindicators for human and ecological health”. *Environmental Monitoring and Assessment* 66 (2000): 23-46.

Risk assessors and risk managers generally either examine ecological health (using bioindicators) or human health (using biomarkers of exposure or effect). In this paper we suggest that it is possible and advantageous to develop bioindicators that can be used to assess exposure and effect for both human and non-human receptors. We describe the characteristics of suitable bioindicators for both human and ecological health, using mourning doves (Zenaida macroura), raccoons (Procyon lotor), and bluefish (Pomatomus salatrix) as examples, and list the general characteristics of other species that would make them useful indicators for assessing both human and ecological health. Bioindicators can be used cross-sectionally to assess the status of ecosystems and risk as well as longitudinally for monitoring changes or evaluating remediation. For both human and ecological risk assessment, there are three sets of characteristics to consider when selecting bioindicators: biological relevance, methodological relevance, and societal relevance. An indicator which fails to fulfill these is not likely to be considered cost-effective and is likely to be abandoned. The indicator should be readily measured and must measure an important range of impacts. For long-term support of a bioindicator, the indicator should be easily understood, and be cost effective. We suggest that bioindicators that can also be used for both ecological and human health risk assessment are optimal.

Elless, M. P., A. Q. Armstrong, et al. "Characterization and solubility measurements of uranium-contaminated soils to support risk assessment." *Health Physics* 72, no. 5 (1997): 716-726.

Remediation of uranium-contaminated soils is considered a high priority by the U.S. Department of Energy because these soils, if left untreated, represent a hazard to the environment and human health. Because the risk to human health is a function of the solubility of uranium in the soils, the objectives of this work are to measure the uranium solubility of two contaminated soils, before and after remedial treatment, and determine the health risk associated with these soils. Two carbonate-rich, uranium-contaminated soils from the U.S. Department of Energy Fernald Environmental Management Project facility near Cincinnati, Ohio, as well as two nearby background soils were characterized and their uranium solubility measured in a 75-d solubility experiment using acid rain, groundwater, lung serum, and stomach acid simulants. Risk calculations and biokinetic modeling based on the solubility data show that the risks from the soil ingestion and groundwater ingestion pathways are the predominant contributors to the total carcinogenic risk, whereas the risk from the soil inhalation pathway is the smallest contributor to this risk. However, kidney toxicity was the greater health concern of the Fernald Environmental Management Project soils. Sensitivity analyses indicate that uranium solubility is a key parameter in defining kidney toxicity; therefore, without proper consideration of the solubility of radionuclides/metals in untreated and treated soils, important factors may be overlooked which may result in soil cleanup goals or limits which are not protective of human health and the environment. We recommend that characterization and measurement of target radionuclides/metals solubilities should also be required by the regulatory community to support the establishment of scientifically-sound, site-specific, soil cleanup goals or limits.

See Section E.1 for additional articles on Site characterization.

2. RISK ASSESSMENT

2.b. RISK CHARACTERIZATION

As applied to the current paradigm, risk characterization includes the assessment of exposure to populations and ecology, the degree to which such exposures can be biologically absorbed or taken up into the target organism, and the expectation of harm (risk) from predicted dose levels. This process is open to many types of uncertainty, and uncertainty analysis becomes vital to understanding the statistical bandwidth within which predicted exposures and outcomes could reside.

Two references, with full text in Appendix 3, have been highlighted out of a more comprehensive set noted below and in Section E. The articles by Jones et al, and by Lioy describe Exposure concepts and provide examples of their application. The Jones article focuses on radiological ecological risk assessment, while the Lioy publication describes conceptual models and elements useful for organizing and evaluating exposure scenarios. The articles, supported by others abstracted in this section, address many of the concepts listed below.

Concepts in Risk Characterization

1) Receptors and their Exposure
   a) Exposure Characterization
   b) Sensitive Eco and Populations
2) Environmental Biomonitoring
3) Bio-availability and Dose to Receptors (Human/ ecological)
4) Dose-Response-time Characterization and Low dose issues
   a) Threshold/non-threshold
5) Risk Calculation, Characterization and Uncertainty Analysis
6) High Risk Groups: Susceptible Populations and Ecosystems
7) Sentinel responses and indicator species
8) Integration of occupational, public health and ecological risks
9) Tests of Risk Assessment Models

Jones, D., S. Domotor, K. Higley, D. Kocher, and G. Bilyard. "Principles and issues in radiological ecological risk assessment." *Journal of Environmental Radioactivity* 66, no. 1-2 (2003): 19-39.

[Available in Full Text in Appendix 3]

This paper provides a bridge between the fields of ecological risk assessment (ERA) and radioecology by presenting key biota dose assessment issues identified in the US Department of Energy's Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota in a manner consistent with the US Environmental Protection Agency's framework for ERA. Current radiological ERA methods and data are intended for use in protecting natural populations of biota, rather than individual members of a population. Potentially susceptible receptors include

vertebrates and terrestrial plants. One must ensure that all media, radionuclides (including short-lived radioactive decay products), types of radiations (i.e., alpha particles, electrons, and photons), and pathways (i.e., internal and external contamination) are combined in each exposure scenario. The relative biological effectiveness of alpha particles with respect to deterministic effects must also be considered. Expected safe levels of exposure are available for the protection of natural populations of aquatic biota (10 mGy d_1) and terrestrial plants (10 mGy d_1) and animals (1 mGy d_1) and are appropriate for use in all radiological ERA tiers, provided that appropriate exposure assumptions are used. Caution must be exercised (and a thorough justification provided) if more restrictive limits are selected, to ensure that the supporting data are of high quality, reproducible, and clearly relevant to the protection of natural populations.

Lioy, P. Assessing total human exposure to contaminants: A multidisciplinary Approach. *Environmental Science and Technology* 24, no. 7 (1990): 938-945.

[Available in Full Text in Appendix 3]

No abstract available

Additional Key Selected Articles

Georgopoulos, P.G. and P.J. Lioy. "Conceptual and theoretical aspects of human exposure and dose assessment." *Journal of Exposure Analysis and Environmental Epidemiology* 4 (1994): 253-285.

A formal, conceptual and mathematical framework for refining the characterization of human exposure and dose, resulting from contact with a toxicant, is introduced. The conceptual approach to the exposure characterization process leads to a mathematical description necessary for formalizing this process. Twelve steps are identified for guiding the information collection, management, and analysis needs for characterization and estimation of exposure and dose. These steps are discussed in terms of ten general principles for exposure and dose assessment that are related to: (1) The complicated character of exposure systems and models, (2) the need for using appropriate metrics associated with the exposure dynamics of individuals, populations and locations, (3) the need to consider exposure as a sequence of coupled events and systems, (4) the need to treat exposure assessment as a dual prognostic and diagnostic problem and (5) as a dual phenomenological and mechanistic problem, (6) the fact that uncertainty in exposure characterization includes both irreducible and reducible components that have to be quantified, (7) the need to specify probability distributions of exposures for individuals and populations, (8) the need for implementing state-of-the-art computational data management methods for exposure related information, (9) the need to formally and thoroughly evaluate exposure assessment modeling studies, and (10) the limitations in the exposure characterization process that affect the current practice of risk assessment. The theoretical approach described here represents an "ideal" characterization model that will rarely, if ever, be fully implemented in practice. However, this approach offers a consistent and general framework that can help identify specific needs for improvement in current measurements and estimation practices, and move exposure assessments closer to "real" exposure systems.

Gray, G.M. "Complete Risk Characterization." *Harvard Center for Risk Analysis* 2 no. 4 (1994).

This article examines the case for better risk characterization to combat false precision, false consistency, and hidden choices in risk assessment. The underlying motivation is concern about the potential for misleading comparisons by risk managers.

Jannik, G.T. “Critical Radionuclide/Critical Pathway Analysis for the U.S. Department of Energy’s Savannah River Site. 19, no. 3 (1999): 417-426.

Many different radionuclides have been released to the environment from the Savannah River Site (SRS) during the facility’s operational history. However, as shown by this analysis, only a small number of the released radionuclides have been significant contributors to potential doses and risks to off-site people. This article documents the radiological critical contaminant/critical pathway analysis performed for SRS. If site missions and operations remain constant over the next 30 years, only tritium oxide releases are projected to exceed a maximally exposed individual (MEI) risk of 1.0E-06 for either the airborne or liquid pathways. The critical exposure pathways associated with site airborne releases are inhalation and vegetation consumption, whereas the critical exposure pathways associated with liquid releases are drinking water and fish consumption. For the SRS-specific, nontypical exposure pathways (i.e., recreational fishing and deer and hog hunting), cesium-137 is the critical radionuclide.

Duan N, Mage DT. “Combination of Direct and Indirect Approaches for Exposure Assessment.” *Journal of Exposure Analysis and Environmental Epidemiology* 7 no. 4 (1997): 439-470.

The direct approach to measuring human air pollution exposure relies on personal monitoring devices, which are costly and vulnerable to sample selection because of the burden on respondents. The indirect approach combines data on activity patterns with data on microenvironment concentrations, which may require estimates from several data sources and their attendant measurement errors. This paper proposes a combined approach to remedy each of these problems: a dual sample that provides both direct and indirect measurements and a separate representative and lower-cost indirect sample. Cross-comparisons can be used to reduce bias, and the lower-cost indirect sample allows for greater precision under certain conditions spelled out in the paper.

Sanchez, J and J. Burger, “Hunting and Exposure: Estimating Risk and Future Use at Nuclear Production Sites *Health, Safety & Environment* 9 (1998): 109.

Decisions concerning the reuse and remediation of contaminated nuclear production sites should be based upon realistic and supportable assumptions of use and risk. We argue that specific rather than generic criteria are needed to make informed decisions, and it illustrates, using one site as an example, that basic land use information can provide crucial data about the risk assessment and reuse decision process. In recent years, a major planning issue for the government (1)and for some regional and local planners,(2) has been the identification of future uses for U.S. Department of Energy (DOE) sites and facilities. Since 1994, twenty DOE sites have been involved in the Future Use Project, a project designed to reconfigure DOE activities and land holdings.(3) Through a formal planning process involving the public, fifteen of those twenty sites have developed recommendations for future land use. Although many factors generally influence the remediation and future use of DOE sites, land suitability and public opinion will likely play increasingly significant roles in determining future use scenarios. Risk assessment concerning site contamination is an important element of the DOE's decision process regarding the future use and remediation of production sites. This is especially important for uses such as recreation which may involve large segments of the population. Consequently, consideration of local preferences and practices will be necessary in developing realistic exposure scenarios for accurate risk assessments.(4) This research concentrates on the recreational use at one DOE site. Specifically, it focuses on the hunting and fishing that took place at the Crackerneck portion of the Savannah River Site in South Carolina during the 1995-96 hunting season.

Washburn, S. T., C. F. Kleiman, et al. "Applying USEPA Risk Assessment Guidance in the 90s." *Hum. and Eco. Risk Assessment* 4, no. 3 (1998): 763-774.

Over the past decade, risk assessment has become increasingly relied upon for helping to make environmental management decisions. This trend has been accompanied by research and refinements in basic risk assessment methodologies to improve our ability to understand and evaluate the human health risks associated with chemical exposures. Despite this progress, significant uncertainties continue to be associated with the risk assessment process. These uncertainties typically derive from gaps in available data regarding chemical toxicity, and from difficulties in reliably estimating the magnitude of chemical exposures. Given these limitations, risk assessment is generally most valuable in evaluating relative risk; for example, when comparing alternatives to achieving a specified goal, setting priorities for protecting human health, or establishing procedures for properly allocating resources. Risk assessment can also be useful for developing regulatory benchmarks such as permit limits for air or water. In many cases, however, the limitations of the risk assessment process make it difficult (if not impossible) to reliably estimate an absolute level of risk, especially for a specific individual in an exposed population. In such cases, risk assessment can be seriously misapplied, and its results misinterpreted. This paper discusses some of the challenges that have been faced by the field of risk assessment during the 1990s. Current trends in risk assessment, and its use by regulatory agencies in making risk management decisions, are also described.

Williams, P. R. D. and D.J. Paustenbach. " Risk Characterization: Principles and Practice," *Journal of Tox. and Environ., Part B*, Oct-Dec (2002): 307-407.

In the field of risk assessment, characterizing the nature and magnitude of human health or environmental risks is arguably the most important step in the analytical process. In this step, data on the dose-response relationship of an agent are integrated with estimates of the degree of exposure in a population to characterize the likelihood and severity of risk. Although the purpose of risk characterizations is to make sense of the available data and describe what they mean to a broad audience, this step is often given insufficient attention in health risk evaluations. Too often, characterizations fail to interpret or summarize risk information in a meaningful way, or they present single numerical estimates of risk without an adequate discussion of the uncertainties inherent in key exposure parameters or the dose-response assessment, model assumptions, or analytical limitations. Consequently, many users of risk information have misinterpreted the findings of a risk assessment or have false impressions about the degree of accuracy (or the confidence of the scientist) in reported risk estimates. In this article we collected and integrated the published literature on conducting and reporting risk characterizations to provide a broad, yet comprehensive, analysis of the risk characterization process as practiced in the United States and some other countries. Specifically, the following eight topics are addressed: (1) objective of risk characterization, (2) guidance documents on risk characterization, (3) key components of risk characterizations, (4) toxicity criteria for evaluating health risks, (5) descriptors used to characterize health risks, (6) methods for quantifying human health risks, (7) key uncertainties in risk characterizations, and (8) the risk decision-making process. A brief discussion is also provided on international aspects of risk characterization.

Kellerer, A.M. " Radiation risk-historical perspective and current issues," *Journal Radiological Protection 22* (2002): A1-A10.

The assessment of radiation risk needs to be seen against the background of a historical development that has reversed the initial belief in a general beneficial effect of radiation to apprehension and fear. Numerical risk estimates are, today, based on large epidemiological studies, and the observations on the A bomb survivors are outlined as the primary source of information. Since the epidemiological findings are obtained from relatively high radiation exposures, extrapolations are required to the much lower doses that are relevant to radiation protection. The evolution of extrapolation procedures up to current attempts at mechanistic modeling is outlined, and some of the open issues are reviewed.

See Section E.2 for additional articles on Risk Characterization.

3. RISK MANAGEMENT

3.a. END STATE DEFINITION

3.a.1. Options Definition

While end states are rarely defined or described in the literature, there are a number of publications that use risk information to form the basis of assessing options for remediation/risk reduction, land use, and stewardship.

We cite the papers here really as a way of illustrating how diverse the types of resources for practitioners to access in order to address their specific issues. The first two of the following articles are available in full text in Appendix 3. Bonano et al give examples and conceptual perspectives on the use of risk-based methods for selecting from among alternatives in defining options for remediation. By contrast, Burger discusses factors that help shape priority setting.

As the concepts in options definition list immediately following this paragraph illustrate, the specific topics are very diverse in this category and the reader is encouraged, particularly for this set of interests, to carefully peruse the additional literature relating to Options Definition or similar concepts as listed both in this Section and in Section E.3.

Concepts in Options Definitions

1) Risk reduction goals
   a) Individuals (public)
   b) Individuals (worker)
   c) Population basis (ecologic or human)
2) Land use goals
   a) Spatial and temporal definition
3) Land Use Categories, Controls and Options
   a) Prohibited Use
   b) Industrial
   c) Commercial
   d) Recreational
   e) Agricultural
   f) Residential
4) Remediation Options
   a) Source removal
   b) Source Isolation/ containment/treatment
   c) Exposure pathway interruption/barriers
   d) Alternative on-site management
5) Stewardship /Assumption /Requirements
6) Economic characterization of options

Bonano, E. J., G. E. Apostolakis "Application of risk assessment and decision analysis to the evaluation, ranking and selection of environmental remediation alternatives." *Journal of Hazardous Materials* 71 (2000): 35-57.

[Available in Full Text in Appendix 3]

A single framework integrating risk assessment and decision analysis methods for evaluating, ranking and selecting preferred remediation alternatives at a contaminated site was developed and demonstrated. The methodology used relies on stakeholder inputs throughout the entire process and employs those inputs to combine the results of multiple risk assessments to arrive at a total impact for each remediation alternative. The total impact values allow the ranking of the alternatives, which in turn, serves as the basis for deliberations among the stakeholders in order to identify the preferred alternative. Six major risk or impact categories were considered in the evaluation of the alternatives: human health and safety, environmental protection, life cycle cost, socio-economics, cultural, archeological and historical resources, and programmatic assumptions.

Burger, J. "Stewardship and Future Land Use at a Department of Energy Site: Does Self-Interest Determine Ratings?" *Journal of Toxicology and Environmental Health-Part A* 63, no. 5 (2001): 383-395.

[Available in Full Text in Appendix 3]

Based on studies at several Department of Energy sites and Superfund sites, as well as elsewhere, it is clear that people prefer that contaminated lands be restored to usable land. Knowing the future uses for such land can inform environmental cleanup and restoration decision making, often determining the level of cleanup, costs, future management, and stewardship. This article examines the relationship between general environmental attitudes, future land use preferences, and recreational activities for people living around the Department of Energy's Savannah River Site in South Carolina. There were few differences in the rating for general environmental problems as a function of recreational activities. Although future land use ratings were generally correlated with the number of days people engaged in particular activities (hunting, fishing, hiking, camping), people who hunted and fished rated nearly every recreational activity higher than did people who only camped or hiked, or than those who engaged in no outdoor activities. Thus, campers and hikers did not rate camping and hiking higher as future land uses than did other groups. These data suggest that there is widespread support for recreational activities as future uses for the Savannah River Site, regardless of whether people participate in them or not, and that current cleanup and stewardship decisions should consider these views.

Additional Key Selected Articles

Klinke, A. and O. Renn "A new approach to risk evaluation and management: Risk-based, precaution-based, and discourse-based strategies." *Risk Analysis* 22, no. 6 (2002): 1071-1094.

Nine risk evaluation criteria, six risk classes, a decision tree, and three management categories were developed to improve the effectiveness, efficiency, and political feasibility of risk management procedures.

Arquette, M., M. Cole, K. Cook, B. LaFrance, M.Peters, J. Ransom, E. Sargent, V. Smoke, A. Stairs. "Holistic risk-based environmental decision making: A native perspective." *Environmental Health Perspectives* 110 (2002): 259-264.

Native American Nations have become increasingly concerned about the impacts of toxic substances. Although risk assessment and risk management processes have been used by government agencies to help estimate and manage risks associated with exposure to toxicants, these tools have many inadequacies and as a result have not served Native people well. In addition, resources have not always been adequate to address the concerns of Native Nations, and involvement of Native decision makers on a government-to-government basis in discussions regarding risk has only recently become common. Finally, because the definitions of health used by Native people are strikingly different from that of risk assessors, there is also a need to expand current definitions and incorporate traditional knowledge into decision making. Examples are discussed from the First Environment Restoration Initiative, a project that is working to address toxicant issues facing the Mohawk territory of Akwesasne. This project is developing a community-defined model in which health is protected at the same time that traditional cultural practices, which have long, been the key to individual and community health, are maintained and restored.

See Section E.3.a.1 for additional articles on Options Definition.

3. RISK MANAGMENT

3.A. End State Definition

3.a.2. Option Selection

The selection of risk management options is multi-factorial. The process must take into consideration how available options will be assessed, how risks will be balanced (different receptors – workers, public, ecology; different time frames – now, near future, long-term future, etc.), how stakeholder preferences are approached, what economic and legal implications exist, and whether long term stewardship needs are adequately met. Literature on various aspects of this issue is extensive. Several references have been selected as a starting point to explore the issues within this study area, with the full texts of Greenberg et al, and Kavanaugh available in Appendix 3.

Greenberg et al uses a scanning process to create lists of items that are relevant to the selection of an option. Kavanaugh looks at potential conflicts between U.S. public policies and the technologies that have been developed but may or may not be applied.

These references are supplemented by an additional list both in this Section and in Section E.3.a.2.

Concepts in Option Selection

1) Decision process definition and communication
2) Risk balancing between potential receptors
3) Stakeholder preferences
4) Economics; Long and Short term
5) Stewardship requirements
6) Legal constraints and requirements
7) Federal/State/Local Policy

Greenberg M, Burger J, Powers C, Leschine T, Lowrie K, Friedlander B, Faustman E, Griffith W, and Kosson D. “Choosing remediation and waste management options at hazardous and radioactive waste sites,” *Remediation. Winter*, (2002a):39-58.

[Available in Full Text in Appendix 3]

This article discusses a process for finding insights that will allow federal agencies and environmental professionals to more effectively manage contaminated sites. The process is built around what Etzioni (1968) called mixed-scanning, that is, perpetually doing both comprehensive and detailed analyses and periodically re-scanning for new circumstances that change the decision-making environment. The article offers a checklist of 127 items, which is one part of the multiple-stage scanning process. The checklist includes questions about technology; public, worker, and ecological health; economic cost and benefits; social impacts; and legal issues. While developed for a DOE high-level radioactive waste application, the decision-making

framework and specific questions can be used for other large-scale remediation and management projects.

Kavanaugh, M. C. Overview of the management of contaminated sites in the US: the conflict between technology and public policy. *Water Science and Technology* 34, no. 7-8 (1996): 275-283.

[Available in Full Text in Appendix 3]

Since the late 1970s, the US has utilized a variety of strategies to manage the problem of contaminated land and groundwater within the 50 states, a problem whose dimension is still not well defined. Recent estimates indicate that the US may spend up to 1 trillion dollars over the next 20 to 30 years undoing the environmental damage caused by improper storage and disposal of hazardous materials and toxic wastes over the past several decades, but predominantly since the end of World War II. Whether these expenditures will provide an equivalent level of benefit or risk reduction to US citizens is a subject of current debate. The effective management and remediation of this complex array of sites is proving both difficult and expensive. Research over the past decade has shown that in many cases, technology is limited in its ability to restore contaminated sites to pre-industrial conditions. In the US, new policy initiatives are being developed that insure both protection of human health and the environment, but at significant reduction in life cycle costs to society. Risk-based decision making is replacing rigid politically driven remediation decisions. The changes in the US model for management of contaminated sites provides valuable insights to other nations who are or will be faced with the same difficult choices balancing the costs of remedial strategies against potential reduction in risks to human health and the environment.

Additional Key Selected Articles

Drew, C.H., and T.L. Nyerges. “Using decision paths to explore three environmental cleanup decisions: a cross-case analysis.” *International Journal of Environment and Pollution* 17, No.3 (2002): 171-201.

Transparent decisions are widely sought by parties interested in and affected by cleanup activities at government-owned facilities. In an approach to transparency, this paper uses decision paths and timelines to compare three decisions at the US Department of Energy Hanford site. A regulatory decision strategy., consisting of seven sequential (linear) steps, is used as the basis for the analysis. We find that the decision path is different for each case, although the timeframe associated with the main steps is similar Also, although decision steps are evident in each case study, the decision process unfolds in cycles rather than following the linear path typically described to stakeholders. Finally, we observe a stronger emphasis on the information-gathering step than on other steps in the decision process. These findings suggest that new ways of representing decision situations are needed if transparency is to be achieved.

Hartman, D. H., and M. N. Goltz. "Application of the Analytic Hierarchy Process to Select Characterization and Risk-Based Decision-Making and Management Methods for Hazardous Waste Sites." *Environmental Engineering and Policy Environ.* 3 (2002): 1-2.

Environmental managers at U.S. Department of Defense (DoD) installations overseas are faced with the challenge of managing contaminated sites at these installations with little information on the extent of contamination or the risk posed by the site. In this regard, DoD managers overseas encounter a situation quite similar to the situation faced by decision makers in the U.S. who are managing Brownfields. Innovative site characterization and risk-based decision-making methods, which are currently being developed for expeditious application at

Brownfield sites in the U.S., may also be appropriate for application at overseas DoD sites. In this paper, the analytic hierarchy process (AHP) is used by DoD decision makers to evaluate and rank innovative site characterization technologies and risk-based decision-making and management methods, for use at installations in Korea. Results indicate that for sites with high potential risk the decision makers preferred site characterization technologies that produce data of high quality and a method that can be used to establish credible risk-based remediation goals. This study provides a framework for applying characterization technologies and risk management to poorly characterized contaminated sites in developing countries, where resources for remedial actions may be limited.

Katsumata, P. T. and W. E. Kastenberg "On using residual risk to assess the cost effectiveness and health protectiveness of remedy selection at Superfund sites." *Reliability Engineering & System Safety* 62 (1998): 1-2.

This article examines the importance of determining residual risk and its impact on remedy selection at Superfund Sites. Within this examination, risks are assessed using probabilistic models that incorporate the uncertainty and variability of the input parameters, and utilize parameter distributions based on current and applicable site-specific data. Monte Carlo methods are used to propagate these uncertainties and variabilities through the risk calculations resulting in a distribution for the estimate of both risk and residual risk. Such an approach permits an informed decision based on a broad information base which involves considering the entire uncertainty distribution of risk rather than a point estimate for each exposure scenario. Using the probabilistic risk estimates, with current and applicable site-specific data, alternative decisions regarding cleanup are obtained for two Superfund Sites.

Tam, E. and P. Byer "Remediation of contaminated lands: a decision methodology for site owners." *Journal of Environmental Management* 64 no.4 (2002): 387-400.

Deciding how to remediate and redevelop contaminated lands should involve more than just selecting remediation techniques to clean a site to meet regulations for a predetermined site use. Owners and their consultants also need to understand aspects such as alternative site uses and liability, and how issues such as uncertainty can affect them. A methodology has been developed that provides a framework for current site owners when making decisions. It clarifies the above issues and details the type of information that is needed. It offers a step-by-step approach to improve decision making when contemplating remediation of contaminated sites by identifying the site use and remedial action combination that maximizes the current owner's net benefits. It examines various factors in decision making-with special emphasis on the timely issues of liability and uncertainty-and how expert opinion can be used to address diverse or incomplete data. Future research should include developing a complementary methodology that incorporates community and ecological objectives, resulting in a unified decision framework.

Wolbarst, A. B., J. Mauro, et al. "Model for estimating population impacts averted through the remediation of contaminated soil." *Health Physics* 75, No. 1 (1998): 67-76.

This is the second in a series of papers that discuss methodologies being developed and employed by the U.S. Environmental Protection Agency in support of its decisions on cleanup levels for radioactively contaminated sites that are to be remediated and released for public use. It describes a model, CU-POP, designed by the U.S. Environmental Protection Agency to obtain estimates of the potential collective radiological health impacts over specific periods of time (100, 1,000 and 10,000 y following cleanup), both on and off site, due to residual radioactive materials in on-site soil. Collective doses and risks are linear in population density for the direct exposure, dust and indoor radon inhalation, and soil ingestion pathways; it is assumed that specific fractions

of all food grown and all groundwater pumped at a site are consumed by on-and off-site populations. The model was developed for application to a set of hypothetical "reference" sites; its testing on a simple generic site is discussed briefly here.

See Section E.3.a.2 for additional articles on Option Selection.

3. Risk Management

3.b. END STATE IMPLEMENTATION

3.b.1. Remedy Implementation

The implementation of a remedy at a contaminated site includes more than difficult and costly removal actions and the application of engineering systems. There is the need for the development of institutional controls, the establishment of monitoring and maintenance systems, the need for information management systems to guide and report on progress, and the requirement of financial instruments that will assure that needed resources will be available throughout the remediation process and into the stewardship phase.

There was not an extensive literature noted for many of the components of the implementation phase. The Zhu and Shaw article (see attached CD-ROM for complete article) was selected as a discussion starting point regarding only one or two of the wide set of remediation implementation issues confronting sites with radionuclide contamination.

Concepts in Remedy Implementation

1) Removal actions
2) Implementation of engineered systems (treatment ,barriers, etc.)
3) Establishment of institutional controls
4) Establishment of monitoring, inspection and maintenance plan
5) Establishment of information management system
6) Establishment of financial instruments

Zhu, Y. G. and G. Shaw. Soil contamination with radionuclides and potential remediation. *Chemosphere* 41: (2000)121-128.

[Available in Full Text in Appendix 3]

Soils contaminated with radionuclides, particularly super(137)Cs and super(90)Sr, pose a long-term radiation hazard to human health through exposure via the food chain and other pathways. Remediation of radionuclide-contaminated soils has become increasingly important. Removal of the contaminated surface soil (often up to 40 cm) or immobilization of radionuclides in soils by applying mineral and chemical amendments are physically difficult and not likely cost-effective in practicality. Reducing plant uptake of radionuclides, especially super(137)Cs and super(90)Sr by competitive cations contained in chemical fertilizers has the general advantage in large scale, low-level contamination incidents on arable land, and has been widely practiced in central and Western Europe after the Chernobyl accident. Phytoextraction of radionuclides by specific plant species from contaminated sites has rapidly stimulated interest among industrialists as well as academics, and is considered to be a promising bio-remediation method. This paper examines the existing remediation approaches and discusses phytoextraction of radionuclides from contaminated soils in detail.

Additional Key Selected Articles

Hourcle, L. R. and N. H. Guenther "Institutional controls for future land use at active Installation Restoration Program (IRP) sites." *Federal Facilities Environmental Journal* 9, no. 2 (1998): 63-76.

One of the strategies now in vogue in hazardous waste cleanup is basing remedial strategies on future land use. The initial thrust of CERCLA for permanent and complete remedies has given way, pushed by concepts like "Brownfields" and base closure and reuse, to strategies often based on "institutional controls" that attempt to stabilize future land uses at a site based on residual risk. The heart of this concept is that instead of removing all wastes from a site, some wastes can safely remain so long as in the future the site is not used in such a way that the residual contamination poses an unacceptable risk to human health and the environment. This article cautions that such a strategy has inherent residual risks that must be understood by those involved in implementing hazardous waste cleanups and those responsible for future uses of contaminated property. Simply put, institutional controls are only as good as the processes that are in place to ensure they are respected in the future. This presents particular problems for active duty installations because most of the protections commonly available to private sector sites are not useful at active installations. This article discusses an initiative by the Air Combat Command to develop a handbook on instituting and maintaining land restrictions. It will also discuss that effort in light of the April 21 EPA Region IV guidance on assuring Land Use Controls at Federal Facilities. This article is based on a paper and presentations given at the 1998 ACC Environmental Training Symposium.

Lowrie, K. and M. Greenberg "Cleaning It Up and Closing It Down: Land Use Issues at Rocky Flats." *Federal Facilities Environmental Journal* 10, no. 1 1999: 69-80.

Rocky Flats Environmental Technology Site, a former nuclear weapons production plant near Denver, Colorado, is scheduled for complete closure within the next decade. A number of important land use issues remain unresolved. High levels of uncertainty about future uses and dependence on decisions from Department of Energy (DOE) headquarters regarding the fate of plutonium make it difficult to produce a land use plan to guide cleanup and reuse decisions, and threaten the site's ability to achieve the accelerated cleanup milestone set for 2006. We recommend a scenario-based participative land use planning process where competing interests, costs, risks, and benefits of alternate future uses are made apparent to all on-site and off-site stakeholders.

Warren, R. W., T. E. Hakonson, et al. "Choosing the most effective hazardous waste landfill cover." *Remediation* 6, no. 2 (1996): 23-41.

Determining the appropriate criteria and designs for hazardous waste landfill covers has spawned much discussion within the environmental remediation arena. Very little reliable comparison of various technologies exists. Researchers at Los Alamos National Laboratory studied the relative hydrologic performance of four landfill cover designs-two capillary barrier designs, one modified EPA RCRA design, and one control cover. Monitoring the fate of natural precipitation for nearly four years showed that the covers with barrier layers more effectively reduced deep percolation than the control cover. Although none entirely eliminated deep percolation, the RCRA cover, incorporating a clay hydraulic barrier, most effectively controlled it. The two capillary barriers reduced deep percolation, but significant amounts were still produced. Over 90 percent of all percolation through the covers, and lateral flow within the covers, occurred during February through May each year, primarily as a result of snowmelt, early spring rains, and low evapotranspiration. The study also showed that gravel mulch surface treatments (70- to 80-percent ground cover) reduced runoff and erosion. Despite additional shrubs planted on one, the two plots receiving the gravel mulch treatments exhibited equally enhanced amounts of evapotranspiration.

Guerin, T. F. "Management and Rehabilitation of Contaminated Sites: International Forums and Emerging Trends." *Land Contamination & Reclamation* 9, no. 3 (2001): 307-18.

International cooperation in the field of contaminated site management has increased dramatically in the past decade. The expected benefits of increased cooperation are reduced duplication of effort, including the co-ordination of contaminated site research, improved synergy between various stakeholders and definition of research and industry needs, enhanced policy development for contaminated sites, information dissemination and technology transfer. The paper briefly discusses key collaborations, partnerships and networks throughout the world relating to contaminated site management and remediation. The experience shared within these groups should prove useful to the application of similar environmental problems in regions where cooperation has been less evident, such as in the Asia-Pacific region. The key value of these partnerships lies in connecting and sharing with them. In addition, the work that these organizations are involved with provides a useful indication of important issues in contaminated site remediation at a global level. These issues are: (i) development and demonstration of innovative monitoring technologies for contamination assessment and remediation; (ii) emergence of risk assessment and inclusion of risk communication to the wider communities in which remediation is occurring, and not just regulators, is becoming common practice; (iii) toxicology, bioavailability and ecotoxicity testing of contamination and remediation residuals is increasing though they lack international harmonisation; (iv) increased need for holistic approaches to contaminated site management, e.g. guaranteed remediation programmes and the need for understanding the implications of financing mechanisms.

See Section E.3.b.1 for additional articles on Remedy Implementation.

3. Risk Management

3.b. End State Implementation

3.b.2. Stewardship

The stewardship components considered in this review include the commitment and resources to maintain long-term institutional controls at sites, to maintain the essential infrastructure, engineering controls, and information management system, to monitor to assure that criteria are met, and to provide risk communication on a periodic or as-needed basis. A Burger article (see complete article in Appendix 3), which demonstrates the application of ecological concepts in long-term stewardship, was selected from a rather short initial list of references that can be found in section E. 3.b.2.

A few other articles that were abstracted include: English and Inerfeld, who look at whether institutional controls are useful or hazardous – depending upon what kind are implemented; Ross and Beljin address a way of evaluating the effectiveness of containment systems; Shobe and Klemic describe the environmental radiologic monitoring process and intent; Burger and Gochfeld speak to the topic of ecosystem protection, and Greenberg et al look at how external stakeholders can influence long-term stewardship.

Concepts in Stewardship

1) Maintain institutional controls
2) Monitoring
   a) System integrity
   b) Environmental media
   c) Ecosystems
3) Maintenance of engineered controls
4) Maintenance of information management system
5) On-going risk communication

Burger, J. “Incorporating Ecology and Ecological Risk into Long-Term Stewardship on Contaminated Sites.” *Remediation* Winter (2002): 107-119.

[Available in Full Text in Appendix 3]

The long-term management of environmental contamination will be a major activity at many sites in the foreseeable future. While human health issues often drive decisions about cleanup, restoration, and long-term stewardship, ecological considerations are also major driving forces and are of paramount importance to the public. Incorporation of ecological considerations into decisions about environmental protection, both short term and long term, requires (1) understanding public perceptions of ecological values, including aesthetics and existence values, (2) understanding contamination issues within a context of the structure and functioning of ecosystems, (3) developing bioindicators of ecological health (including human), (4) developing indicators of ecosystem functioning, and (5) developing and implementing a biomonitoring plan before, during, and after remediation so that adverse effects can be

ascertained before they become irreversible. Both remediation/restoration and long-term stewardship goals must be informed by public policy mandates that include public participation and healthy human and ecological systems. This article examines these issues as they relate to cost-effective, long-term protection of human and ecological health on contaminated lands.

Additional Key Selected Articles

Burger, J. "Restoration, Stewardship, Environmental Health, and Policy: Understanding Stakeholders' Perceptions." *Environmental Management* 30, no. 5 (2002): 631-40.

In recent years there has been considerable interest in the health of humans and the environment, restoration of contaminated or otherwise degraded lands, and in long-term stewardship of public lands. Unfortunately, it is unclear whether governmental agencies and the public hold similar views about the meanings of these concepts, making policy decisions about restoration and stewardship difficult. In this paper, I explore how the public conceptualizes restoration and stewardship by examining the relative rating of several attributes of restoration, stewardship, environmental health, ecological health, environmental restoration, and ecological restoration. People were interviewed in Santa Fe, New Mexico, USA, near the Department of Energy's Los Alamos National Laboratory. The ratings of attributes of environmental health and ecological health reported in this paper can be used to understand how the public understands these concepts. The attributes rated most highly by the subjects were more similar to definitions in the scientific literature for these terms than they were to those used by the Department of Energy. For environmental health, the highest rating related to human sanitation, while for ecological health the highest rating was for maintaining functioning ecosystems. Reduction of exposure to hazardous substances was rated the second highest for both environmental and ecological health. The wise use of natural resources, preservation of natural resources, and hazardous waste site cleanup were rated the highest attributes of stewardship. These data suggest that both expert and non-expert perceptions about restoration and stewardship should be incorporated into environmental management decisions.

English, M. R. and R. B. Inerfeld "Institutional controls for contaminated sites: help or hazard?" *Risk Health Safety & Environment* 10, no. 2 (1999): 121-138.

Institutional controls such as zoning regulations and private land use restrictions have failed to prevent hazardous contamination of numerous industrial, chemical, and defense-related sites. The 1980 federal Superfund law addressed the most severely contaminated sites, but now there is growing acceptance of a risk-based approach to remediation, where the main goal is to minimize health and environmental risks rather than to eliminate contaminants. This article looks at the efficacy of institutional controls, including deed restrictions based on common law or on state laws, local land use controls such as zoning, and other controls such as fencing, notification systems, and monitoring.

Greenberg, M., K. Lowrie, et al. "External Stakeholders' Influence on the DOE's Long-Term Stewardship Programs." *Federal Facilities Environmental Journal* 13, no.1 (2002): 65.

This article explores the effect of external parties (public and public interest groups; contractors/consultants; elected federal, state, and local government officials, and their staff) on the direction and cost of DOE stewardship programs. The article argues that the DOE needs a much clearer understanding of these parties' views about long-term stewardship and should require that explicit long-term stewardship impacts assessments be made for projects proposed for DOE sites.

Shobe, J. and G. Klemic "The US approach to environmental radiological monitoring." *Radiation Protection Dosimetry* 92, no. 1-3 (2000): 115-121.

Environmental monitoring is performed to assess the dose to the general public as a result of radiological activities. All source pathways must be considered when assessing the total effective dose to the public. Comparison programmes exist, but accreditation programmes are not yet in place for most environmental processes. Several bodies are working on the development of accreditation protocols. This could become a vital issue with the increase in the number of sites undergoing decontamination and decommissioning efforts. Pilot testing is complete, and an American National Standards Institute standard for the testing of environmental dosemeters, which could lead to an accreditation programme, will be submitted for approval. The various standards and programmes available in the United States at this time and the efforts to establish traceability for environmental-level radiation measurements are presented. Finally, a discussion on the US emergency preparedness for nuclear accidents is presented.

See Section E.3.b.2 for additional articles on Stewardship.

4. RISK COMMUNICATION

A vast literature exists on risk communication. Out of a long use of relevant publications, we selected two references (Carnes et al, and Chess and Purcell) for initial reading, with full text available in Appendix 3. We focused on actual examples of risk communication as well as the concepts of what constitutes successful risk communication. Additional articles may be found in section E. 4.

Concepts in Risk Communication

- Techniques
- Stakeholder identification and participation
- Content, Timing, Ongoing Process
- Stewardship Responsibilities
- Mapping of sites

Carnes, S.A., M. Schweitzer, E.B. Peelle, A.K. Wolfe, and J.F. Munro. "Measuring the success of public participation on environmental restoration and waste management activities in the U.S. Department of Energy." *Technology in Society* 20 (1998): 385-406.

[Available in Full Text in Appendix 3]

The value added by public participation to decision-making in the Office of Environmental Management (EM) in the Department of Energy (DOE) can be enhanced through better organization, improved participation strategies and mechanisms, and integration with other aspects of decision-making (e.g., problem definition, mission development, identification and evaluation of decision alternatives, and decision implementation). The opportunity to improve the value added by public participation, however, is contingent on being able to demonstrate that the resources devoted to such activity is a sensible and worthwhile investment. This article summarizes research conducted to expand those savings and improvements and facilitate other improvements by developing a set of performance-based indicators, based on discrete attributes of successful public involvement, for use in evaluating public participation programs and activities in EM, with special emphasis on activities implemented in the field offices of DOE. The success attributes and indicators were developed through reviews of appropriate research literatures and through intensive interviews with and surveys administered to diverse stakeholders, including DOE project managers and public participation specialists, contractor project managers and public participation specialists, representatives of tribal, state, and local governments, federal and state regulatory authorities, environmental interest groups, and other interested parties, at nine DOE facilities in the United States.

Chess C. and Purcell K. 1999. Public participation and the environment: Do we know what works? *Environmental Science & Technology* 33 (16), 2685-2692.

[Available in Full Text in Appendix 3]

This paper presents a literature review of studies on public meetings, workshops, and community advisory committees. The authors' conclude that the form of public participation does

not determine process or outcome success. However, they do find some empirical support for the widely accepted "rules of thumb".

Additional Key Selected Articles

Atman, C. J., A. Bostrom, B. Fischhoff, and M. G. Morgan. Designing Risk Communications: Completing and Correcting Mental Models of Hazardous Processes, Part I. *Risk Analysis* 14, no. 5 (1994): 779-88.

Many risk communications are intended to help the lay public make complex decisions about risk. To guide risk communicators with this objective, a mental models approach to the design and characterization of risk communications is proposed. Building on text comprehension and mental models research, this approach offers an integrated set of methods to help the risk communication designer choose and analyze risk communication content, structure, and organization. An applied example shows that two radon brochures designed with this approach present roughly the same expert facts as a radon brochure widely distributed by the U.S. EPA but meet higher standards on other content, structure, and organization criteria.

Bradbury, J. A. (1994). "Risk communication in environmental restoration programs." *Risk Analysis* 14, no. 3: 357-363.

The author advocates adoption of a convergence model in place of the traditional source-receiver model of communication for communicating with members of the public who have a stake in remediation of a nearby site. The source-receiver model conceives of communication as the transmission of a message from a risk management agency (sender) to a target audience of the public (receivers). The underlying theme is that the sender intends to change the perception of the receiver of either the issue or the sender of information. The author draws on her experience at a Department of Energy (DOE) site undergoing remediation to illustrate why the convergence model is more appropriate in the context of cleanup. This alternative model focuses on the Latin derivation of communication as sharing or making common to many (i.e., as involving a relationship between participants who engage in a process of communication). The focus appears to be consistent with recently issued DOE policy that calls for involving the public in identifying issues and problems and in formulating and evaluating decision alternatives in cleanup. By emphasizing context, process, and participants, as opposed to senders and receivers, the model identifies key issues to address in facilitating consensus concerning the risks of cleanup.

Burger, J. "Environmental Monitoring on Department of Energy Lands: The Need for a Holistic Plan." *Strategic Environmental Management* 1, no. 4 (1999): 351-67.

The Department of Energy (DOE) is faced with a monumental environmental remediation and restoration task that may take decades and cost over 300 billion dollars. In this article I suggest that there is a need for a holistic environmental monitoring plan that can be used both to aid in remediation decisions as well as to evaluate remediation and restoration. The current operable unit approach of the DOE manages and remediates small hazardous waste sites without taking into account the vastness of the large DOE sites. This piecemeal approach never allows for an evaluation of the broader environmental problems or of the value of existing ecosystems established on the buffer lands around the restricted industrial sites. I suggest that an overall biological monitoring plan should be established that includes all levels of ecological organization, from single species indicators to ecosystem measures, and that includes bioindicators that can be used for both human and nonhuman receptors. A sound biomonitoring plan should provide information on all levels of ecological organization, including individual species, populations and communities, ecosystems, and landscapes. For biomonitoring to be effective, it must be relevant biologically, methodologically, and societally. Key elements in the plan must include indicators of all ecological levels that meet the criteria of these three

relevancies. Although I provide some examples of key metrics, and particular species or species groups that are suitable for the Savannah River Site, I suggest that any plan will require modification. However, such a plan must address the three types of relevancies, and five levels of ecological organization.

Greenberg, M. and K. Lowrie. A Proposed Model for Community Participation and Risk Communication for a DOE-Led Stewardship Program. *Federal Facilities Environmental Journal* 12 No. 1(2001): 125-142.

As some federally owned military and nuclear facilities are downsizing, sometimes remediating wastes and closing, program decision makers will need to develop long-lasting, robust, and effective means to ensure adequate levels of community involvement. In this article, we suggest six elements for a national plan for public participation intended to apply to the U.S. Department of Energy's (DOE's) nuclear weapons sites as part of their stewardship responsibility. We then discuss the organizational placement of these activities, and recommend a set of components for site-specific plans. We conclude with observations of the current DOE context and challenges that must be faced to implement these participation processes.

LaMontagne, A. D., M. V. Van Dyke, et al. (2002). Development and piloting of an exposure database and surveillance system for DOE cleanup operations. *AIHAJ* 63 No. 2: 213-224.

An industrial hygiene exposure database and surveillance system was developed in partnership between National Institute for Occupational Safety and Health (NIOSH)-funded independent investigators and practicing industrial hygienists at the Rocky Flats Environmental Technology Site (RFETS) in Golden, Colo. RFETS is a former U.S. Department of Energy nuclear weapons plant that is now in cleanup phase. This project is presented as a case study in the development of an exposure database and surveillance system in terms that are generalizable to most other industries and work contexts. Steps include gaining organizational support; defining system purpose and scope; defining database elements and coding; planning practical and efficient analysis strategies; incorporating reporting capabilities; and anticipating communication strategies that maximize the probability that surveillance findings will feed back to preventive applications. For each of these topics, the authors describe both general considerations as well as the specific choices made for this system. An important feature of the system is a two-tier task-coding scheme comprising 33 categories of task groups. Examples of grouped analyses of exposure data captured during the system pilot period demonstrate applications to exposure control, medical surveillance, and other preventive measures.

Renn, O. The Role of Risk Communication and Public Dialogue for Improving Risk Management. *Risk Decision and Policy* 3, no. 1 (1998): 5-30.

Risk communication serves three main objectives: to make sure that all receivers of a risk message are able and capable of understanding the meaning of the message; to persuade receivers to change or modify attitudes or behaviour; and/or to provide the conditions for a two-way communication process as a means to resolve risk conflicts. This paper focuses on the third objective: conflict resolution. It introduces the theoretical framework of arena theory and explains how this theory can be used for developing participatory communication programmes. In addition, the three main levels of risk conflicts, i.e. cognitive dissent, trustworthiness and difference in values and worldviews, are analysed and integrated into a set of criteria for designing programmes of public participation. Without a systematic procedure to reach consensus on values and preferences, the public's position often appears as unclear. Participatory processes are thus needed that combine technical expertise, rational decision making, and public values and preferences. To accomplish such an integration, the paper describes the model of cooperative discourse and discusses several applications of this model in Europe and the United States. At the end the paper entails some guidance on how to use novel conflict resolution models to cope with public involvement in decision making with respect to technological risk.

Slovic, P. (2001). The Perception of Risk. LLC, Dulles, Va: Stylus Publishing.

The Perception of Risk brings together the work of Paul Slovic, one of the world's leading analysts of risk, risk perception and risk management, to examine the gap between expert views of risk and public perceptions. Ordered chronologically, it allows the reader to see the evolution of our understanding of such perceptions, from early studies identifying public misconceptions of risk to recent work that recognizes the importance and legitimacy of equity, trust, power and other value-laden issues underlying public concern. New methods for assessing perceptions of risk are described, and the implications for regulation and public policy are discussed. In a new departure, the perceptions of adolescents are also examined. The issues covered include: Societal risk taking; Decision-making in mental health law; Rating risks; Facts versus fears; Informing and educating the public about risk; Intuitive toxicology; Perceived risks and the politics of nuclear waste; Perceived risk, trust and democracy; Technological stigma.

Siegrist, M. and G. Cvetkovich. Perception of hazards: The role of social trust and knowledge. *Risk Analysis* 20, no. 5 (2000): 713-719.

Recent research indicates that social trust of those who manage a hazard is strongly correlated to judgments about the hazard's risk and benefits. The present study investigates the more specific question of "For which hazards is this?" It was postulated that when an individual lacks knowledge about a hazard, social trust of authorities managing the hazard determines perceived risks and benefits. On the other hand, when an individual has personal knowledge about a hazard and therefore does not need to rely on managing authorities, social trust is unrelated to judged risks and benefits. Participants (N = 91) assessed risks, benefits, and trust in managing authorities and personal knowledge associated with 25 hazardous technologies and activities. As expected, strong correlations between social trust and judged risks and benefits were observed for hazards about which people did not possess much knowledge. No significant correlations between social trust and judged risks and benefits were found for hazards about which people were knowledgeable. Results suggest that the lay public relies on social trust when making judgments of risks and benefits when personal knowledge about a hazard is lacking. Replicating findings of other studies, the present study also found negative correlations between perceived risks and perceived benefits. When social trust was controlled for, correlations between perceived risks and benefits diminished. Implications of the results for risk management are discussed.

Wylie, J. and N. Sheehy. Contaminated Land and Risk Communication: Developing Communication Guidelines Using a Mental Models Approach. *Land Contamination & Reclamation* 7 no. 4 (1999): 285-290.

As the government encourages the redevelopment of inner city and industrial sites for residential, commercial and industrial use, the issue of contaminated land is receiving more attention than ever before. A lack of knowledge and understanding of contamination and remediation, coupled with fears about risks to personal safety, can lead to situations where members of the public feel threatened by development on contaminated land. Consequently there is a need for effective communication between all concerned parties which enables everyone to make good decisions about the issues. This paper describes a study which increases our understanding of risk perception and expands our knowledge of risk communication. The mental models approach is used to explore people's understanding of contamination and remediation. Information obtained will be used to prepare guidelines for risk communication on contaminated land. Participants include the local authorities and members of the public who live close to a former gasworks site in Northern Ireland which is undergoing remediation.

See Section E.4 for additional articles on Risk Communication.

5. RELATIONSHIP OF RISK TO REGULATION

Regulations deal in very diverse ways with the very large and complex site issues within DOE's area of responsibility. Most promote the use of risk but enter it into the decision process in very different ways and give risk different levels of priority among decision factors. New and more dialogue between DOE, its regulators, and other stakeholder groups, informed by concepts seeking to bridge or better link the concepts is key. There is a small but growing body of literature and research relevant to the relationship between risk and regulation. A few key articles are highlighted as a starting point for inquiry. The complete texts of the Geisinger and the Stewart articles are provided in Appendix 3. Additional articles relating to this topic may be found in Section E. 5.

Stewart, R.B. "Environmental Regulatory Decision making under Uncertainty". In *An Introduction to the Law and Economics of Environmental Policy: Issues in Institutional Design*, Volume 20: 71-126.

[Available in Full Text in Appendix 3]

Strong versions of the Precautionary Principle (PP) require regulators to prohibit or impose technology controls on activities that pose uncertain risks of possibly significant environmental harm. This decision rule is conceptually unsound and would diminish social welfare. Uncertainty as such does not justify regulatory precaution. While they should reject PP, regulators should take appropriate account of societal aversion to risks of large harm and the value of obtaining additional information before allowing environmentally risky activities to proceed.

Geisinger, A. "Rethinking Risk-Based Environmental Cleanup." Indiana Law Journal 376 (2001): 367-402.

[Available in Full Text in Appendix 3]

No abstract available

Additional Key Selected Articles

Abernathy, C. O., and W. C. Roberts. "Risk Assessment in the Environmental Protection Agency." *Journal of Hazardous Materials* 39, no. 2 (1994): 135-142.

Risk assessment is the general process used to determine the potential risk of an adverse health effect occurring from exposure to an agent. It consists of a hazard identification, a dose-response evaluation, an exposure assessment and a risk characterization. At the U.S. Environmental Protection Agency, risk assessments are used to estimate risks from environmental contaminants. Risk management uses the risk characterization along with such variables as economic, social, legal, technical, analytical and political factors to arrive at a regulatory level. The public is informed of regulatory actions prior to and after promulgation of the final rule through the process of risk communication.

Downey, D. C., L. A. Benson, S.A. Taffinder. Trends in regulatory acceptance of risk-based cleanup goals and natural attenuation for site closure. *Remediation* 8 , no. 1 (1997): 71-86.

Since 1994, there has been a significant regulatory shift toward risk-based cleanup standards based on the site-specific risk of the more toxic and mobile compounds; namely, benzene, ethyl benzene, toluene, and xylene (BTEX). This regulatory shift has been accompanied by a growing acceptance of natural attenuation as an important component of petroleum site remediation. This article briefly reviews regulatory progress toward risk-based remediation and describes the successful application of risk-based corrective actions (RBCAs) at two fuel contaminated sites on Air Force installations. By developing site-specific cleanup goals, and combining natural attenuation, source reduction, and land use controls, innovative risk-based closure plans have been implemented on these sites.

Hersh, R. and K. Wernstedt. Land use, risk, and Superfund cleanups: At the nexus of policy and practice*. Public Works Management & Policy* 4, no. 1 (1999): 31-40.

In the Superfund reauthorization debate, many argue that protective cleanups can be achieved more efficiently by utilizing broader risk-based approaches that eliminate the pathways by which individuals are exposed to unacceptable levels of contamination. These approaches rest centrally on assumptions made about the future land use at a site. Assumptions help risk assessors and regulators determine who may be at risk at a site, how much risk these individuals may bear, and how much contamination should be removed, treated, or contained to ensure protective cleanups. This article first describes how future land use assumptions are currently incorporated into Superfund cleanup decisions, a subject of considerable confusion. It then examines the repercussions of this policy in relation to the transparency of cleanup decisions, the participation of various stakeholder groups, and the long-term management of contamination left on site via institutional controls.

See Section E. 5 for additional articles on Relationship of Risk to Regulation.

E. ADDITIONAL READING ORGANIZED BY PARADIGM CATEGORY

E. 1 SITE CHARACTERIZATION

Bertozzi, G., M. D. Hill, J. Lewi, and R. Storck. *Long-Term Risk Assessment of Geological Disposal: Methodology and Computer Codes*. Edited by R. Simon, 1986.

Cairns, J. Jr., "The genesis of biomonitoring in aquatic ecosystems." *Environ. Profess* 12 (1990):169-176.

Cairns, J. Jr and B. R. Niederlehner,. "Developing a field of landscape ecotoxicology." *Ecol. Applic*. 6 (1996):780-796.

Campbell, J. E., B. S. Langkoft, R. L. Iman, and M. Reeves. *Sensitivity Studies of the Swift Radionuclide Transport Model*, 1980.

Carignan, V. and M. A. Villard, "Selecting indicator species to monitor ecological integrity: a review," *Environ. Monit. Assess*. 78 (2001): 45-61.

Chapman, Peter M. "Toxicity Measurement and Reduction Procedures Biomonitoring and Tre Programs," *Water Pollut Res J Can* 24, no. 3 (1989): 425-34.

Clarke, J.H., A.N. Clarke, and J.S. Smith, "Environmental Forensics- Using Science to Resolve Adversarial situations," *Environmental Protection* September, (1999): 49-54.

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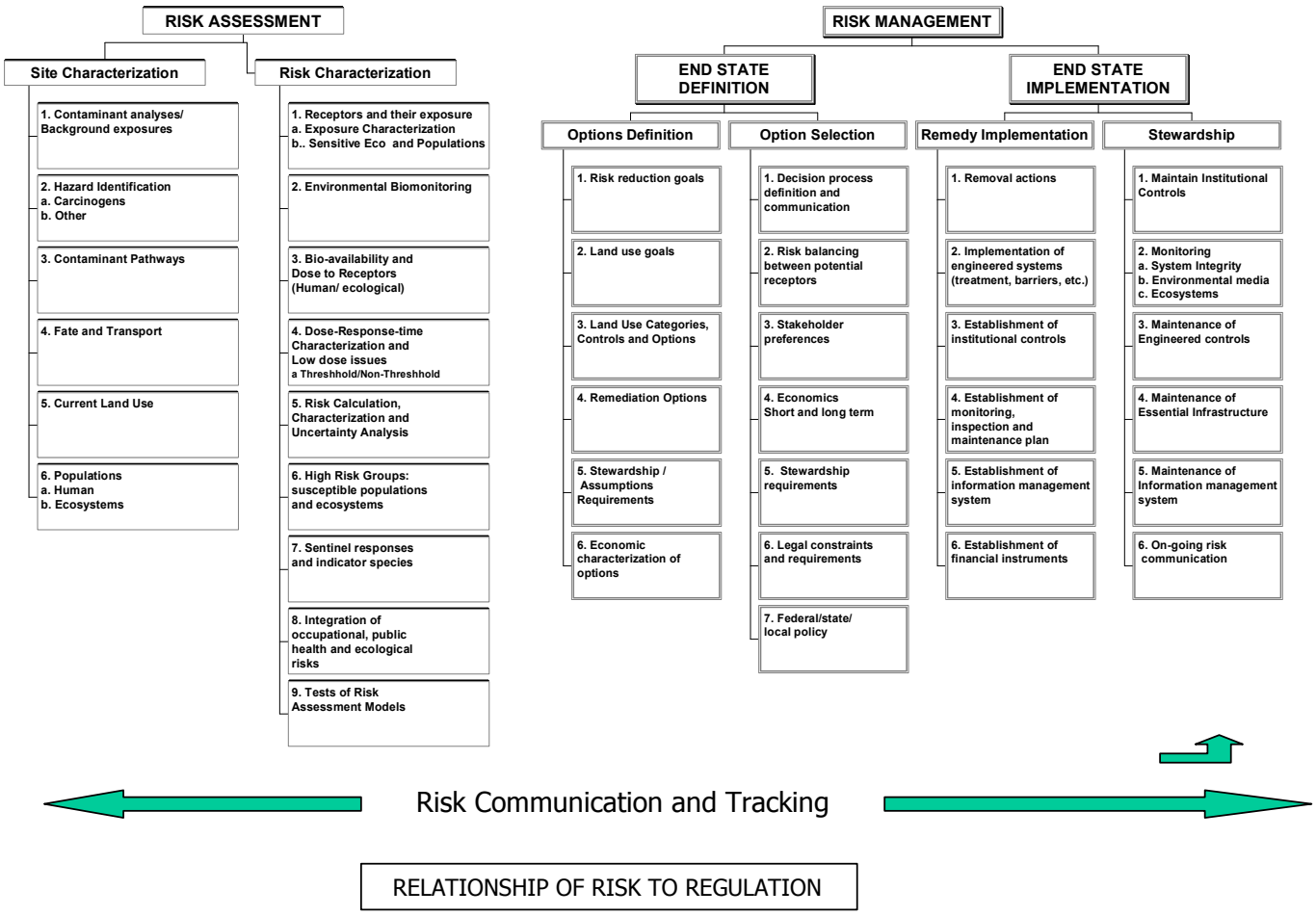
APPENDIX 1: WHOLE RISK PARADIGM

The Whole Risk Paradigm Applied to Contaminated Sites



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APPENDIX 3: SELECTED KEY RISK ARTICLES

The following full text articles can be requested from the CRESP web site at http://www.cresp.org/rbes/order_articles.html

CONCEPTS	KEY ARTICLES
Introductory Articles	• The Presidential / Congressional Commission on Risk Assessment and Risk Management. "Framework for environmental health risk management: Final Report, (1997) Volume 1. • McClellan, R.O. "Risk assessment: Replacing default options with specific science. " Human and Ecological Risk Assessment 9, no.1 (2003): 421-438.
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