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Risk/Impact Technical Report for the Hanford Groundwater/Vadose Zone Integration Project

December 1999

Prepared for the U.S. Department of Energy - Center for Risk Excellence

Center for Risk Excellence

Argonne National Laboratory
University of Chicago

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NOTATIONS

The following is a list of the acronyms and abbreviations, including units of measure, used in this report. Notations used only in tables or figures are defined in those tables and figures.

ATSDR	Agency for Toxic Substances and Disease Registry
BHI	Bechtel Hanford, Inc.
CDC	Centers for Disease Control and Prevention
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic foot (feet) per second
CRCIA	Columbia River Comprehensive Impact Assessment
CRE	Center for Risk Excellence (DOE)
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy, Richland (Washington) Operations Office
EM	Office of Environmental Management (DOE)
EPA	U.S. Environmental Protection Agency
FY	fiscal year
GIS	geographic information system
GW/VZ	groundwater/vadose zone
HAB	Hanford Advisory Board
HEAST	Health Effects Assessment Summary Tables (EPA)
HEDR	Hanford Environmental Dose Reconstruction
HLW	high-level (radioactive) waste
HSRAM	Hanford Site Risk Assessment Methodology
INEL	Idaho National Engineering Laboratory (now Idaho National Engineering and Environmental Laboratory [INEEL])
IRIS	Integrated Risk Information System (EPA)
MCi	megacuries
MEI	maximum exposed individual
MEPAS	Multimedia Environmental Pollutant Assessment System
MeV	million electron volts
mrem/yr	millirem(s) per year
MUST	miscellaneous underground storage tank
NEPA	National Environmental Policy Act
NOAEL	no observed adverse effect level
NTP	National Toxicology Program
PCBs	polychlorinated biphenyls
pCi/L	picocurie(s) per liter
PRD	Priest Rapids Dam
PEL	permissible exposure limit
PNNL	Pacific Northwest National Laboratory
RCRA	Resource Conservation and Recovery Act
RPH	Richland Pumphouse
S&T	science and technology
SAC	System Assessment Capability
TLV	threshold limit value

EXECUTIVE SUMMARY

BACKGROUND

Beginning in the early 1940s, the Hanford Site was used for radiological and chemical research and weapons production in support of the nation's defense program. With the end of the Cold War in the late 1980s, the site's mission changed from production to cleanup, and a formal environmental management program was established. A number of individual projects were identified for this program ranging from managing nuclear reactors and other facilities to managing waste storage and disposal areas (including underground tanks and past burial or discharge areas). Past projects also addressed contaminants that had moved into and through the soil to groundwater and the Columbia River.

Under increasing pressure the site cleanup program has been accelerated, and a substantial amount of remediation work is expected to be completed by the year 2006. However, in many areas it is technically or economically infeasible to clean up the site to levels compatible with unrestricted use, nor does the recent land use plan identify on-site residential use as an intended option. In many cases, radioactive wastes that remain at Hanford will pose hazards far longer than the life of the controls designed to contain them. Thus, the completion of active remediation will not mean the end of environmental responsibilities. Recognizing this, DOE intends to incorporate a long-term stewardship perspective into its remedial action and waste management decisions. Stewardship efforts face two profound challenges: long-term uncertainties associated with site barrier failure and institutional change over multi-generation time periods, and short-term uncertainties associated with the inability to precisely predict future factors that will affect exposure and risks.

Tribal Nations, Federal and state regulators, and a number of stakeholders have voiced concerns about the potential threats posed by site contaminants to resources at Hanford and in the Columbia River region, and about the overall long-term effectiveness of the environmental program. Many of these concerns were brought together in a 1998 report prepared for the Columbia River Comprehensive Impact Assessment (CRCIA) initiative. In response to these concerns and in recognition of program efficiencies to be gained by linking similar activities of multiple ongoing projects more closely, DOE established the Ground Water/Vadose Zone (GW/VZ) Integration Project in late 1997. As the project team delved further into designing a framework for the sitewide assessment, it was determined that a targeted plan would be helpful in defining a path forward for the central, cross-cutting element of risk. In October 1998, at the request of the DOE Headquarters Offices of Environmental Restoration and Waste Management, the Center for Risk Excellence[1] became involved in the project in support of the U.S. Department of Energy Richland Operations Office and its integrating contractor, Bechtel Hanford, Inc., to provide input to that plan.

This report has been prepared to support the risk plan being developed by the Hanford GW/VZ Integration Project team, to help guide future environmental research and contribute to effective decisions on site cleanup and long-term management. The specific intent is to assist in:

- Compiling existing information on how to assess different types of risks and effects, to help define a way forward for the site's integrated risk/impact assessment process;

[1] The Center for Risk Excellence (CRE) was established at the Chicago Operations Office in February 1997 by the DOE Headquarters Office of Environmental Management (EM). A primary mission of the Center is to assist DOE sites in addressing critical risk issues to achieve sound environmental decisions. The Center operates through a network of scientists, engineers, and risk specialists from DOE Field Office sites, national laboratories, academic institutions, and the private sector to respond to specific requests for technical support.

- Identifying approaches and tools that can produce high-quality results that will inform site decisions to protect and maintain human health and the environment;

- Developing a scientifically sound framework for integrating risk and impact assessments across multiple contamination sources and environmental resources into the long-term future;

- Defining information gaps – both in basic scientific knowledge about methodologies, capabilities, and effects, and in technologies – to suggest scoping studies and future research that can provide the foundation for solving key site problems; and

- Presenting site risk information in a clear, transparent manner that promotes broad understanding and acceptance.

The scope of the Integration Project for which this document was prepared encompasses radioactive and chemical contaminants from all major site sources that could affect the vadose zone, groundwater, or Columbia River in the near or long term. The focus of this report is on four general categories of risk and impact assessment issues: human health, ecological, sociocultural, and economic. It does not address regulatory issues, site-related agreements, or cleanup goals.

At its most basic level, the question facing the GW/VZ Integration Project is: "How serious a problem is the Hanford GW/VZ contamination, notably in terms of the potential for contaminants to migrate through soil and groundwater to the Columbia River?" If the risks are not trivial, then a related question arises: "What management strategies are most likely to succeed in avoiding major impacts?"

The challenge lies in defining focused questions and developing a process for answering them that applies to each of the key exposure/receptor combinations potentially affected. The seriousness of the problem may be judged on the basis of: risk to human health, risk of ecological function impairment or resource loss, and impact to cultural resources (which includes loss of access occasioned by health or ecological risks). These considerations drive the formulation of a quality-of-life and economic impact assessment process. A set of targeted questions can be applied to define the specific risk issues to be investigated:

- What is the magnitude of risk from current and future GW/VZ contamination, to what receptors and resources in what locations, and in what time frame?

- What are the dominant factors driving the risk?

The Center team has developed approaches that can help focus the responses to these questions and define a path forward for conducting an integrated risk/impact assessment for the Hanford Site. We recognize that others have and will continue to define different issues and approaches, and we offer this as our independent technical view of assessment needs and the strategies that can be used to address them.

RECOMMENDED STRATEGY FOR ADDRESSING RISK QUESTIONS

This report recommends strategies for dealing with three sets of issues that affect development of a framework for assessing site risks and impacts. These issues are (1) the long-term strategy for protective maintenance within which risks and impacts must be evaluated, (2) a process for managing hazards under uncertainty, and (3) assessment of complex and inter-related risks and impacts of hazard exposure.

The risk assessment design involves identifying key affected locations and selecting topics (impacts) for study from larger candidate sets that comprise the conceptually possible considerations. Exploratory and scoping studies are needed to investigate the potential for key impacts that are not well understood or that require a more innovative investigative approach. These studies could initially be undertaken with a limited or generic scope to demonstrate the validity of the concern or the applicability of a proposed approach, or even to determine the feasibility of further evaluations.

Our recommendations for three basic areas of study that affect the overall design of the risk/impact assessment are summarized as follows.

- **Resolve Inventory Issues** – Develop an integrated view of the contaminant inventory by starting with current estimates of inventory and historical knowledge. Work with affected parties to identify additional inventory locations and categories that may not have been included in previous inventory estimates. Develop bounding estimates of inventory sources. (An extensive evaluation is ongoing to address these issues as part of the GW/VZ Integration Project.)

- **Estimate the Future Hazard Trajectory** – Use environmental transport models with intermediate-level complexity to develop "best estimates" of the hazard trajectory for the site and other potentially affected locations. Identify time limitations of the safety envelope (time until significant contamination would reach release points).

- **Develop Reality Checks** – Increase general acceptance of estimates by using the model-free or model-lite approach, which is more conceptual and descriptive than calculational, to validate intermediate-level model estimates of breakthrough times for significant contamination.

With regard to involvement of the broad interested community, one of the unique aspects of the Hanford GW/VZ Integration Project compared with projects at many other sites is the central role that concerns of affected parties play in the overall risk assessment planning process. Ultimately, the success of the project could hinge on the effectiveness of the arrangements for involving multiple parties in this process, which also entails extensive formal interactions with oversight agencies and direct consultations with Tribal Nations. Building on the ongoing work of the Integration Project team, it is suggested that the following actions be highlighted. The aim is to help ensure that risk-informed decisions developed through the GW/VZ Integration Project reflect the priorities and concerns of the full range of interested parties.

- It is important for the technical risk/impact assessment approach to be determined and implemented through an explicitly defined consensual process, involving a working group that includes both community and technical representatives;

- It is very useful for the deliberations of such a group to be supplemented with systematic and extensive opportunities for wider community review and input;

- The best available risk communication principles and processes should be implemented; and

- Technical reviews should be conducted by external risk experts.

These elements are to varying degrees already in place as part of the GW/VZ Integration Project, and we encourage their continued development.

1 INTRODUCTION

This technical report describes methods for evaluating different kinds of human health and ecological risks and other impacts that could result from multiple contamination sources at the U.S. Department of Energy's (DOE's) Hanford Site in Richland, Washington. The goal is to strengthen the scientific foundation of environmental decisions to be made so as to help advance the groundwater/vadose zone component[1] of Hanford's environmental management program through the assessment and implementation phase with the best knowledge available.

Diverse concerns have been expressed by many interested parties about potential risks and impacts at the site under current conditions and into the long-term future. The active participation of these parties – including regulatory agencies; Tribal Nations; local industries and community residents; technical experts on the project team; scientists at universities, national laboratories, and other institutions; and the private sector – is critically important to the success of the risk assessment and related decision-making processes for this site.

Risk and impact assessments are conducted to predict what might happen from the actions we plan to take, or not to take, so we can make decisions that best protect human health and welfare and the environment. Over the next 50 years as the site is remediated, we will continue to learn more about its environmental conditions, and our assessment methods will further evolve with technological advances in such fields as microchip sensors and genotoxicity tests. As they become available, the new data gained will be incorporated into site decisions and field work to ensure that the best and most effective actions are taken. This report provides an initial framework for assessment methods that reflects current understanding of Hanford Site conditions. This framework will continue to be enhanced as our scientific knowledge and understanding of the site increase.

A brief background on the Hanford Groundwater/Vadose Zone (GW/VZ) Integration Project is provided in Section 1.1, including a discussion of the involvement of the DOE Center for Risk Excellence. The objectives and scope of this risk/impact report are described in Section 1.2. An overview of the other chapters of this report is presented in Section 1.3. The following discussion provides a context for use of the terms *risk* and *impact* in this report.

The term *risk* can have different definitions, depending on the setting. In environmental assessments, the term *risk* is usually taken to represent the probability of an adverse effect on a human or ecological receptor, due to exposure to a given chemical, radiological, or physical hazard – such as drinking contaminated water or being hit by a falling brick. To be most conservative (protective), risk assessments usually assume a probability of 1 for the exposure event, even though this does not typically reflect reality. From this assumption, the risk value is simply the probability of an indicated harm given an exposure event. In this report, *risk* is used in this conditional manner, that is, to refer to the likelihood of harm assuming a receptor is exposed to a given hazard.

Impact is a more general term used to describe any effect. In the environmental arena, the term has long been used to represent effects on the total human environment, considering physical-chemical, biological, economic, and sociocultural components. This use extends back 30 years to promulgation of the National Environmental Policy Act (NEPA). An impact can be beneficial, adverse, or somewhere in between, and the term is broadly applied across all resources, including groundwater and surface water, soil, cultural,

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[1] As used in this report "groundwater/vadose zone" is a generic term referring to the hydrologic system that includes the geologic area between the land surface and the underlying water table (vadose zone), groundwater beneath the Hanford Site, and associated surface water.

ecological, and human. In this report, *impact* is used as described here, to broadly refer to effects of all types for all resources.

For contaminated sites, potential impacts are typically viewed as harmful and are commonly referred to as *risks*. Use of this term to represent the likelihood of an adverse effect on a human or ecological receptor stems from the regulations and risk assessment guidance developed for Superfund sites by the U.S. Environmental Protection Agency (EPA).

An impact can be direct or indirect – i.e., the direct result of an event or exposure to a given hazard, or a related effect that follows from it, which can be separated in time or location. For example, discharging warm cooling water from a power plant into a receiving pond can reduce the level of dissolved oxygen in that pond – which is a direct or primary effect. This reduction in oxygen level could in turn cause fish to die or a certain type of algae to flourish. These are indirect, or secondary, effects.

Indirect effects also include changes in human activity in response to risk information or perceptions of a risk. For example, impacts could occur in sociocultural and economic systems if contaminants from the Hanford Site were to reduce the reproductive success of a key species, such as salmon. In this case, the reproductive effect on the salmon is a direct ecological health effect, and the associated impacts are indirect effects. It is important to clarify that whether we are considering a health or ecological risk from exposure to a hazard – or a related effect derived from our response to the hazard as a social, cultural, or economic sector – has no bearing on the associated level of concern. That is, both primary and secondary effects can be *primary issues*.

The distinction between risk and impact often blurs, because the two terms are frequently used interchangeably in discussing contaminated sites. Although risks can be considered a subset of potential impacts, the term *risk* has often been generalized to simplify discussions. Thus, in many cases *risk* is used to also represent the general overall term – as in discussing risk-based decision making, risk communication, or a resource being "at risk" of incurring some impact. In this report, the general aim is to use the term *risk* when referring to an adverse impact on human or ecological health.

1.1 OVERVIEW OF THE INTEGRATION PROJECT AND RISK CENTER INVOLVEMENT

Beginning in the early 1940s, the Hanford Site was used for radiological and chemical research and weapons production in support of the nation's defense program. With the end of the Cold War in the late 1980s, the site's mission changed from production to cleanup, and a formal environmental management program was established. A number of individual projects were identified for this program, ranging from managing nuclear reactors and other facilities to managing waste storage and disposal areas (including underground tanks and past burial or discharge areas). Past projects also addressed contaminants that had moved into and through the soil to groundwater and the Columbia River.

Over the past decade, Tribal Nations, Federal and state regulators, and stakeholders have continued to voice concerns about the potential threats posed by site contaminants to resources at Hanford and in the Columbia River region. Many of these concerns were brought together in a report prepared for the Columbia River Comprehensive Impact Assessment (CRCIA) initiative (Part II) (DOE 1998). In response to these concerns and in recognition of program efficiencies to be gained by linking similar activities of multiple ongoing projects more closely, DOE established the GW/VZ Integration Project in late 1997. As described in the summary description of that project (DOE 1999), its mission is:

> *To ensure that Hanford Site decisions are defensible and possess an integrated perspective for the protection of water resources, the Columbia River environment, river-dependent life, and users of the Columbia River resources, the mission of the*

Groundwater/Vadose Zone Project is to develop and conduct defensible assessments of the Hanford Site's present and post-closure cumulative effects of radioactive and chemical materials that have accumulated throughout Hanford's history (and which continue to accumulate). To support this mission the Groundwater/Vadose Zone Project will identify and oversee the science and technology initiatives pursued by the national laboratories (as necessary) to enable the assessment mission to be successfully completed.

The GW/VZ Integration Project's vision is that completing this mission will establish broad trust and collaboration and result in credible decisions, based on defensible science, that effectively and efficiently protect water resources.

During 1998 and 1999, a number of important activities were initiated by the DOE Richland Operations Office (DOE-RL); Bechtel Hanford, Inc. (BHI, the lead contractor for the Integration Project); Pacific Northwest National Laboratory (PNNL); and Fluor Daniel Hanford Company (the Hanford Site integration contractor) and its on-site contractors. The specific objectives, scope, general schedule, and roles, responsibilities, and authority for this project are described in a recent three-volume set of reports (DOE 1999). Those reports also provide an extensive summary of the current understanding of site conditions, including what types and levels of contamination are present at different locations and how contaminants have been and are being released to and moving through the environment. These reports highlight several major project accomplishments, which include:

- Preparing several key scoping and planning documents that address the administrative and technical design of the project;

- Coordinating scientists from many DOE national laboratories to develop an applied science and technology plan and roadmap to support site cleanup and other operational decisions;

- Establishing a panel of independent experts to provide technical recommendations and oversight;

- Creating an open participatory process to promote interactions with and obtain input from the many parties interested and involved in site activities; and

- Forming a System Assessment Capability (SAC) work group that is moving forward on technical elements of the integration process, with input from many interested parties.

Both the full Integration Project team led by BHI and the focused SAC group have conducted numerous open meetings – which have included open phone lines – to share evolving project information and solicit input from interested parties. A project Web site has also been established to provide additional opportunity for review and input to the project's developing plans and activities by interested parties (see http://www.bhi-erc.com/vadose/vadose.htm).

Work on five technical components of the GW/VZ Integration Project began during 1998: system assessment, inventory, vadose zone, groundwater, and the Columbia River. The scope of these elements includes identifying the amount and location of contaminants and their physicochemical characteristics; describing the geologic, hydrologic, geochemical, and biological characteristics of the site; understanding the nature of contaminant release, transport, and dispersion mechanisms and identifying dominant factors; and determining areas that could be affected and receptors that could be exposed to the contaminants.

While the initial activities conducted by the Integration Project team focused on these five technical elements, the team also defined a broad range of potential impacts that, conceptually, could be associated with Hanford contaminants. This definition was based on the recent CRCIA activity, and it considered potential impacts under current conditions and into the long-term future.

As the project team delved further into designing a framework for the sitewide assessment, it was determined that a targeted plan would be helpful in defining a path forward for the central, cross-cutting element of risk. In October 1998, at the request of the DOE Headquarters Offices of Environmental Restoration and Waste Management, the Center for Risk Excellence became involved in the project in support of DOE-RL and its integrating contractor, BHI, to provide input to that plan.

Thus, specific project work on the Hanford risk technical element formally began at the start of fiscal year (FY) 1999. (As used generally by the Hanford team, "risk" represents a broad set of potential impacts, beyond harm to human or ecological health and safety.) This risk element aims to integrate the evaluation of impacts related to the vadose zone, groundwater, and surface water; to address key concerns of interested parties; and to provide useful information to decision makers. In support of the Hanford project team activity on the risk element, the Center mobilized a multidisciplinary team of experts to interact with various parties involved in the project and to assess the status and needs of a sitewide assessment.

As background, the Center for Risk Excellence (CRE) was established at the Chicago Operations Office in February 1997 by the DOE Headquarters Office of Environmental Management (EM). A primary mission of the Center is to assist DOE sites in addressing critical risk issues to achieve sound environmental decisions. The Center operates through a network of scientists, engineers, and risk specialists from DOE Field Office sites, national laboratories, academic institutions, and the private sector to respond to specific requests for technical support.

The Hanford GW/VZ Integration Project team asked the Center to prepare a technical report on risk/impact evaluation to support the SAC's overall risk plan. The Center was asked to help identify and refine approaches that could be applied for a comprehensive assessment of impacts across multiple environmental resources. Among the issues to be considered was the manner in which uncertainties and unknowns could be addressed. It was recognized that from the broad list of possible impacts identified through the CRCIA process, the resources and receptors that were likely to actually be impacted would need to be identified to constructively focus an initial assessment. Using spatial overlays of projected future contaminant concentrations and receptors was among the options discussed for identifying possible exposures to site-related hazards in order to achieve this focus.

The Center team met with the project team at the Hanford Site in December 1998 to discuss key environmental data and assessment issues. After these limited team discussions, the Center team released a preliminary working draft report in early January 1999 for broad public review and comment. That early draft report identified initial concepts and issues regarding various assessment principles and methods.

This approach of presenting preliminary ideas at the beginning of the process was extremely important to the Center team. The intent was to provide opportunity for early input from the many interested parties, essentially at the outset of the framework development. It was hoped that suggestions and recommendations could be received early enough to help guide the development process. This approach reflects the strong team belief that front-end participation by interested parties in any such initiative is essential. This belief is also reflected in the open nature of the Integration Project work and the SAC process, which continues to be actively maintained by the Hanford project team.

This final report reflects many helpful comments received on the preliminary working draft from a number of interested parties, including the Hanford Advisory Board (HAB), EPA, the State of Washington, Tribal members, other community members, and DOE Headquarters advisory groups. It is the intent and desire of the Center that this report serve as a means for soliciting further important input as the integrated assessment framework for the project continues to evolve.

In October 1998, the Center was also asked to contribute risk information to the project-level science and technology (S&T) roadmap being developed under the leadership of PNNL. That roadmap is intended to help target future research on data or knowledge and enhanced technology and methodology capabilities needed to answer basic questions about environmental conditions and assessment uncertainties that directly apply to Hanford problems. The Center was asked to address major uncertainties and unknowns with regard to risks and impacts, to help focus future environmental research on health and other effects, transport phenomena, and other key information needs. Preliminary input to the S&T roadmap was submitted to the project as a separate report (Wilkey et al. 1999).

1.2 OBJECTIVES AND SCOPE OF THIS REPORT

This report has been prepared to support the risk plan being developed by the Hanford Integration Project team, to help guide future environmental research and contribute to effective decisions on site cleanup and long-term management. The specific intent is to assist in:

- Compiling existing information on how to assess different types of risks and effects, to help define a way forward for the site's integrated risk/impact assessment process;
- Identifying approaches and tools can high-quality results that will inform site decisions to protect and maintain human health and the environment;
- Developing a scientifically sound framework for integrating risk and impact assessments across multiple contamination sources and environmental resources into the long-term future;
- Defining information gaps – both in basic scientific knowledge about methodologies, capabilities, and effects, and in technologies – to suggest scoping studies and future research that can provide the foundation for solving key site problems; and
- Presenting site risk information in a clear, transparent manner that promotes broad understanding and acceptance.

The scope of the Integration Project for which this document was prepared encompasses radioactive and chemical contaminants from all major site sources that could affect the vadose zone, groundwater, or Columbia River in the near or long term. The focus of this report is on four general categories of risk and impact assessment issues: human health, ecological, sociocultural, and economic. It does not address regulatory issues, site-related agreements, or cleanup goals.

Unbiased risk and impact information is critical to defensible, broadly balanced environmental decisions for the Hanford Site. An integrated framework for future assessments that considers the multiple contamination sources, the planned response actions, and the outcome of their collective implementation is important to achieving that balance. We recognize that others have and will continue to define different risk/impact issues and approaches for the Hanford Site, and we offer this as our independent technical view of assessment needs and the strategies that can be used to address them.

The ultimate objective of this report is to provide a scientific basis for assessing risks and impacts and a mechanism for soliciting input from interested parties on this evaluation process. A phased assessment approach is being pursued, with an emphasis on identifying those key risk issues that warrant attention in the near term, considering what is possible with available data and tools. The risk approach being developed by the Hanford team is expected to contribute to the national understanding of how assessments for multiple sources and environmental effects can be effectively integrated to support comprehensive decisions.

1.3 REPORT ORGANIZATION

Each of the following chapters addresses a key issue related to the assessment of risks and other impacts, as noted below.

- Chapter 2 (evaluating key considerations): This chapter outlines the basic risk/impact questions underlying the GW/VZ Integration Project and identifies a framework for organizing the assessment process. The focus is on the goals of the assessment, strategies for dealing with source and transport uncertainties that affect the assessment, and strategies for an efficient, effective analysis of highly complex impact possibilities.

- Chapter 3 (developing the assessment framework): This chapter briefly summarizes key elements of recent risk and impact assessments for the site and presents a conceptual framework for an integrated analysis, including combined effects across multiple resources. The purpose is to provide an approach for assessing risks and impacts in a highly complex setting and to suggest strategies that can improve the clarity and transparency of the assessment process.

- Chapter 4 (risk/impact assessment methodologies): This chapter describes various methods for assessing human health, ecological, sociocultural, and economic effects. The purpose is to summarize estimation approaches and methods that can be integrated across various impact types.

- Chapter 5 (implementation issues): This chapter identifies methodology and information issues that affect implementation of the risk/impact assessment. It also recommends criteria for developing study sets of effects and receptors for assessment from candidate sets (from CRCIA). The purpose is to provide suggestions for next steps that can advance the analytical process.

In addition to the five chapters, two appendices are provided to illustrate an assessment of changing conditions and the role of conceptual models:

- Appendix A presents an analysis of tritium contamination in the Columbia River. The purpose is to illustrate how space and time factors can be incorporated into the analysis of the behavior of a key contaminant and how associated risk implications can be presented in the context of background concentrations.

- Appendix B presents example illustrations of how conceptual models can be developed to help organize the assessment process.

REFERENCES FOR CHAPTER 1

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U.S. Department of Energy, 1999, *Groundwater/Vadose Zone Integration Project Summary Description, Background Information and State of Knowledge, and Science and Technology Summary Description*, DOE-RL-98-48 Volumes I-III, Rev. 0, U.S. Department of Energy, Richland, Wash., June.

Wilkey, P. L., et al., 1999, *Risk Science and Technology Element of the Applied Science and Technology Plan for the Hanford GW/VZ Integration Project*, Center for Risk Excellence, Chicago, Ill., Feb.

2 CONSIDERATIONS FOR AN INTEGRATED RISK/IMPACT ASSESSMENT IN THE CONTEXT OF THE INTEGRATION PROJECT

This chapter lays the basis for the following chapters on the risk/impact assessment framework and methods. It summarizes the basic questions that need to be addressed and then recommends a broad strategy for conducting the assessment. That strategy depends in large measure on the approaches taken for protective maintenance of the site, for managing uncertainties in the near and the long terms, and for assessing a complex network of impacts. The basic DOE-EM Principles for Risk Analysis (available at http://www.em.doe.gov/irm/principl.html) would be followed through this process and are not formally discussed here. The considerations discussed in this chapter are more specifically oriented toward factors affecting risk/impact assessment for the GW/VZ Integration Project.

2.1 THE RISK QUESTIONS FACING THE INTEGRATION PROJECT

Because contamination has moved into the GW/VZ in certain areas of the site, related risks and other impacts must be determined so the adequacy and appropriateness of various alternative measures to protect human health and the environment can be evaluated. At this time, it is uncertain exactly how much contamination is present in the GW/VZ, precisely how far it has spread, and what its specific future movement will be. These uncertainties, however, do not necessarily preclude sufficient evaluation of impacts and risks to support effective decision making.

2.1.1 Major Site Contamination Challenges

The aim of the Hanford Integration Project is to evaluate potential risks and other impacts associated with current and possible future release of contamination to the GW/VZ and Columbia River. A major purpose of this assessment is to inform decision makers so that they can take appropriate actions to protect human health and the environment in both the near term and the long term.

An understanding of the hazard source is needed to assess risks. Therefore, the risk estimation process depends on knowledge of the contaminant inventories across areas of the Hanford Site that were used for production and disposal operations. Under current plans, a considerable amount of radioactive and hazardous waste will remain on-site at the completion of the operational and cleanup mission. These materials include wastes currently contained in storage and disposal facilities (such as the B Plant and the Environmental Restoration Disposal Facility), as well as radionuclides and chemicals that have been released to the environment from past practices. The complex materials involved, the types of facilities historically used for processing and storage, and the disposal practices and nature of record keeping in the early years (which were standard for that time) all contribute to current uncertainty regarding the combined inventory, its present locations, and future movement.

The vadose zone has been contaminated by both current and past disposal practices and recent leaks (such as from the single-shell tanks), and groundwater beneath the site has also been affected. Contaminants are moving from the groundwater into the Columbia River through riverbank springs and seeps, as well as from the river bed interface. Some of the identified release points are currently being remediated by pump and treat systems. It is likely, however, that certain future remedial actions may result in release of some additional contaminants to the subsurface (DOE 1999a). For example, the baseline retrieval technology for tank waste (sluicing) could increase the level of subsurface contamination at the tank area and increase the potential that additional contamination may reach the river at some point in the future (DOE 1996). Because the original source term is not precisely known (and probably never will be), innovative ways need to be developed to estimate the amount of contamination currently present in the vadose zone and the amount that may move into and out of that zone over time. For example, methods used to assess the extent of ore bodies (including statistical techniques such as kriging, whereby interpolations are made in consideration of local features) can be considered for application at this site. Such methods could also provide an independent evaluation of the current mass balance approach to estimating the collective contaminated "source term" (the material that has been or potentially can be released to the environment).

Because of current and past practices, the Hanford Site has five principal risk-related components that must be considered in the risk and impact assessment:

- Man-made features (structures and equipment),
- On-site vegetation,
- Groundwater/vadose zone,
- Riparian areas and vegetation, and
- Columbia River flow.

These five components are linked, with the contaminated groundwater/vadose zones serving as source terms for riparian areas along the Hanford Reach and for the Columbia River flow out of the Hanford Reach. The contaminated soils surrounding various site facilities are a source of contaminant leaching to groundwater. Contaminated surface soils also represent a source of additional impacts to the environment, including those associated with direct radiation (external gamma exposure), airborne transport and subsequent impact, and uptake into vegetation with subsequent ingestion by biota. The man-made features include all Hanford facilities, including those operating and those that have been shut down. Such facilities, including waste tanks and disposal areas, are being assessed for their potential to impact the vadose zone and groundwater.

2.1.2 The Risk Questions

At its most basic level, the question facing the Integration Project is: "How serious a problem is the Hanford GW/VZ contamination, notably in terms of the potential for contaminants to migrate through soil and groundwater to the Columbia River?" If the risks are not trivial, then a related question arises: "What management strategies are most likely to succeed in avoiding major impacts?"

The challenge lies in defining focused questions and developing a process for answering them that applies to each of the exposure/receptor combinations potentially affected. The seriousness of the problem may be judged on three primary bases: risk to human health, risk of ecological function impairment or resource loss, and impact to cultural resources (which includes loss of access occasioned by health or ecological risks). These considerations drive the formulation of a quality-of-life and economic impact assessment process. To define the specific risk issues to be investigated, a set of targeted questions must be applied:

- What is the magnitude of risk from current and future GW/VZ contamination, to what receptors and resources in what locations, and in what time frame?

- What are the dominant factors driving the risk?

These questions imply the need to define the source term and characteristics of receptor situations simultaneously. This work is a major emphasis of ongoing inventory analyses by the Hanford team. For screening purposes, an approach to bounding uncertainty regarding the source term is needed. On the receptor side, the sheer number of possible impact situations warrants development of a screening approach to identify the most sensitive and/or key receptor situations or combinations of situations (e.g., multiple exposures of the same receptor or effects on multiple components in an ecological system). This process involves identifying the controlling exposure scenarios, across both short-term and extended time frames, for each major combination of location and of health or ecological impact category.

Estimating the source term for exposures in a particular location requires that a series of questions be addressed and a trajectory of future conditions be developed:

- What are contaminant levels in the river? An example of consideration of this issue is provided in Appendix A for past and current tritium contamination. It is helpful to conduct such assessments for future time periods such as 50 years, 500 years, and 1,000 years, based on the questions that follow.

- What are contaminant levels in the groundwater now and what may move to groundwater from the vadose zone in the future?

- What are contaminant levels in the vadose zone now and what may move to the vadose zone in the future?

- What contaminants exist in the man-made environment of facilities and waste disposal sites that may move to the vadose zone and beyond in the future?

Similarly, assessing the receptor side of the risk equation involves a series of interrelated analyses, of which the following are representative:

- What are the key exposure locations, now and in the future?

- At those locations, what receptors and biological systems are potentially at risk?

- What are the pathways of exposure to receptors and biological systems and what is the uptake potential?

- Are there linkages among receptors and biological systems that may affect the nature or degree of cumulative impacts?

- Are there potential interactions among site-related contaminants or between those contaminants and other environmental stressors that may affect the nature or degree of cumulative impacts?

Once the targeted potential exposure/receptor locations are identified, a set of guiding questions related to potential impacts needs to be developed. Given present information, we have identified four crucial issues related to potential Hanford Site GW/VZ impacts that warrant evaluation by an integrated risk/impact assessment. (We recognize that others will define the representative core issues differently.)

- **Human Health Risks –** Protecting the health of the public is a core commitment of DOE. Further, if such risks were to occur, they could result in social, political, and economic impacts.

- **Threats to Salmon Reproduction –** The Columbia River salmon are a key resource that is under stress from a variety of causes. Potential threats to the spawning beds in the Hanford Reach associated with the Hanford Site should be assessed, and if a hazard is present, it should be controlled and mitigated. (We also note that the site's presence has served as a benefit to the salmon because it has precluded commercial development along this stretch of the Columbia River.)

- **Site Access and Protection of Cultural Resources –** It is important to determine whether cultural resources are protected and health risks are sufficiently low to permit access by Native Americans and others to various site locations for collection of food, medicinal, ceremonial, and craft materials, and for other cultural purposes.

- **Economic Impacts –** Major contamination of the Columbia River, in either the short or long term, could cause significant economic impacts on the surrounding region and related markets. Ascertaining the potential for significant contamination to occur and, if such a potential exists, identifying ways to avoid its occurrence must be a priority. In addition, economic impacts may be generated by stigma even in the absence of major contamination. The mechanisms of this process need to be understood and means developed to avoid it.

2.2 RECOMMENDED STRATEGY FOR ADDRESSING RISK QUESTIONS

A sound and appropriately structured analytical framework is needed to effectively address the risk questions outlined above. The following sections describe our recommended strategies for dealing with three sets of issues that affect development of such a framework for assessing risks and impacts at the Hanford Site. These issues are (1) the long-term strategy for protective maintenance within which risks and impacts must be evaluated, (2) a process for managing hazards under uncertainty, and (3) assessment of complex and inter-related risks and impacts of hazard exposure. In discussing hazard management under uncertainty, the examples given are related to projecting potential contaminant releases and concentrations at receptor locations. These issues are emphasized because they constitute what we view as the most important site-specific sources of uncertainty affecting the risk assessment. (We recognize that others will have different views of the issues and strategies for addressing them.)

2.2.1 Operational Principles for Protective Maintenance

Over the past 10 years, the Hanford Site has been under increasing pressure to address the environmental legacy of its Cold War weapons production program. The site cleanup program has been accelerated, and a substantial amount of remediation work is expected to be completed by the year 2006. However, in many areas it is technically or economically infeasible to clean up the site to levels compatible with unrestricted use (DOE 1997), nor does the recent land use plan identify on-site residential use as an intended option (DOE 1999b). In addition, in some facilities, such as the Hanford reactors, potentially high radiation doses to remediation workers may necessitate postponement of major actions until radiation levels decrease (or appropriate robotic technologies become available). These and other considerations have increasingly lead to the realization that:

- Not all areas of the Hanford Site can be returned to hazard levels acceptable for unrestricted use;
- Some materials and locations will require isolation and maintenance far into the future; and
- A long-term maintenance program is needed to ensure continued protection.

Thus, the completion of active remediation does not mean the end of environmental responsibilities, and there is an obligation to continue to protect human health and the environment after the cleanup program is complete. Recognizing this, DOE intends to incorporate long-term stewardship into its remedial action and waste management decisions. Implementing a stewardship program may ultimately involve a wide variety of activities, depending on the nature of the site conditions at completion of the cleanup program and the residual hazards at that time. It is expected that these activities would be directed toward the following goals:

- Eliminate current hazards to the maximum extent practical;
- Provide stabilization for at least 50 years (one generation), but designed to be carried forward by future generations;
- Minimize the area footprint to be passed forward for continuing stewardship;
- Minimize long-term monitoring and maintenance costs; and
- Provide information and research to enable future generations to sustain and improve on health and environmental protection.

Following stabilization of contaminated areas in a manner designed to meet these goals, barriers will separate the remaining hazards from key receptor groups (e.g., workers, the public, and the environment). These barriers may be engineered features (to stabilize and/or contain or isolate waste) or institutional/ administrative controls (to restrict certain uses and hence exposures, provide important stewardship information, or maintain appropriate security). In many cases, however, radioactive wastes that remain at Hanford will pose hazards for far longer than the life of the original barriers designed to contain them.

The finite life span of engineered solutions and the potential for loss of institutional control present special challenges for long-term protective maintenance. It is unlikely that any nation has the ability to design an initial system that will surmount these challenges and successfully isolate hazardous wastes for the thousands of years that may be required. However, just as we have gained extensive knowledge within the past 50 years, continued advances are likely to equip future stewards with new science and technology tools.

In addition to the long-term challenges, a protective maintenance program must also address the short-term uncertainties that arise from incomplete knowledge of the current inventory, the inability to completely characterize subsurface environments, and the inability to predict near-term exposure conditions with precision – including those resulting from uncommon environmental events (such as upstream dam failures and floods). Thus, stewardship efforts face two profound challenges: long-term uncertainties associated with site barrier failure and institutional change over multi-generation time periods, and short-term uncertainties associated with the inability to precisely predict future factors that will affect exposure and risks.

2.2.2 A Strategy for Managing Uncertainties

Two approaches exist for handling the issue of protective maintenance posed by long-term and short-term uncertainties. One is to develop computer models and other means to predict conditions and events far into the future and then to build containment and other safeguard systems on the basis of these predictions. The disadvantage of this approach is that it is virtually impossible to perform analyses and measurements today that will reduce to acceptable levels uncertainties over hundreds of years. Since uncertainties cannot be eliminated when the system is initiated, barrier systems are often overdesigned, which greatly increases costs. Moreover, this approach assumes that current technological solutions will be adequate for hundreds to thousands of years.

An alternative approach is to reasonably bound uncertainties in an iterative process that seeks to maintain barrier integrity and institutional controls for a generation (50 years) and then passes responsibility to the next generation. This approach assumes that the sites will require continuous management and dynamic responses to changing future conditions. The principle of this approach is to address uncertainty through further site investigation and future development of enhanced barriers. However, it does not strive to eliminate all major uncertainties prior to beginning the protective maintenance process; instead, it manages potential deviations from control during stewardship through aggressive monitoring and contingency planning.

This process is similar to the way in which flood control and water supply management systems on the nation's rivers have been reevaluated and modified over time. Projects have been assessed and implemented as needs have changed and as additional technological possibilities have emerged. While it is not possible to know the precise future trajectory of present site conditions, it is possible to define an envelope of plausible future situations that bounds uncertainty. Additional site characterization and/or barrier improvements can be used to eliminate potential future situations with uncontrollable consequences. Thus, the multi-generation uncertainty associated with long-term hazards can be managed through an iterative process of constraining site conditions over successive 50-year intervals to a set that sustains hazard control. Ultimately, the challenge is to implement a continuous framework that ensures that hazards are contained, appropriate monitoring and contingency plans are in place, and knowledge regarding existing hazards is communicated to future generations. A recommended hazard management framework is as follows:

- **Define Expected Conditions** – On the basis of current knowledge, identify the most probable sequence of events over the next 100 years (two generations), assuming gradual barrier degradation. To assist in development of contingency plans, formulate detailed projections of site conditions for a 100-year period and perform general trending analysis for a 1,000-year period.

- **Identify Plausible Deviations from a Controlled Trajectory** – Evaluate vulnerabilities of the barriers separating public, worker, and environmental receptors from site hazards to provide a qualitative evaluation of the likelihood and consequences of barrier failure. Examples of potential vulnerabilities include degradation of isolation systems, failure of administrative controls, lack of understanding of subsurface environment, degradation of packaging, criticality, and the presence of contamination outside containment systems. Next, accounting for uncertainty in current knowledge, develop reasonable bounding estimates of the consequences of plausible deviations.

- **Develop Contingency Plans for Plausible Deviations** – Develop contingency plans for detecting and responding to plausible deviations from a controlled status. Evaluate the cost, design, construction, detection, and contingency challenges presented by these deviations. The need to respond to deviations from control requires the parallel development of support (e.g., funding) mechanisms.

- **Eliminate Deviations that Would Result in Loss of Control** – Perform additional site investigations and actions sufficient to eliminate deviations that pose insurmountable challenges from a technical or cost perspective. The iterative investigation process can be stopped when remaining uncertainties are unlikely to lead to unacceptable loss of control.

- **Monitor for Deviations** – Institute a rigorous surveillance and maintenance program to ensure that barriers remain reliable and surrounding site conditions remain safe. Specific performance and monitoring objectives should be developed on the basis of probable conditions and reasonable deviations. Action thresholds should be identified that define the maximum deviation that will be tolerated before contingency plans are implemented. Again, the need for continued monitoring requires development of support mechanisms.

- **Improve Site Conditions and Management Iteratively** – Increasingly advanced levels of scientific and technological knowledge should be incorporated by each generation to produce increasingly safe containment, so that each generation can pass the site to the following generation in at least as good a condition as that when it was received. Accomplishing this also would require access to funds or other forms of support as needed.

2.2.3 Risk Assessment Methods for a Complex Aggregate of Impacts

The CRCIA process identified the need to evaluate a broad range of ecological, social, and cultural issues beyond those usually included in an impact assessment. In fact, there is a growing recognition in the practice of risk assessment that a wide range of issues must be addressed and that risks should be evaluated cumulatively. Expanding the scope of a risk assessment along these lines without rendering the analysis infeasible or making it exorbitantly expensive requires that substantial attention be given to focusing assessment resources on the most important issues. The discussion that follows is directed toward identifying ways in which impact assessments can evaluate site conditions at a level of detail appropriate to the situation.

Two distinct categories of impacts are to be investigated in the GW/VZ Integration Project. These are shown in the context of closely related technical elements in Figure 2.1. The first category (designated here as “primary”) is direct in causation, generally occurring as a result of biological processes due to exposure of an organism to contamination. Human health effects and ecological effects are the main components of this category, which is represented by the risk term. The other category (designated “secondary”) comprises impacts not directly due to biological processes (i.e., cancer or noncarcinogenic illness), such as sociocultural and economic impacts. This category includes impacts that either derive from primary (health) effects, from actions taken by the public to avoid perceived risks of primary effects, or from actions taken by responsible parties (such as governmental agencies) to prevent those effects. Economic consequences of decreased demand for products that might become contaminated and community impacts of controversy over human or ecological health are examples of this type of impact. If risks of primary effects were sufficiently high to warrant government action to prevent health effects to the public or major ecological effects, secondary impacts could also result from such actions.

In focusing the risk and impact assessment to provide information for decision making, the relationship between primary and secondary impacts provides a basis for avoiding unnecessary analyses. If a primary effect is identified as unacceptable by comparison with regulatory mandates, health standards, federal responsibilities, stakeholder agreements, or other defined values, the site management alternative resulting in conditions that would lead to that effect could be eliminated from further consideration.

This discussion points to the need for a screening analysis of primary effects as the basis for defining the scope of any assessment of secondary impacts. Such screening analyses should employ the principle of dominance in identifying important contaminants, pathways, and receptors. Interrelationships among contaminants and pathways that compound risks to a given receptor or endpoint need to be incorporated to the extent that adequate information is available. Uncertainties can be incorporated in the analysis through use of bounding techniques. Dependency webs, as conceived by Harris and Harper (1998), can be useful in tracing relationships and in ensuring that important links are not overlooked. The effort to be comprehensive in identifying pathways for dominant contaminants to the most affected receptors should have the effect of somewhat reducing the level of uncertainty usually associated with screening-level analyses.

Those site management alternatives that do not result in “show-stopping” primary impacts in the screening assessment can then be evaluated with a full-scale impact assessment for both primary and secondary impact categories. In concert with the hazard management strategy recommended above, these

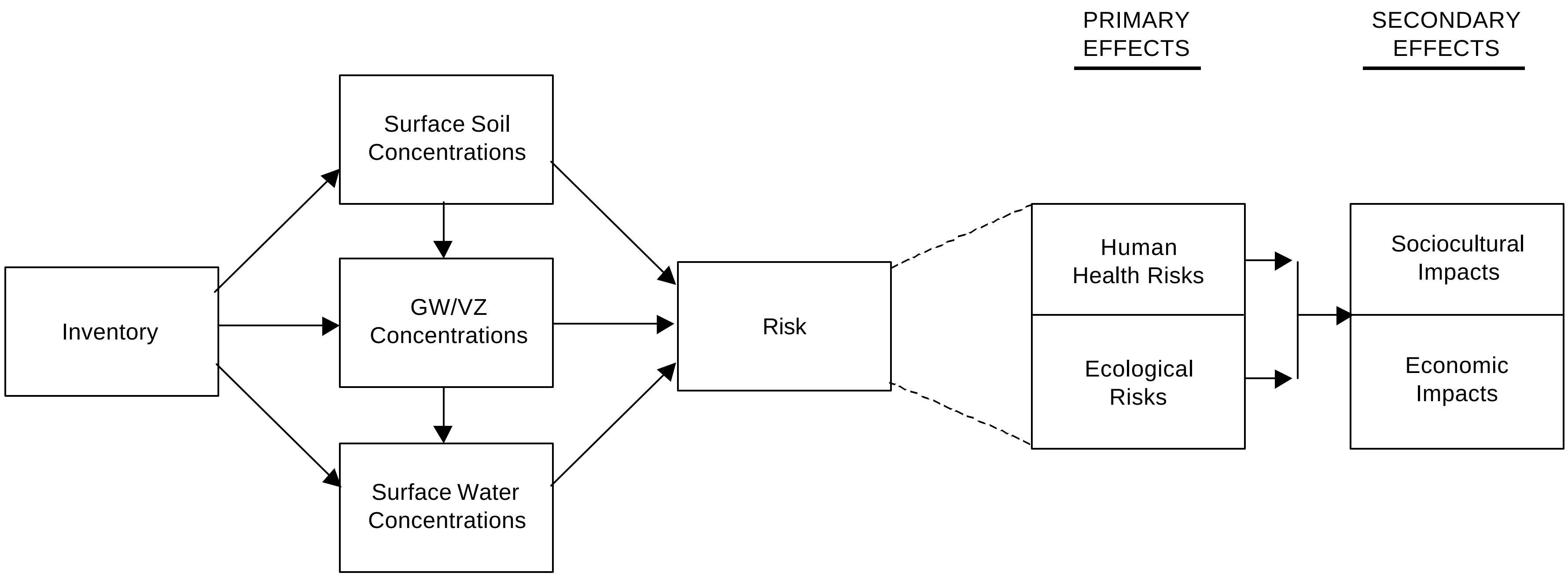

FIGURE 2.1 Overview of the GW/VZ Integrated Risk/Impact Assessment Process

assessments would focus on impacts for a single generation (50 years). Impacts beyond that period would be treated primarily in more qualitative or relative terms, with an expectation of iterative transfers of responsibility for ongoing assessments to assure a risk-based evaluation of site conditions over time (as described in Section 2.2.2). (While impacts may be projected for 1,000 years to satisfy the DOE expectations for performance assessment and composite analysis [DOE 1996, 1998; INEL 1998], it should be recognized that there is insufficient knowledge to place meaningful bounds on the uncertainties for such estimates.) Within the single generation, the assessment process should be iterated as needed to provide necessary information for site management decisions.

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3 FRAMEWORK FOR INTEGRATED RISK/IMPACT ANALYSIS

An integrated risk/impact analysis approach is needed to take account of the many factors that influence the risks and impacts posed by materials at the Hanford Site and the way in which these risks and impacts are perceived. Lessons can be learned from the numerous assessments that have been carried out for the site. Valuable information already gained can be applied to the current effort, and any previous inadequacies can be addressed. Many approaches and methods are available to assess risks and impacts, some traditional and others newly developed. A powerful assessment framework can be developed by using different methodologies in the right combinations. Implementation of such a framework would enable assessments to be carried out to address the principle concerns of regulators, Native American Tribes, members of the public, and other stakeholders to provide direction for remediation and cleanup activities.

3.1 LESSONS LEARNED FROM HANFORD IMPACT ASSESSMENTS

Numerous risk/impact assessments have been performed for various activities, facilities, and environmental media at the Hanford Site to support ongoing regulatory and planning processes. An initial activity of the GW/VZ Integration Project involved identifying those completed assessments that could provide input to the understanding of the overall site risk profile. It is beyond the scope of this report to provide a comprehensive review of all site assessments, but limited information on the scope and approach used in several recent studies is presented in Section 3.1.1. Some lessons learned from those studies are described in Section 3.1.2.

3.1.1 Highlights of Approaches Used and Related Issues

A variety of approaches have been used in several recent studies to assess contaminant behavior and related impacts on human health and the environment at the Hanford Site. Selected information from these studies is highlighted below.

3.1.1.1 Hanford Environmental Dose Reconstruction (HEDR)

The HEDR Project provided individualized radiation dose estimates (with uncertainty) to any person who lived within a 75,000-square-mile area around the Hanford Site during a period of nearly 50 years (1945-1994). Both atmospheric and Columbia River exposure pathways were included. A Technical Steering Panel directed the project, which was ultimately placed under the purview of the U.S. Centers for Disease Control and Prevention (CDC). In addition to other parties, nine Columbia Basin Native American Tribes and Nations were involved in the study.

The primary computational software developed for this project dealt with one radionuclide (0.74 mega-curie [MCi] of iodine-131) in the air and five in Columbia River water (2.5 MCi of arsenic-76, 6.3 MCi of neptunium-239, 0.23 MCi of phosphorus-32, 12.0 MCi of sodium-24, and 0.49 MCi of zinc-65). It was estimated that these radionuclides accounted for more than 94% of the potential radiation dose from the river pathway. Spatial resolution was 6 miles for the air pathways and several discrete segments of the Columbia River. Temporal resolution included hourly meteorology, river hydrology, and air releases; daily human locations; monthly dose estimates; seasonal variations in agricultural practice; and annual changes in food distribution networks. Exposure pathways considered were swimming and boating; air immersion; inhalation; ground deposition; and consumption of leafy vegetables, other vegetables, fruit, cow and/or goat milk, meat, eggs, drinking water, fish, and shellfish. The analysis included 100 realizations of each parameter at each of 1,102 locations.

All models developed for the project were stochastic. (Parameter uncertainty distributions were propagated using Monte Carlo/Latin Hypercube methods.) A modular approach was used in the stochastic simulations for situations where massive data storage was used to retain time/space correlations between derived parameters. Code tests, walkthroughs, and independent verifications were used for quality assurance.

3.1.1.2 Hanford Remedial Action Environmental Impact Statement

The purpose of the Hanford Remedial Action Environmental Impact Statement was to establish future land use objectives for the Hanford Site (DOE 1999a). The analysis considered 892 waste sites and facilities, which did not include the single- and double-shell high-level waste (HLW) tanks. Data for hazardous constituents were aggregated within grid cells of 1 km by 1 km, and a number of effects (health, ecological, cultural, and socioeconomic) were analyzed. The Multimedia Environmental Pollutant Assessment System (MEPAS) was used to evaluate environmental transport.

3.1.1.3 Tank Waste Remediation System Environmental Impact Statement

The purpose of this project was to assess 177 single- and double-shell tanks and 40 miscellaneous underground storage tanks (MUSTs) in the 200 Area of the site and the cesium and strontium capsules in storage (DOE and State of Washington 1996). Tank waste (containing 177 MCi of radioactivity), MUSTs (containing less than 0.9 MCi), and the cesium and strontium capsules (68 MCi) combined represent 97% of the radionuclides in the 200 Area (254 MCi). Another 1 MCi is estimated to have been released or leached to the ground, and 5 MCi was disposed of in the solid waste burial grounds on the site. Exposure scenarios evaluated include Native American, residential farmer, industrial worker, recreational shoreline user, and recreational land user. Vadose zone and groundwater flow and contaminant transport were simulated with the VAM2D transport code.

3.1.1.4 Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau

The purpose of this study was to estimate cumulative radiological impacts from active and planned low-level radioactive waste disposal actions and other waste disposal sources that will remain following Hanford closure (Kincaid et al. 1998). The radiological inventory that was evaluated included 50,000 Ci of carbon-14, 345 Ci of chlorine-36, 17.1 Ci of iodine-129, 1,050 Ci of selenium-79, 24,900 Ci of technetium-99, and 66,000 Ci of uranium-238. Human exposure scenarios evaluated included agricultural, residential, industrial, and recreational. Groundwater flow and contaminant transport were simulated with three-dimensional transport codes, while a one-dimensional code simulated vadose zone flow and contaminant transport.

3.1.1.5 Retrieval Performance Evaluation Methodology for the AX Tank Farm

The purpose of this study was to estimate (with uncertainty) the doses from the AX tank farm (DOE 1999b). The radiological inventory of the AX tank farm was estimated to be 12 MCi for the current inventory of the four tanks, 0.2 MCi for the ancillary equipment, and 0.034 MCi for past leaks. Vadose zone and groundwater flow and contaminant transport were simulated with the PORFLOW transport code. An uncertainty analysis was performed with the MEPAS transport code, fitted to the transport results of PORFLOW. Model sensitivities were dominated by source term and receptor exposure parameter uncertainties.

3.1.2 Lessons Learned

Certain insights gained from these past assessments are indicated below.

3.1.2.1 Inventory

There are two areas of concern in the estimation of the site inventory. The first is that although there is fairly good agreement on the major contributors to the inventory, some stakeholders are concerned about uncertainties in these estimates. These uncertainties can be illustrated by the differences among assessments with regard to the number of waste sites and facilities. However, the major concerns relate to multiple small sources that are currently not included in the inventory estimates, obtaining a reasonable bounding estimate of the inventory presently in the vadose zone and groundwater, and potential future contributions from these other minor sources. These lessons can help guide what still needs to be addressed and how to improve the assessments.

3.1.2.2 Vadose Zone

The inventory and distribution of radionuclides in the vadose zone is not fully understood. For example, new data from a recently completed demonstration of methods by Los Alamos National Laboratory (Agnew and Corbin 1998) indicates that the volume of past leaks from 4 of the 149 single-shell waste tanks may be greater than previously estimated. That study was commissioned in the summer of 1996, after it was discovered that radioactive waste from the SX tank farm had reached a substantially greater depth than previously assumed. Study results indicated that 1 MCi more of cesium may have entered the vadose zone from the four tanks studied than earlier estimated (DOE 1998). This new finding substantiates the need for a more comprehensive assessment of the sources impacting the vadose zone and groundwater at Hanford. Nevertheless, the results of all past studies indicate that the current vadose zone and groundwater contamination is not presenting an imminent health hazard to the public or danger to the environment. This finding means that DOE has the time needed to conduct a more thorough and integrated assessment to determine if there are any potential long-term impacts and to design corrective actions as appropriate if potential adverse impacts are identified.

3.1.2.3 Impact Types

Most assessments have focused on traditional human health measures and a limited set of ecological impacts. However, certain stakeholders and Tribal governments have identified a broad range of nontraditional values and concerns that lie outside the standard human health and ecological risk paradigm. Also, concern has been expressed over the need to more explicitly consider a variety of additional toxicological and ecological endpoints (beyond the limiting critical effect) – including multi-generational considerations (i.e., potential long-term effects on future generations). An integrated assessment approach can account for such nontraditional issues as cultural and religious values, tribal and other unique life styles, economic issues, and the cumulative effect of exposures to multiple contaminants. It can also provide a framework for more closely examining the possibility of additional toxicological and ecological endpoints of concern as they are identified by scientific advances over time.

3.2 OVERVIEW OF APPROACHES

Risk/impact assessment is a broad field with a variety of approaches. The choice of a particular approach depends on such factors as the effect of interest (health, ecological, economic, or sociocultural) and the objective of the assessment (e.g., scoping, regulatory, or building stakeholder confidence). We consider the current program at the Hanford Site to be governed by what might be called the classical regulatory approach. The regulatory and several other possible approaches are summarized below.

3.2.1 Classical Regulatory Approach

The classical regulatory approach relies on a formal risk assessment process prescribed by EPA and state regulators that is described in numerous guidance documents (notably the Risk Assessment Guidance for Superfund, EPA 1989). This process has been endorsed by a variety of national organizations, including the National Academy of Sciences, many stakeholder groups, and most local and state regulators. In addition, it is a feature of the State of Washington's Model Toxics and Control Act that applies to the Hanford Site. The regulatory approach provides structure and focus for quantifying health and environmental impacts at a site. Large numbers of modeling tools, including groundwater and atmospheric models, exist to support this approach, as does guidance on physicochemical (transport), exposure, and toxicological factors.

The classical regulatory approach essentially represents what is viewed as the "best science" approach overall. It is most useful in choosing among remedial alternatives and guiding development of residual contaminant targets. Its limitations are that (1) it can be demanding in terms of time and data requirements; (2) it typically is applied to one problem at a time (thus composite effects are often not addressed), and (3) stakeholders tend to be distrustful of the models employed. Even with these limitations, the standard regulatory approach is the first line of defense against environmental pollution. In some situations, it can be useful to augment this approach with other risk/impact assessment frameworks. A few such approaches are discussed below.

3.2.2 Quantitative/Qualitative Hybrid Approach

The quantitative/qualitative approach combines quantitative data – both measured and modeled – with descriptive information where those data are not available. A good example of this hybrid approach is the classification method being pursued for carcinogens, whereby a more extensive discussion of available data is presented to craft an overall weight-of-evidence "story" rather than simply listing a single assigned category. The descriptive portion of this approach is illustrated by the dependency webs being developed by members of the project team as input to the conceptual model aimed at supporting quantitative assessments for the Hanford Site. These webs indicate potential impact categories (biological, economic, cultural) at different exposure locations. While the dependency web approach can be useful in communicating a broad picture of potential impact categories and possible interrelationships, as currently developed it is a qualitative tool only and must be used in conjunction with quantitative tools to place contaminant concentrations, or other values, in a realistic context.

3.2.3 Model-Free Approach

The model-free approach (more appropriately called "model-lite" approach) is an outcome-based conceptual approach for assessing environmental transport and risk, with minimal reliance on traditional modeling techniques. It is not a single methodological approach but a collection of approaches that strive to scope problems by providing reasonable bounds on consequences and identifying major system sensitivities. Characteristics of this approach are:

- **Relies on Measurement Data** – The model-free approach relies as much as possible on simplified higher-level analysis and mainly depends on the use of measured (rather than modeled) data.

- **Identifies Major System Components** – It identifies the major system components contributing to variability in performance.

- **Bounds System Response** – The model-free approach attempts to bound total system response rather than the response of system components.

The model-free approach attempts to provide transparency for stakeholders by using systems that are conceptually easy to understand and that rely on measured data as opposed to model predictions. This approach is not meant to substitute for more complicated models, but rather to be used in parallel with them. The more complicated models address issues of scientific credibility, while the model-free approach addresses the issue of stakeholder credibility. The strength of this approach lies in its communication value for developing public acceptance of proposed remedial approaches. The following examples are provided to further clarify the definition of the model-free approach.

- A model-free approach may be used to estimate transfer of contaminants from the Hanford aquifer to the Columbia River. The increase in water concentration of contaminants in the river may be evaluated by measuring concentrations in the river above and below segments of the Hanford Reach. Multiplying the difference by measured volumetric flow data yields an estimate of the mass of the contaminant released from the Hanford Site into the Columbia River per unit time. These estimates can be compared with current predictions of the Hanford groundwater model. In addition, use of measured groundwater contaminant concentrations near the river at the time of the transfers may make it possible to estimate the volumetric flow rate of Hanford groundwater into the Columbia River along the Hanford Reach. Appendix A develops this approach for tritium concentrations in the Hanford Reach. Tritium is the focus because it is the major contaminant that has reached the river through GW/VZ plumes. Information currently available is insufficient to conduct a similar analysis of potential future concentration increments in the river from certain other plumes.

- A model-free approach can also be developed to predict groundwater transport of contaminants using the historical groundwater data for tritium, iodine, strontium, and other contaminants. This approach could help eliminate uncertainties present in incorporating modeled characteristics for subsurface geological formations (a major concern of some state regulators) and their contaminant retardation characteristics. The historical measured concentration data already integrate subsurface geologic factors.

- The major uncertainty in the Hanford groundwater/vadose zone project is characterization of the transfer of contaminants through the vadose zone. The complexity of the vadose zone in the 200 Area may be such that additional monitoring data cannot reduce uncertainties to a level that all stakeholders would have confidence in. Current vadose zone modeling indicates a range of breakthrough times for contaminants in the vadose zone ranging for example from 50 to 65 years for contaminants with no retardation to more than 1,000 years for contaminants with retardation. Because of heterogeneity in the subsurface environment, uncertainties exist in both the magnitude and timing of breakthrough curves. A model-free approach to assessing this uncertainty could bypass vadose zone modeling altogether by hypothesizing the shape of various breakthrough curves (magnitude and duration) and evaluating the impact on the indicated endpoint effects. This approach could identify and prioritize those vadose zone uncertainties (e.g., subsurface heterogeneity, inventory magnitude, and inventory composition) that significantly affect the impact assessment. Such an approach could provide information both to better focus further environmental sampling efforts and to increase public confidence in final risk/impact estimates by identifying major sources of uncertainty.

3.2.4 Classical Uncertainty Analysis Approach

Models are very powerful tools for predicting and estimating risks/impacts but uncertainties are introduced by the nature of assumptions that have to be made, as well as by the uncertainties inherent in the data that are used. The classical uncertainty analysis approach attempts to provide bounds on model outcomes and to identify model parameters that most influence system variability. Typically, a most probable future trajectory is defined, and Monte Carlo statistical techniques are used to propagate model parameter variability to obtain bounds on future trajectories. Under Monte Carlo analysis, the model is run for a given number of iterations (e.g., from 100 to 10,000) with parameter values randomly selected from their respective distributions for each model run. The resulting family of risk estimates provides a statistical range of possible model outcomes rather than a single value. Monte Carlo analyses can improve upon deterministic approaches by explicitly incorporating variability in model data and highlighting major model sensitivities. The difficulty with this technique is that when impacts are being projected over long time periods, the uncertainty bounds may be so large as to make the best estimate meaningless. In such cases, only the width of the uncertainty estimate itself has meaning.

3.2.5 Uncertainty Bounding Approach

The uncertainty bounding approach is used to augment traditional uncertainty analysis. In the bounding approach, rather than starting from the most probable trajectory and working outward to define bounds on uncertainty, the analysis starts from the outside and defines the bounding envelope of possible future trajectories. The bounding approach is particularly effective in situations where uncertainties exist not just in model parameters, but in the actual conceptualization of site conditions. Rather than focusing on traditional Monte Carlo analysis and its resultant characterization of parameter variability, one attempts to establish reasonable bounds on possible deviations from the most probable conceptual model of site conditions. These deviations can be used to establish the bounding edges of the uncertainty envelope. Focused environmental monitoring can then be used to reduce the width of this envelope.

3.2.6 Barrier/Monitoring Approach

The barrier/monitoring approach addresses situations in which not all areas of a site can reasonably be returned to hazard levels compatible with unrestricted use, and thus barriers would be needed to separate remaining hazards from receptor groups. Since barriers have finite life spans, monitoring is employed to ensure that barriers are functioning as planned and that surrounding site conditions remain safe. Under the barrier/ monitoring approach, one can identify the most probable sequence of events over the next 100 years (two generations) assuming gradual barrier degradation. Next, one can identify plausible deviations from the controlled trajectory and develop bounding estimates of the consequences of those deviations. Contingency plans can then be developed for detecting and responding to all plausible deviations from the controlled status. The advantage of this approach is that it does not strive to eliminate all uncertainties before beginning the protective maintenance process. Instead, it manages potential deviations from control during stewardship through aggressive monitoring and contingency planning.

This approach is used in conjunction with standard risk assessment and risk management approaches, it is not a substitute for the classical regulatory approach. Understanding gained from the risk assessments can inform the monitoring activities. That is, the monitoring program can be designed to look for pollutants representing the dominant risks and to address any key uncertainties identified during the risk assessment. The locations and timing of samples to be collected are also informed by risk assessments designed to predict the most likely future trajectories and reasonable deviations for the site.

3.3 EXPANDED PERSPECTIVE FOR RISK/IMPACT ASSESSMENT

The standard risk assessment approach for typical hazardous waste sites involves developing a conceptual site model that identifies contaminant sources, release mechanisms, transport pathways to receptors, and potential exposure routes. Different types of risks (primarily cancer and limited non-cancer effects) are then often evaluated in a discrete rather than a concurrent, integrated manner, especially for smaller sites with limited contamination and transport/exposure routes. That approach is insufficient to address the uncommon extent and complexity of the Hanford Site, with its broad range of nontraditional issues and concerns that have been expressed by local Tribes and other interested parties. In response, the GW/VZ Integration Project team has proposed an expanded risk/impact assessment perspective that emphasizes various areas and associated receptors more than a standard approach typically would.

Information on the network of relationships among resources at locations affected by contamination is inportant input to an integrated assessment. Links to larger biological, sociocultural, and economic systems can also be developed as conceptual input. Two types of dependency webs – location-specific and receptor-specific – have been developed by the project team to help identify these links for integrated risk/impact assessments at the Hanford Site. These webs are further discussed in the following sections.

The high-level relationships among core elements developed by the dependency webs is illustrated in Figure 3.1, considering the Hanford Reach. For certain locations such as this, the potential for risks of biological effects is notable. In other situations the major risk could be physical or of some other type. Certain risk types can trigger sociocultural, economic, or other impacts. Examples of the chains of relationships among risks and impacts developed for the Hanford Reach of the Columbia River are provided in Appendix B.

3.3.1 Location-Specific Dependency Webs

Potential impact areas identified through contaminant transport modeling that has been conducted for the site serve as key input to the effects assessment. Dependency webs can be used to support this assessment by providing a qualitative identification of potential impact categories (biological, sociocultural, and economic) at different exposure locations. The concept of dependency webs was developed by Harris and Harper (1998a) in response to the Columbia River Comprehensive Impact Assessment (CRCIA) team's requirements, and these webs are intended to provide a holistic examination of impacted elements. The aim is to use these webs to identify complex interrelationships among potential receptors, including humans, fauna, flora, habitats, and environmental resources, at various key locations. The dependency webs continue to be developed by Harris and Harper to support the Integration Project's assessment process.

To provide a basis for further defining a conceptual model that could be used to guide quantitative risk/impact assessments for the site, it would be helpful if the dependency webs could be expanded to include the following elements:

- Specific response elements within each impact location,
- Exposure pathways linking response elements with contamination at impact locations,
- An effects web for each response element defining effect categories (such as cancer, job loss, or loss of cultural continuity), and
- A metric for evaluating magnitude of impact within each effect category.

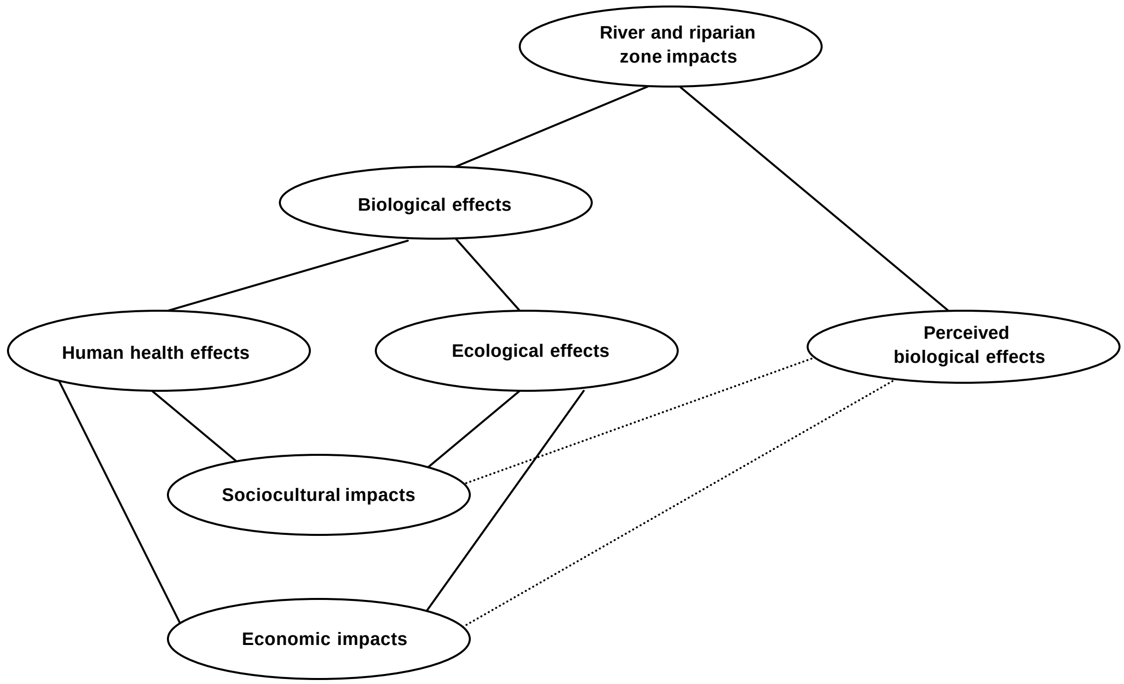

FIGURE 3.1 Use of the Dependency Web Concept to Identify Areas for Consideration in the Risk/Impact Assessment

3.3.2 Receptor-Specific Dependency Webs

The receptor-specific dependency webs of Harris and Harper define the network of resources and activities associated with key receptors (or resources, such as an ecological community or system) that have been identified as potentially subject to significant biological effects. These associated resources contribute to the uses and functions of the key receptor. For example, a web for salmon that identifies its food chain, economic, cultural, and other functions would be useful if impairment of salmon reproduction in the Hanford Reach were projected because of contamination in that location. Delineation of associated resources and their linkages to each other and to a key receptor can serve as a basis for evaluating the value of a given receptor. In continued support of the integrated assessment process, it would be helpful if these webs could encompass the following elements:

- Associated resources linked to the key receptor,

- Functional requirements of each associated resource (e.g., minimum quantity of the key receptor, condition requirements, and status of substitute resources),

- A metric for evaluating the magnitude of degradation in functions of the associated resources, and

- An aggregate measure for each loss to associated resources as a result of degradation of the key receptor.

In furthering the development of these useful dependency webs for locations and receptors, it would also be helpful to delineate the analytical requirements, methods, and metrics for adequately assessing each applicable element. As these dependency web elements are established (i.e., identified, defined, and assessment requirements determined), the developers are expected to support the SAC group in facilitating determination of the complex relationships and selection of assessment methods appropriate for those elements.

3.4 FRAMEWORK FOR THE RISK/IMPACT ASSESSMENT

An integrated risk/impact assessment requires a framework that facilitates the evaluation of uncertainties and accommodates an iterative process to develop the information needed for risk management decisions. This section first describes principles and objectives for such a framework. A discussion of the analytical process follows, and examples of screening and bounding techniques for managing uncertainties are then presented. The section closes with an overview of the elements constituting an approach for an integrated risk/impact assessment and suggestions of appropriate phases for the analysis.

3.4.1 Principles and Objectives

The analysis framework outlined below for the risk/impact assessment builds on lessons learned from previous assessments. Also, it is consistent with the principles of utilizing sound science, considering cumulative effects, addressing interdependencies among various risks/impacts, and evaluating uncertainties. It emphasizes the importance of involving affected parties regarding input to key decisions on the risk/impact assessment approach throughout the process. Application of these guiding principles implies an integrated assessment that considers, at least initially:

- All hazard sources and plausible release scenarios for the range of cleanup activities and end states considered for the Hanford Site;

- Receptor exposures from all contaminant species, including exposures that occur simultaneously and could lead to synergistic or antagonistic effects;

- All types of receptor locations; and

- Time frames that cover a realistic planning horizon and extend into the long term.

With the complexity of the Hanford Site and its impact zones, an attempt to be fully comprehensive in each of the above aspects would present a major challenge. By necessity, the project design must also recognize the practical limitations of constraints on budget, time, and analytical capabilities. Key objectives and considerations affecting their implementation in the integrated risk/impact analysis are summarized in Table 3.1.

TABLE 3.1 Objectives and Associated Considerations for the Hanford GW/VZ Integration Project Risk/Impact Assessment

Objectives	Considerations
Reconcile the disparate methodologies, assumptions, and data used in past assessments and anticipated to be used in future assessments.	No single assessment approach is intended for all applications.
Identify a baseline set of science and technology activities to serve the needs of future assessments.	Certain effects of lesser potential risks/impacts would require less definition.
Consider the full range of possible effects, including health, environmental, economic, and sociocultural.	Do not attempt to combine all effects into a single value.
Employ a consistent approach for evaluating the same types of risks/impacts for different population groups.	Do not assume common values for all groups; different risks/impacts may require different approaches.
Account for the influence of existing environmental, sociocultural, and economic conditions.	Do not attempt to establish absolute risk/impact levels of existing conditions, but focuses on potential changes in levels.
Consider cumulative effects of multiple sources.	A cut-off point should be established for inclusion of cumulative effects.
Consider the individual and cumulative effects of uncertainties.	Focus on major uncertainties determined by sensitivity analysis.
Consider synergistic effects of multiple contaminants.	Incorporate new information as it is developed, as the range of possible effects at environmental levels is currently poorly known.
Evaluate risks/impacts at near-, intermediate-, and long-term time scales	The near term may be addressed quantitatively; the longer term is best treated qualitatively.

3.4.2 Analytical Process

The uncertainties regarding hazard levels and locations require an iterative approach to evaluation in which initial studies of reduced scope or detail provide an indication of where further studies should be focused. Figure 3.2 provides an example of this type of approach. Several types of studies (including those completed previously) can be used in the initial phases to direct subsequent studies. By judicious selection of a limited range of source terms, contaminants, pathways, receptor locations, and effects, a limited study can provide robust indicators of potential impacts and risks. Such an approach was used in the HEDR project, in which an evaluation focused on five radionuclides was estimated to account for more than 94% of the potential radiation dose from the river pathway (see Section 3.1.1).

Past assessments of the Hanford Site (particularly the Composite Analysis [Kincaid et al. 1998]) provide valuable insights into contaminant migration (both directions and rates) and the most likely geographic areas impacted. These assessments provide a basis for initial scoping of the integrated problem (most important contaminants, most probable impact areas, and time to most serious impact). These initial scoping studies should be conducted as a cooperative effort with input from regulators, local Tribes, local stakeholders, and others. The purpose of this initial scoping effort is to obtain a global picture of the problem. As the assessment proceeds, the global picture can be focused as appropriate, drawing from previous assessments and ongoing fate and transport modeling, site characterization, and environmental monitoring efforts.

With an approach in which study design is refined in several steps, continued consultation with stakeholders must proceed in parallel with the analyses. The purpose of this parallel consultation is to ensure that at project completion there would be general agreement that the limited scope of studies provides adequate information upon which decisions can be based. The decisions on study scope and design for each iteration would be the responsibility primarily of the project team, with review by stakeholder representatives and the wider community.

A preliminary example of how a succession of screening and detailed analyses might be applied to address the GW/VZ risk/impact questions is presented below. These analyses would be an iterative overlay on the analytical process.

What is the magnitude of risk/impact from the current and future GW/VZ contamination?

Step	Bounding Analysis	Method	Process Step
1a	Any significant biological risk/impact if all GW/VZ sources reach release points within 50 years from present?	Simple models	If no, do #2a; if yes, do #3a
2a	Any significant biological risk/impact if GW/VZ sources 10 times greater?	Simple models	If no, end analysis; if yes, do #3a
3a	When would significant risk/impact occur given simplified migration assumptions?	Intermediate-complexity models (such as RESRAD or MEPAS)	If in <500 years do #4a; otherwise end analysis
4a	What source locations/contaminants drive risk/impact?	Iteration of Steps 1-3 for source areas	Do #5a
5a	Evaluate alternatives for risk/impact reduction	Intermediate or specialized models	

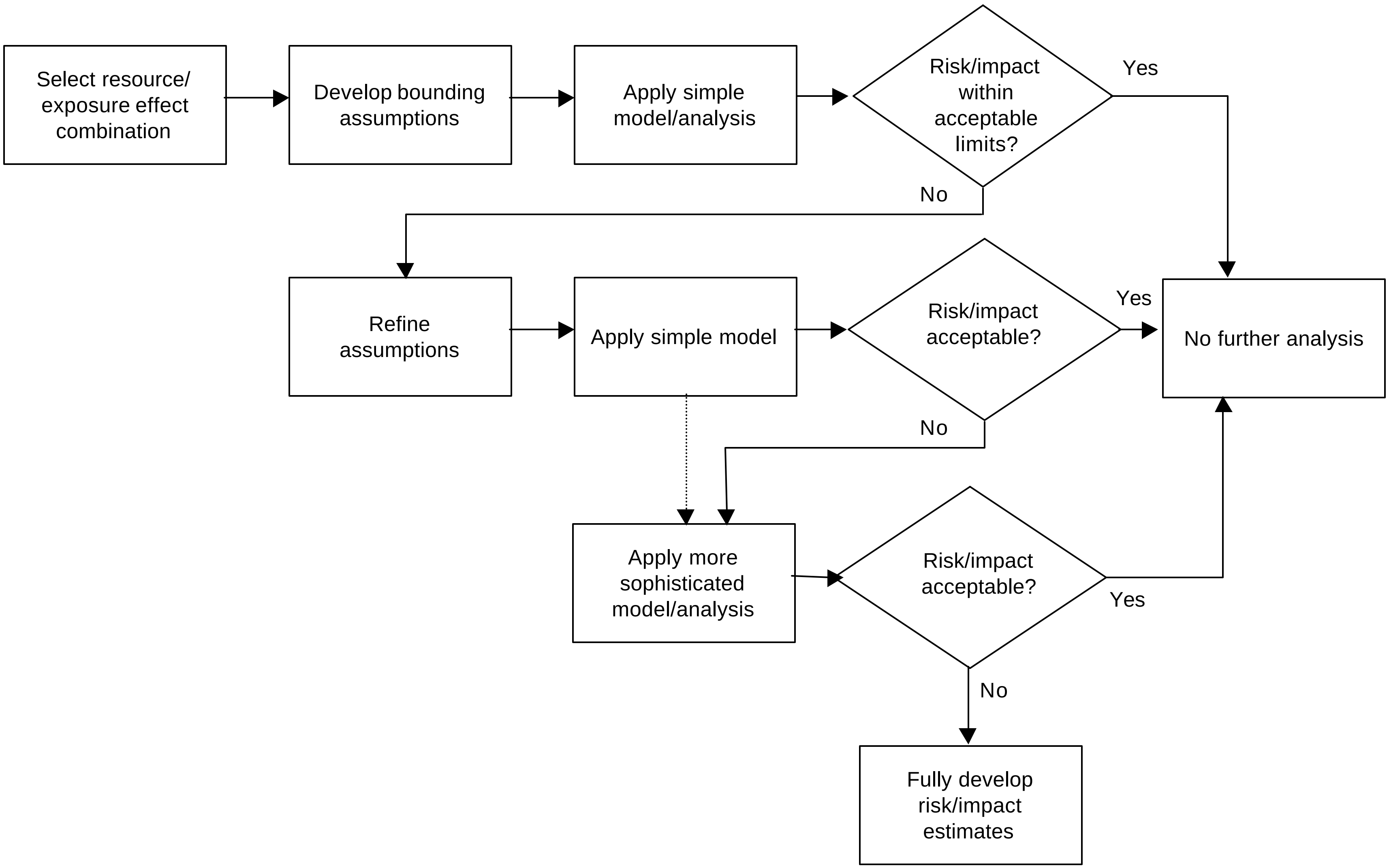

FIGURE 3.2 Iterative Process for Focusing Risk/Impact Analysis

If significant risk would occur in less than 500 years, assess impacts under the conditions identified as generating the risk. Iterate analysis for remediation alternatives.

What locations (impact areas) and which receptors or resources would be affected?

Step	Analysis Element	Method	Process Step
1b	Would contaminant concentrations exceed criteria levels in key risk/impact locations?	Screening analysis	Identify study locations and do #2b
2b	Identify maximum exposure pathways and receptors in study locations	Standard methods plus dependency webs	Do #3b
3b	Any significant biological risk/impact?	Screening analysis	If no, end analysis; if yes, do #4b
4b	Any significant biological risk/impact?	Combination of standard and supplementary estimation methods	If no, end analysis; if yes, do #5b
5b	Magnitude of secondary risk/impact?	Combination of standard and supplementary estimation methods	

3.4.3 Integrated Approach

We suggest that the impact assessment would be most effective if it were designed to encompass the classical regulatory approach, but with adaptations to accommodate both uncertainties regarding potential concentrations of contaminants at release points and the concerns of affected parties. These adaptations could take several forms. The first is more extensive use of screening and bounding approaches than is standard, as a means of addressing uncertainties associated with both the source term in the impact calculations and with cumulative effects of exposure. Second, a quantitative/qualitative hybrid approach such as the dependency web concept could be used as a means of moving in the direction of increased comprehensiveness, but extended to specify exposure pathways and uptakes for biological resources. In addition, we recommend employing a model-free approach in certain contexts to provide reality-based bounds on projections and to enhance stakeholder communication. Figure 3.3 illustrates the complementary approaches discussed in Section 3.2 that could be used to facilitate an integrated assessment.

3.4.4 Phases of Analysis

The structure of the contamination and environmental relationships underlying the GW/VZ integrated risk assessment could be addressed most cost effectively by employing a phased approach within the general framework outlined above. While some exploration of methods and issues related to follow-on stages of analysis is warranted, the outcome of initial stages would determine the need for and focus of later stages.

We recommend that the risk/impact assessment process be conducted in three major stages, as illustrated in Figure 3.4. Within each of these stages, the type of iterative process shown in Figure 3.2 can be applied to focus and refine the analysis. In the first stage, exposure concentrations of contaminants would be projected for the relevant set of exposure location types. At a minimum, these types include on-site

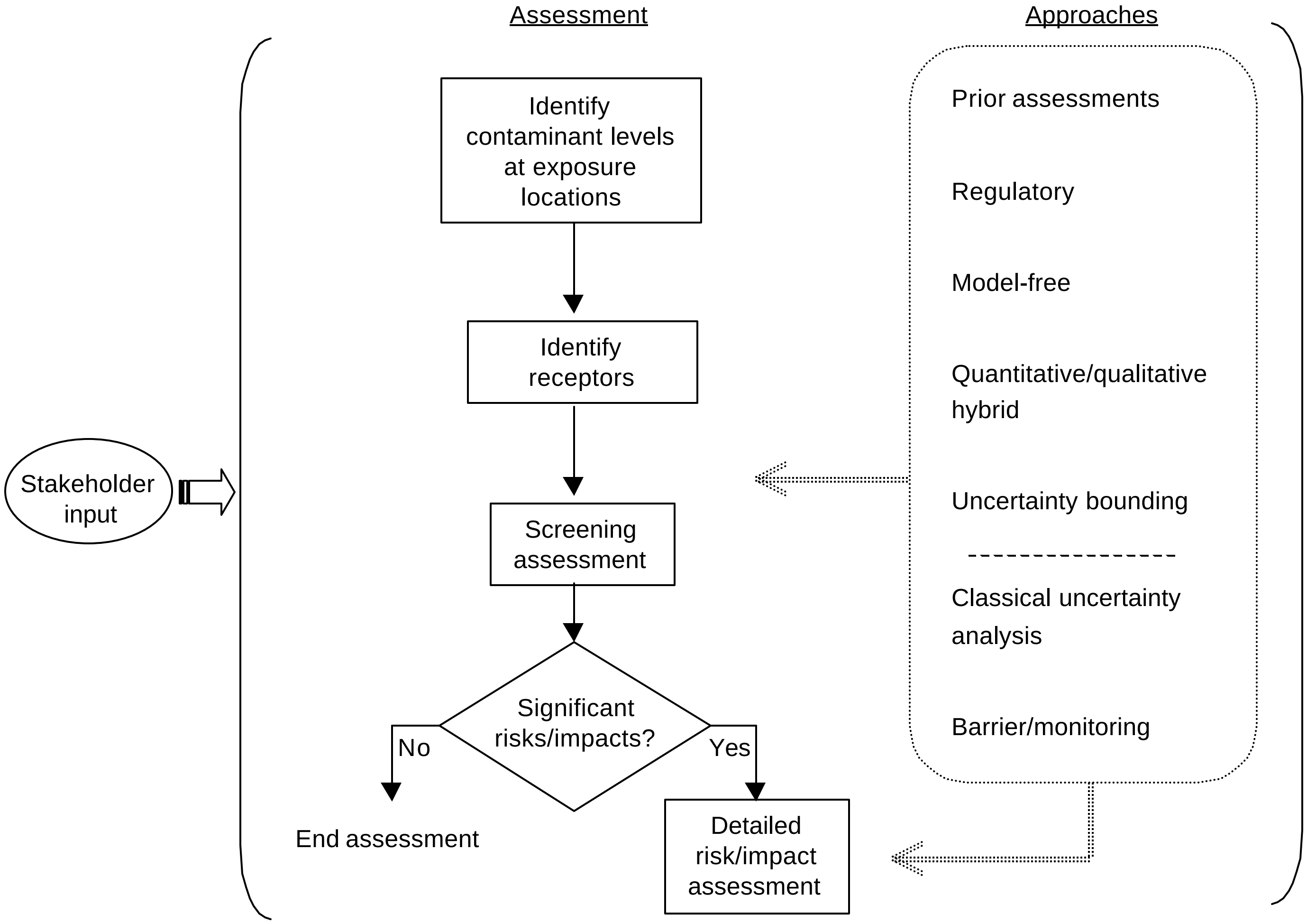

FIGURE 3.3 Overview of Information in the Integration of Approaches

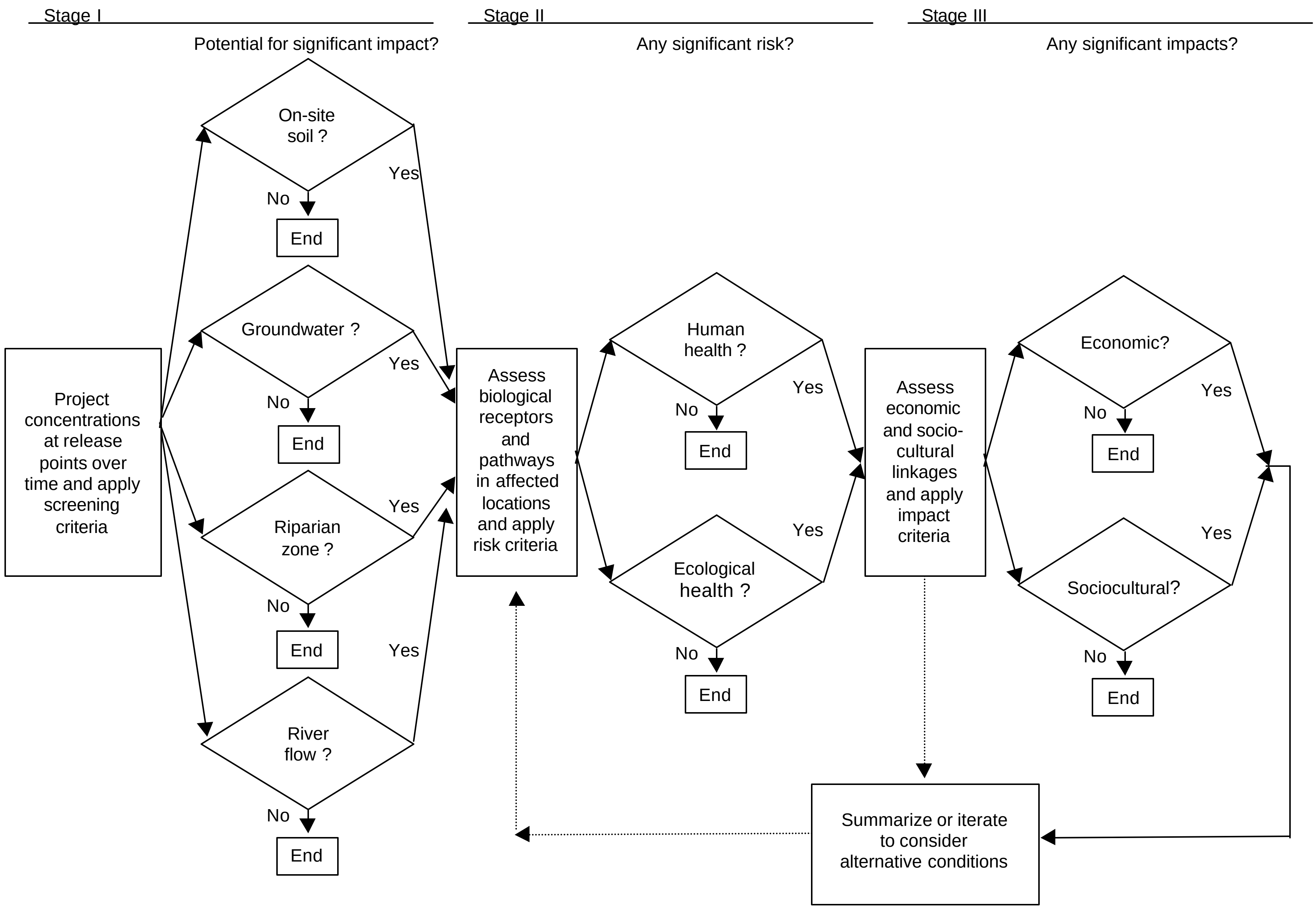

FIGURE 3.4 Phased Approach to the Integrated GW/VZ Risk Assessment

soil, on-site groundwater, the riparian zone in the Hanford Reach, and the Columbia River flow at appropriate points upstream from McNary Dam. The bounding concentrations would be for short time intervals (e.g., 10 years) within a 50-year period and for longer periods (e.g., hundreds or thousands of years) thereafter. Development of these concentration estimates would permit identification of any significant levels of contaminants at any of the locations, based on screening criteria applied to contaminants individually and in the aggregate. This analysis provides a basis for identifying the appropriate set of impact area and contaminant combinations for detailed study.

The second and third stages would apply to that study set. In the second stage, the analysis would proceed to the identification of biological receptor and pathway scenarios for the study set of contaminants and impact locations. This step could build on the conceptual dependency web information, but it also would require development of well-specified and quantified information. On the basis of the exposure scenarios and the projected contaminant concentrations, risks to health and ecological resources, and possibly impacts to sociocultural resources could be assessed. This assessment would cover individual contaminants and, to the extent possible, cumulative and synergistic effects. The study set of significant risks and impacts could be identified from this set of second-stage assessments.

In the third stage, the impacts that could result from estimated biological effects would be assessed. This assessment would require identification of sociocultural and economic linkages to affected resources, which could be based in part on the conceptual dependency webs and to a major extent on standard practice in scoping sociocultural and economic assessments. Input on cultural practices and resource linkages would be important and should be developed in close coordination with the cultural groups involved and in direct consultation with Tribal Nations. From these analyses, the set of significant impacts could be identified and summary estimates prepared. The second and third stages could then be iterated to consider alternative response options, if appropriate.

3.5 IMPLEMENTATION ISSUES

Three types of implementation issues are discussed in this section: (1) the process of identifying receptors and pathways to support a relatively comprehensive impact assessment, (2) modeling strategies to address uncertainties, and (3) stakeholder participation in the assessment process.

3.5.1 Receptor/Pathway Identification

The dependency webs that have been developed for use in the GW/VZ Integration Project are expected to serve as a useful tool for communicating with regulators, Tribal Nations, local citizens, and other stakeholders about what could be "at risk" from potential site-related environmental contamination. The webs developed to date can be considered a key part of the extensive process of identifying receptors and pathways for potential study, as augmented by standard methods for this identification.

3.5.2 Modeling Strategies

Within each stage of the assessment discussed in Section 3.4.5, the approach could be iterative, moving from bounding to more detailed analyses. It should begin with relatively simple models that provide an upper bound on the contamination level at a potential receptor location, or the uptake by a particular receptor, or the extent of public avoidance of a perceived risk/impact. These upper bound measures could be used in an assessment that takes into account information on pathways and linkages to the greatest feasible extent. If the conservative upper bound leads to projected impacts that are less than agreed-upon upper limits, the analysis is complete, a decision can be made, and a formal uncertainty analysis does not need to be performed. This would be the case for many contaminants. However, it is generally not possible to eliminate concerns about all contaminants with a bounding analysis. Thus, in certain cases more detailed estimates of release and transport, uptake, or avoidance behaviors would be needed. Bounding or "worst-case" analyses have serious disadvantages when used to establish specific target levels, e.g., for cleanup, but is a cost-effective tool for focusing analytical resources.

This sequence of model level applications would need to be reversed in situations where the primary issue is increased uncertainties over time. In such cases it might be most appropriate to move from a relatively detailed short-term model, to an order of magnitude model for the longer term, and to a bounding model for the very long term (Casman et al. 1999).

In general, the simplest model that is consistent with the data and that produces the information needed to support decision making should be used in the analysis. The simpler the model, the more transparent the results will likely be to most stakeholders. Furthermore, more sophisticated models generally require more data, and therefore the sources of uncertainty (although not necessarily its magnitude) increase. Development or use of more sophisticated models should only be pursued when it is clear that simple models cannot be used to support the decision and that there is a high probability that a more sophisticated model would be useful in decision making. A determination to use such a model implies that the data are available or can be reasonably obtained and that uncertainties can be evaluated.

An example of how the difference in levels of modeling detail affects uncertainty is illustrated by examining approaches used to model interactions between a contaminant and the host medium or media (such as soil or rock and water). To simplify the chemistry involved, contaminant transport calculations for impact assessments commonly use a parameter known as the distribution coefficient. This coefficient is a lumped parameter that represents many physicochemical interactions (including sorption, ion exchange, precipitation, and dissolution) between the contaminant and the carrier media.

A more sophisticated approach could explicitly model these individual interactions. Such a geochemical model would require data on all the major components of the groundwater: mineral phases in the soil, chemical form of the contaminant, and interaction parameters between the contaminant and the components of the system. To comprehensively address uncertainties in contaminant behavior would require examination of all these parameters. In contrast, addressing uncertainties caused by chemical interactions in a model using only a distribution coefficient would require analysis of only one parameter.

The Groundwater Peer Review Panel (Gorelick et al. 1999) recommended development of a suite of conceptual models as a means of addressing uncertainty issues caused by a variety of conditions, including heterogeneity in subsurface structures. It is possible that the available data would be insufficient to define a single model as the most appropriate for use. In such cases, the model that results in the highest exposure can be used initially in the risk/impact assessment to provide an upper bound for an initial screening assessment.

3.5.3 Community Participation

One of the unique aspects of the Hanford GW/VZ Integration Project compared with projects at many other sites is the central role that concerns of interested parties play in the overall risk assessment planning process. The Hanford Site is also implementing an intensive participatory process to facilitate ongoing assessment and decision making for environmental management activities at the 200 Area and tank farms. Several national studies of environmental decision making have suggested that technical and stakeholder processes should be placed on an equal footing to achieve effective decisions that are defensible and lasting (National Research Council 1994; Presidential/Congressional Commission on Risk Assessment and Risk Management 1997). The need for input from the broad community, including regulators, Tribal Nations, and local residents and businesses – while already clearly recognized as important to the overall Hanford GW/VZ Integration Project – warrants special attention. Community concerns about risks are closely tied to the generation of sociocultural and economic impacts and thus are key inputs to the integrated assessment efforts for the project. Ultimately, the success of the Integration Project could hinge on the effectiveness of the arrangements for involving multiple parties in the risk assessment process.

Building on the extensive ongoing work of the full project team and System Assessment Capability (SAC) group, it is suggested that the following actions be highlighted. The aim is to help ensure that risk-informed decisions developed through the GW/VZ Integration Project reflect the priorities and concerns of the full range of interested parties.

- It is important for the technical risk/impact assessment approach to be determined and implemented through an explicitly defined consensual process within a working group that includes both community and technical representatives,

- It is very useful for the deliberations of such a group to be supplemented with systematic and extensive opportunities for wider community review and input,

- The best available risk communication principles and processes should be implemented, and

- Technical reviews should be conducted by external risk experts.

These community involvement mechanisms are to varying degrees already in place as part of the GW/VZ Integration Project and we encourage their continued application. The following discussion indicates approaches that could enhance or make more explicit the objectives, organizational structures, and roles of individual elements, in particular as they apply to risk and impact assessment activities for the Integration Project. These approaches could help strengthen the soundness and feasibility of implementing risk-based decisions for the site.

The ongoing consensus-building activities of the GW/VZ Integration Project are expected to continue to encompass a range of broad community involvement activities aimed at consistent inclusion of all interested parties in the effort. It would be useful to continue to plan, schedule, support, and document these activities in ways that enable participants to contribute to site assessment, remediation, and long-term management plans. Specific recommendations are as follows:

- We encourage establishment of a structured “partnership agreement” between interested parties (including Tribal Nations, regulators, and stakeholders) and the Hanford Integration Project.

- We encourage giving the project team/SAC working group primary responsibility for designing and implementing the risk element. For the process to remain transparent, it is useful for information on methodologies, data input, assumptions, results, and broad participatory interactions to be frequently distributed in a simplified, highly visual format that can be understood by a wide sector of the interested parties.

- We encourage the team/working group to solicit input from a broad spectrum of affected parties in seeking consensus before proceeding on major initiatives, including those regarding methodologies, data, assumptions, membership, and roles. We would also suggest that the structure and operations of the working group be formally designated by DOE and, in addition to technical risk experts, include individuals with related technical expertise and perspectives from the broad community. These functions would be developed in coordination with the project team/working group.

- We encourage including in the formal procedures provisions for dealing with issues on which the team/working group cannot reach agreement.

- We encourage the team/working group to continuously seek input from members of the broad community of affected parties to augment their more specific (technical) discussions. It is further recommended that this input be documented in terms of its content and impact on project implementation.

At various stages in the site restoration effort, it is useful for different types of information to be shared among the broad community and program managers. Table 3.2 provides a preliminary example of how program phases and the information gathering and community review could be linked.

TABLE 3.2 Implementation Approach for Public Participation in Program Decision Making: Preliminary Design

Phase	Type of Information Needed	Methods for Obtaining Information	Objectives
Pre-Decision Phase: Approximately 1999-2000 Period of expanded research on the vadose zone and groundwater and of risk/impact scenario development (potential health, social, and economic impacts).	Who are the affected parties for the various risk/impact zones?	Interviews with Hanford Advisory Board (HAB) members and with representatives of other entities that may have a stake in the potential impacts to a specific zone, and direct consultation with Tribal Nations.	Ensure that the broad community of affected parties are recognized by program managers. Ensure that the broad community of affected parties' concerns are known to the program managers. Obtain guidance for designing a set of focus groups.
	What type of information do these parties want about the assessments and likely near-term remediation plans and their bases?	Focus groups (focused group interviews) with purposefully selected sets of "stakeholders" to discover what they "know" about the site assessment and remediation program and what their questions and concerns are.	Ensure that the GW/VZ study addresses the community's questions and be able to explain the likely knowledge gaps in the early stages of the study. Ensure that relevant social and economic implications of the remediation options are evaluated for use with the community and in program decisions.
Decision Phase: Approximately 2001-2005 Period when better GW/VZ information is being factored into near-term decisions for the 200 Area and remediation options are being compared and selected.	What concerns and questions does the affected community have about the GW/VZ and risk/impact scenarios that have been developed to facilitate comparison of options?	Focus groups (focused group interviews) with purposefully selected sets of "stakeholders."	Facilitate analysis of the concerns and satisfactions of the various "impact zone" communities. Inform a citizen group that will work with the program managers to seek areas of agreement on the proposed alternatives.
	Can the program move ahead on decisions about remediation and controls?	Analysis of discussions of representatives of the broad community, as an input group specific to the remediation program that meets periodically to review materials and raise issues and questions for the program managers (like the HAB).	Permit program managers to address issues and concerns as they emerge during the decision phase. Gain assurance that the major affected parties consider the remediation options and controls acceptable, given available information on effectiveness, program costs, and impacts.
	What are domains of concern of the general community (e.g., environmental, health, social, economic)?	Phone or mail survey focused on the populations in the local and river basin regions. Monitoring and analysis of reactions to information campaigns and public discussions of options and controls.	Continuously consider community concerns, ideas, and information needs, which can be used to guide further research needs and consideration of adjustments in the program.
Implementation Phase: Approximately 2005 and beyond Period when execution of the major remediation plan has begun, including interventions (controls) related to movement of contamination in the GW/VZ.	Are adjustments needed in the remediation program and contamination controls, based on emerging information and issues (e.g., environmental, health, social, economic)?	Monitoring and analysis of input group discussions and concerns about the remediation program.	Ensure that the social and economic scenarios related to the remediation options and controls reflect current research and are relevant to local and regional conditions and trends.

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4 APPROACHES FOR ASSESSING IMPACTS

Approaches, methods, and some specific methodological issues associated with conducting impact assessments are discussed in this section. Topics associated with estimation of the two components of biological effects are presented first — human health in Section 4.1 and ecological effects in Section 4.2. Discussions of the impacts that devolve from these effects are presented in Section 4.3 for sociocultural impacts, including quality of life issues, and in Section 4.4 for economic impacts. As described in Chapter 1, risks are considered to apply to human and ecological health and safety, because they reflect direct or primary biological effects potentially associated with site-related hazards. Impacts that reflect *sociocultural* and *economic responses* to the presence of those hazards are considered secondary impacts for purposes of this report. (This terminology is simply used to highlight the interfacing and interpretive role of humans in the process. We recognize and appreciate that others apply a different terminology.)

4.1 HUMAN HEALTH EFFECTS

Widely accepted approaches for assessing human health risks based on chemical potency or toxicity, exposure pathways, and receptor characteristics have been developed by the U.S. Environmental Protection Agency (EPA 1989, 1996, 1997a). These approaches emphasize the use of site-specific values for exposure factors when available, but with use of generic default values when necessary. Use of site-specific values is emphasized to provide more appropriate risk estimates than use of default values, notably for nontraditional types of exposures (such as occur in the region of the Hanford Site). Also included in this standard process is use of toxicity information for cancer and noncancer health endpoints. This information is obtained from the scientific literature, as summarized in the Integrated Risk Information System (IRIS, available on the Internet at http://www.epa.gov/iris) and compiled by the Agency for Toxic Substances and Disease Registry (ATSDR) in individual toxicological profiles (available on the Internet at http://www.atsdr.cdc.gov/toxpro2.html). This EPA framework has been incorporated into the Hanford Site Risk Assessment Methodology (HSRAM) process.

Building on the outcome of the extensive Columbia River Comprehensive Impact Assessment (CRCIA) effort, a variety of exposure considerations and potential health endpoints have been identified for possible evaluation through ongoing efforts of the System Assessment Capability (SAC) working group. Key elements of a process for assessing contaminants of concern, appropriate exposure scenarios, and possible health implications are summarized below. The nature of this health risk evaluation is expected to range from qualitative to semiquantitative, as determined by the scientific information available, with ongoing input from interested parties.

For human health effects to occur, humans must be exposed to a contaminant or group of contaminants at levels sufficient to cause harm. Predictions of the potential for this harm are often based on current contaminant measurements in areas of concern (impact locations) combined with toxicity data. Assessing the potential for human health effects in the extended future is problematic because of the difficulty in predicting contaminant fate and transport and the distribution, activities, and status of humans.

Fate and transport modeling activities for the Hanford site have identified a number of locations within the Columbia River basin that do not currently contain measurable concentrations of contaminants but that may receive contaminant input at some future time. Results of ongoing and future fate and transport modeling results may also predict increases in contaminant concentrations above current levels at locations for which human health risk assessments are already underway. The human health assessments undertaken for the Hanford GW/VZ Integration Project will include an evaluation of potential human health effects in the future, based on modeled concentrations. Input from stakeholders will be sought on appropriate assumptions about future human receptors (e.g., considering populations and resource use).

4.1.1 Toxicity Assessment

Toxicological effects from acute or chronic exposures to contaminants in specific impacted locations that are expected to be considered as part of the evolving assessment process include:

- Cancer endpoints and related genetic effects, such as mutagenicity.

- Noncancer endpoints, including various critical effects, reflected in EPA's reference doses, and other indicated endpoints – including teratogenic, developmental, and reproductive toxicity; neurological and immunological effects; respiratory and cardiovascular effects; and gastrointestinal and dermal effects.

It is suggested that the set of candidate contaminants be screened against the range of potential health endpoints by use of a matrix developed to organize relevant state-of-the-art information from numerous sources. The matrix would serve as the master set of toxicological data for the health effects assessment. This information would include data from EPA's Integrated Risk Information System (IRIS) and Health Effect Assessment Summary Tables (HEAST); ATSDR toxicological profiles; epidemiological studies; and ongoing toxicity testing, including animal studies (e.g., of the National Toxicology Program [NTP]), genetic testing programs, and microtoxicity assays. Information from the international community (including the International Agency for Research on Cancer) would also be evaluated. The EPA National Center for Environmental Assessment would be consulted to develop case-specific toxicity values, as needed. It would also be essential to coordinate with this office on the mixtures assessment.

Additional guidelines and regulatory standards would also be evaluated, with an emphasis on relevant health databases. These other sources include Occupational Safety and Health Administration standards (permissible exposure limits [PELs] and threshold limit values [TLVs]); standards and guidelines developed under the framework of the Resource Conservation and Recovery Act (RCRA) (including toxicity/leaching tests and exit levels), and reportable quantities developed under the framework of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended. State standards and preliminary remediation goals developed by EPA Region IX would also be reviewed.

The suggested matrix approach for summarizing existing toxicity information for all contaminants identified at impacted locations could provide a consistent framework for evaluating possible combined effects from exposures to multiple chemicals, through identification of contaminants with similar modes of action and target organs/endpoints. The concentrations of co-located contaminants in key impact locations could thus be considered more readily as a group in evaluating their potential for causing adverse human health effects. This concept is discussed in greater detail in Section 4.1.3.

Figure 4.1 suggests a screening process for developing a focused set of study contaminants from the candidate set. The initial screen would use the matrix of values on the full candidate set to identify the substances known to be toxic or for which toxicity is probable. A second screen could compare current and projected chemical concentrations in specific impact locations (e.g., in the riparian zone or river) with concentration benchmarks for toxicity to further focus the study set. For this second screen, it would be important to retain flexibility in defining a specific risk "cutoff level" (e.g., increased lifetime cancer risk of less than 1 in ten thousand or 1 in one million) as the basis for the focus versus defining a "significant" fractional (percent) contribution to the overall risk estimate as the basis. Additionally, flexibility would be required in evaluating the groups of chemicals identified as having the potential to exert interactive effects. On the basis of the indicated potential for such effects, certain substances would likely be retained in the focused set even when not expected to exceed concentration benchmarks for toxicity based on their individual effects.

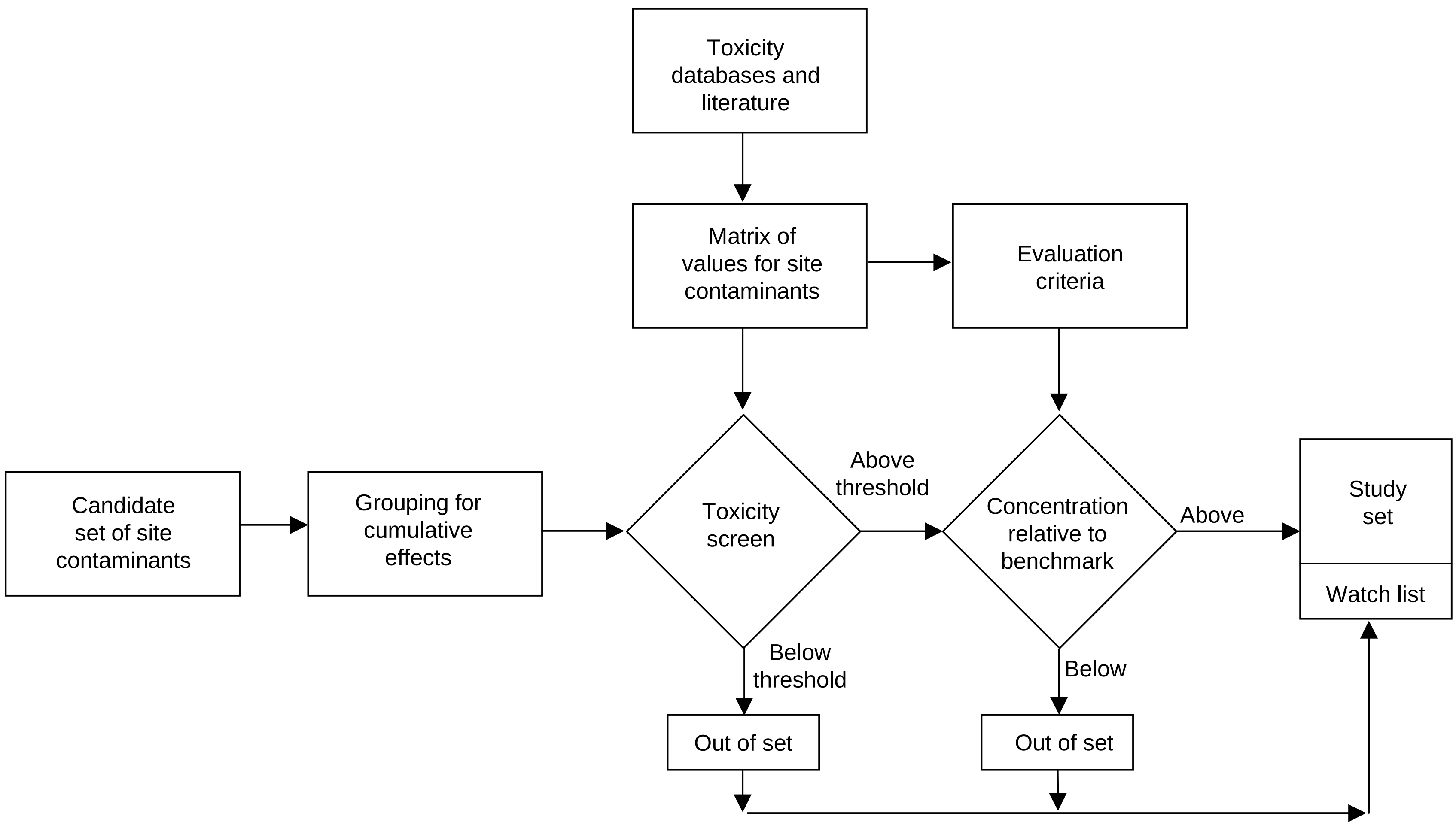

FIGURE 4.1 Toxicity Assessment Process

In determining the study set, those contaminants for which scientific evidence indicates significant health effects at existing or predicted concentrations would be considered for priority evaluation. Additionally, groups of contaminants in which some or all are present at below-threshold toxicity concentrations, but which as a group have the potential to exert significant synergistic effects, would also be considered for priority evaluation.

Those contaminants and health endpoints for which no evidence yet exists for a causal relationship at indicated site levels could be carried forward in the matrix as a "watch list." These contaminants would be given further consideration in the event of new information developed through future scientific discoveries (such as through studies being conducted through DOE research and research programs for the NTP and National Institute of Environmental Health Sciences). This approach would involve an iterative consideration of additional chemicals and endpoints for inclusion in quantitative risk assessments for the Hanford project over time. An example of such a scientific area for which new information is expected to be developed is the effects from exposures to multiple chemicals (mixtures).

4.1.2 Exposure Assessment

Various exposure considerations have been identified by the project team on the basis of the previous CRCIA efforts (DOE 1998). Exposure factors are affected by the activities or behaviors of populations and individuals. Key combinations of impacted locations and related activities provide the foundation for this assessment, taking into account life styles with potentially unique exposures. These considerations include:

- Current and potential future populations and sensitive subpopulations (such as the elderly, children, women of child-bearing age, and nursing women), and ethnicity-specific and gender-specific factors.
- Central tendency and maximum exposed individual (MEI) estimates, and population estimates.

The evaluation of sensitive subpopulations and ethnicity-specific and gender-specific factors would be considered on a case-by-case basis, as indicated for the exposure scenario (discussed below) and as has been done as part of the initial CRCIA effort and many other Hanford project assessments. For individuals, both the representative average individual and the MEI could be considered. Population risks could be estimated for the cancer endpoints, for example if significant risks were identified for a hypothetical MEI who represents a larger group who would all be expected to incur those exposures. However, population estimates are not appropriate for the noncarcinogenic effects, as these are ratio-based estimates rather than statistical likelihood estimates.

The set of exposure scenarios and primary impacted locations to be evaluated would continue to be developed in concert with all interested parties. This process would include consideration of external gamma irradiation, ingestion, inhalation, and dermal absorption of the "parent" contaminants, degradation or decay products, and active metabolites, as indicated by the contaminants and media in the focused study. Basic components of this process could include:

- Identifying a list of realistic exposure scenarios for impacted locations, with input from regulators, Tribal members, local citizens, and other stakeholders. These scenarios would include consideration of individuals, sensitive subpopulations, and unique exposure activities as indicated, considering the given location and plans for future use (DOE 1999).

- Developing a targeted set of “indicator scenarios” from this list to reflect a representative range. This set can be focused by evaluating the elements and relationships identified in the project’s conceptual dependency webs together with existing data and methods, and developing more quantitative conceptual models to guide the focused assessment. For those who might be interested in additional scenarios, a unit-based screening tool could be provided to allow “personalized construction” of a broad range of scenarios reflecting unit concentrations and unit exposure times together with contaminant-specific toxicity values for the indicated exposure routes. The amount of both the contaminant and the exposure could be scaled to fit the indicated location and behavior pattern of interest. Activity-specific elements of a given scenario could be combined to produce a range of individualized estimates for this initial screen, but interactive effects would need to be addressed in a detailed assessment.

The study set criteria being developed through the project team’s risk assessment process would be used to guide the selection of scenarios to be assessed for impacted locations in the first phase of the study. This process would emphasize the evaluation of a limited, representative range rather than a full suite of possible scenario options, as this suite could be separately evaluated by a smaller set of interested parties.

A general exposure assessment process is outlined in Figure 4.2. In this process, the starting point is the study set of contaminants derived through the toxicity assessment/screening process. Scenarios targeted for impacted locations in which a contaminant or contaminant group is, or is projected to be, at a level of potential health concern would be used to evaluate exposures. Contaminant/pathway combinations for which no likely exposure scenario is indicated would be eliminated from further analysis at this stage. The remaining set of exposure pathways could be prioritized for analysis by magnitude, severity, and likelihood of exposure. Thus, the steps of a health effect assessment could be:

- Develop a toxicity matrix for all contaminants identified at or predicted to migrate to a given key location. Use the available fate and transport modeling results to identify chemicals for inclusion (i.e., those currently present and those that may become hazards in the future).

- Conduct a contaminant screen on the basis of these current and predicted future concentrations compared with existing concentration-based standards and guidelines (per EPA and state protocols, also considering other approaches, including those applied in the international community). Explicityly account for and reflect anthropogenic and natural background levels in this screen.

- Identify appropriate exposure scenarios and receptors (including sensitive subpopulations) for the given impacted location.

- Quantify potential exposures and risks for these receptors on the basis of existing and innovative methods, as practicable. (For example, EPA’s revisions to the Cancer Assessment Guidelines [EPA 1996, 1999] would be incorporated into the evaluation of carcinogenic risk.) Also, provide qualitative discussions where quantitative data, notably toxicity values, are not yet available to complete the risk calculation. Uncertainties in the estimated risks should be clearly stated and discussed. Quantitative uncertainty analysis would be appropriate for portions of this assessment.

It would be helpful to integrate results of this assessment with the overall impact assessment effort currently under way for various areas and activities at the Hanford Site so inputs and outcomes could be more readily linked.

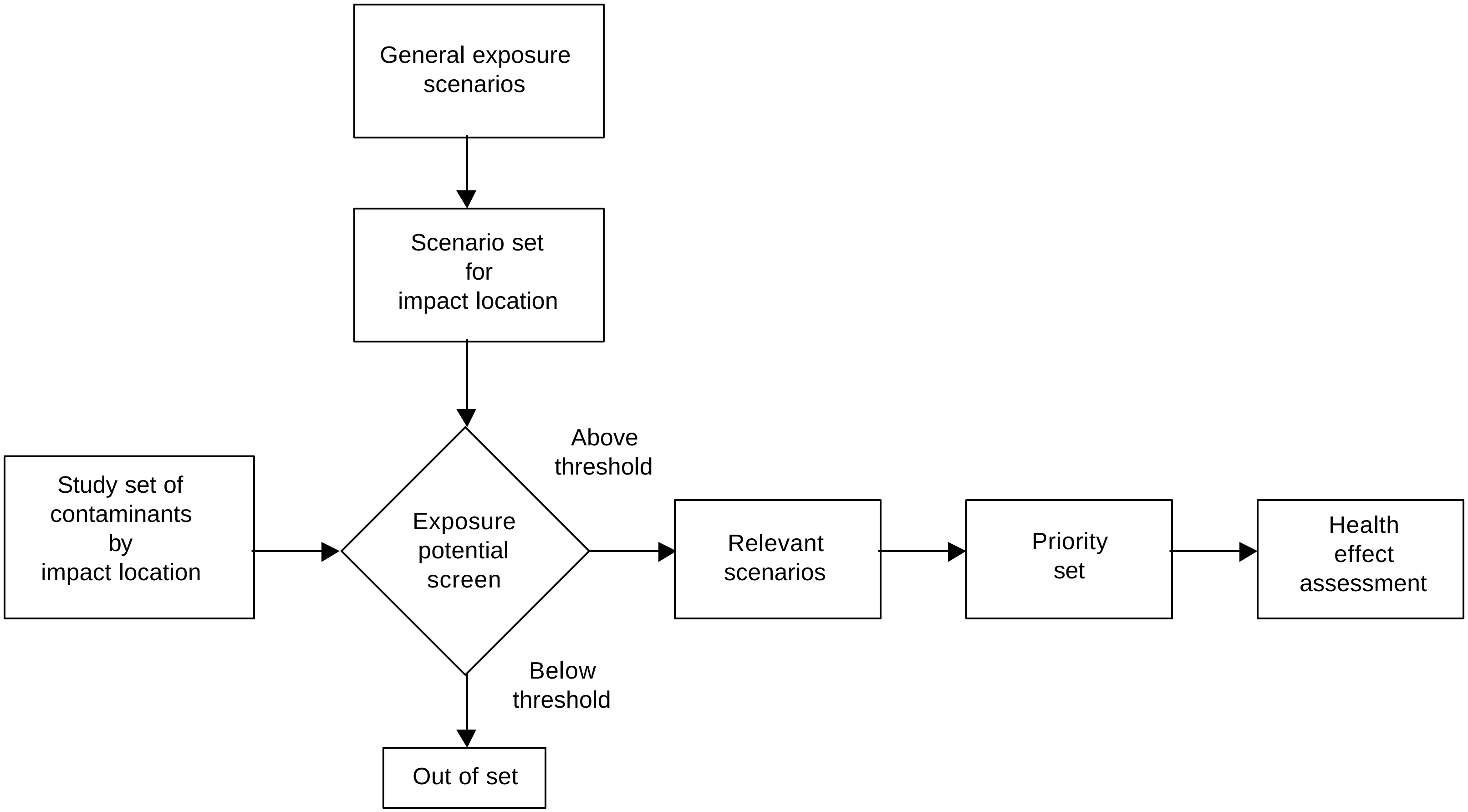

FIGURE 4.2 Exposure Assessment Screening Process

4.1.3 Methods for Addressing Synergistic Effects

Standard methods of risk evaluation generally pursue a sequential process. The initial screening step may consist of an individual comparison of the concentrations of all chemicals that have been identified in an environmental medium at a site against risk-based standards or guidelines, with the elimination from further consideration of those substances present at concentrations lower than the screening levels. Alternatively, or as a second step, the total carcinogenic or noncarcinogenic risk from all the substances may be calculated, with substances contributing less than some defined portion of the total being deleted from further consideration. (This latter method is suggested in the most standard reference, EPA's *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual* [EPA 1989].)

A problem of increasing concern with respect to traditional risk assessments is the potential for synergistic effects to go unreported. This possibility exists when contaminants are eliminated from the assessment based solely on a comparison of each contaminant's individual concentration against a benchmark level, prior to any consideration of whether that chemical may interact with other chemicals present to exert combined toxic effects. An example would be the synergistic effect of smoking and radon on the risk of developing lung cancer. The critical effect used to develop a substance's reference dose (to estimate the noncancer effect) is the adverse effect observed at the lowest dose, such as decreased body weight. However, this critical effect may not represent the endpoint of concern for synergistic effects.

The toxicity matrix approach outlined in Section 4.1.1 is intended to help identify possible impacts (notably for noncarcinogenic endpoints) at the outset. This matrix would indicate not only the critical effect associated with a substance, but also the other types of toxic effects associated with that substance. In addition, when known, the modes and mechanisms of toxic action would be included in the matrix. The following example of a matrix format could be used to develop and assess the study set for health effects on the basis of chemical toxicity information together with impact location and specific exposure considerations:

Impact Location	**Primary Exposure Scenario**	**Applicable Exposure Routes** *(e.g., inhalation, ingestion, dermal, immersion)*	**Key Contaminants and Active Metabolites (and levels)**	**Critical Effects (and associated levels)**	**Additional Toxicological Endpoints of Primary Concern (and associated levels)**	**Modes and Mechanisms of Action**

Contaminants with similar toxicological endpoints of concern and modes and mechanisms of action would be grouped. The current and projected future concentrations in the different media would be considered for the group (e.g., using a "hazard index" type approach). Professional judgment would be required in deciding whether to exclude any contaminants in the group from further consideration. The evaluation would also consider whether the grouped substances could be taken up via the same exposure routes and whether the applicable exposure scenarios included those routes. In addition, the toxicity matrix would identify contaminants for which available data indicate the potential for synergistic effects. It would be useful to conduct a screening "mixtures" risk assessment for these chemicals in accordance with the approach being developed by EPA.

4.1.4 Innovative Approaches

The process being applied to estimate risks associated with Hanford Site contaminants is consistent with applicable regulatory frameworks and reflects standard practice being applied nationwide. This approach can be augmented by innovative assessment methods that will continue to evolve based on future scientific and technological developments. By staying current with these advances and reflecting them in their risk analyses, the Hanford team can provide national leadership in state-of-the-art risk assessments for complex sites. The hazard identification process, exposure assessment techniques, toxicity and effects models, and risk characterization models could all be improved by new data and tools being developed. While many of these tools are still in the early exploratory stage, others are already beginning to be used in test studies to conduct better health risk assessments. They include:

- Genetically engineered indicator organisms that can detect the presence of a given chemical or potential for genetic effects;

- Microchips, such as deoxyribonucleic acid (DNA)-based biochips to screen for possible human factors relating to allelic frequencies and polymorphisms that can affect genetic susceptibility to disease, or dye-based chemichips that can be used to indicate contaminant exposure levels; and

- Biomarkers, which can be used as indicators of exposure to radiation or chemicals.

Incorporation of new information as it is developed is consistent with the theme of EPA's recent cancer guidelines, which recognize the importance of reflecting new toxicity data in risk assessments.
One way that risk assessment can be streamlined for complicated sites with multiple chemicals is to develop a matrix that presents key factors that can be combined to assess different chemicals at various impacted locations. This process allows ready comparison among chemicals and radionuclides contributing to estimated cancer risks and noncancer effects, to identify those of most concern and thus deserving of priority attention for decision makers and further study.

4.2 ECOLOGICAL EFFECTS

The evaluation of ecological risks is also an evolving science that is open to new ideas and methodologies. This section discusses some of the ways in which the GW/VZ Integration Project may be able to build upon the full body of scientific information that has been collected at the site by Pacific Northwest National Laboratory (PNNL) scientists and others. The PNNL work, along with studies done by the U.S. Fish and Wildlife Service, has produced a very strong baseline of ecological information that provides the cornerstone for assessing potential future ecological risks. The ecological conditions at the Hanford Site are relatively well characterized as a result of over 50 years of ecological research, site monitoring, and site-specific impact assessments.

Major aims of the ecological risk assessment include identifying and communicating potential risks, especially those to key biological receptors. An integrated assessment should consider ecological resources at appropriate spatial (locations both on and off the Hanford Site) and temporal scales and should address the general ecological resources identified as the candidate set in the CRCIA requirements. It is important that this assessment be conducted in a scientifically defensible manner that identifies risks to ecological resources of concern at both local and regional scales and in the present and the future. It also should permit linkage of the ecological risk results to other impact sectors (including human health, sociocultural, and economic).

The scope and complexity of any ecological risk assessment related to the Hanford Site would depend on the scale of the particular evaluation under consideration. Because of the vast size of the site, any regional assessments should initially be qualitative in nature, identifying ecological and contaminant conditions and focusing on exposures across a large spatial scale. More quantitative assessments to evaluate effects could be conducted at the impact-site specific level. As the body of data for a particular ecological receptor increases, these site-specific assessments could be incorporated into reevaluations of the regional assessment. The integration of the ecological risk assessments with other impact sectors and a process for developing and applying regional and site-specific ecological risk assessments for the Hanford Site are described below. The overall ecological risk assessment process, including the relationships of contaminant and receptor study sets, is depicted in Figure 4.3. This figure illustrates the relationships between contaminants in particular locations and the assessment of receptors in those locations. In selecting the receptor study set, both the ecological role of the receptor and its cultural, economic, and health values must be considered.

4.2.1 Linkage of the Ecological Risk Assessment with Other Impacts

To fully meet the needs of the GW/VZ Integration Project, it is important that the ecological risk assessments conducted at the Hanford Site be designed and implemented, and their results managed, in consideration of other impact sectors (e.g., human health, sociocultural, and economic). Dependency webs (as discussed in Section 3) provide one approach for illustrating how these different sectors are linked. For example, the assessment endpoints to be evaluated by the ecological risk assessment would be based on ecologically important considerations and also would include endpoints deemed important from sociocultural, economic, and human health perspectives.

4.2.2 Identifying Receptors and Habitats for Evaluation

For the ecological risk assessment, an assessment endpoint is defined as a measure of a particular aspect of the ecosystem that is considered desirable to protect, and thus it serves as a focus of the assessment. For example, an assessment endpoint that might be identified for a seep area discharging to the Columbia River could be "maintenance of salmon reproduction at levels similar to adjacent sites not exposed to site contaminants." The number of assessment endpoints identified for any particular ecological risk assessment will be a function of the receptors, contaminants, ecological resources, and ecological exposure routes associated with a site or region, as well as considerations of sociocultural, economic, and human health concerns.

While conceptually simple, the identification of appropriate assessment endpoints is a challenging task requiring extensive interactions and consultations among appropriate parties. Clearly defined endpoints provide direction and boundaries for the risk assessment and serve as the basis for development of site-specific studies (the measurement endpoints) that evaluate potential risks and impacts to the assessment endpoints.

Initially, selection of the assessment endpoints would begin with an evaluation of the candidate receptor set identified in the CRCIA II requirements. These candidate receptors could include threatened and endangered species, critical or other important habitats, functional categories, and others. In addition, the dependency webs could identify additional ecological receptors for inclusion in the assessment. Criteria for selecting candidate receptors would include, to the extent appropriate, the requirements identified in

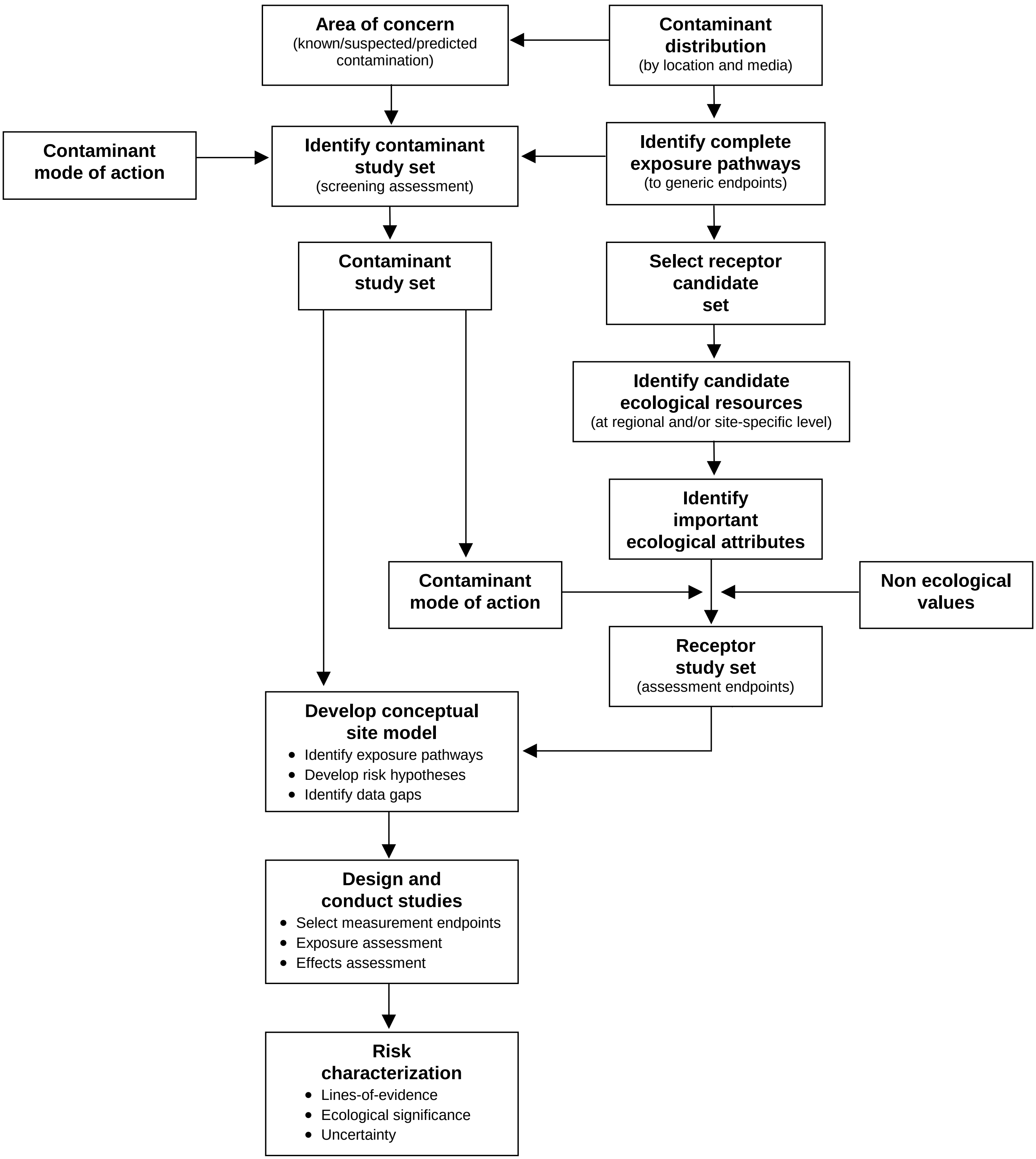

FIGURE 4.3 The Ecological Risk Assessment Process

the CRCIA II document (DOE 1998). After an appropriate candidate set had been selected, specific study set receptors would be identified for detailed evaluation. Factors recommended for consideration in selecting the study set of receptors include:

- The study set receptor is representative of the candidate set receptor,
- The study set receptor is known or suspected to be susceptible to the contaminant(s) of concern,
- The study set receptor is known or expected to come in contact with the contaminant(s) of concern, and
- The study set receptor provides an important ecological function or service.

As with the selection of the candidate set receptors, study set receptor selection should include input from the other impact sectors.

4.2.3 Assessing Ecological Risks on a Regional Scale

Assessing ecological risks from site contaminants at a regional scale could follow three general steps:

- Characterization of the distribution of the candidate receptor set across the region of interest;
- Characterization of the nature and extent (distribution) of contamination across the region of interest; and
- Qualitative characterization of risk on the basis of an evaluation of the extent of overlap between the two distributions and the known or expected effects of the contaminant exposure.

Initially, the regional assessment would involve development of a regional-scale conceptual model and would be based on both site-specific (as available) and literature-derived effects data. As site-specific effects data were generated by local-scale investigations, these data could be used to reduce uncertainty and strengthen the regional assessment. Data available on the distribution of receptors and the nature and extent of contamination at the Hanford Site and surrounding region are extensive. The sitewide Hanford geographical information system (GIS) contains extensive information on existing environmental conditions, ecological resources, and hazards at the site.

Ecological risks from non site-related stressors (such as urbanization, industry, agriculture) may be evaluated at a regional scale in a similar manner by evaluating the degree of overlap among ecological receptors and the distribution and extent of the stressors. Cumulative impacts may be evaluated by examining the degree of exposure overlap of the site and nonsite stressors among the receptors. The results of the regional assessment could be used to prioritize site-specific ecological risk assessments by identifying locations within the region implicated to be at greatest risk from contaminant exposure.

4.2.4 Assessing Ecological Risks on a Local Scale

At the local or site-specific level, the ecological risk assessment could follow a three-phase process that consists of the following:

- A screening-level assessment aimed at focusing the analyses on the key contaminants and resources of concern at a site,
- A baseline risk assessment that employs site-specific investigations targeting specific contaminants, receptors, and ecosystem functions or values, and
- A risk characterization component for determining the significance of any identified risks.

Although risk characterization occurs as part of the screening assessment, it is relatively rudimentary and addresses whether to proceed to an integrated baseline assessment. It focuses on identifying the specific contaminants and broad receptor groups that would be evaluated in detail in the baseline assessment. As site-specific risk assessment results are obtained across the Hanford Site, they could be incorporated into the regional risk assessment. The role of the screening-level assessment is to identify the constituents associated with a particular site that may pose an unacceptable risk to ecological resources, while the baseline risk assessment evaluates potential risks associated with exposure to the constituents identified by the screening assessment. Because of the very conservative nature of a screening assessment, the screening level would overestimate potential risks and result in a very protective list of constituents to be further evaluated in the baseline assessment.

A conceptual model would be developed as part of the site-specific assessment. This model would describe the known, expected, and/or predicted relationships among the site contaminants and the assessment endpoints (including study set receptors). Development of the conceptual model would require site-specific information regarding:

- Contaminant fate and transport,
- Distribution of habitats and associated biota,
- Trophic levels and functional components of the exposed ecosystems,
- Exposure routes (food webs) among biota,
- Contaminant modes of action,
- Ecologically relevant attributes for the functional components, and
- Assessment endpoints and study set receptors.

Once the conceptual model was developed and agreed upon by all pertinent parties, an appropriate set of specific methods (defined as the measurement endpoints [EPA 1997b]) could be developed to evaluate effects to the assessment endpoints. The specific nature and extent of the methods would vary from site to site, depending on the nature of the assessment endpoints, the contaminants of concern and their modes of action, and the affected media. For example, if the contaminant of concern affects reproduction, one or more measures of reproductive success (e.g., eggshell thickness, eggs hatching, and young surviving to fledge) could be used as the assessment endpoints.

The goals of the risk characterization are to estimate the risks to the assessment endpoints identified in problem formulation, interpret the ecological significance of these risks, and provide support to risk management decisions. In contrast to human health risk characterization, there are no standard target levels (such as 10^{-4} to 10^{-6}) for ecological risk characterization that are applicable to all types of studies that would be conducted in the assessment. Instead, ecological risk estimation would be based on a lines-of-evidence approach (EPA 1997b; Menzie et al. 1996). This approach makes a qualitative estimation of risk on the basis of the quantitative results for each assessment and measurement endpoint, together with considerations of which measurement endpoints take precedence and the ultimate interpretation of the different study results.

Upon completion of the risk estimation, the ecological significance of risks must be evaluated to identify those risks that may warrant remedial action. Determining the ecological significance of impacts is arguably the most important aspect of the risk characterization process. Interpretation of ecological significance should answer the following questions.

- Which assessment endpoints are most at risk?
- Where is the greatest risk/impact likely to occur?
- What is the expected magnitude and duration of the impact?

- What does the impact mean ecologically?
- What is the potential for recovery of the affected assessment endpoint?

Evaluation of the risk estimate relative to these parameters would rely heavily on the professional judgment of the risk assessors, together with consultations and discussions with all appropriate parties.

4.2.5 Evaluating Risks under Future Environmental Conditions

The same approaches identified for the regional- and local-scale assessments could be used in the assessment of ecological risks in future time periods. However, such assessments would be more problematic because of the difficulty in predicting very far into the future contaminant fate and transport, future distribution and status of ecological receptors, and future human activities and development. Fate and transport modeling would likely identify a number of locations within the Columbia River basin that might receive contaminant input at some future time. Because of the current absence of site-related contaminants at these locations, it is unlikely that any ecological risk assessments would have been conducted at these locations. The ecological risk assessment of these types of sites under future conditions would thus necessarily be similar to a screening level assessment: comparing predicted concentrations to non-site-specific, literature-derived screening effects values. As site-specific screening values were developed for other locations in the Hanford impact area, they might be used in preference to literature values.

Fate and transport modeling results might also predict increases in contaminant concentrations above current levels at locations where ecological risk assessments have been completed or are underway. At such sites, the evaluation of future risks would involve applying the predicted environmental media concentrations to the site-specific effects data developed by the current-conditions risk assessment.

4.2.6 Methods for Evaluating Risks

The assessment of risks to ecological resources should consist of three basic elements:

- An exposure assessment to quantify the actual exposure or potential exposure of each receptor to contaminants from the GW/VZ,

- An effects assessment to quantitatively link contaminant concentrations to adverse effects in receptors and to provide dose-response information, and

- A risk characterization to bring together information from the first two elements in order to estimate the risk that the site poses to receptors on the basis of current conditions, future conditions, or conditions that would result from hypothetical scenarios.

Because ecological conditions are largely unique at every site and because of the wide variety of assessment endpoints that can be selected, there is no one "standard" methodology for conducting exposure and effects assessments for ecological risk assessments. However, a variety of contaminant-, media-, and receptor-specific standard methods can be combined. At any particular site, specific methods for obtaining data about exposure and effects should be selected on a habitat-by-habitat basis, according to the specific assessment and measurement endpoints selected, the types of organisms to be sampled, and the contaminants being evaluated. Once the assessment and measurement endpoints have been selected, the available methods should be narrowed to those that are feasible for the given situation.

Regardless of the methods selected for the exposure and effects assessments, the importance of obtaining measurements from suitable reference areas needs to be emphasized, especially for study locations that are already contaminated. Collection of samples from upstream or upgradient locations is necessary to identify incremental risks associated with the site under evaluation and to differentiate them from effects or risks caused by environmental stressors from other sources (e.g., upstream discharges). Because the analysis of samples from a reference site is intended to provide a way of isolating effects due to contaminants from the site under evaluation, reference areas should be ecologically similar to the site, but not necessarily "pristine" locations. Adequate resources must be allocated to obtaining information from reference sites for meaningful comparisons to be made.

4.2.6.1 Exposure Assessment

Three general approaches are used to conduct ecological exposure assessments. First, contaminant concentrations in environmental media can be directly measured, and doses to receptors can be estimated with contaminant uptake, food web, and dose models. Second, contaminant concentrations in receptor tissues can also be directly measured. Third, exposures can be evaluated through the use of biomarkers. It is likely that a combination of these methods would be needed to adequately evaluate exposure for all assessment endpoints. However, wherever feasible, direct measurement of contaminant concentrations in tissues of biota is preferable to contaminant uptake modeling or use of biomarkers because it reduces uncertainty in the exposure estimate. Measures that are not destructive of life (e.g., using eggshells, blood samples, or antlers) are preferable where feasible, but some use of destructive tissue sampling would probably also be necessary. In all cases, consideration of adequate sample size, as well as aspects of data quality would be necessary to ensure the appropriateness and usefulness of the data used in the exposure assessment.

Direct measurement of contaminants in tissues may also allow development of site-specific bioconcentration and bioaccumulation factors for contaminants of potential concern. Because it is highly desirable to link the amount of exposure to the magnitude of effect, any biomarker methods selected should allow the degree of exposure to be quantified rather than simply providing an indication of whether or not exposure has occurred.

It is also important to consider variability in exposure levels and to make a concerted effort to identify the range of likely exposures. This information permits a better understanding of the degree of risk and would be crucial in remediation decisions. If a receptor has no exposure to a particular contaminant (either because the contaminant does not reach the receptor or because the contaminant is in a form that is not bioavailable), then the contaminant poses no risk to that receptor.

4.2.6.2 Effects Assessment

In effects assessment, concentrations of the contaminants of concern are quantitatively linked to adverse effects to assessment endpoints. The goal is to develop dose-response information for use in evaluating risk from concentrations of contaminants at the site. Effects assessments are typically based on information currently available in the literature or on site-specific information obtained through field or laboratory studies, including toxicity testing. Table 4.1 identifies some general categories of ecological studies that may be appropriate for evaluating ecological risks relative to Hanford contaminants.

TABLE 4.1 Applicable Ecological Risk Evaluation Categories and Associated Relative Risk Levels for Determining Current and Future Risks for Different Levels of Ecological Complexity

Level of Ecological Complexity[a]	Temporal Scale of Evaluation	Mortality Studies	Growth Studies	Reproduction Studies	Biodiversity Evaluations	Ecosystem Function or Service Studies	Relative Risk Estimate Uncertainty[b]
Individual	Current	+[c]	+	+	-[c]	+	Low
	Future	+	+	+	-	+	High
Population	Current	-	+	+	-	+	Low
	Future	-	+	+	-	+	High
Community	Current	-	-	-	+	+	Moderate
	Future	-	-	-	+	+	High
Ecosystem	Current	-	-	-	+	+	High
	Future	-	-	-	+	+	High
Habitat	Current	-	-	-	+	+	Moderate
	Future	-	-	-	+	+	High

[a] These levels represent the ecological complexity that may be appropriate for evaluation in a regional- or local-scale ecological risk assessment. For any particular assessment, the selected complexity level will be a function of the specific contaminants and media to be evaluated, the candidate set and study set receptors selected for evaluation, and consultations and concurrence with all appropriate parties (Tribal Nations, regulators, trustees, and other stakeholders).

[b] The relative uncertainty is based on the availability of standard, well-documented, and accepted methods for evaluating contaminant effects at the indicated complexity level. The actual uncertainty will be a function of the study design (and associated methods) developed for the assessment.

[c] A '+' indicates that the general category of study may be appropriate for evaluating risks at the indicated complexity level. A '–' indicates that the general category of study may not be appropriate for evaluating risks at the indicated complexity level.

Available literature pertaining to toxicity mechanisms and dose-response information for a variety of possible effects can be evaluated to identify potential effects. Some of this information has been assembled as part of the CRCIA II effort (DOE 1998). In addition, field studies may be used to evaluate whether current site effects and risks differ from those at reference locations. These studies should be coordinated with chemical sampling of media and biota in order to associate the degree of effects to the degree of contaminant exposure. Furthermore, toxicity testing could be conducted with media from areas of concern and reference locations to determine whether media are toxic to specific categories of biota and to develop toxicity-response profiles for the contaminants in those media. Note that it is important to identify effects for a range of exposure levels (e.g., encompassing the no observed adverse effect level [NOAEL]) so that cleanup criteria can be developed, as well as to assist with evaluation of residual risks for natural resource damage assessment issues.

Given the highly stochastic nature of ecological parameters, it would be extremely difficult to construct a valid model for determining conditions of ecological resources in the distant future (e.g., population levels or community structure 100 or 1,000 years from now). Instead, it is proposed that an approach be adopted whereby the current ecological conditions of suitable reference areas are used as the baseline. Hydrogeological and other fate and transport modeling could then be used to estimate the exposure concentration of contaminants at some point in the future and, using the dose-response relationships developed during the effects assessment, evaluate the effects of those concentrations on the baseline ecological conditions.

Other scenarios (e.g., contaminant concentrations associated with catastrophic failure of containment systems) could be evaluated in a similar manner. In cases where ecological receptors are not currently exposed to contaminants but may be in the future because of transport mechanisms, evaluation of potential effects would be limited to screening-level assessments or would require additional laboratory evaluations.

4.2.7 Uncertainties

Uncertainty associated with both the regional- and local-scale assessments must be considered throughout the risk assessment process, and implications of uncertainties in making risk management decisions must be understood. Areas of uncertainty may include:

- Limited contaminant effects data for fish and wildlife in natural settings,
- Limited information on effects of exposure to contaminant mixtures,
- Incomplete characterization of the distribution and ecology of receptors,
- Limited species-specific physiological data,
- Limited capabilities to predict future ecological conditions,
- Limited capabilities to predict current and future contaminant fate and transport, and
- Limited capabilities to predict future economic and sociocultural conditions.

The level of uncertainty associated with risk assessment for future conditions is most likely to be much greater than the uncertainty associated with assessments of current conditions, regardless of the nature of the specific assessment endpoints under evaluation (see Table 4.1). The level of uncertainty also increases as levels of ecological complexity increase. For example, an assessment evaluating a single species, such as a threatened or endangered species, would have much greater certainty than would assessments evaluating risks at the community or ecosystem level. This situation is due to the greater complexity of interactions in the latter cases and to greater ignorance of biological processes at the community and ecosystem levels. Baseline ecological risk assessments of current conditions should employ site-specific studies designed to reduce uncertainty to acceptable levels. In contrast, ecological evaluations of future environmental conditions (e.g., 100 years from now) should employ predicted environmental concentrations and non-site-specific screening values, or predicted environmental concentrations and current site-specific effects data. In both cases, the degree of uncertainty would be much greater than that anticipated for current condition assessments.

4.3 SOCIOCULTURAL IMPACTS

The scope of sociocultural impact assessment covers three major areas. To establish a baseline of information about potentially affected populations and communities, basic information pertaining to their current status and potentially affected activities and institutions is needed. To the extent possible, likely changes due to GW/VZ contamination need to be projected. This social impact assessment area employs techniques that have become somewhat standard in environmental impact assessment. A second major area is that of assessing potential changes in the quality of life of affected groups. Involvement of the broad community and use survey research techniques are central to this assessment. The third area is more focused and addresses potential impacts that are particular to Native American Tribal cultures. This area involves direct consultations in accordance with specific treaty and trust rights and responsibilities.

4.3.1 General Social Impact Assessment Principles

The level and scope of the social impact assessment needed depends on the particular context of specific health or environmental risk considerations and the potentially affected communities and activities. Stakeholders and communities affected by remediation program decisions will vary for different potential impact zones associated with each risk scenario. Thus, for each plausible scenario of health or environmental risk, a zone of impact needs to be identified for evaluation. Table 4.2 provides a preliminary example of how impact zones and affected groups might be characterized.

TABLE 4.2 Potential Impact Zone Definitions and Stakeholders

Potential Impact Zones	Major Stakeholders
On-site area, including groundwater	Privatization enterprises, Federal government, local business and industry, groundwater users, agriculturists, Tribal governments, Washington State government, city and county governments
Columbia River - Benton/Franklin County (e.g., Tri-Cities) and the region upstream from the McNary Dam	Local business and industry, agriculturists, Tribal governments, Washington State government, city and county governments
Columbia River - downstream from the McNary Dam	River basin region business and industry, including agriculture, fisheries, manufacturing, recreation; community residential water agencies; Tribal governments; Washington and Oregon State government, city and county governments

The basic steps of a general social impact assessment related to the GW/VZ Integration Program could be as follows.

- Conduct a social assessment that identifies relevant populations, communities, and social structures within the potential impact zones, (i.e., the social environment).
- Identify ways in which the social environment would change in response to the range of impacts associated with the remediation program alternatives.
- Based on the descriptions of the remediation program alternatives, project social changes associated with each proposed alternative.
- Compare the types and magnitudes of social changes among the various remediation alternatives.
- Reevaluate elements of the analysis as new information becomes available.

Methods and tools for conducting social assessments are based in long-established social science methods for describing communities, social and economic structure, perceptions, opinions, and values. Council on Environmental Quality guidance on social assessment in NEPA implementation is available on the Internet at http://ceq.eh.doe.gov/nepa/nepanet.htm and a summary of guidelines and principles for the social impact assessment process has been published by the U.S. Department of Commerce (1994). Likewise, a substantial body of social science literature exists on case studies of social responses to actual, projected, or perceived changes in a community's environment, including risks of environmental contamination, that may guide inquiry into conditions likely to provoke a social response.

The use of both primary and secondary (archival) data to conduct a social assessment is preferred because the combination provides a broader base of information about what is important to the population at risk, rather than just to the social scientists, official data collection agencies, and the program managers. Also, comparing statistical data from agencies and anecdotal data from community experts and leaders provides an opportunity for validation of community characteristics.

The typical principal approaches for gathering primary data are interviews and focus groups (structured group interviews). The quality of the information obtained from these approaches depends on the rigor of the processes by which the respondents are selected and the questions designed. An iterative process involving archival data and initial interviews is generally used to formulate the initial domains for inquiry. Then interviewing techniques may be used that permit adjustments to be made in the researchers' initial hypotheses.

Broadscale mail or phone interviews with random samples of the public can be used, but these techniques are expensive to design and conduct and fraught with credibility pitfalls. In the case of the remediation program alternatives, a broadscale public survey would not be advisable until a well-defined outline of the remediation options and impacts is available. Such a survey could be used to augment understanding of public visibility, credibility, and acceptability of the program alternatives being formulated.

Secondary, or archival, data are usually used to obtain a profile of the social and economic structure of specific locales. This type of profiling has been conducted on several occasions for the Tri-City area in the past three decades, providing a starting point for updating the profiles with the most recent data from official sources. Measures of the social environment include the region's demographic characteristics; business and industrial activities; occupational and labor force characteristics; employment and income characteristics; community facilities, services and fiscal resources; sources of revenue; and other aspects. Other sources of archival data, such as local histories, news files, and past studies of the area, can provide related information, such as the locale's historical response to related situations, attitudes toward

Hanford Site activities, economic and political linkages, community diversity and complexity, distribution of resources, and bases for cooperation on significant issues.

A plan for characterizing the region along the Columbia River below the Hanford Site and extending to the Pacific Ocean would be more difficult to design and execute. A significant amount of archival data is currently available from the U.S. Geological Survey, U.S. Army Corps of Engineers, Northwest Power Planning Council, and other institutions and agencies in connection with the current debate over restoration of Columbia River salmon runs. This information can be supplemented through primary data collection.

4.3.2 Quality of Life Assessment

An evaluation of the quality of life is directly related to the more general social impact assessment process, so much of this discussion tracks with that in the previous section. However, it also includes broader elements (linking to the other impact types) and different considerations, so related information has been presented in this separate section. According to the EPA (1993), "non-quantifiable social losses include the sense of loss in community cohesion or cultural continuity, the anxiety of living near an environmental threat, the issue of intergenerational equity and leaving a degraded natural heritage to future generations, or the lost enjoyment value of open spaces." Thus, the presence of residual contamination could have a negative impact on the quality of life of proximate communities.

Although communities may vary in specifics and intensity, the same general quality of life indicators may be relevant to many: community and individual well-being, spirituality, concern for future generations, peace of mind, resource access and use, and sustainability of a worldview. Certain cultural communities may be defined as subsets of larger communities that are linked by heritage, occupation, interest, or background. The term can encompass hunters, farmers, former Hanford Site landowners, and others.   General requirements to determine any negative impact on the quality of life derive from NEPA. For impacts to Tribal Nations, treaty and trust obligations represent crucial requirements. Direct consultations in addition to the less formal ongoing interactions with Native Americans are essential to an appropriate understanding of cultural issues, needs, and expectations of the assessment.

In general, cultures might be conceived of as having two components: a general worldview (e.g., the value of nature) and social or physical manifestations of that worldview (e.g., appropriate access to or use of natural resources). Human health and ecosystem risk assessments of the physical manifestations are an input to the assessment of quality of life for a community with a particular culture. Figure 4.4

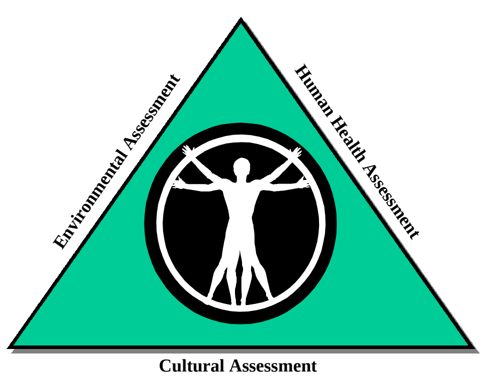

FIGURE 4.4 Relationship of Assessment Elements for the Evaluation of Quality of Life Impacts

illustrates this relationship. Health and ecological risk findings are not the singular endpoint in the quality of life evaluation but they do provide essential information to the process. Clearly, an exposure causing a potentially unacceptable risk to a resource or from an important resource to its users could negatively impact quality of life. However, even if by scientific or regulatory definitions no human health or ecological risk exists, patterns of life might be disrupted to the point that the culture is harmed. Such a situation could happen if access to or use of resources is constructively restricted or banned by a governmental authority (e.g., there is no risk as long as salmon intake is limited to a certain number of pounds per year). It could also happen because of perception (e.g., the perception that contamination in the river may have contaminated the salmon so they are no longer pure or safe.)

Assessing impacts to the quality of life of the cultures affected by conditions of the Hanford Site depends on assessment of the nature and extent of any human health and/or ecological risks and of the potential for any changes in resource access or use. From that basis, cultural impact assessors seek to determine if and how the patterns of life associated with the values and systems that make up the culture are affected. The presence of human health or ecological risks certainly would affect those patterns and therefore must be integrated into a quality of life assessment.

Determining cultural impacts begins with identification of the major cultural communities that use resources whose quality would be degraded or to which access would be restricted. Once identified, the cultural communities within the potential impact area could be screened to determine which are most likely to be affected. The equity interests being assessed include who bears the biggest impact (proportionality), who bears the impact the longest (temporality), who is physically closest to the source of the risk (spatiality), and who is most directly affected (immediacy). The cultural communities judged most likely to carry the greatest impact are the ones that should be studied in greater detail. A further crucial factor for Tribal Nations is the issue of rights and responsibilities per treaties and trusts, and direct consultation is an important element of the evaluation and subsequent decision making process.

The “rules of engagement” of a cultural impact assessment process should be developed in coordination and consultation with multiple affected parties and broadly communicated. These rules should be designed to establish how the integrated study will be conducted and how the results will be used. Decision makers and community members should be aware that results of the cultural risk assessment are valuable and will be factored into plans and decision along with information on health and ecological risks, and economic effects, as well as other factors.

Social science tools such as questionnaires, interviews, expert elicitation, focus groups, and ranking of topics of concern might also be useful to assess certain cultural impacts. These tools need to be developed in conjunction with the cultural communities being studied. Community members should also be involved in developing the cultural health indicators, developing data-gathering techniques, gathering the data (after capacity building, such as training in conducting interviews), evaluating the data (discussing findings that may be in conflict), and determining how proprietary (such as Tribal or business) information will be gathered, analyzed, communicated, and protected.

The final part of the cultural impact assessment process is communicating the findings of the study to all affected communities and the general public. It is also important that the draft and final decision documents describe how the study factored into the decision process.

In summary, a quality of life risk assessment could include the following elements.

- Developing culturally sensitive exposure scenarios for human and ecological risk assessments,
- Acquiring knowledge of the resource access or use patterns valuable to the cultures under study,
- Developing an understanding of how those patterns can be disrupted,
- Determining if those disrupted patterns negatively impact the health of the culture, and
- Determining the extent of the impact.

Table 4.3 lists indicators and assessment measures that could be used in a quality of life assessment. Some of these indicators may require qualitative rather than quantitative assessments based on descriptive statements, evaluation by representatives of affected groups, and constancy of concern. The service-acre-year approach (Harris and Harper 1997) that assesses impacts of environmental contamination in spatial and temporal terms and loss of services is an example of one measure that could provide useful perspective on one portion of the quality of life assessment. Caution must be taken in scoping the quality of life assessment to ensure that the impacts to the culture being assessed focus on site-related issues such as the loss of use of resources or locations or the presence of residual contamination as opposed to larger societal impacts or other issues.

TABLE 4.3 Quality of Life Indicators and Assessment Measures

	Quality of Life Assessment Measures					
Quality of Life Indicators	*Scale*	*Reversibility*	*Temporality*	*Severity of Impact*	*Involuntariness*	*Equity/ Inequity*
Community Well-Being						
Individual Well-Being						
Future Generations' Well-Being						
Peace of Mind						
Resource Access/Use						
Sustainability of Worldview						

Assessment methods used to gather data on the quality of life indicators can include expert elicitation (oral interviews by people trained in both the subject matter and interviewing techniques), surveys, questionnaires, and discussion/focus groups. The actual methods and their format should be determined or developed through a dialogue with the potentially affected cultural communities. The quality of life evaluation process is illustrated in Figure 4.5, which demonstrates the potential interrelatedness of ecological and human health risks with cultural impacts.

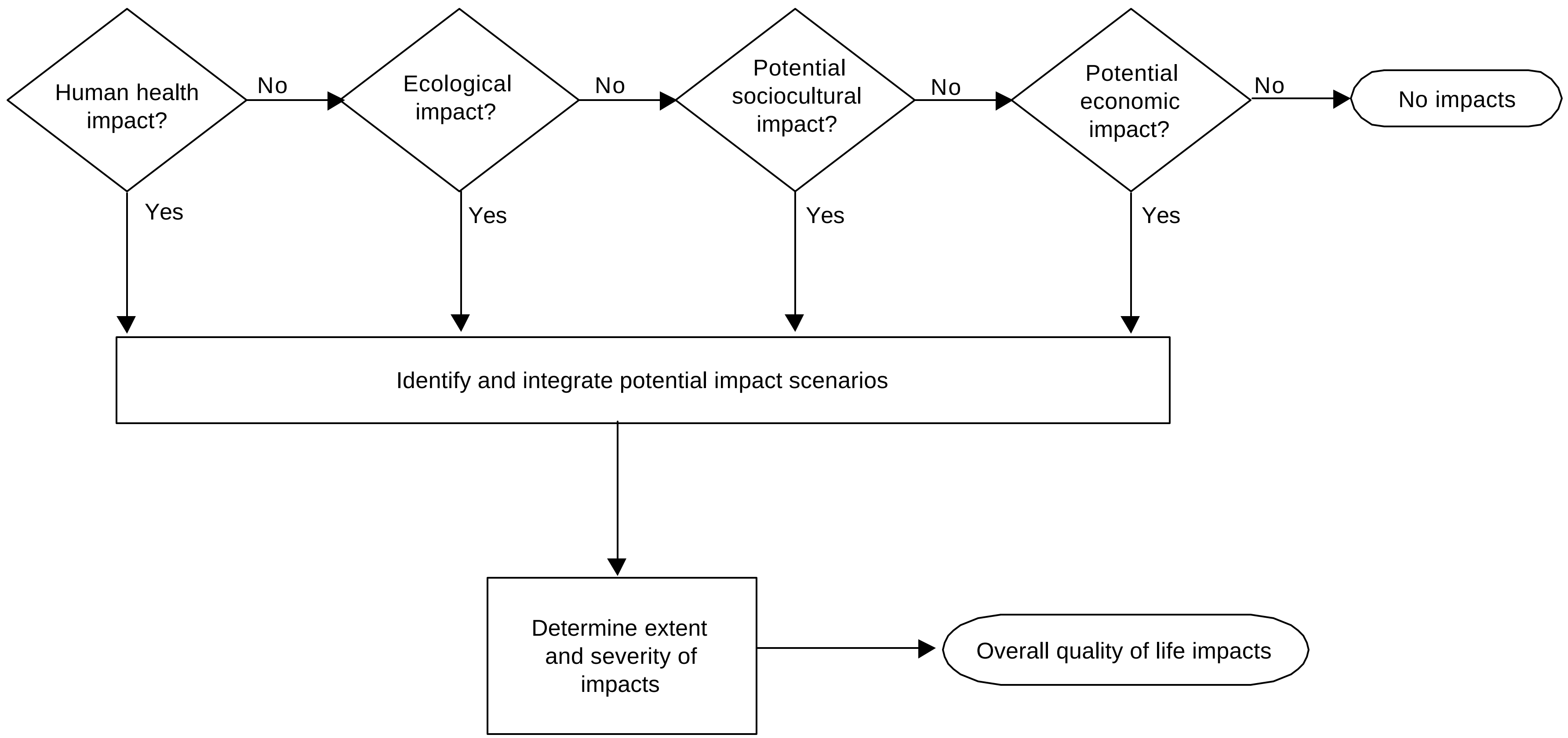

FIGURE 4.5 Quality of Life Evaluation Process

4.3.3 Native American Cultural Impacts

The link between the worldview and its manifestations can take on a much strong significance in certain Native American cultures, in which the symbolic content of nature takes on a greater significance than its visible material content (Hanes 1995, citing Murdock 1980). Some note that a Native American perspective can hold nature to be intrinsically spiritual, as sacredness is imbedded in all phenomena, which results in the development of sacred emotional attachment to native plants and animals and to natural landform features (Hanes 1995). Loss of access to a place may have a worldview impact even though the place is not contaminated. Other cultures can also experience the same phenomenon.

4.3.3.1 Tribal Culture

The methods for assessing effects on tribal culture should be primarily qualitative and based on direct consultations and additional interactions that define and address key indicator variables. These might include the health of ecosystems and ethno-habitats, integrity of culturally important places, and prospects for cultural survival. The following factors, in addition to those listed in Table 4.3, might be considered as such indicators:

- Landscape ecology conditions that are stable and resilient over time,
- Stable habitat trends and population trends for species with viability concerns,
- Stable habitat trends for species without viability concerns, and
- Degree of access to trust, traditional, or treaty resources and assets.

The first step can be to develop a general listing of species (plant and animal, both terrestrial and aquatic) or landforms of tribal interest. Tribal proprietary interest in certain resources and places limits availability of this information (Hanes 1995). However, sufficient documentation of Tribal concerns and practices and ongoing interactions may exist to allow a broadscale, qualitative analysis of impacts. The general process could be narrowed to core species of concern and matched with a list of species with viability concerns. Methods for gathering this information can include the use of expert elicitation (interviews) and unstructured surveys (Harris and Harper 1997). Identification of ecosystem viability and habitat trends could be accomplished through a viability panel assessment. General indices for ecosystem viability include (1) trends toward resilient and healthy areawide ecosystems; (2) reliable and predictable habitats for culturally important wildlife, aquatic species, and plants; and (3) trends toward a generally desired future condition. Ranking approaches could also be useful, for example composite ecological integrity could be rated high, moderate, or low compared to historical integrity. Again, direct consultations and less formal interactions with Tribal members are crucial to this assessment process.

4.3.3.2 Access Issues

Access to ethno-habitats is of critical importance to Tribal peoples for a range of reasons, including harvesting of culturally important species, use of sacred areas, and cultural survival through passing knowledge between generations. The Harris and Harper (1997) service-per-acre-year metric can be useful in providing one indication of potential impact. Beyond assessing the negative impact to tribal culture from the loss of access to ethno-habitats, it is also important to minimize future impact of such loss. It is highly unlikely that Tribal Nations will regain total access (for unrestricted use) to the Hanford Site in the foreseeable future. However, Tribes may regain total or periodic access to portions of the site for particular purposes. It is important to identify those actions that can be taken now to minimize the impact of any potential access restrictions or resource losses. Again, Tribal proprietary interests may limit identification of specific areas but may allow general areas of the site to be identified.

4.4 ECONOMIC IMPACTS

4.4.1 Introduction

Scenarios for economic impacts should be developed consistent with the scenarios that emerge from studies about the migration of contaminants. However, special considerations affect the economic impact scenarios. Economic effects can be driven by both physical changes to the environment and by perceived impacts and benefits of the Hanford Site to residents of the region and to participants in regional markets.

The following discussion provides illustrative examples of approach for economic assessment, rather than attempting to identify a complete study set of impacts and suggest an approach for each. The focus is on suggesting an overall framework of analysis and a process for moving from the general to specifics.

Discussion of the assessment process covers the need to develop an understanding of the economic structure within which impacts may occur. This need is tied directly to the definition of scenarios for the conditions under which impacts could develop and the economic sectors that would be affected. A presentation of issues and detailed recommendations for delineating the assessment scope follow. An overview of available methods follows, and is a final section deals with integration issues.

The selection of methods for economic impact assessment of GW/VZ contamination is highly dependent on the scenario of change in resource quality or access being considered. The set of changes in public information regarding human health risks and ecological system functioning resulting from changes in resource quality would stimulate any economic impacts. Therefore, the choice of methods for impact estimation and valuation must be tied directly to findings of the health and ecological risk assessments and scenarios of public perception of change.

4.4.2 Develop Understanding of Potential Economic Impact Processes

A general model of the economic impact process is shown in Figure 4.6. For economic impacts, the process may be thought of as having two major components. The first component consists of “impact trigger mechanisms,” or sequences of physical and human behavior changes in response to, or resulting from, human health or ecological risks. The second component reflects the processes by which particular trigger mechanisms induce impacts. This component consists of both economic market effects and changes in resource or activity values that are directly generated, as well as indirect regional economic impacts that occur through “ripple effects” from the direct impacts. Both components are driven by information inputs from the human health and ecological risk assessments.

Two chains of events may lead to economic impacts, one tied to human health risks and the other to ecological risks. As shown in Figure 4.6 for human health risks, the first crucial juncture in assessing the generation of economic impacts lies in evaluating whether information as to risk levels would lead to protective actions to prevent exposure. Protective actions could involve government proscription of resource use, avoidance of products or locations by the public, or both. Projecting the potential for protective action to be taken is complicated by the fact that available information may or may not accurately portray physical risks. Regardless of their relation to health risk estimates, protective actions of almost any type are likely to lead to some economic impact. The magnitude of economic impacts so induced depends on the duration of the protective action, the geographical scope and types of resources affected, and the extent of public involvement. In the case of government proscription, compliance is rarely complete, and where avoidance is voluntary, rates of participation are likely to vary between local and nonlocal users of the avoided resource.

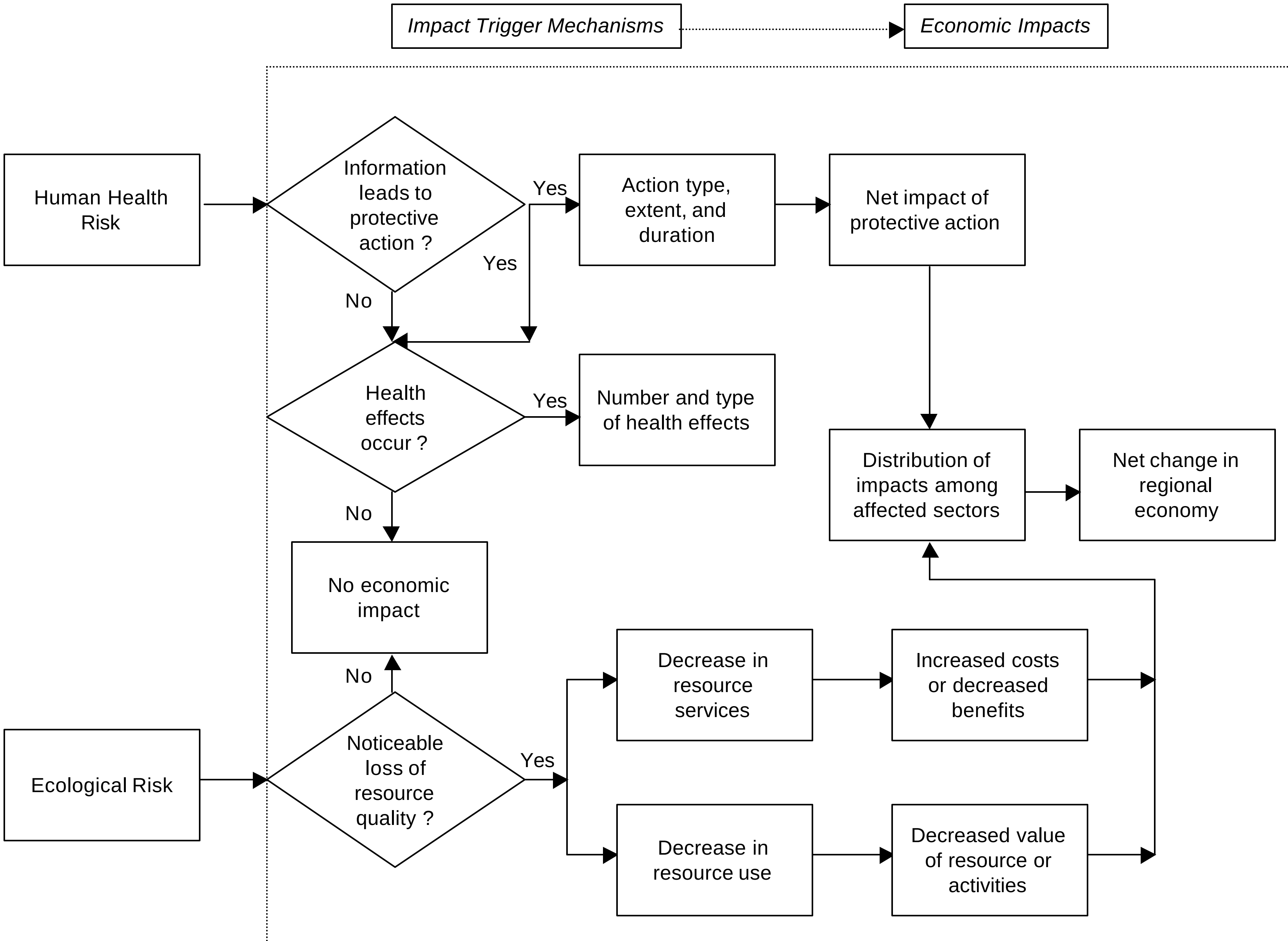

FIGURE 4.6 The Economic Impact Process as It Relates to Human Health and Ecological Risks

If protective actions have the effect of preventing health effects, then all health effect impacts, including any economic ones, would be avoided. If health effects do occur, then they must be accounted for as impacts. Economic values of health care costs, lost productivity, and pain and suffering associated with health effects can be estimated; however, doing so is not recommended because of controversies surrounding the methodology for such an assessment.

If the human health risk were so low that no one would be likely to take protective action, and, even without protective action, no significant health effects would occur, then there would be no economic impacts. Economic impacts would also be avoided if ecological risks were so low that no noticeable changes would be induced in ecological resources, their functions, or services.

Economic impacts derived from ecological risks are triggered when ecological resources are degraded such that their quantity or quality declines or there is a decrease in the services that they provide. Impacts may also occur if resources are *perceived* to be degraded to the point that people change their use of the resources or the value that they place on the resource use. Impacts may be stimulated by degradation of a resource, whether the resource has a dollar value or not. Impairment of a resource may result in changes in its use, either through government prohibition (because of an unacceptable risk level) or through public avoidance of use because of fears about safety. Such changes in resource use may create impacts in both the sector affected and the broader regional economy. Even if the resource does not have a market price, loss of use reduces the user’s level of well-being, which can be valued in economic terms. Economic impacts can also result in more complex ways, such as from changes in ecological functions that affect the cost or quality of other goods. The total economic impact of a resource change is the sum of direct, indirect, and nonmonetized effects.

In situations where resource degradation or health risk is not obvious (through visible changes) to all potential resource users, there is an intervening factor in impact development: the timing, accuracy, and extent of dissemination of information regarding the resource condition. As a result of the role of information in impact generation, the severity of the resource impairment is only a partial indicator of the likely severity of the associated indirect impact. Nonetheless, the impact of avoidance behaviors that are based on uncertainties or misinformation can have major economic repercussions that are likely to persist until there is a change in public perceptions of the situation. A literature search related to food product “scares” showed that consumer avoidance of products associated with health risks generally dissipates in less than a year, if the risk situation is rectified.

Changes in resource use can lead to direct economic impacts in the form of either increased costs or decreased revenues, or both. For instance, in the case of Columbia River contamination, increased costs would be incurred to provide alternative water supplies to persons presently dependent on river water for drinking. Also, revenues might decrease for establishments that cater to tourists. There could also be losses of enjoyment by participants of boating and water skiing activities that do not have specific prices. Although the value of lost enjoyment does not affect the regional economy, it affects the overall well-being of persons in the impact zone. The values of these activities can be estimated and are a valid part of the overall economic impact assessment.

Indirect impacts on the regional economy develop from the impacts on the sectors that are primarily affected. Such an impact could occur because, for example, any increases in costs of water that might be borne by local residents would leave them with less disposable income for other goods and services. Decreases in revenues of local firms would similarly leave them with decreased funds available for salaries and other expenses. Both types of changes cause the regional economy, where funds recirculate among economic sectors, to shrink.

As a basis for estimating economic impacts, a clear understanding is needed of:

- The extent and probability of particular effects on environmental resource quality or on human health,
- The ways in which these resources are linked to local economies or in which changes in risks may affect activities, and
- The ways in which the local economies are tied to the larger regional and national economies.

Developing such an understanding would require participation of a wide range of experts and stakeholders, but also would provide a foundation for development of specific impact scenarios that focus on the most important potential impacts to the region and to specific subareas and subpopulations.

Possible impact process scenarios, based on detailed knowledge of the area's economic structure, need to be developed with participation of appropriate stakeholders. These scenarios should address the nature, extent, and timing of impact-triggering mechanisms (i.e., information or misinformation regarding contamination and the related degree of public reaction). Scenarios of initiating mechanisms must then be related to the structure of the regional economy and its trade and financial linkages to the national and affected state economies. This information then would provide a basis for identifying the sectors and regions that should be included in an impact assessment.

A situation with considerable uncertainty regarding slight contamination of the Columbia River could lead to risk-averting behaviors on the part of the public that would substantially affect agricultural or fishery product sales over a broad region.

An example of combinations of levels of trigger mechanisms, impact processes, and potentially affected areas and sectors that need to be considered is provided in Table 4.4, focusing on Columbia River water. For each trigger mechanism, there may be several impact processes, each affecting the same, or different, geographic areas and markets. Once impacts have been identified, the potential for differential effects on population subgroups, such as Tribal people or agricultural migrants, needs to be considered in relation to the chains of process linkages for impacts on fisheries and agriculture, respectively. It is possible to have impacts that are minor from a regional economic perspective but major from a sector or population subgroup perspective, and this possibility should be explored in an impact assessment.

Figure 4.7 shows an example of an impact scenario for river contamination that is measurable but insufficient to lead to any official restrictions on water use. As shown, scenarios need to explicitly address the timing and degree of changes in resource use. These scenario assumptions should be based on information from comparable events in other locations (e.g., imposition of "fish advisories") or be created as bounding cases. All reasonable possibilities of impacts should be considered in constructing a candidate set of scenarios. These possibilities then should be screened for the potential magnitude of the impact, relative to the activity affected, and for the likelihood of any impact occurring through the linkage specified.

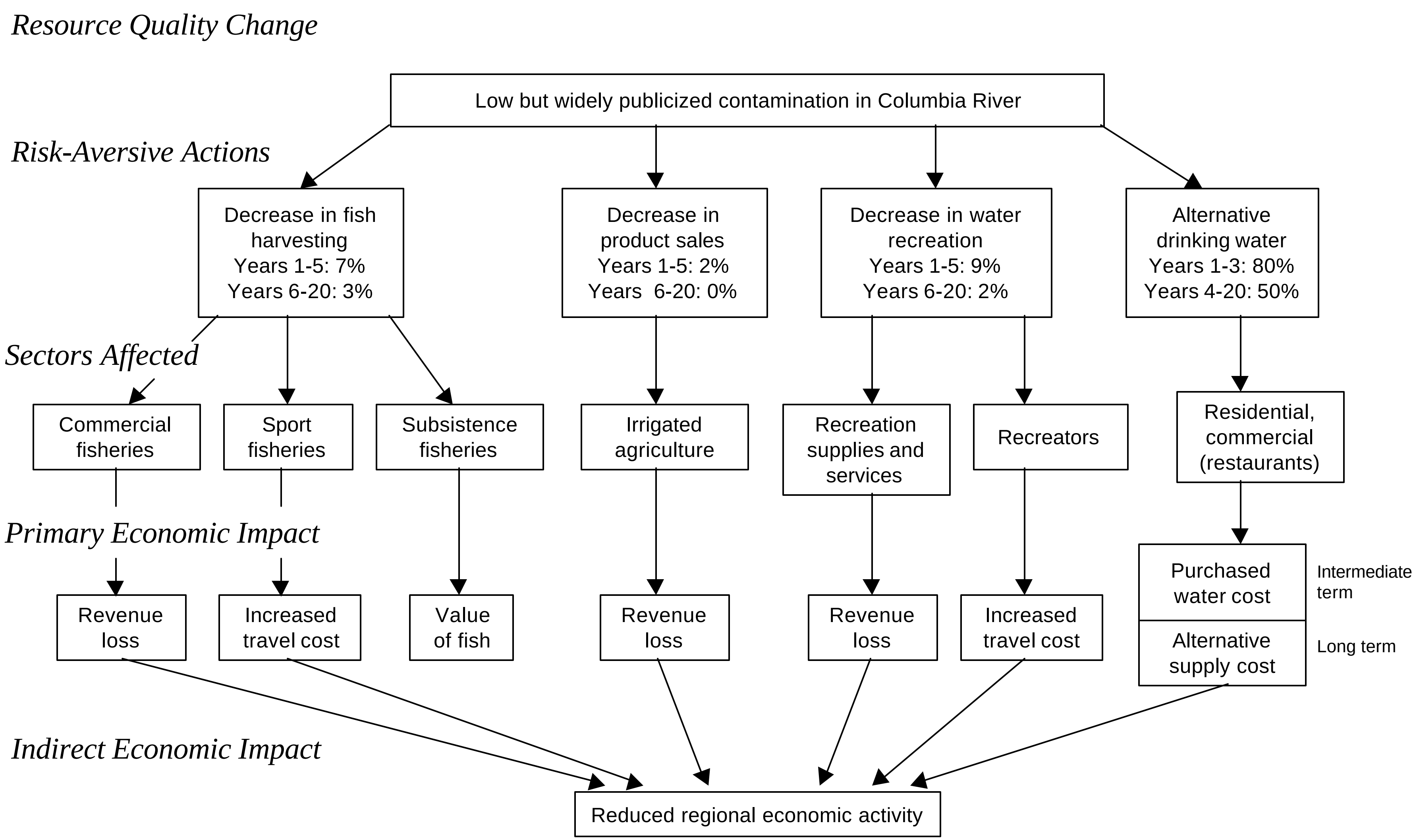

FIGURE 4.7 Example of an Economic Impact Scenario Framework

TABLE 4.4 Example of Elements in Economic Impact Scenario Development

Trigger Mechanisms	Impact Process Scenarios	Geographic Areas of Potential Impact	Markets or Sectors Potentially Affected
Substantial Columbia River contamination	Interdiction of water use for months to years	Tri-Cities area Lower Columbia River region	Industrial, residential, agricultural, and commercial sectors; fisheries; recreation
Low but widely publicized contamination in Columbia River	Substantial avoidance of water and products for months to years	Tri-Cities area Lower Columbia River region	Residential and agricultural sectors; fisheries; recreation Agriculture; fisheries; recreation
Uncertainty regarding Columbia River contamination or conflicting public information	Partial avoidance of water and products for months to years	Tri-Cities area Lower Columbia River region	Residential and agricultural sectors; fisheries; recreation Recreational and subsistence fisheries
Risk from material stored on closed site	Long-term avoidance of water and products	Tri-Cities area	Industrial, residential, agricultural, and commercial sectors; fisheries; recreation

4.4.3 Define the Economic Assessment Scope

One of the most basic steps in defining the assessment scope is to establish the baseline conditions against which changes will be evaluated. The economic impacts of GW/VZ contamination reaching the Columbia River must be distinguished from the economic impacts to the Tri-Cities from the closing of the Hanford site since these are separate events. Because of the degree to which DOE activity at the Hanford Site drives the economy of the Tri-Cities area it would be quite difficult to separate impacts of site closure from impacts of river contamination if both were to occur in the same time frame. Econometric modeling of the regional economy is the technique generally used to estimate impacts of employment change in a particular sector, such as DOE in the case of Hanford. Such models are good for estimating the impacts of incremental changes within the range of recent historical experience. However, the uncertainties associated with impact estimates would be very large if the employment change is extreme and, especially, if historical precedent in a similar situation (size of economy, degree of economic diversification, magnitude of regional linkages, etc.) is lacking.

Compounding of impacts is much less likely for localities along the Columbia River that could be impacted by contamination of the river but that are not economically dependent on the Tri-Cities area. Because of complexity of the impact situation, there are potentially two types of impact zones: one in the Tri-Cities region with potentially reinforcing economic contractions due to site closing and to contamination effects. There is also a larger zone along the Columbia River where any potential impacts would primarily derive from river contamination or concern about possible contamination.

As impact scenarios are developed, stakeholders and others with a detailed knowledge of the affected area can identify economic sectors and population subgroups that may be affected through each chain of impact processes. The magnitude of potential impacts relative to the regional economy or relative to activity of the sector or population group affected should be used to select the more important effects for detailed study. In screening to determine what sectors and subgroups should be examined bounding estimates and similar techniques can be used to estimate potential magnitudes of impacts. In addition to impacts on affected sectors, local households, and the regional economy, the scoping effort has to deal with of any potential health effects. Economic theory supports valuing health effects and aggregating the value of health impacts with other categories of impacts to determine the overall impact value of a program alternative. Estimates of the value of health and life are available but are very controversial, and their use is opposed by many public advocacy organizations. Given this situation, there is substantial precedent for leaving economic values of health impacts out of the overall impact estimates. Thus, the basis for comparing program alternatives would be an estimate of economic costs plus estimated numbers or risks or health effects.

4.4.4 Select Appropriate Methods and Data Sources to Estimate Impacts

Measuring the impact of significant environmental contamination resulting from the Hanford GW/VZ on the social institutions and the economy of the region should be possible using standard methods. For instance, costs of lost economic productivity due to severe contamination (e.g., similar to the recent impacts to the English cattle industry from biological contamination, [mad-cow disease]) can be estimated with conventional econometric modeling techniques.

The measurement of impacts resulting from very low-level contamination, particularly where the public tendencies toward risk aversion are amplified, is likely to present significant challenges. However, this situation would have many similarities to the Three Mile Island incident and its aftermath, for which a number of impact estimates were developed. The major difficulty lies in projecting the degree to which the public would shift to risk aversive behaviors and the length of time that these behaviors would persist. Public reactions are likely to be highly dependent on media portrayal of the situation, credibility of responsible agencies and authorities, and the extent of uncertainty or conflicting information. Results of recent studies dealing with the impact of Yucca Mountain development on economic activity in Nevada might be useful in developing metrics dealing with various types of risk aversive behaviors.

To the extent that the affected resources are unique (e.g., the Hanford Reach of the Columbia River), do not have market prices (e.g., resource use in Tribal cultural practices), or are highly subsidized (e.g., irrigation water), estimating economic impacts will require adaptation of state-of-the-art methods to the particular situation. Valuation of changes in ecological system functioning is a particularly difficult issue, for which methods are currently under development (see Scott et al. 1998 for an example related to shrub-steppe land). For several years, the EPA and the National Science Foundation have had a jointly funded grants program to develop valuation methodologies that apply to ecological impacts. Reports from this program should be reviewed for applicable techniques. Recent approaches should be evaluated for feasibility and applicability. If methods and data are inadequate for quantification, these impacts may have to be analyzed qualitatively.

Quantifying losses from contamination-related events affecting Tribal economies, in some of which many activities and exchanges are not monetized, would be more difficult, if not impossible, within acceptable levels of uncertainty. Valuing losses of resources that are used entirely in subsistence, rather than market-based, functions (such as reeds for baskets used at home rather than sold) is often accomplished through contingent valuation methods. However, even in typical uses of contingent methods (e.g., establishing the value of protecting endangered species or preserving “old growth” forests) there can be a significant problem with "protest bids." These are cases where people essentially are indicating that they would require an infinite amount of compensation for loss of a resource to which they felt entitled. Since such attitudes are more likely to be the norm than an exception in indigenous communities, standard contingent valuation methods may be unworkable (and may provoke outrage). New methods or adaptations of existing methods are likely to be needed. A search of the literature related to the U.S. Agency for International Development or World Bank economic impact studies in traditional societies may provide a starting point. However, methods are not going to be directly transferable. Participation of Native American leaders in the effort will be crucial to the development of any new methods.

Table 4.5 provides examples of general methods that are available and types of impacts for which they are relevant. There are many variants of these methods that may be applied.

TABLE 4.5 Summary of Methods for Estimating Economic Impacts

Type of Impacts	Estimation Methods	Comments
Changes in resource or product prices or quantities in relatively competitive markets	Econometric modeling	Detailed, time-series data required; results beyond 10- to 20-year projections are highly uncertain.
Changes in resource or product prices or quantities in subsidized markets	Econometric modeling plus correction for subsidies	Additional uncertainty added by need to estimate subsidies and their market effects.
Loss of marketed resources (e.g., drinking water)	Cost estimates for alternative sources or for decontamination	
Loss of nonmarketed resources (e.g., subsistence fishing)	Costs for alternative sources or valuation methods to be suggested by Tribal groups	Validity of estimates is highly uncertain regardless of method.
Secondary regional impacts	Econometric or input/output modeling	Likely to be existing models that could be adapted.

Where the impaired resource is tied directly to markets in which products are relatively unsubsidized and competitively priced, standard economic metrics and methods could be applied for the affected sectors or markets. Table 4.6 shows some examples for the irrigated agricultural production that is common in the Tri-Cities area. These methods would be applicable, for instance, if there were a likelihood that vegetable crops like asparagus, cherry and apricot orchards, and high-value specialty products like wine would be affected.

TABLE 4.6 Examples of Methods Available to Estimate Potential Economic Impacts on Agricultural Markets

Resource Impact	Metric for Direct Economic Impact	Direct Impact Methods	Metric for Indirect Economic Impacts	Indirect Impact Methods
Severe contamination/ interdiction	Lesser of (1) water supply replacement cost or (2) difference between value of land and fixed equipment in irrigated agriculture and its value in dry-land farming	(1) Engineering cost basis (2) Econometric study of agricultural land values	Change in value of regional goods and services	Econometric (or input/output) model of regional economy with agricultural sector detail
Slight contamination but deemed safe for agriculture	Value of loss in product quantity sold or in selling price due to consumer avoidance	Market impact scenario construction with econometric model of product market	Change in value of regional goods and services	Econometric (or input/output) model of regional economy with agricultural sector detail

Some potential impacts, such as loss of recreational activity, may require a combination of techniques to quantify impact values. This need results from the fact that aspects of participation in the activities are essentially free, in that there is no access charge, only the cost to the participant of any required equipment and of travel to the recreation location. Thus, the value of the activity to participants is generally greater than their out-of-pocket costs. In such situations, contingent valuation (i.e., survey methods) is often used to develop estimates of the value of the activity to potential participants, including the value of the "free" aspects. These methods are relatively costly, however, so estimates of out-of-pocket costs are commonly used to provide a lower bound estimate of economic impact.

Once impacts of each remediation alternative have been estimated for the affected locations and time periods, they need to be converted to a consistent basis for comparison. Economists generally advocate the application of a discount factor in evaluating streams of costs or revenues over time. This procedure is useful to provide an estimate in current dollars of the amount of funds involved and is comparable to considering the interest-earning potential of alternative investments. Among economists, there is virtually no controversy about the need to apply a discount factor; the controversy is over the appropriate value to apply, within a quite narrow range.

Within a broad decision framework, discounting of impact estimates is needed to avoid major misallocation of current resources among competing projects that serve the public good. If the impacts of major contamination of the Columbia River lasting for thousands of years were estimated without discounting, the estimate could indicate that it would be worthwhile to invest the entire U.S. Federal budget (neglecting education, health, defense, etc.) to avoid contamination. While this sort of finding may serve the purposes of some segments of the public, it is not particularly useful in a broad decision-making context. Some of the objections to discounting by segments of the public may be countered by presenting impact estimates in both discounted and nominal dollars. Magnitudes of impact values over time can be shown graphically, without discounting, to help inform the discussion.

Public objections commonly arise to the placing of economic values on loss of human health or life. Considerable basis and justification exist for developing such estimates, but the controversy that arises may be greater than the value of information added by developing impact estimates for health. It would be advisable to present health effects separately from the economic impact estimates for other effects. The economic impact estimates would still account for the costs and losses due public behaviors whose purpose is avoidance of health risks.

4.4.5 Integrate Economic Impact Evaluation Results into the Overall Impact Study Process

The economic impact evaluation needs to be closely coordinated with the health, ecological, and sociocultural components of the risk analysis. Like the rest of the impact assessment, the economic evaluation needs to incorporate probabilities and timing of effects and to explicitly indicate uncertainties regarding underlying assumptions of the estimation process. An economic analysis may provide information indicating that program alternatives merit additional effort to reduce uncertainties, because of the magnitude of the related economic effects. For example, the cost of providing alternative water supplies or the value of potential impacts to agriculture or fisheries could be so high as to warrant evaluation of additional investments to avoid resource contamination.

There is no computational limit to the number of years to which impact estimates can be projected, but estimates for periods greater than 10 to 20 years generally fail the reality test of time (Casman et. al., 1999). While relative rankings of alternatives may be more stable over time than absolute value estimates, both are subject to considerable uncertainty. Both economies and social behaviors are affected by factors, such as resources, technology, politics, environment, culture, and finances, that are too diverse and variable to be captured by a tractable socioeconomic model. As a result, the uncertainties associated with projections beyond about 20 years tend to make the confidence interval around the projections so broad as to be of little use. This limitation implies that impacts in the longer term should simply be ranked or categorized by rough magnitude.

An illustration of how a summary-level conceptual model for economic effects can be linked with those for sociocultural effects and health and ecological risks is presented in Figure 4.8.

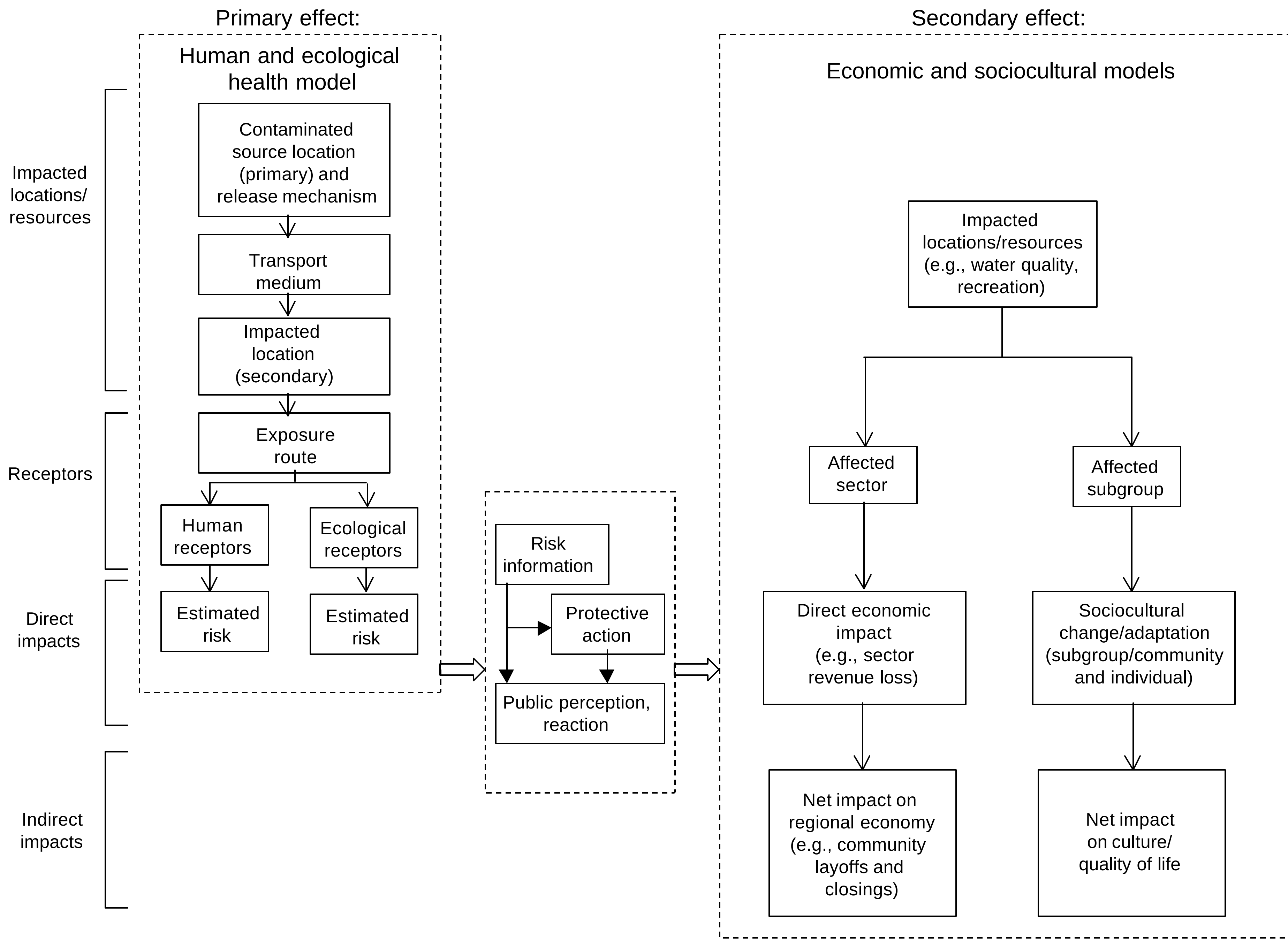

FIGURE 4.8 Illustration of Integrated Conceptual Models

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5 NEXT STEPS FOR FOCUSING AND IMPLEMENTING THE RISK/IMPACT ASSESSMENT

This chapter highlights discussions of previous chapters to make suggestions on how various methods can be combined to develop a path forward for an integrated assessment. After methodological options have been identified, the next steps in the risk assessment design involve identifying key affected locations and selecting topics (impacts) for study from larger candidate sets that comprise the conceptually possible considerations. Key issues in projecting impact locations are identified in Section 5.1. Criteria for developing candidate and study sets of impacts are presented in Section 5.2.

Exploratory and scoping studies are needed to investigate the potential for key impacts that are not well understood or that require a more innovative investigative approach. Suggestions for such studies are presented in Section 5.3. These studies could initially be undertaken with a limited or generic scope to demonstrate the validity of the concern or the applicability of a proposed approach, or even to determine the feasibility of further evaluations. Examples of studies of this type include investigations of current knowledge of chemical interactions among multiple pollutants (e.g., synergistic and antagonistic effects); effects on critical species such as salmon; and effects of major demographic, hydrologic, climatic, or geologic changes. Continued exploration of the use of dependency webs in delineating exposure pathways and illustrating key relationships would also be useful.

5.1 STUDIES TO AID IN PROJECTING THE SOURCE TERM AT IMPACT LOCATIONS

Three general areas of study that affect the overall design of an integrated risk/impact assessment are outlined below. Definition of the contaminant source term at receptor locations is a central theme.

- **Resolve Inventory Issues** – Develop an integrated view of the contaminant inventory by starting with current estimates of inventory and historical knowledge. Work with affected parties to identify additional inventory locations and categories (such as piping and cribs) that may not have been included in previous inventory estimates. Develop bounding estimates of inventory sources. (An extensive evaluation is ongoing to address these issues as part of the SAC effort on inventory.)

- **Estimate the Future Hazard Trajectory** – Use environmental transport models with intermediate-level complexity to develop "best estimates" of the hazard trajectory for the site and other potentially affected locations. Identify time limitations of the safety envelope (time until significant contamination would reach release points).

- **Develop Reality Checks** – Increase general acceptance of estimates by using the model-free or model-lite approach, which is more conceptual and descriptive than calculational, to validate intermediate-level model estimates of breakthrough times for significant contamination.

5.2 CRITERIA FOR SELECTING STUDY SETS FROM CANDIDATE SETS OF IMPACTS

For each of the main impact categories, issues for study need to be prioritized from a candidate set. Criteria for developing the candidate set and for selecting the study set for each impact type are being developed by the project team. Related information is presented in the following discussions.

5.2.1 Human Health Risks

5.2.1.1 Potential Criteria for the Human Health Assessment Candidate Set

The objective in selecting the candidate set for the human health assessment is to be as inclusive of potential health endpoints, receptors, and other influencing factors as possible so that no potential adverse impacts are excluded from consideration at an early stage of analysis. The two main categories of human health endpoints that are investigated in risk assessments are: increased cancer risk and noncancer effects. Typical receptor scenarios include current and future residents, workers, and recreational visitors both on a site and in the surrounding area. Because of its large size and unique setting, the scope of these categories is expanded from the more traditional scope to identify a broad candidate set for initial consideration at the Hanford Site.

Human Health Endpoints. In assessing increased cancer risks associated with GW/VZ contaminants, carcinogenicity data from multiple sources should be evaluated. For example, data and potency estimates from the EPA should be reviewed as well as data from the International Agency for Research on Cancer and other scientific organizations. Additionally, mutagenicity data should be evaluated and screened for conclusiveness (considering weight of evidence and including mode of action), to be used qualitatively in conjunction with quantitative potency estimates.

For both cancer and noncancer effects, the contaminant concentration present in a given environmental medium is generally translated into an exposure point concentration for a given receptor. For noncancer effects, the estimated intake is then compared with the critical effect level, which is the lowest level at which any adverse effect has been observed in association with animal or human exposure to that contaminant. In selecting the candidate set for human health assessment, a matrix could be developed from a comprehensive review of current toxicity information for at least the major site contaminants. This matrix would consider toxicity observed in various studies, going beyond the critical effect, including teratogenicity/embryotoxicity, developmental, reproductive, cardiovascular, respiratory, gastrointestinal, neurological, and immunological data. Information on the mode of action and mechanism of action where available should also be summarized.

The expanded consideration of health endpoints would allow for chemicals to be grouped according to various key factors, such as mode and mechanism of action, target organ/system, and type of toxicity exhibited. This approach would be complemented by a comparison of the estimated intakes per site contaminant concentrations with the critical (and other) effect levels. Such an updated toxicity synthesis would facilitate identification of contaminants with the same or similar mechanisms of action and target organs/systems so that potential for additivity, synergism, and antagonism could be more readily assessed, to the extent data are currently available or become available within the time frame of the assessments.

Receptors and Exposure Parameters. Site-specific data and stakeholder input are very important in evaluating the exposure scenarios used to assess the potential for adverse human health effects. Nonclassical types of exposures such as those relevant to the Native American community and other unique populations in the vicinity of the Hanford Site should be evaluated as part of this process. Input from affected community members could guide the evaluation of chronic exposures (such as via fish and water consumption), as well as of exposures that occur only seasonally or intermittently. The evaluation of population subgroup receptors, such as children and the elderly, would be further delineated based on exposure potential. Assumptions regarding population projections and distributions would also be guided by stakeholder input.

Other Influencing Factors. In addition to the targeted consideration of potential health effects and exposure parameters, the candidate set should include evaluation of cofactors that may influence toxicity potential in the exposed populations. Such factors may include socioeconomic status (including access to health care), nutritional and dietary quality, and existing prevalence of various health conditions.

5.2.1.2 Potential Criteria for the Human Health Assessment Study Set

The current candidate set of impacts and receptors is very broad and inclusive, and many may not be applicable to the contaminants of concern, impact locations, and actual receptors at those locations. The following criteria can be used to help focus an investigation for an initial integrated assessment, noting that the project team is already applying these types of considerations. We further suggest that those contaminants not retained for quantitative assessment nevertheless be retained for qualitative consideration, such that any new toxicity data that become available could be more readily incorporated in the ongoing assessment process.

- For carcinogenicity, individual contaminants that contribute more than 1% to the total incremental cancer risk could be retained. Another consideration is to retain all contaminants that contribute to risks on the basis of a given point of demarcation that may be defined at another level per results of a screening calculation (e.g., based on the percent of all contaminants). The concentrations of contaminants that have positive mutagenicity data but have not been classified as carcinogens under either U.S. or international classification schemes could also be examined to determine if they should be retained in the risk assessment or put on a watch list pending the availability of further information.

- For noncancer effects, estimated exposure levels should be compared with existing benchmark criteria, and those contaminants exceeding health-protective criteria should be retained. Additionally, hazard indexes for all contaminants segregated by specific health endpoint, considering target organ and mode/mechanism of action, should be constructed to screen for potential additive, synergistic, or antagonistic effects. This approach could lead to including some contaminants for further evaluation that might have been excluded had the only criterion been comparison with benchmarks. However, where data do not indicate that exposures are likely to cause toxicity, contaminants should be eliminated from further initial assessment.

- For receptor/exposure scenarios, the inclusive list of scenarios developed for the candidate set should be organized into groups of similar receptors (e.g., those exposed at the same type of impact location and via the same exposure routes). As appropriate, the receptor in each of these consolidated groups with reasonable potential for the greatest exposure and/or health impacts from a given pathway could be selected as representative of the “high end” for that group (as other receptors would be impacted to the same or a lesser degree), also considering the likelihood of that exposure. Limiting the number of scenarios/receptors evaluated in the risk assessment by such an approach would help focus interpretation of the risk results.

- Other influencing factors should be assessed on a case-by-case basis for relevance to the most plausible exposures and related health effects associated with Hanford Site contaminants.

5.2.2 Ecological Risks

The development of study sets for ecological risk evaluation would include two components: (1) identification of the study set of contaminants of potential ecological concern; and (2) identification of the study set of ecological resources to be evaluated in the risk assessment. Identification of these study sets would necessitate the development of candidate sets of ecological resources and potential contaminants from which the specific study sets would be drawn.

5.2.2.1 Potential Criteria for the Ecological Risk Assessment Contaminant Candidate Set

The contaminant candidate set should include all chemicals and radionuclides identified through the evaluation of Hanford process history, available site data, and appropriate model predictions. In addition, the identification of a candidate contaminant set should at first consider all media (groundwater, sediment, soil, surface water, and air). For the ecological risk assessment, soil, sediment, and surface water are the media most likely to be associated with exposure of ecological resources.

5.2.2.2 Potential Criteria for the Ecological Risk Assessment Contaminant Study Set

Although the initial evaluation may identify a large number and variety of contaminants that may potentially pose an ecological risk, it is likely that only a subset of the candidate set will actually warrant further, detailed evaluation with regard to ecological risk. Identification of this study set of contaminants should be a function of completeness of exposure pathways to ecological resources and of the contaminant-specific ecotoxicological mode of action.

A screening process for selecting a contaminant study set is depicted in Figure 5.1. For a risk to be present, the contaminant exposure must be of sufficient magnitude to cause harm, and this factor serves as the basis for identifying the study set contaminants. The screening process should examine the known or expected distribution of contaminants together with the known or suspected distribution of ecological receptors. The identification of contaminant exposure should encompass all media and would likely result in different contaminant subsets for each environmental media. For example, organic compounds may dominate the contaminant list for sediment, while metals may dominate the surface water contaminant list.

Contaminants for which complete exposure pathways are identified or indicated should be retained and evaluated further with regard to toxicity and effects. For this evaluation, reported or predicted media concentrations should be compared to “safe” benchmark media levels. These latter values represent regulatory or other media concentrations below which ecological risks are expected to be acceptable. For example, the EPA Ambient Water Quality Criteria consist of surface water concentrations of selected contaminants that are considered to be protective of freshwater and marine biota.

In addition to the media concentrations being evaluated, the candidate set contaminants should also be evaluated with regard to unacceptable dose levels to wildlife. For this evaluation, receptor-specific models must be developed, “safe” dose benchmarks identified, and contaminant-specific doses from all exposure pathways estimated. Based on evaluations of media concentrations and dose, those candidate set contaminants for which one or more complete exposure pathways are indicated and that also occur at levels exceeding safe concentrations should be retained as the contaminant study set that would be evaluated in detail in the risk assessment.

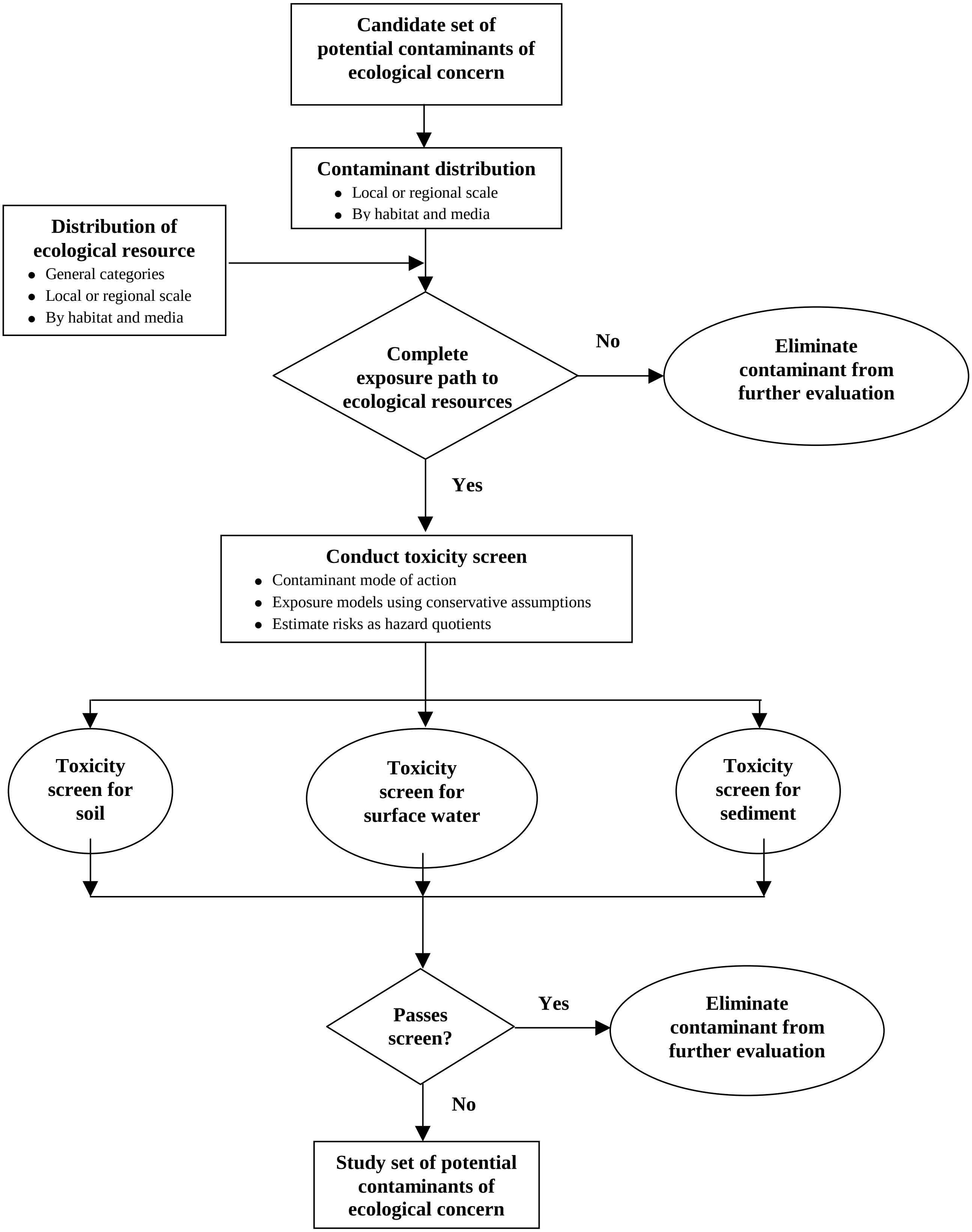

FIGURE 5.1 Framework for Identifying Study Set Potential Contaminants of Ecological Concern

5.2.2.3 Potential Criteria for the Ecological Risk Assessment Receptor Candidate Set

The candidate set of ecological receptors should encompass all ecological resources potentially affected by or within the sphere of influence of the Hanford Site. This candidate set should include ecological resources across a range of ecological organization (e.g., individual, population, community, and ecosystem) and habitat type (e.g., terrestrial, aquatic, forest, shrub-steppe, and palustrine). The nature of the candidate set for a specific location or area will be a function of the environmental setting at the location of concern.

5.2.2.4 Potential Criteria for the Ecological Risk Assessment Receptor Study Set

Selection of the ecological receptor study set should be based on three evaluations:

- An evaluation of the functional categories (e.g., trophic levels) and ecologically relevant attributes (e.g., provides nesting habitat, maintains nutrient cycling, critical for pollination) of the candidate set receptors at the site under investigation,

- An evaluation of the known or suspected co-occurrence of candidate receptors and the study set contaminants of concern, and

- An evaluation of the mode of action (known or suspected) of the contaminants with regards to each exposed candidate set receptor.

In addition, the candidate receptor set should be evaluated for the presence of species or other ecological receptors (such as communities or habitats) that have a known regulatory (e.g., protected by law), economic (e.g., support a commercial activity), or cultural (e.g., spiritual or religious) importance. Figure 5.2 depicts a framework for developing an ecological receptor study set on the basis of these evaluations.

The first step consists of identifying functional categories and/or ecologically relevant attributes of each candidate set receptor. For example, a wetland habitat has a number of ecologically relevant attributes, including contributing to nutrient cycling; providing nesting, nursery, and foraging habitat for fish and wildlife; and purifying water. In contrast, the relevant attributes of a primary consumer, such as the harvester ant, may include seed dispersal, mechanical and chemical soil processing, soil nutrient dynamics, and serving as a food source for insectivorous wildlife. A top trophic level predator, such as Harlan's hawk, may have an important role in maintaining small mammal populations at a site. While this identification of functional categories and ecologically relevant attributes alone will not identify specific study set receptors, it provides the basis for selecting study set receptors that are ecologically important at the site (or region) under investigation.

In addition to this strictly ecological evaluation, all candidate set receptors should be evaluated with regard to their regulatory importance. For example, the candidate receptor set should be evaluated for the presence of species (e.g., the Federally protected bald eagle) or other ecological resources (e.g., habitats such as wetlands) that are protected by Federal, state, or other law. The candidate receptor set should also be evaluated for resources of commercial or recreational importance. These receptors may include actively managed commercial fish stocks, wildlife such as deer and waterfowl that support recreational hunting, and habitats such as parks and nature areas that support hiking, camping, and other similar recreational activities. The candidate receptor set should also be examined for the presence of receptors known to be of cultural importance.

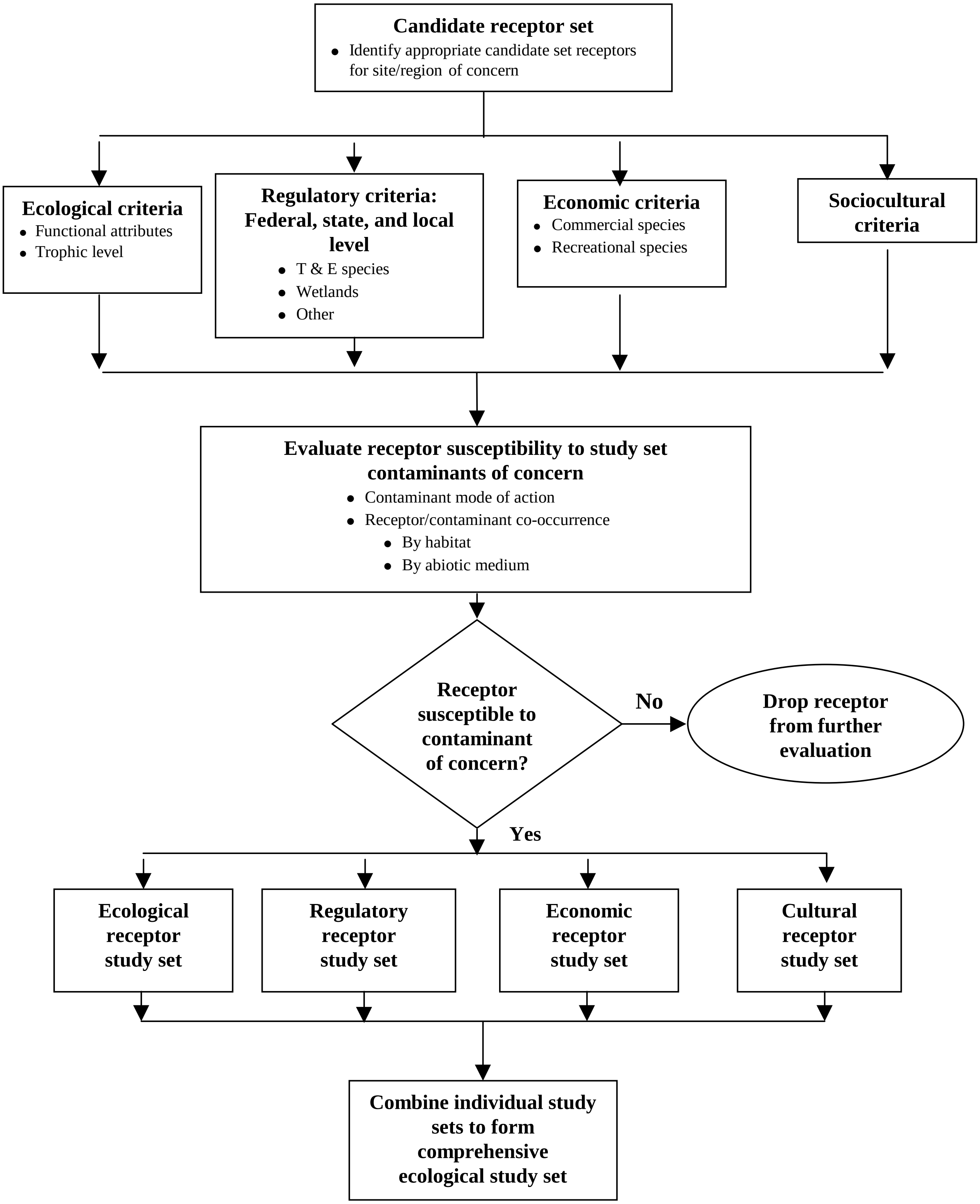

FIGURE 5.2 Framework for Developing a Comprehensive Study Set of Ecological Receptors

At the conclusion of these evaluations, the receptors in the initial candidate set will have been characterized on the basis of their ecological, regulatory, economic, and sociocultural roles and importance. Next, the distributions of each candidate set receptor and each study set contaminant of concern should be evaluated to identify which candidate set ecological receptors are being exposed (or could be exposed on the basis of fate and transport modeling predictions) to which study set contaminants. For example, at a particular site, polychlorinated biphenyls (PCBs) may occur within sediments but not in the water column or in soils. Thus, only those candidate set receptors that inhabit (e.g., infaunal macroinvertebrates) or come in contact with (e.g., foraging shorebirds such as the avocet) sediments should be further evaluated for adverse effects from PCB exposure.

Each candidate receptor/contaminant study-set pair should next be evaluated to determine whether the receptor is susceptible to the known or suspected mode of action of the contaminant. Receptors unlikely to be affected by the contaminants should be dropped from further evaluation. For example, a site may have cadmium present in both surface water and soil at concentrations slightly elevated over background levels. However, cadmium is acutely toxic to aquatic biota because its primary mode of action is to affect gills, while terrestrial biota are largely unaffected by cadmium except at very high doses. Thus, on the basis of the known mode of action of cadmium, only aquatic biota would need to be retained for the evaluation of ecological risks associated with cadmium exposure.

Following the evaluation of co-occurrence and susceptibility, the remaining candidate set receptors (i.e., those that co-occur with one or more of the study set contaminants and that are susceptible to the known or expected effects of the contaminants) are retained as the ecological receptor study set. This study set reflects not only the potential exposure and susceptibility of ecological resources to site contaminants, but also includes considerations of ecological regulatory requirements and the concerns of other impact sectors. For example, the study set receptors identified for evaluating cadmium exposure in surface water may include fish species that serve as an important prey item to higher trophic level fish, as well as those that are protected by law, used for recreational fishing, or that are culturally important to some groups.

The receptor study set selection process also serves to categorize the study set receptors on the basis of their ecological roles and functions, which will aid in the selection of study set receptors that may serve as surrogates for, or are considered as representative of, larger functional categories. For example, the deer mouse may be selected to serve as a surrogate for the small mammal component of the primary consumer trophic level in upland habitats. Although many members within this group play an important role as the prey base for higher trophic level predators and in maintaining plant community composition, it would not be possible to evaluate all small mammals at the site. By selecting the deer mouse as a surrogate on the basis of its ecological role and function, available staff and budgetary resources can be focused on a single receptor so as to collect sufficient data (in terms of both quantity and quality) to support a risk characterization of the site.

In summary, the candidate contaminant set should be developed on the basis of the known or expected occurrence of contaminants, as determined from evaluation of characterization data, modeling results, and knowledge of site process history. The study contaminant set should then be derived on the basis of the known or expected presence of complete exposure pathways to any ecological resources and on the known or predicted exceedence of “safe” benchmark concentrations of the contaminants. The ecological receptor candidate set should be determined on the basis of the ecological resources known or expected to occur within the area of influence of the site under evaluation. The study set of receptors can then be derived on the basis of the co-occurrence of the receptor candidate set and the contaminant study set, the mode of action of study set contaminants, and the functional categories and ecologically relevant attributes of the candidate set receptors.

5.2.3 Sociocultural Impacts

5.2.3.1 Potential Criteria for the Sociocultural Impact Candidate Set

The objective in selecting cultural impact candidate sets is to be sufficiently comprehensive to include all sociocultural communities whose quality of life could be impaired. Impairment could occur, for example, through loss of access to or limited use of the Hanford Site or resources affected by Hanford contaminants, such as salmon or specific plants.

5.2.3.2 Potential Criteria for the Sociocultural Impact Study Set

Communities that should be included in the study set are those likely to endure the greatest sociocultural harm – in the short term as well as the long term. A cultural community should also be included in the study set if the government owes a particular responsibility to that community's welfare. Moving from candidate sets to study sets requires consideration of treaty and trust responsibilities, as well as application of methods for determining if the sociocultural harm results from loss of access or resources due to effects of GW/VZ contamination or to unrelated co-stressors. The candidate set should be structured to allow assessment of both the magnitude and distribution of impacts. The magnitude of total effects is important, but not to the exclusion of consideration of who bears the burden of those impacts.

5.2.4 Economic Impacts

5.2.4.1 Potential Criteria for the Economic Assessment Candidate Set

The economic assessment candidate set of impacts and receptors should provide comprehensive coverage of regional economic activity (i.e., greater than 95% of overall activity). It should also be comprehensive in its inclusion of components of the economic system at various levels of economic organization (i.e., populations, population subgroups, firms, economic sectors, and markets). Two major types of entities need to be evaluated to identify subcategories for inclusion in the candidate set:

- Economic sectors of production and employment (e.g., agriculture, fisheries, tourism), and
- Population subgroups with special economic interests (e.g., migrant workers, subsistence fishers, households using river water for drinking).

Assessing impacts for these two types of entities differs in that the economic sectors are composed of firms that may be adversely affected by either increased production costs or decreased demand for their products. Impacts on firms then filter down to impacts on individual people. Populations may be affected directly, similarly to firms, but additionally, may experience losses of goods, such as access to a particular site or recreational fishing opportunities, that are not reflected in market data. Both types of impacts, market and nonmarket, need to be considered in the evaluation. For assessment purposes, these two types of entities must both be delineated in terms of the region or market in which they are economic actors. Thus, the candidate set needs to be defined in terms of either sectors or population groups within, or associated with, particular locations or markets that would be affected by GW/VZ contamination.

The relative magnitude of potential impacts should be considered in determining if the set is sufficiently inclusive. For instance, impacts that affect less than 1% of economic activity in the impact region should probably be excluded, unless the components affected are crucial to the economic well-being of a population subgroup considered to be potentially affected.

The candidate set should be structured to allow assessment of both the magnitude and the distribution of impacts. Sufficient regional, sectoral, and population subgroup detail is needed to determine whether particular entities are likely to be simultaneously affected by multiple impacts, developed through different processes. (This is conceptually similar to the consideration of synergistic effects in the health risk assessment.)

In summary, the candidate set should:

- Include all major potentially affected economic units (e.g., those contributing more than 1% to the regional economy or that are critical to a population subgroup),

- Cover specific markets and the regional economy sufficiently comprehensively to account for 95% of economic activity,

- Permit assessment of both magnitude and distribution of impacts among sectors and population subgroups, and

- Include both market and nonmarket effects.

5.2.4.2 Potential Criteria for the Economic Assessment Study Set

To focus the assessment of potential economic impacts, three criteria are proposed for selection of the study set of impacts/receptors from the candidate set.

- **Relative importance of impacts** – Threats to major components of economic activity of a sector or a population subgroup should be evaluated. A threshold of 10% of income for an economic sector or subgroup might be an appropriate minimum impact magnitude for inclusion in the study set. Nonmarket impacts should be included if they are a major factor in the well-being of a population subgroup.

- **Econometric model availability/adaptability** – Given the immensity of the task of assessing potential impacts, effective use of analytical resources will be important. To this end, existing analyses and economic models for the potentially affected region and sectors should be used or adapted for use if possible.

- **Data availability** – Some of the required analyses for an assessment can be conducted with currently available data. Other analyses, for instance the cost of providing alternative drinking or irrigation water supplies or the value of a site sacred to Tribal people, may require considerable new work to develop. Availability of necessary data should be considered (weighted by the relative importance) of impacts, in selecting the study set. Potentially important impacts for which quantitative data are lacking should not be omitted from the evaluation, but should be treated qualitatively.

Where data or analytical tools are unavailable, impacts should be assessed qualitatively or placed on a watch list for future evaluation.

5.3 ANALYSES RELATED TO SPECIFIC IMPACT CATEGORIES

This section provides suggestions for studies to test methods or refine scopes that apply to each of the categories of impacts. Effort is also needed on identifying and further developing linkage methods, as illustrated by the dependency web concept, to focus on the appropriate pathways, receptors and uptake/intake factors for the quantitative study.

5.3.1 Human Health Risks

- Conduct a toxicity-concentration screen to identify primary contributors to estimated risk, including consideration of mixtures and multiple endpoints, as indicated.
- Evaluate biochemical structure/molecular models and other information to aid in assessing contaminants for which toxicity data are lacking.
- Evaluate bases for grouping contaminants and receptors to help prioritize and streamline the assessment.

5.3.2 Ecological Risks

- Evaluate existing information to identify where candidate set receptors and site contaminants are known or suspected to co-occur.
- Develop ecotoxicological profiles that identify toxicological mode of action (e.g., increased mortality, reduced reproductive success, or impaired kidney function) and associated threshold values, contaminant fate characteristics relative to biological systems (e.g., water solubility), and potential for bioaccumulation.
- Design and conduct constituent-specific studies to address ecotoxicological data gaps.
- Identify broad generic assessment endpoints (e.g., protection of wetland function or maintenance of the raptor community) for the appropriate candidate set receptors.
- Identify functional categories (e.g., trophic levels) and ecologically relevant attributes (e.g., provides nesting habitat or maintains nutrient cycling) associated with each candidate set receptor and associated assessment endpoint.
- Conduct toxicological evaluations of Hanford GW/VZ contaminants for species anticipated to be included in an ecological risk assessment.
- Develop any necessary benchmarks and calculate appropriate biomagnification factors on the basis of the specific contaminants, receptors, and habitat availability and use.
- Collect reference site data for species, population, community, and ecosystem parameters at a comparable unaffected site; such data are essential to an adequate assessment of ecological risks to Hanford area receptors.
- Compile results of any studies addressing biodiversity parameters if necessary; diversity indices that incorporate species richness and evenness, such as the Shannon-Weiner index, should be developed for Hanford locations and reference sites if not already available.

5.3.3 Sociocultural Impacts

- Review existing methods and data related to indicators of sociocultural health to compile relevant examples.

- Identify techniques that need to be developed or enhanced, including in areas such as historical analysis of cultural patterns, expert elicitation of cultural information, linguistic analysis (loss of language or terms), and open-ended surveys to assess key indicators.

- Develop an approach that includes building assessment capacity as indicated, whereby the affected parties can gather the information needed to identify social and cultural resources that could be at risk and develop appropriate biological exposure scenarios to guide protection plans. (Appreciating that information on cultural patterns and other data can be proprietary, certain information is important for developing appropriate exposure scenarios to assess human health and ecological risks and to ascertain cultural resources and patterns that could be at risk so site plans can best address those concerns.)

- Identify methods to determine when the potential harm of remediation/restoration outweighs the risks of allowing contaminants to remain in place. This is important because harm to all resources and overall quality of life can come from the act of environmental remediation or restoration that involves disturbing the environment and its valued components.

5.3.4 Economic Impacts

- Identify the availability and applicability of existing sectoral (e.g., fishing industry in the Northwest, irrigated agriculture in the West) and regional (e.g., Columbia Basin or Portland area) economic models.

- Identify prior studies of sectors that could be impacted (e.g., Columbia River fisheries and tourism) and evaluate their applicability to the impact assessment.

- Develop a basis for projecting relationships between various types of events related to GW/VZ contamination and stigma-based economic impacts; evaluate information on the nature, severity, and duration of changes in public behaviors/activities that have resulted from different types of events; examine the effects of various strategies for risk management and risk communication in the exacerbation or diminution of stigma-based impacts.

- Review methods of assessing values of nonmarketed goods that would be potentially impacted (e.g., subsistence fishing).

- Develop methods of valuing cultural resource losses to Native American communities.

APPENDIX A

EVALUATION OF THE RADIOLOGICAL CONTAMINATION IN THE HANFORD REACH OF THE COLUMBIA RIVER

A.1 INTRODUCTION

This appendix describes tritium concentrations measured in the Columbia River flow within the Hanford Reach for the last 17 years and characterizes groundwater contaminant profiles on the Hanford Site. It combines that information with projected changes in those profiles as a function of time to provide an estimate of current and future risks that might result from drinking Columbia River water.

Both chemical and radiological contaminant concentrations are routinely measured upstream of the Hanford Reach (near the Priest Rapids Dam) and downstream (at the Richland Pumphouse). The positive difference between these measurements (i.e., any increase of the downstream concentrations compared with upstream concentrations) can be taken to represent the incremental contribution of contaminants from Hanford Site area groundwater flows to the Columbia. Over the past 17 years, only three radioactive materials, tritium, iodine-129, and total uranium had significant measured differences. Over the most recent 5-year reporting period (1993-1997), the average downstream concentration increases were 46 pCi/L for tritium, 0.00008 pCi/L for iodine-129, and 0.07 pCi/L for uranium. No significant differences between upstream and downstream measurements of strontium-90, technetium-99, or plutonium concentrations were found (Dirkes and Hanf 1998). While technetium-99 concentrations of 900 pCi/L occur in the 100-H Area of the Hanford Site relatively near the river, no elevated levels have yet been detected in the river at the site or downstream. The annual average technetium-99 concentrations were actually higher upstream than downstream during 1996 and 1997 (Bisping 1997, 1998).

For uranium, a major contributor to the upstream-downstream concentration gradient may be irrigation water from Franklin County across the river from the Hanford Site. Total uranium concentrations in the Ringold and Byers Landing irrigation return canal water were reported to be 10 times higher than background concentrations in the Columbia River (Dirkes 1990). Given that uranium is a naturally occurring radionuclide known to be present in groundwater in Franklin County, it is not unexpected for it to be found in the springs entering this stretch of the river. A likely contributor to higher concentrations in the irrigation return water may be the phosphate fertilizer applied to this agricultural land, because the source ores for this type of fertilizer commonly contain elevated levels of uranium (Dirkes 1990).

In terms of concentration, tritium currently is the major radioactive contaminant of Hanford groundwater and the Columbia River. It is the most mobile of radioactive contaminants, moving at essentially the same speed as water. The tritium plume contours may be considered a frame of reference for the general behavior of other mobile contaminants. It has reached the river in concentrations higher than 20,000 pCi/liter (and as high as 200,000 pCi/L) for at least 10 to 15 years. However, during that periodm the difference between upstream and downstream measurements has never exceeded 67 pCi/L.

A.2 COLUMBIA RIVER CONTAMINANT CONCENTRATIONS, 1981-1997

Table A.1 shows the tritium data for the Priest Rapids Dam (PRD) and the Richland Pumphouse (RPH) for the 1981-1997 interval. Average annual Columbia River flows were used to calculate the tritium material balance for the river. Both the curies and mass of tritium added to the Columbia River from Hanford groundwater flow for each year are shown in the second and third columns from the right. The average tritium flow was about 5,500 curies per year, or about 0.57 grams per year (grams of tritium = curies of tritium multiplied by 2.8 x 10^{-6} times the atomic weight [3] and half-life [12.3 years]).

TABLE A.1 Estimated Tritium Added to Columbia River by Hanford Groundwater, 1981 to 1997

Year	Flow (cfs)	PRD, (pCi/L)	RPH, (pCi/L)	Hanford Increment, (pCi/L)	Curies per Year	Grams per Year	MEI Dose, mrem/yr
1981	132,000	167	199	32	3800	0.39	0.006
1982	140,000	159	216	57	7100	0.74	0.011
1983	131,000	103	135	32	3700	0.38	0.006
1984	112,000	127	169	42	4200	0.44	0.008
1985	107,000	112	152	40	3800	0.39	0.008
1986	108,000	98	149	51	4900	0.51	0.010
1987	101,000	73	128	55	5000	0.52	0.010
1988	100,000	70	135	65	5800	0.60	0.013
1989	99,000	64	128	64	5700	0.59	0.013
1990	137,000	53	105	52	6400	0.66	0.010
1991	141,000	45	112	67	8400	0.87	0.013
1992	101,000	50	101	51	4600	0.48	0.010
1993	91,000	40	96	56	4600	0.48	0.011
1994	94,000	38	94	56	4700	0.49	0.011
1995	113,000	35	83	48	4800	0.50	0.010
1996	161,000	31	68	37	5300	0.55	0.007
1997	170,000	28	61	33	5000	0.52	0.007

[a]Notation: cfs = cubic feet per second; pCi/L = pica curves per liter; MEI = maximum exposed individual; mrem/yr = millirems per year.

Source: Patton (undated).

Although both upstream and downstream concentrations are declining because of the relatively short half-life of tritium (12.3 years), a trend in the annual tritium flow is not clearly established. However, the 5-year moving average for the tritium flow into the Columbia has declined from 6,300 to 4,900 curies per year from 1991 to 1997. In fact, the concentration of tritium at the Priest Rapids Dam has declined more than can be attributed to radioactive decay. Over a 16-year period, the initial tritium concentration of 167 pCi/L would be reduced to 68 pCi/L by radioactive decay; however, the 1997 value was 28 pCi/L. If this anomaly is attributable to improvements in analytical technology, a back-calculated value of 69 pCi/L could be inferred for the 1981 upstream concentration.

Figure A.1 shows the yearly average tritium concentration increment between the upstream and downstream measurement points from 1981 to 1997. As listed in Table A.1, the maximum difference occurred in 1991. A general decline has been observed since 1991. Figure A.2 shows the inferred mass flow of tritium from groundwater into the Columbia River in grams per year. As pure tritiated water, HTO, this is equivalent to about 3.5 grams per year.

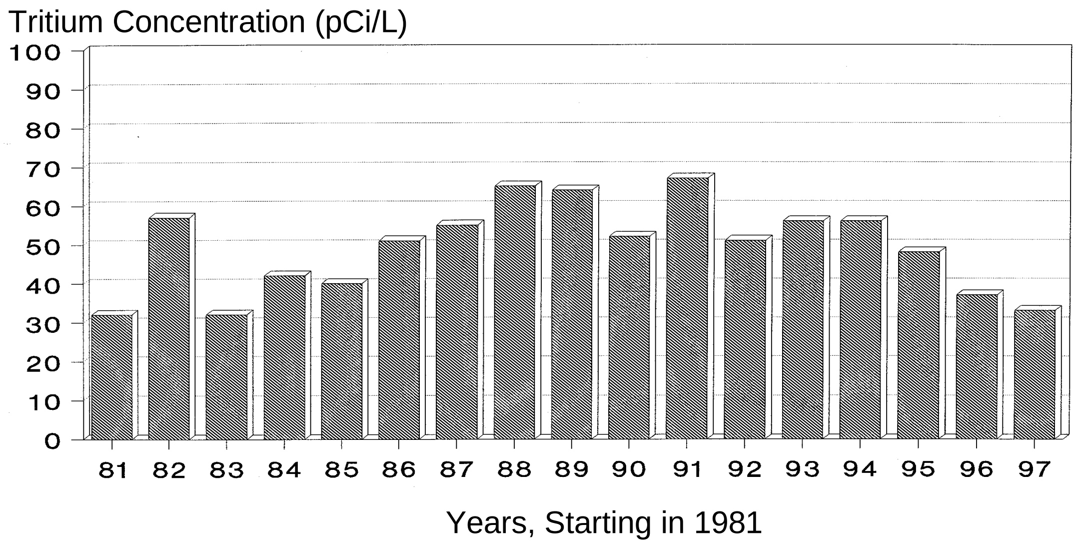

FIGURE A.1 Incremental Tritium Concentration Change (difference between Richland pumphouse and Priest Rapids dam concentrations) in the Columbia River

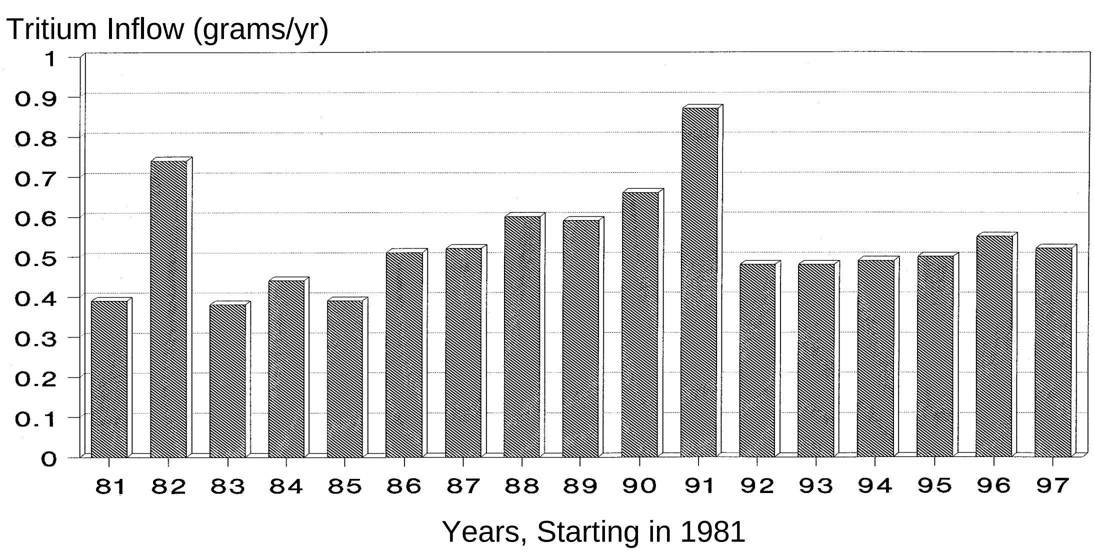

FIGURE A.2 Mass Flow of Tritium from Hanford Site Groundwater to the Columbia River

A.3 POTENTIAL RADIOLOGICAL DOSES FROM INGESTION OF COLUMBIA RIVER WATER

Figure A.3 shows the annual whole-body dose estimated for a hypothetical maximum exposed individual (MEI), in mrem. For this calculation, it is assumed that the MEI drinks 2 liters of water from this portion of the Columbia River every day of the year (730 liters per year).

The basis for this dose calculation is the U.S. Environmental Protection Agency (EPA) drinking water standard (EPA, Title 40, Code of Federal Regulations, Part 141), which uses a tritium concentration of 20,000 pCi/L as the concentration that would produce an annual dose of 4 mrem. The range of incremental tritium concentrations in the Columbia River for the 17-year period produces annual doses in the range of 0.007 to 0.013 mrem. The average annual dose to the hypothetical MEI is about 0.01mrem.

In practical terms, one would have to drink 10,000 glasses of Columbia River water containing tritium to get the same dose as is obtained from drinking a single glass of 2% milk. Milk contains about 2,000 pCi/L of natural potassium-40, compared with about 50 pCi/L of tritium in the Columbia River water. The decay energy of potassium-40 is 1.46 MeV, while the decay energy of tritium is 0.0186 MeV (General Electric Co. 1977). The ratio of the drinking water standard for tritium to that of potassium-40 is 267 to one (Nuclear Regulatory Commission, Title 10, Code of Federal Regulations, Part 20, Appendix B). Taken together, the product of the 40-fold concentration difference and the 267-fold difference in the drinking water standard is about 10,000. The estimated population dose commitment to the local population of 380,000 for 1997 is 0.2 person-rem; the estimated average dose is about 0.0005 mrem (Dirkes and Hanf 1998).

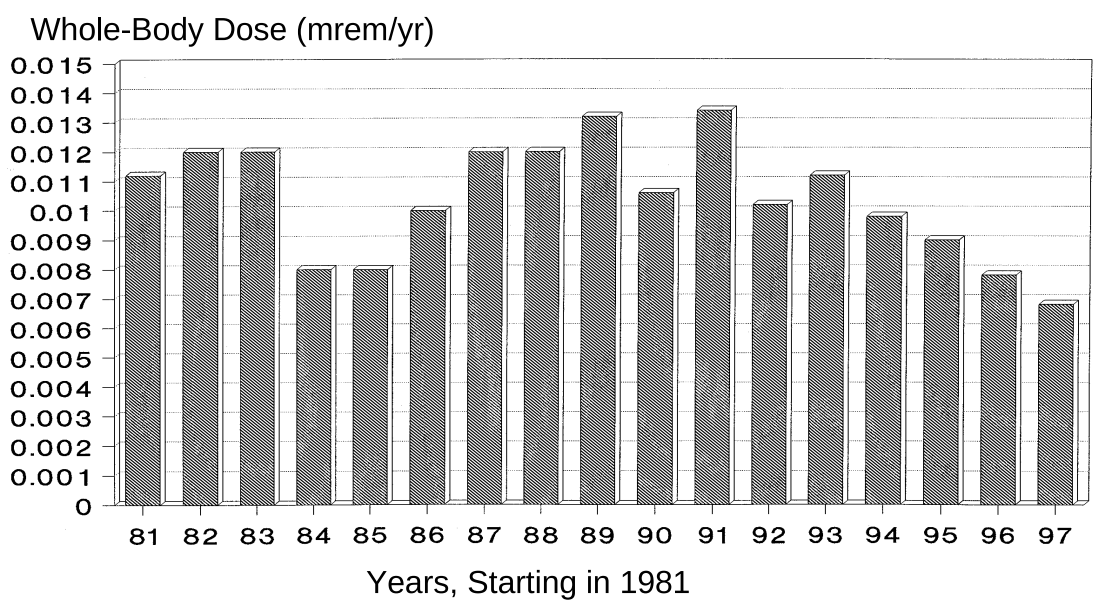

FIGURE A.3 Annual Whole-Body Dose for an Individual Drinking 730 Liters per Year of River Water

The estimated 0.01 mrem per year MEI dose from the hypothetical 2 liter per day ingestion of river water is roughly equivalent to the difference in cosmic radiation exposure encountered by a 1-foot change in the altitude at which a person lives. The average population dose would be equivalent to an altitude change of about 5/8 inch. While individual social, cultural, ideological, or psychological factors could affect personal attitudes toward such exposures, the 0.01 mrem per year MEI dose appears to be insignificant on the basis of human health or environmental risks.

A.4 TRITIUM CONCENTRATION PROFILES IN HANFORD SITE GROUNDWATER

The Hanford Groundwater Monitoring Project has used data from monitoring wells to produce contour maps of tritium concentrations for more than three decades. The major sources of tritium were the discharges of process condensates from fuel dissolution operations at the 200-West and 200-East facilities. Tritium was also manufactured by irradiation of lithium-containing targets in site reactors from 1949 to 1952; in the late 1960s, tritium was produced in the N-reactor. The major operating campaigns in the 200-East PUREX facility took place in the 1956-1972 and the 1983-1988 periods. Although the leading edge of the tritium groundwater plume from the latter campaign has been observed near the Central Landfill, the effects have not yet been detected near the Columbia River. The 1956-1972 campaign produced much higher tritium concentrations than the second campaign (Dirkes and Hanf 1998).

Figure A.4 shows historical tritium concentration contours in groundwater at the Hanford Site in 1964, 1974, 1983, and 1988 (Dirkes and Hanf 1998). The tritium plume from 200-East operations reached the Columbia River in the mid-1970s. In the later periods, the 20,000 pCi/L contour around the 200-East facility diminished, reflecting the 11-year gap in operations.

|While the effect of the hiatus in operations was observed near the 200-East facility, the extent of the 20,000 pCi/L contour at the Columbia River interface broadened over the next decade, as shown in the following illustrations for 1990, 1993, and 1997. Tritium concentration contours of 200,000 pCi/L are shown for 1990 and 1993 at the river interface near the Old Hanford Townsite (OHT), and concentrations as high as 140,000 pCi/L were still found in that region in 1997. These observations are consistent with the peak concentration increments shown in 1989-1991, as listed in Table A.1 and shown in Figure A.1.

Figure A.5 shows two 200,000-pCi/L contours for 1990, one extending to the southeast from the 200-East area and the other bracketing the area of the six monitoring wells around the OHT (Woodruff and Hanf 1991).

From this scale of illustration, the 20,000-pCi/L and the 200,000-pCi/L contours contiguous to the southeastern corner of the 200-West facility appear to show little change in the 1990 and subsequent maps. Scientists at PNNL have conducted a three-dimensional analysis of future groundwater flow conditions and contaminant plume transport in the Hanford site unconfined aquifer system (Cole et al. 1997). This analysis predicted that the tritium plume from the 200-West area would migrate under the 200-East area and be reduced by dispersion and decay. The plumes from the 200-East area are predicted to continue to flow toward the Columbia River.

Figure A.6 shows tritium contours for 1993 (Dirkes et al. 1994). The width of the 200,000 pCi/liter contour near the OHT appears to have narrowed at the Columbia River interface while the lower concentration contours appear to have slightly broadened at the interface relative to 1990.

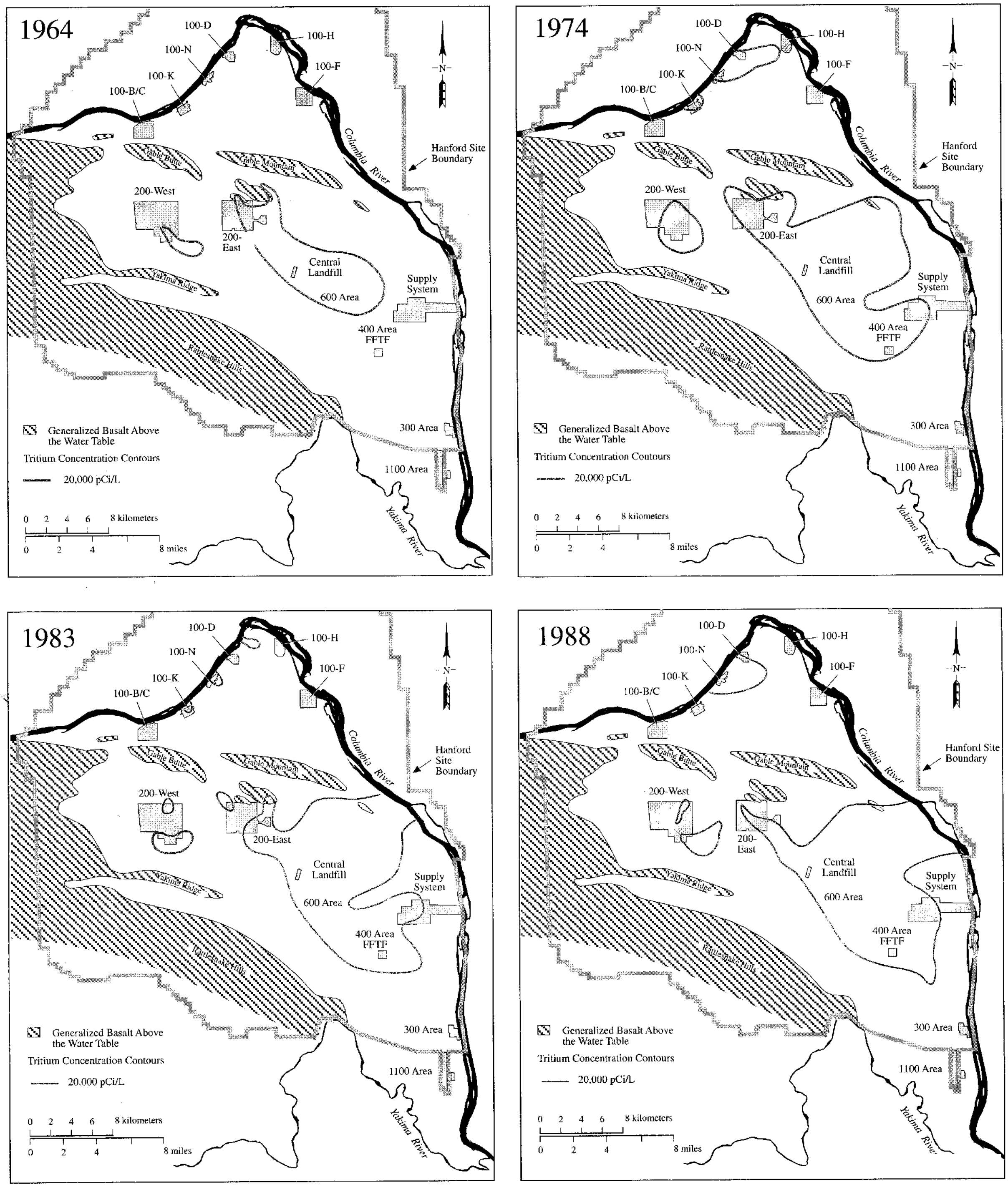

FIGURE A.4 Historical Tritium Concentration Contours (Source: Dirkes and Hanf 1998)

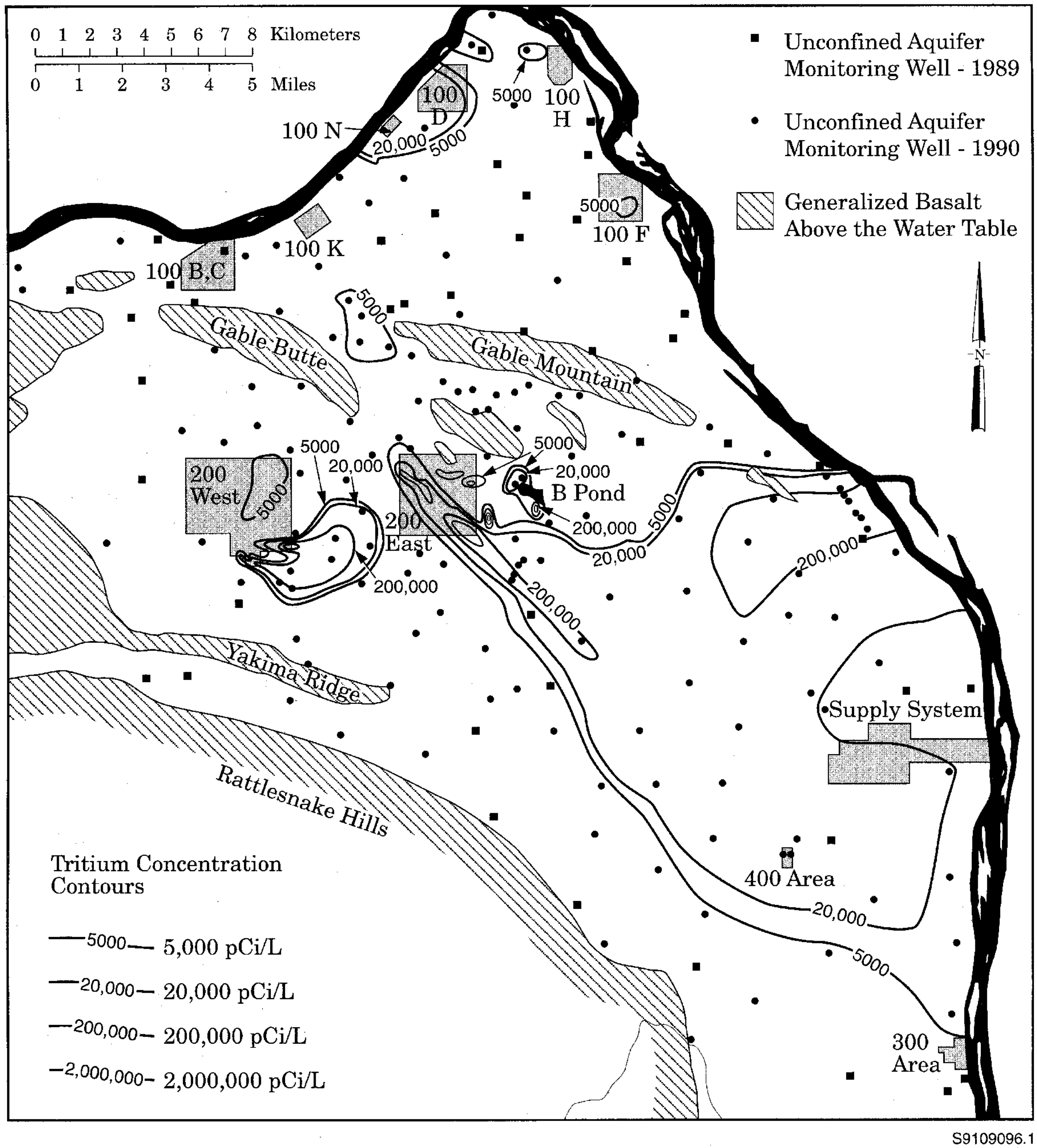

FIGURE A.5 Tritium Concentration Contours for 1990 (Source: Dirkes and Hanf 1998)

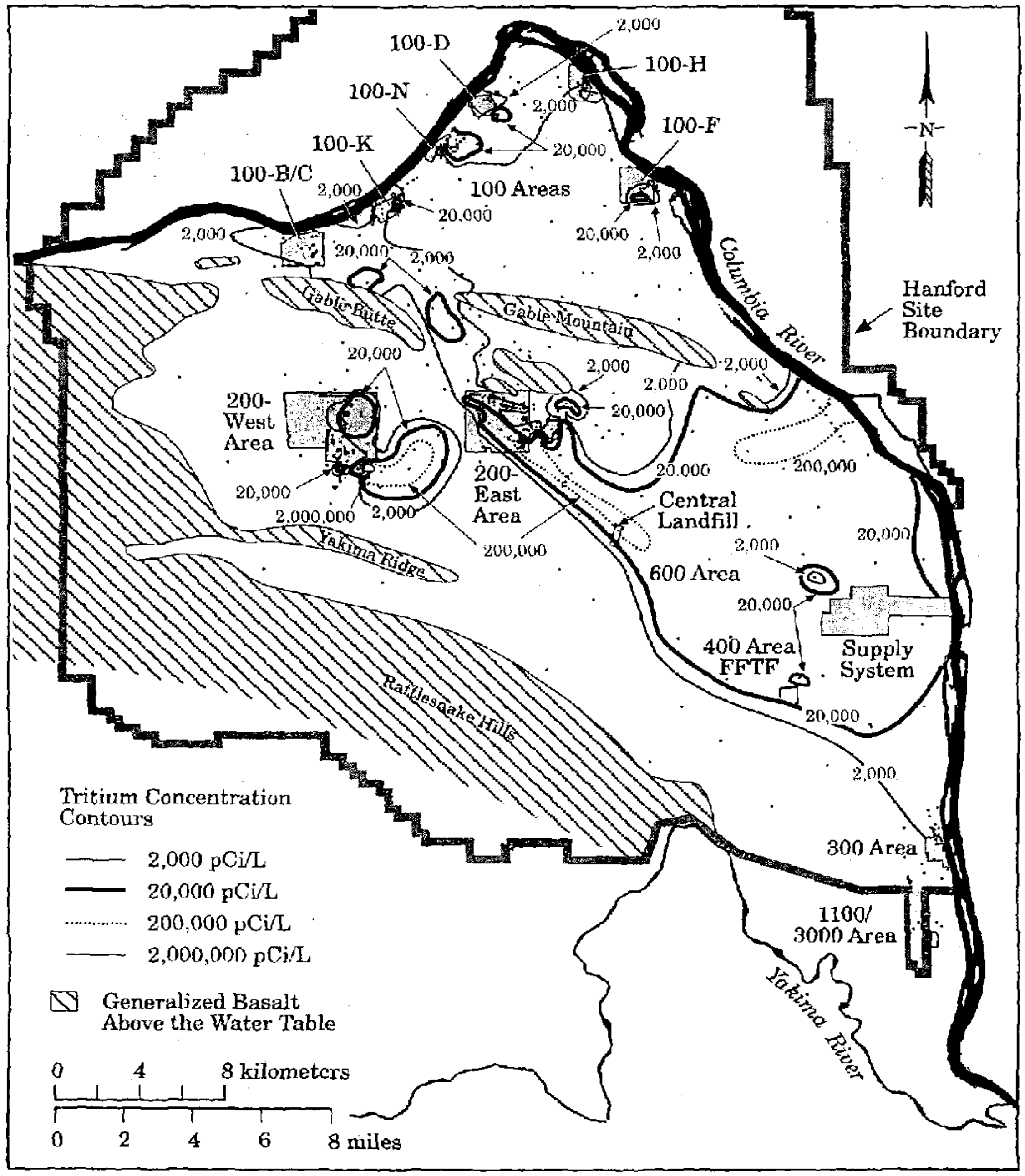

FIGURE A.6 Tritium Concentration Contours for 1993 (Source: Dirkes and Hanf 1998)

Figure A.7 illustrates the 1997 tritium contour data for the Hanford Site (Dirkes and Hanf 1998). The 200,000-pCi/L contours have disappeared, although detailed well data for the OHT area and the general area to the west-southwest still have tritium concentrations in the 100,000-140,000-pCi/L range. The effects of the last operating campaign in the 200-East area were first observed at the Central Landfill in 1987, with concentrations exceeding 200,000-pCi/L in the 1989-1992 period. By 1997, the concentration peak had passed, and the average concentration had dropped below 100,000-pCi/L.

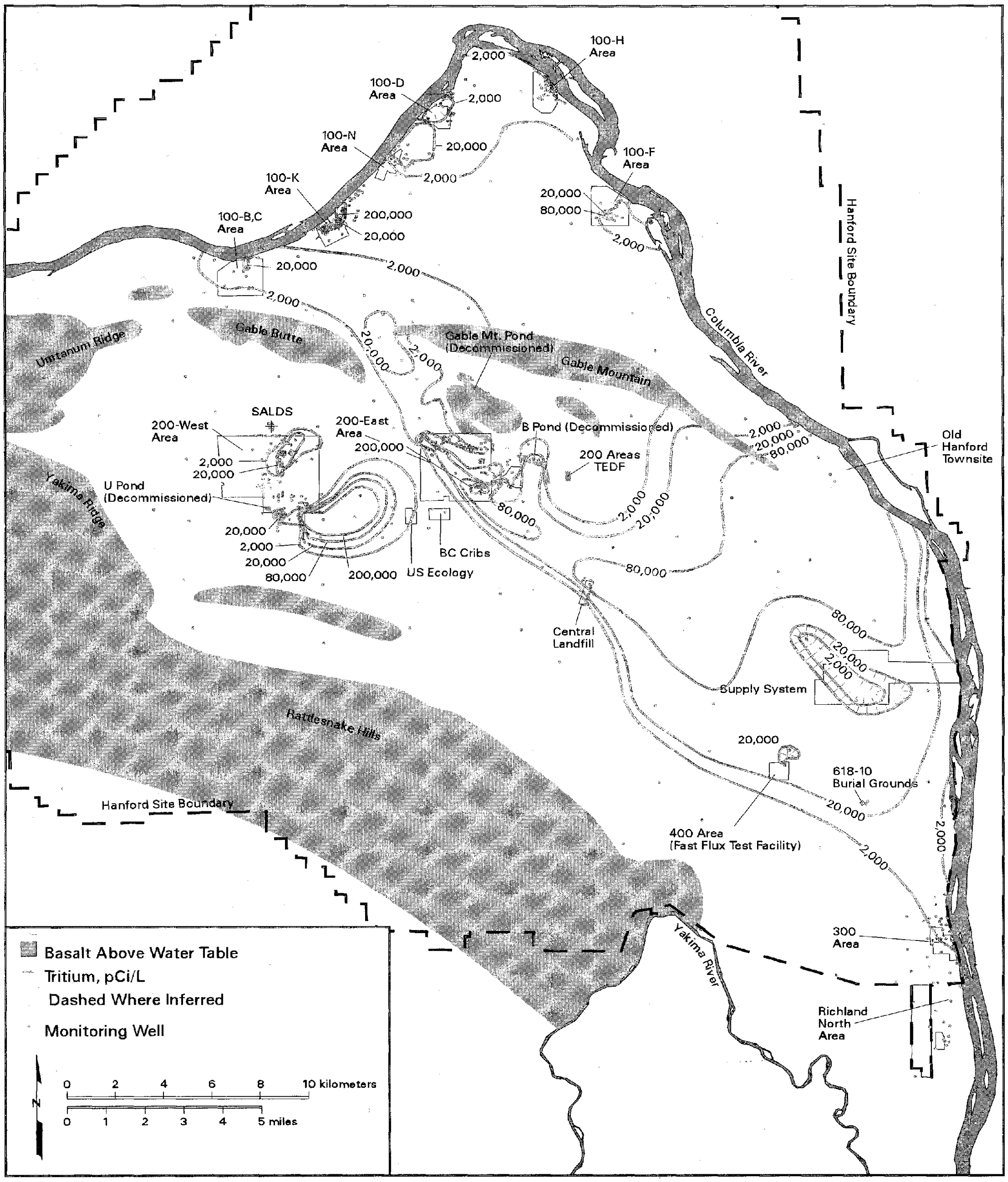

FIGURE A.7 Tritium Concentration Contours for 1997 (Source: Dirkes and Hanf 1998)

The foregoing sequence of contour maps provides a set of initial conditions for both an examination of the complex set of phenomena that control the characteristics of the tritium concentration profiles in the groundwater and a review of the long-term projections for contamination plumes reported in the three-dimensional analysis report by Cole et al. (1997).

A.5 PROJECTED TRITIUM PLUMES IN HANFORD GROUNDWATER AND COLUMBIA RIVER

The long-term behavior of tritium and other radioactive contaminant plumes in Hanford Site groundwater is a function of:

- Contaminant source terms and their histories;
- Site geology, including both physical configuration and soil characteristics;
- Water recharge rates;
- Axial and lateral diffusion;
- Mass flow rates of groundwater to the Columbia River; and
- Radioactive decay.

The concentration of tritium in the Columbia River is a function of the combined effects of the above factors, the natural and man-made global inventories of tritium, and the flow rate of the Columbia River. In 1963, the global inventory of tritium was 3.1 billion curies; about 97.7% of this tritium was produced by atmospheric testing of nuclear weapons. The remaining 2.3% was produced by the effect of cosmic rays in the upper atmosphere, with collisions of by-product neutrons and nitrogen-14 producing tritium and helium, or in other cases, carbon-14. Tritium may also be transported into the atmosphere by direct transport in cosmic rays, primarily from the sun.

The natural production rate of tritium is about 4 million curies per year. The natural steady-state inventory is about 70 million curies, with 5 million curies in the atmosphere and the majority of the remaining 65 million curies in the hydrosphere (oceans, lakes, and rivers) (Brown et al. 1983).

The following ordinary differential equation representing these inventories and rates can be solved to assess the global inventory of tritium over time:

$$dN/dt = A - BN$$

where: A = the natural global tritium production rate, 4 million (4E6) curies per year
B = the natural logarithm of 2 divided by the half-life of tritium, 0.0562
N = is the global tritium inventory in curies; N_0 is 3.1 billion C3.1×10^9 curies
t = the elapsed time in years

therefore, $N = A/B - (A/B)e^{-Bt} + N_0e^{-Bt}$

Substituting for the values of the parameters, the solution of this equation is:

$$N = 71E6 - 3.029E9e^{-0.0562t}$$

yielding changes in the global inventory from 1963 to 1998 as follows:

Year	Tritium *(million curies)*
1963	3,100
1968	2,360
1973	1,800
1978	1,370
1983	1,060
1988	814
1993	632
1998	495

Figure A.8 shows the predicted global inventory of tritium, not including any potential future nuclear weapons detonation products, for the1963-2063 period. The global inventory should decline to about 82 MCi over this period. The tritium concentration at the Priest Rapids Dam can also be expected to decline in these relative proportions.

While the global inventory declines, the inventory in Hanford groundwater is also decreasing. Although the definitive inventory of tritium in the groundwater is not known, radioactive decay alone will reduce the inventory by a factor of 50 between now and the year 2068, as shown in Figure A.9. In fact, radioactive decay may be the major factor in reducing tritium discharge to the Columbia River, as the declining tritium mass flow rate in groundwater, now about 5,000 curies per year, will be a minor contributor to the overall reduction in tritium concentration.

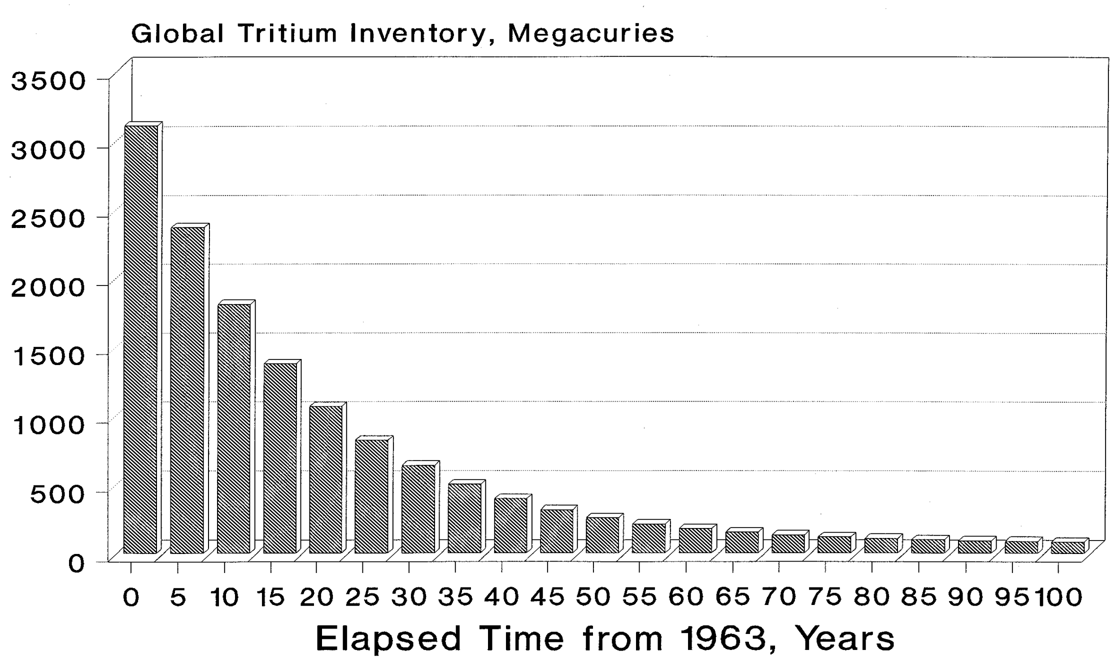

FIGURE A.8 Approach of Global Tritium Inventory to Steady-State Value of 71 MCi

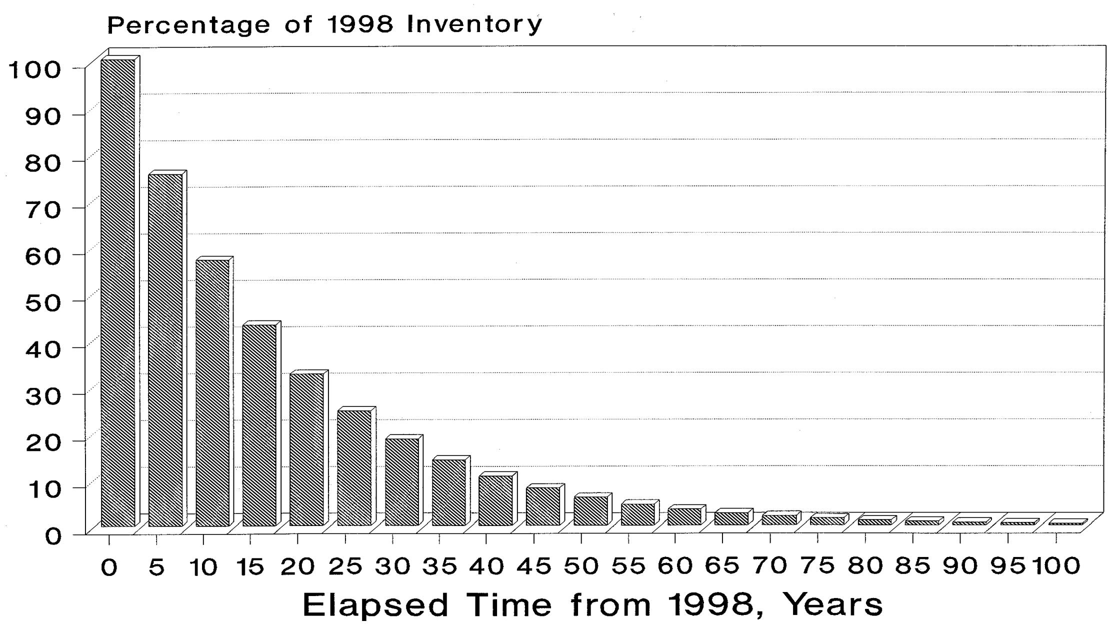

FIGURE A.9 Remaining Hanford Groundwater Tritium Inventory as a Percentage of 1998 Value

Assuming no future addition of tritium to the Hanford Site groundwater, both the tritium plumes and discharge rates to the river should essentially disappear by the middle of the next century. This is to be expected because of the combination of site geological characteristics, reduced recharge rates to the water table, mass flow to the Columbia, and radioactive decay. Whatever residual concentrations remain in the groundwater and the river will be small fractions of current levels. Estimated on a conservative basis, the current 50 pCi/L increment between upstream and downstream concentrations should be less than 1 pCi/L by 2068.

A.6 MATHEMATICAL MODELING OF HANFORD CONTAMINANT FLOWS

The three-dimensional analysis of the Hanford groundwater environment by Cole et al. (1997) used a finite-element approach to predict long-term behavior of both the hydrologic and contaminant elements of the problem. Validation of model performance was provided by initiation of transport calculations for known conditions in 1979, and projecting site hydrological conditions and contaminant levels through 1996. The success in duplicating current conditions offers a validation point for the model.

Figure A.10 shows the predicted changes in site water table levels between 1996 and 2350 (Cole et al. 1997). With the exception of areas near the river, the water table is projected to drop as much as 10 meters below current levels because of the elimination of process water recharge to the groundwater. In general, the farther from the river, the greater the change in the water level. The pattern appears to have developed progressively during the period. The net effect would be substantial reductions in the mass flow rate from the groundwater to the river.

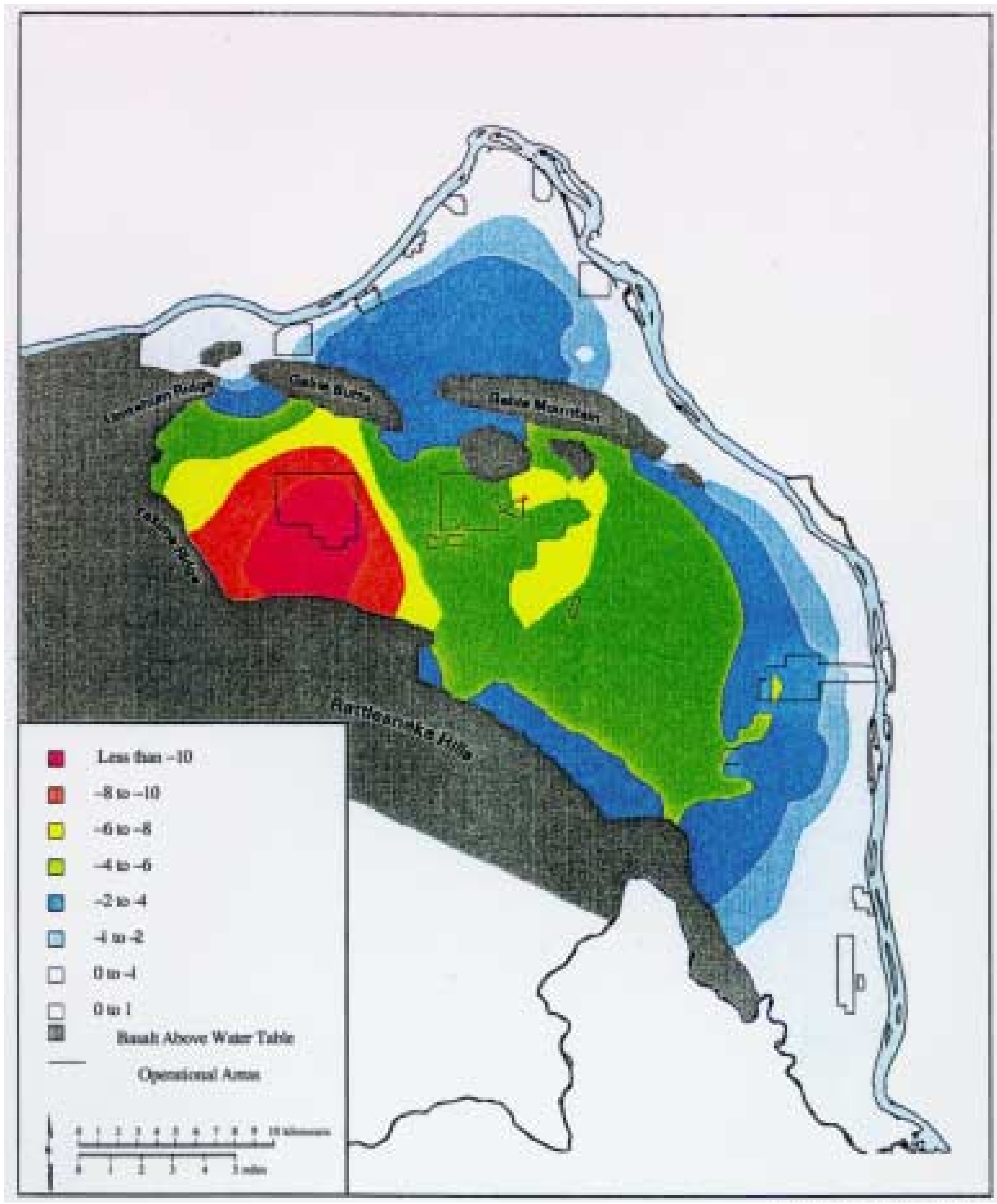

FIGURE A.10 Estimated Changes in Water Table Levels (Source: Cole et al. 1997)

A major contributor to the long-term lowering of the groundwater level was the sharp reduction in effluent discharges from the 200-West and 200-East operating areas. During the 1980s, the average discharge rate was on the order of 60 million liters per day. In 1996, the rate dropped to about 3 million liters per day. Figure A.11 reflects that reduction, and uses the lower rate for future Hanford site projections (Cole et al. 1997).

Figures A.12-A.15 illustrate the predicted progression of the tritium contaminant plume over the next century.

Figure A.12 shows the modeled version of the 1996 conditions; it is essentially a duplicate of the 1997 data illustrated in Figure A.7.

In Figure A.13 for 2020, the predicted 80,000-pCi/L contour area is reduced in both area and extent at the river interface. The 2,000-pCi/L contour in the 100-Area is broadened.

The predicted 80,000-pCi/L contour disappears in Figure A.14 for 2050; the 20,000-pCi/L contour shows about a five-fold area reduction. In the 100 Area, the 2,000-pCi/L contour recedes from the river interface.

Figure A.15 shows the disappearance of all tritium plumes of 2,000-pCi/L and greater by the year 2100. While not all of the residual tritium would have disappeared, the potential impact on both the Hanford Site and the Columbia River would be minimal.

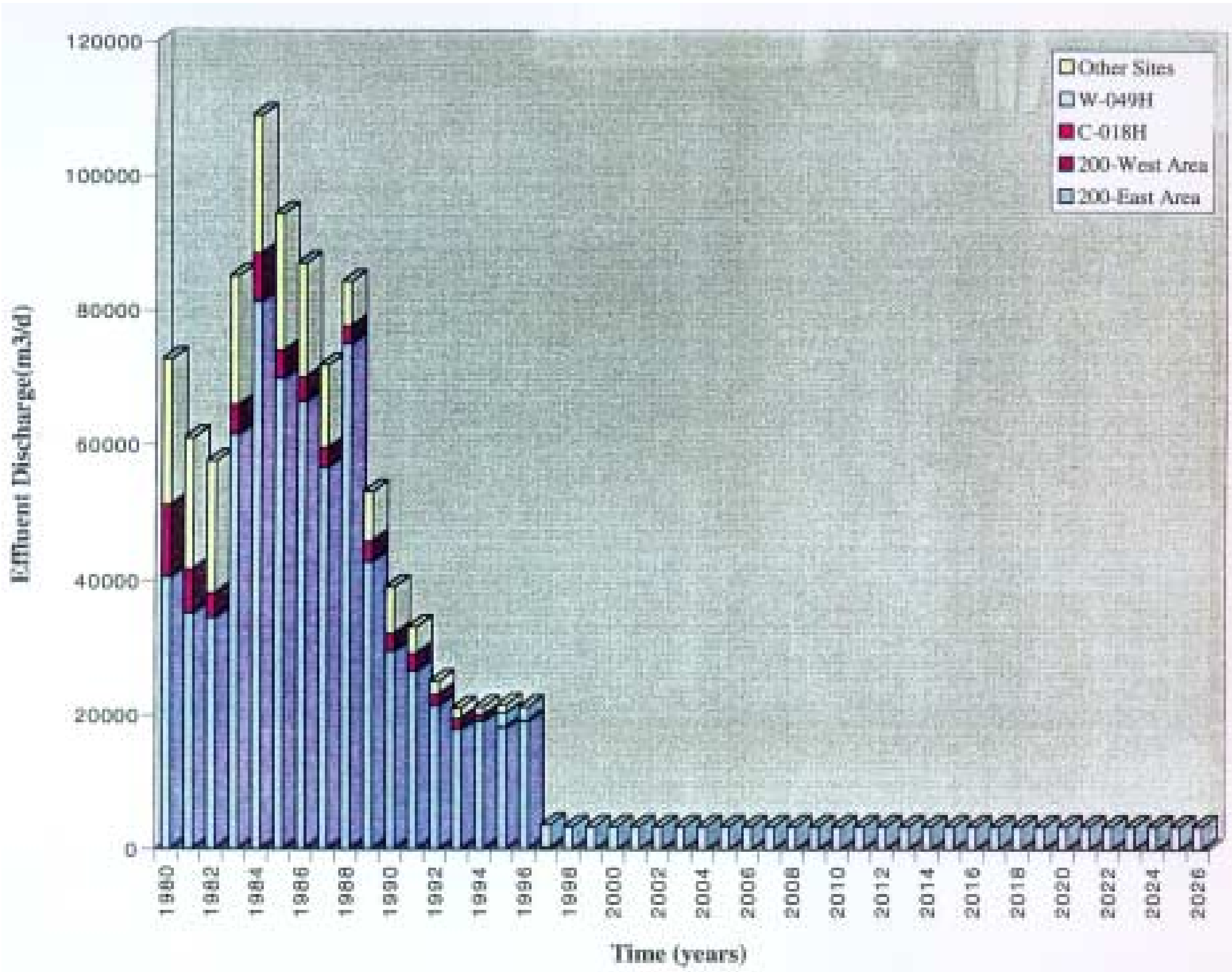

FIGURE A.11 Estimated Annual Effluent Discharge Rates Used as a Basis for Three-Dimensional Modeling (Source: Cole et al. 1997)

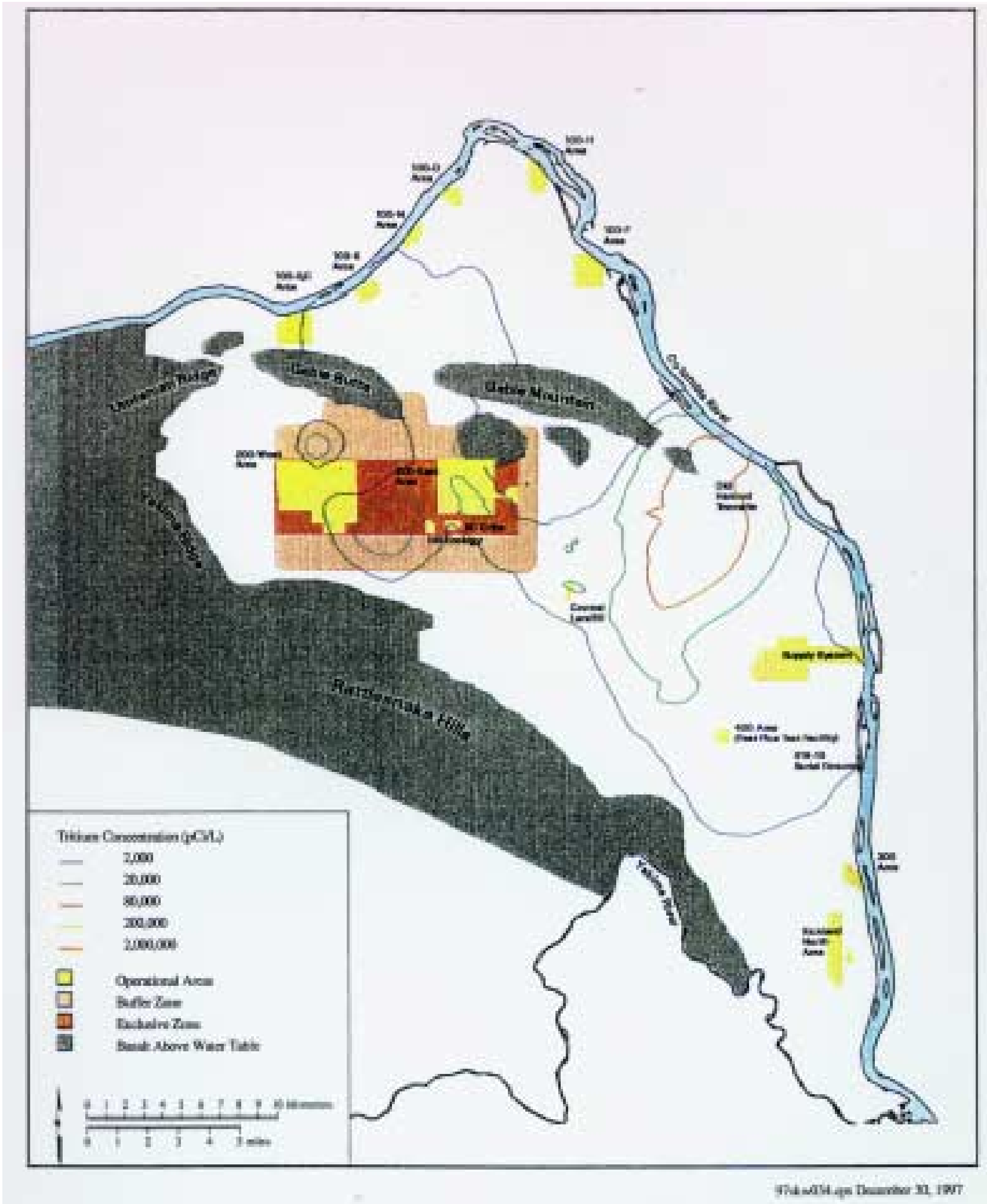

FIGURE A.12 Tritium Contours Predicted by the Three-Dimensional Analysis for 1996
(Source: Cole et al. 1997)

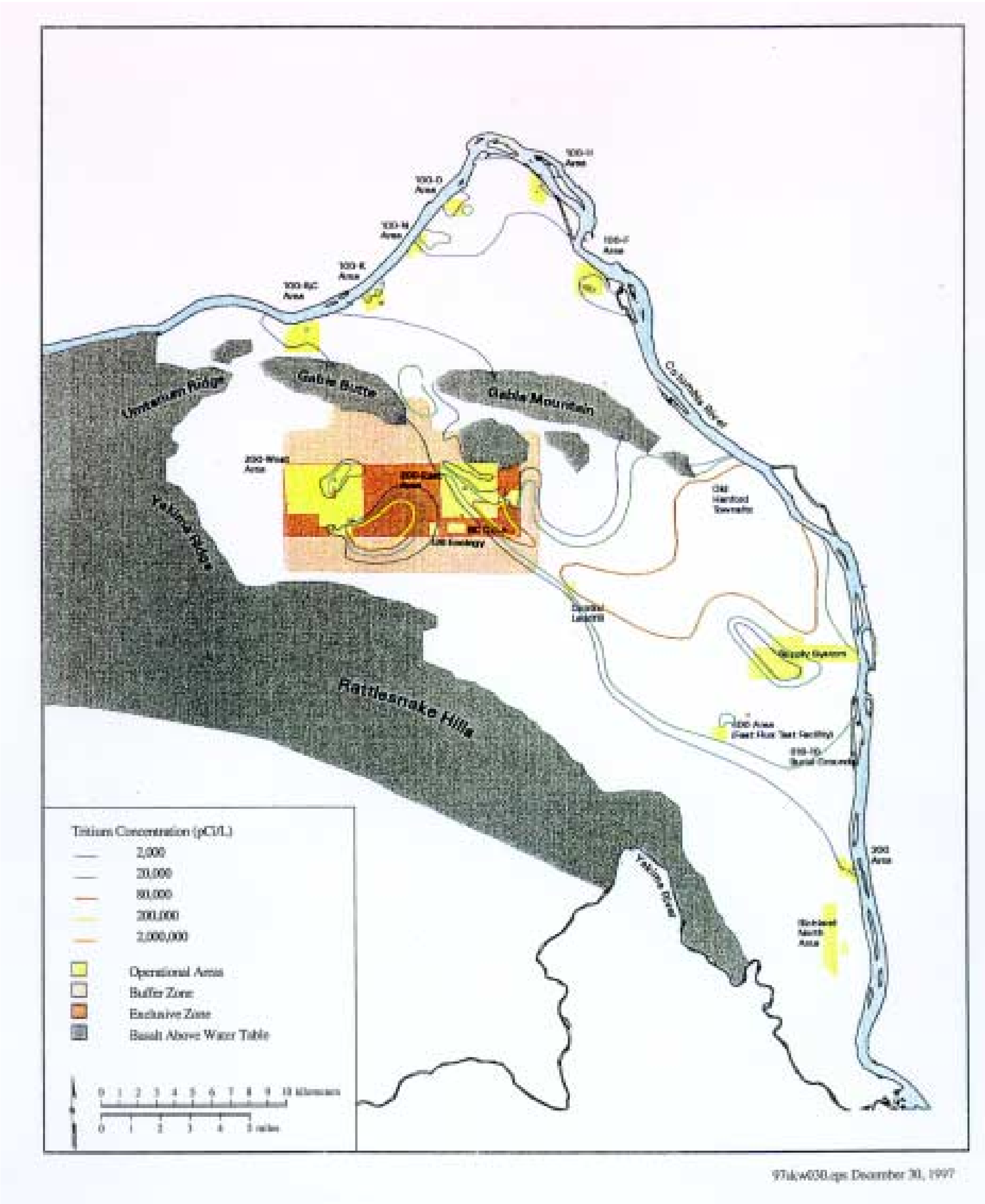

FIGURE A.13 Tritium Contours Predicted by the Three-Dimensional Analysis for 2020
(Source: Cole et al. 1997)

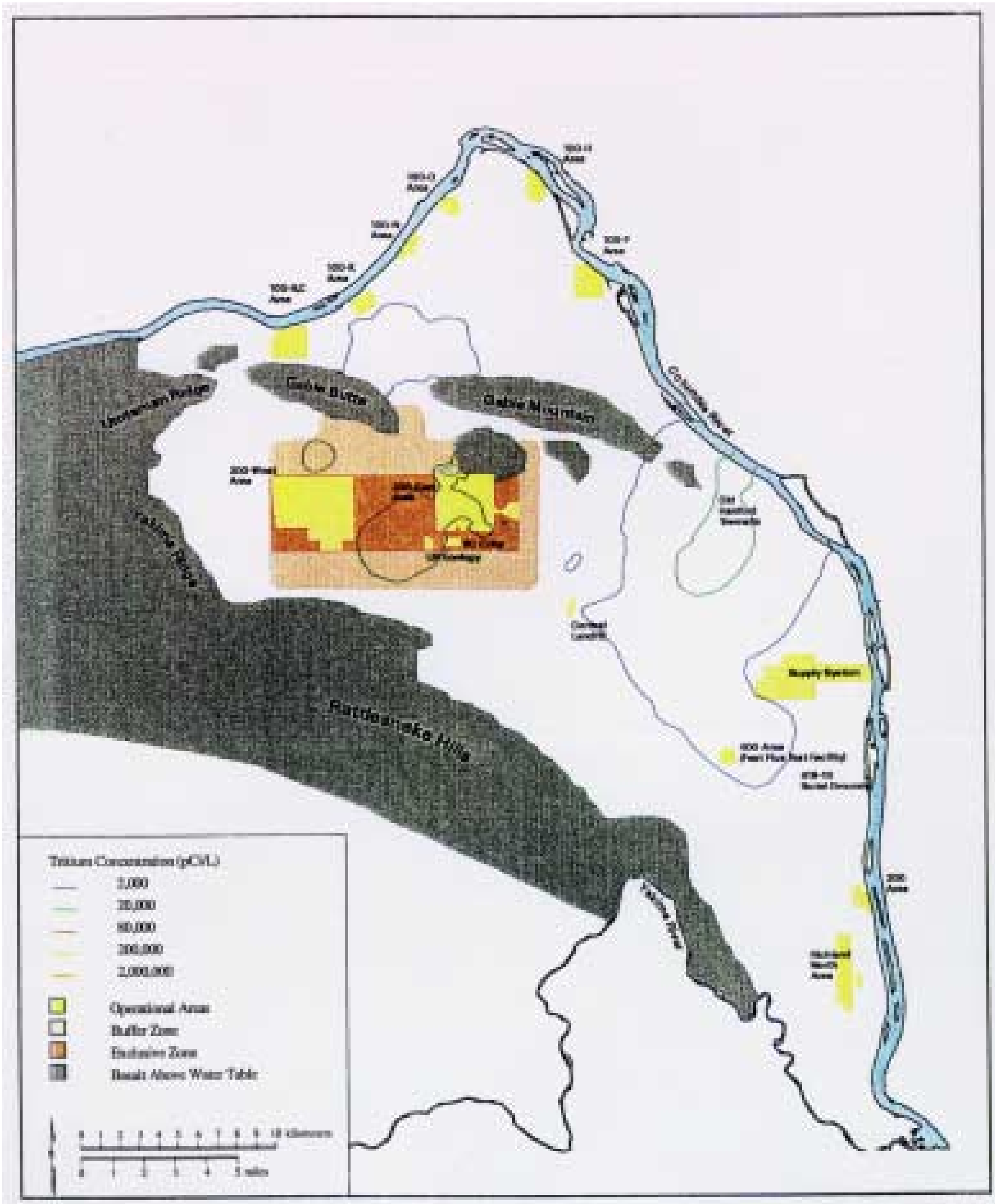

FIGURE A.14 Tritium Contours Predicted by the Three-Dimensional Analysis for 2050
(Source: Cole et al. 1997)

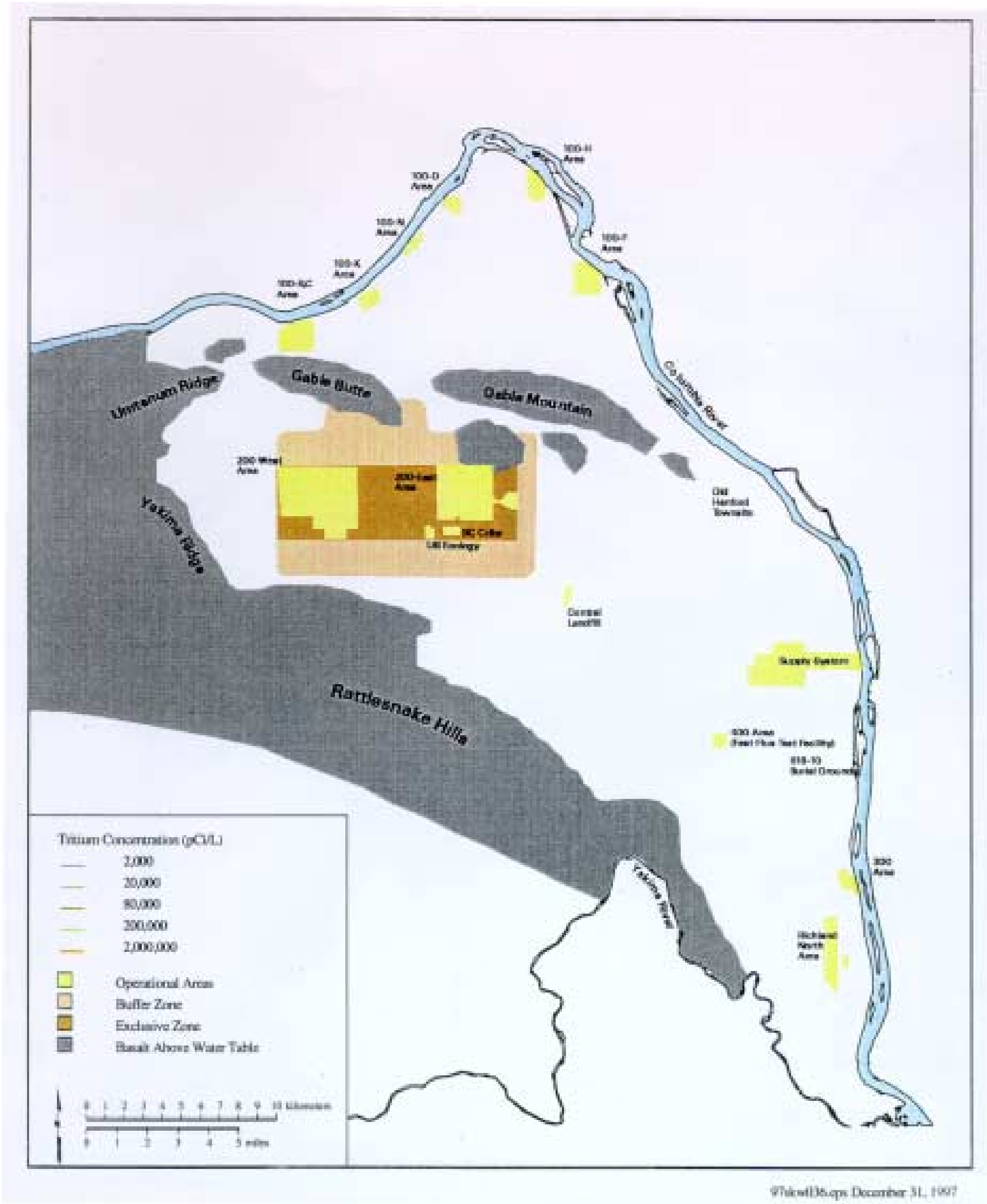

FIGURE A.15 Tritium Contours Predicted by the Three-Dimensional Analysis for 2100
(Source: Cole et al. 1997)

A.7 OBSERVATIONS

The current and projected effects of groundwater migration of tritium from the Hanford Site to the Columbia River appear to be minimal in terms of human and environmental health. However, these projections are based on the assumption of current conditions in terms of the Hanford Site hydrogeology and GW/VZ contamination.

Three hypothetical changes in current conditions, two on-site and one off-site, should be considered in terms of potential risks to the future state of the Columbia River. They are:

- Major leakage or increases in mass transfer rates from the tank farm or waste storage areas,
- Changes caused by decontamination, cleanup, or other remediation efforts, and
- Impacts of catastrophic failure of one or more of the seven upstream dams in Washington.

The effects of the two on-site changes could be evaluated by an extension of the three-dimensional analysis (Cole et al. 1997). Modeling of sets of assumed maximum credible conditions could provide upper bounds for potential impacts on the river. If significant risks were projected for certain scenarios, this information could be used to establish priorities for both the degree and timing of corrective actions.

Seven dams are upstream of the Hanford Site in Washington. Although five of the seven have relatively small impoundments, the Grand Coulee and Chief Joseph reservoirs hold more than 442 billion cubic feet of water when full (information from www.usbr.gov/cdams/dams/grandcoulee.html and Reeves 1999). The failure probabilities associated with these two major concrete structures may be much lower than the historical failure rate of large dams, about 1 in 10,000 per dam-year (Brown 1977). However, the risks to the Hanford Site and the Columbia River associated with the set of individual or multiple failures should be included in a complete risk analysis for Hanford. As noted for the on-site scenarios, the set of risks associated with dam failures could be used to establish priorities for corrective actions if found to be significant.

If these analyses did not yield significant risk estimates for the Columbia River, the major foci for the GW/VZ risk project could then be the environmental, health, and other impacts of projected remediation activities for the site facilities, soil, GW/VZ, and riparian areas.

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APPENDIX B

EXTENSION OF THE DEPENDENCY WEB CONCEPT TO DEVELOP INITIAL CONCEPTUAL MODELS

The dependency web concept developed by Harris and Harper (1998), discussed in Section 3.3, provides a helpful tool to illustrate interrelationships among locations and resources that could be affected by Hanford Site contaminants. These webs can be extended to develop initial conceptual models to help guide the integrated risk/impact assessment. The figures that follow represent a preliminary attempt at structuring the relevant information, using the Hanford Reach of the Columbia River as a basis for this illustration. These figures should be viewed only as examples of a conceptual approach; they should not be considered to be final or comprehensive.

These example models follow two major chains of relationships: the risk of physical damages to ecological resources and human health, and the resulting economic impacts and impacts to quality of life for affected cultural groups. Figure B.1 shows the major types of possible biological effects from contaminant release and the categories of ecological receptors or human health effects for which risk assessment needs to be conducted. Within the ecological effects, the categories of receptors range from individual species to broad constructs, such as habitats and ecological processes. Key relationships affecting ecological risks are shown at a higher level of detail in Figure B.2. Here the focus is on just one of the categories of potentially affected receptors shown in Figure B.1, individual species. The development of information progresses through the exposure modes to important effects and relevant metrics.

A similar level of detail for human health effects is shown in Figure B.3. Although humans are the broad receptor category, there are groups within the population, such as hunters, swimmers, and subsistence fisherpersons, whose exposures need to be specifically assessed. These groups will have somewhat different exposure pathways that need to be considered. This assessment leads to estimation of risks and noncarcinogenic health effects from individual contaminants.

Figure B.4 presents the relationship between biological effects and both sociocultural and economic types of impacts. Major categories of impacts within each of these broad types are also identified. More detailed relationships are presented in Figures B.5 and B.6 for economic impacts. Figure B.5 addresses two major categories of resource use and activity that could be affected by contaminant release – use of the riparian area and water use. Each of these major types of use has subcategories of potentially affected activities that require separate evaluation in the risk assessment. Finally, Figure B.6 shows additional subcategories of activities associated with recreational use of water that need to be considered and suggests appropriate metrics for impact assessment.

REFERENCE FOR APPENDIX B

Harris, S., and B. Harper, 1998, “Using Eco-Cultural Risk in Risk-Based Decision Making,” *Proceedings of the American Nuclear Society Environmental Sciences Topical Meeting*, Richland, Wash., April 4.

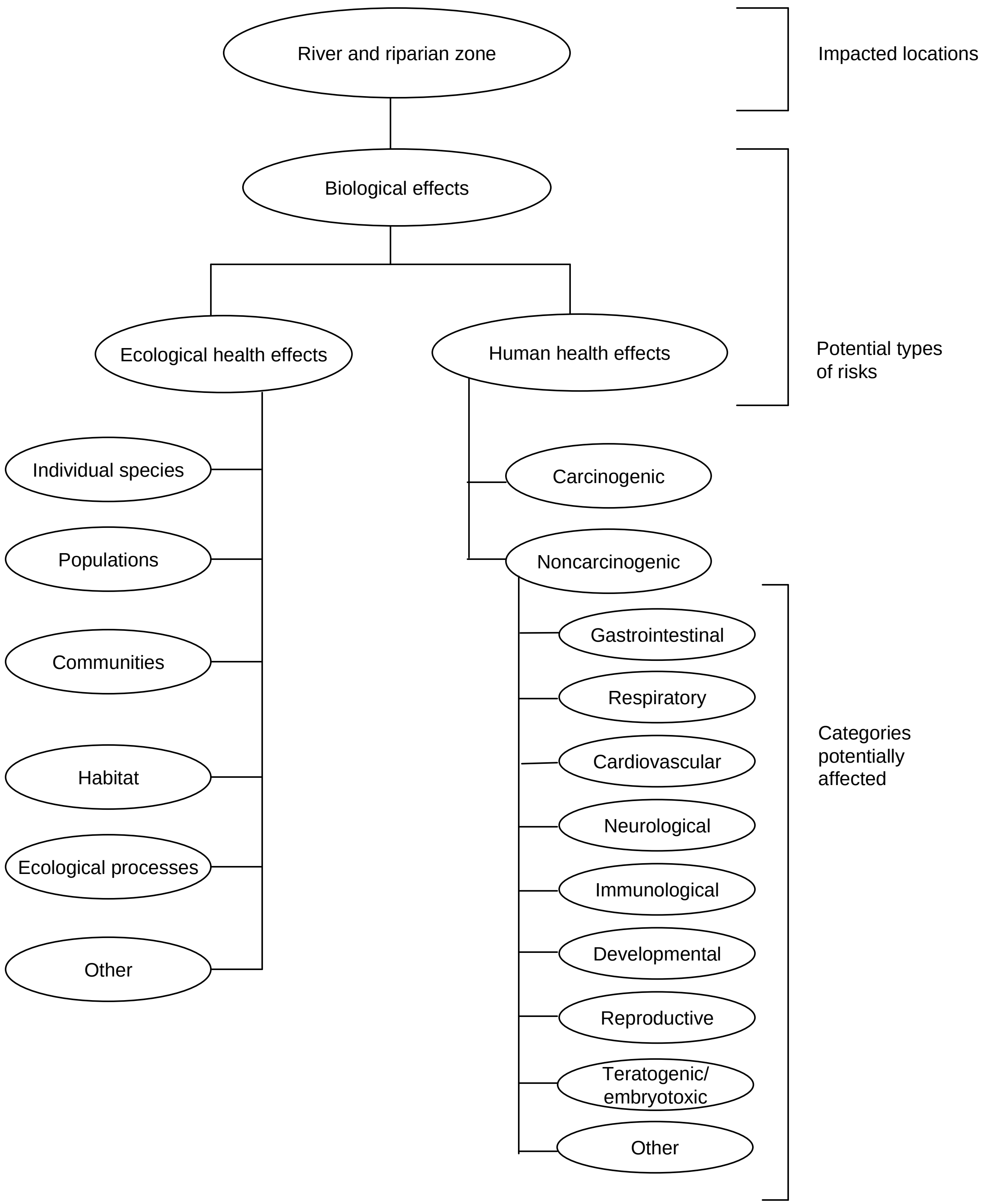

FIGURE B.1 Example of a First-Level Risk Model for the Hanford Reach

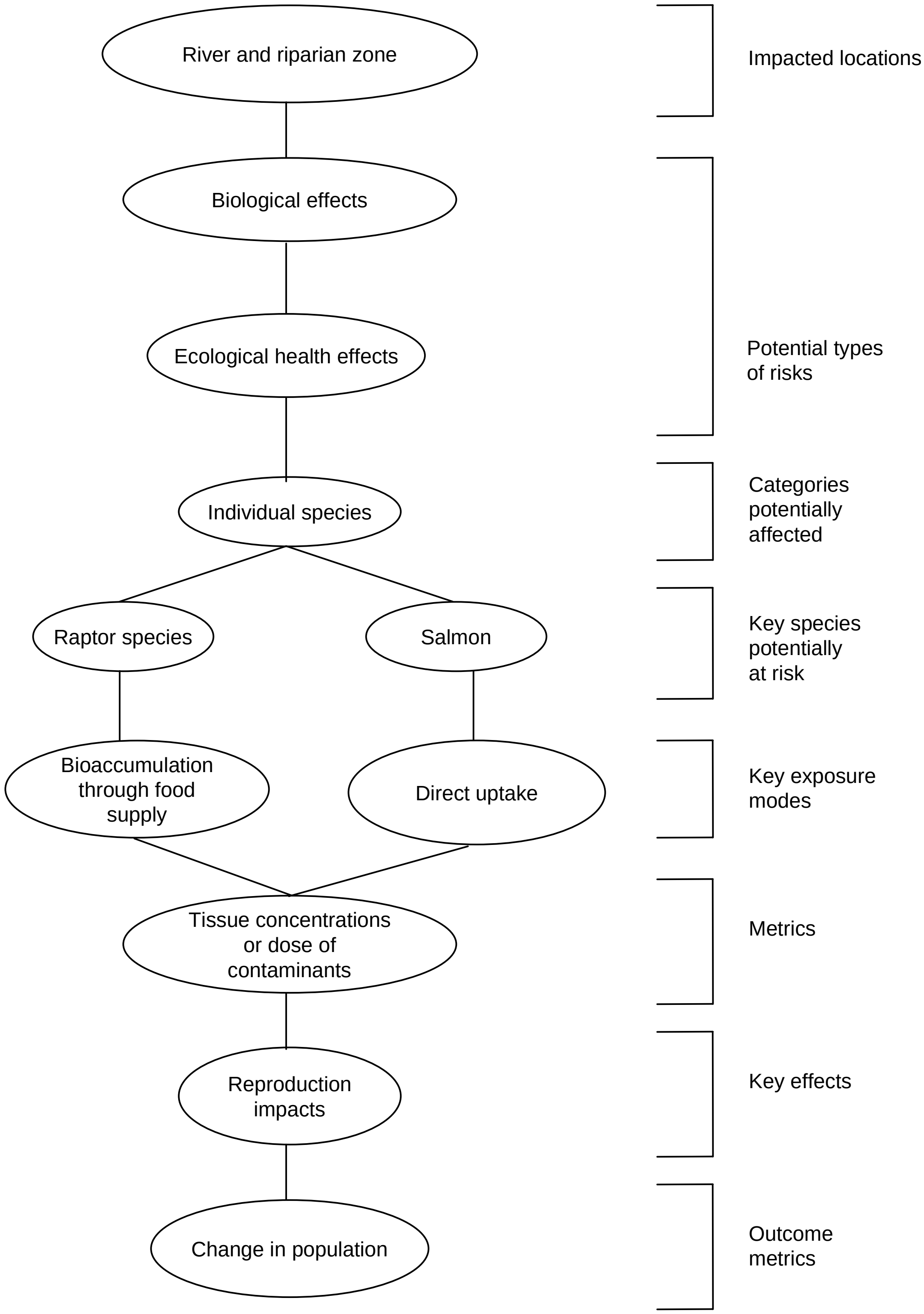

FIGURE B.2 Example of a Second-Level Ecological Risk Model for the Hanford Reach

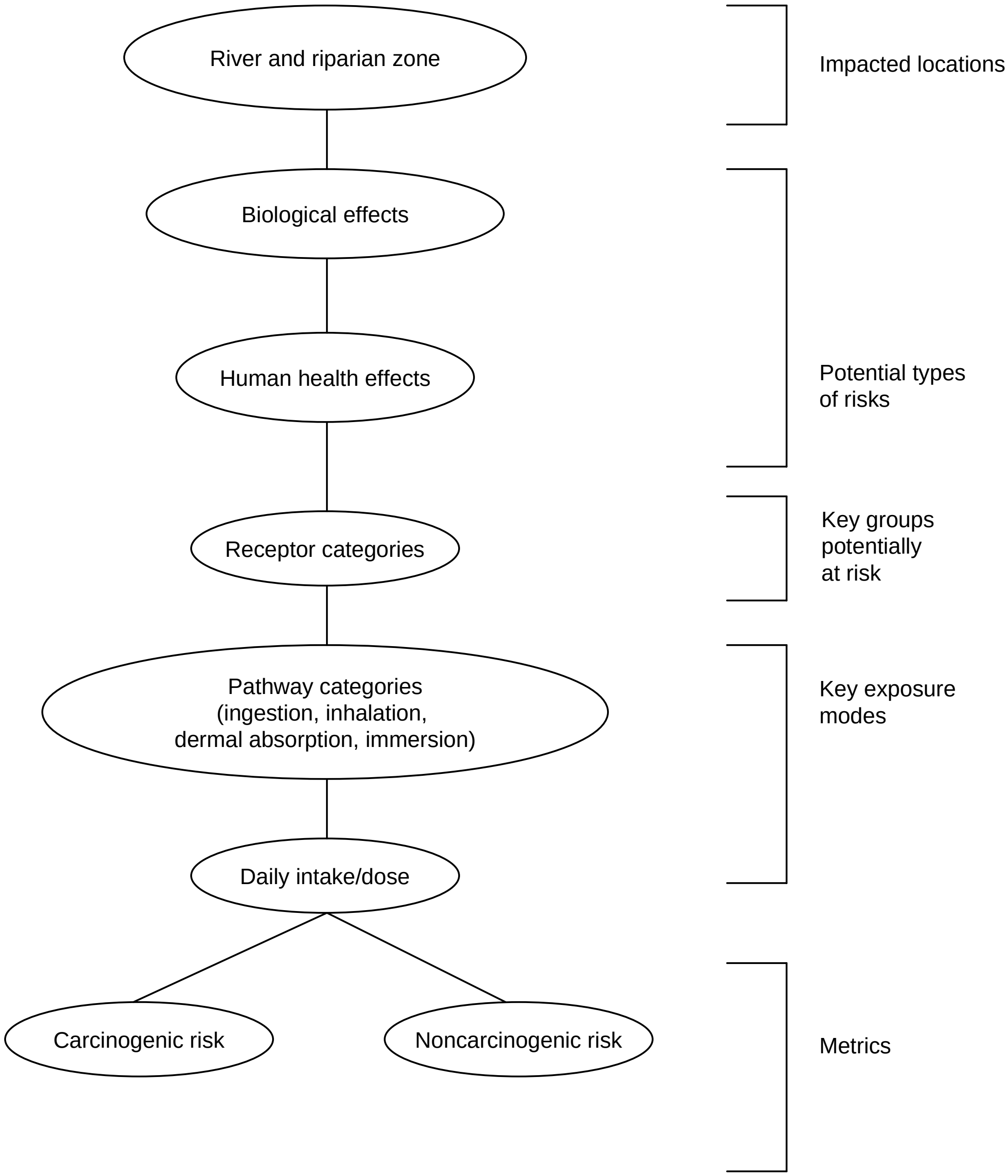

FIGURE B.3 Example of a Second-Level Human Health Risk Model for the Hanford Reach

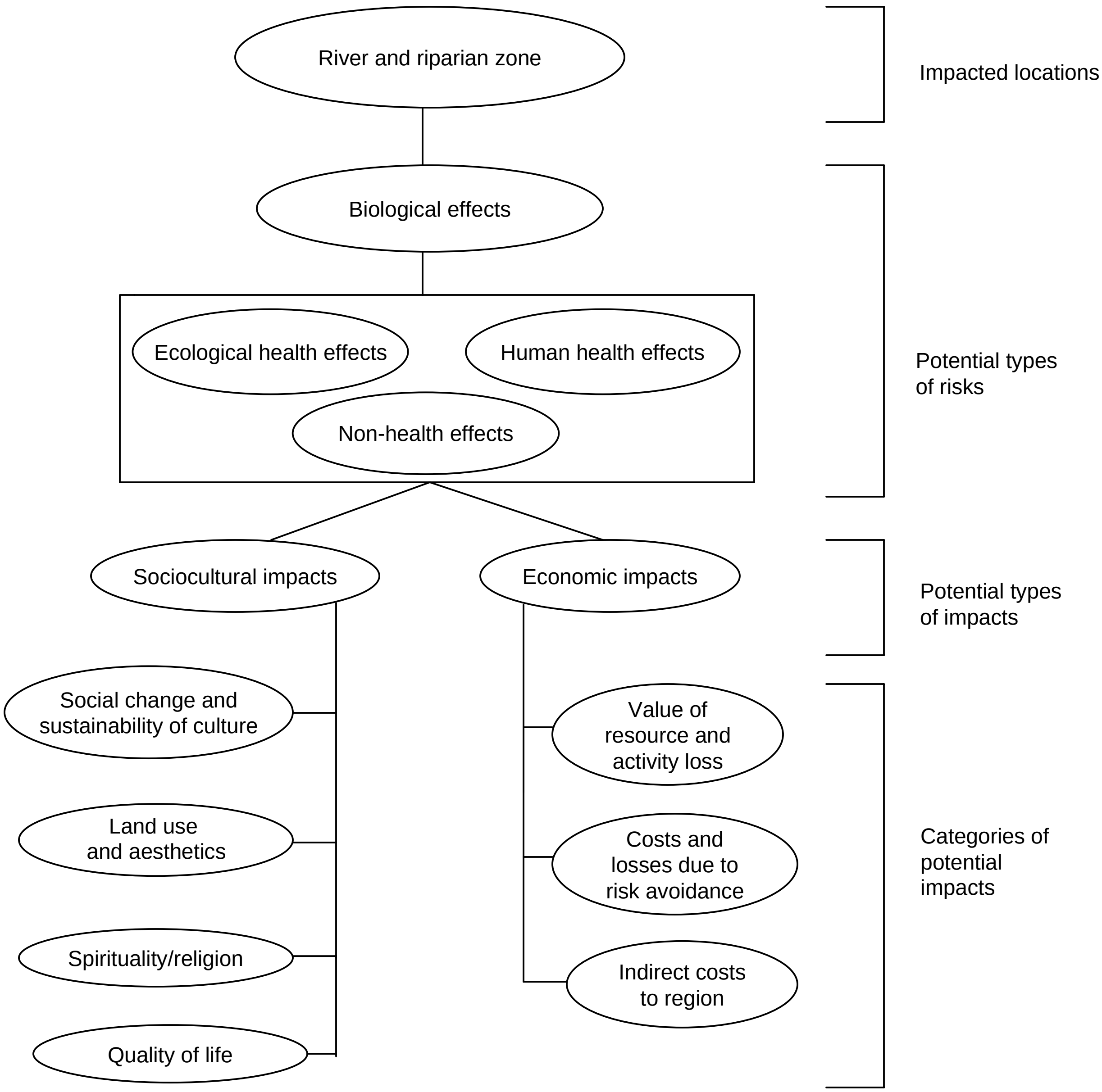

FIGURE B.4 Example of a First-Level Integrated Impact Model for the Hanford Reach

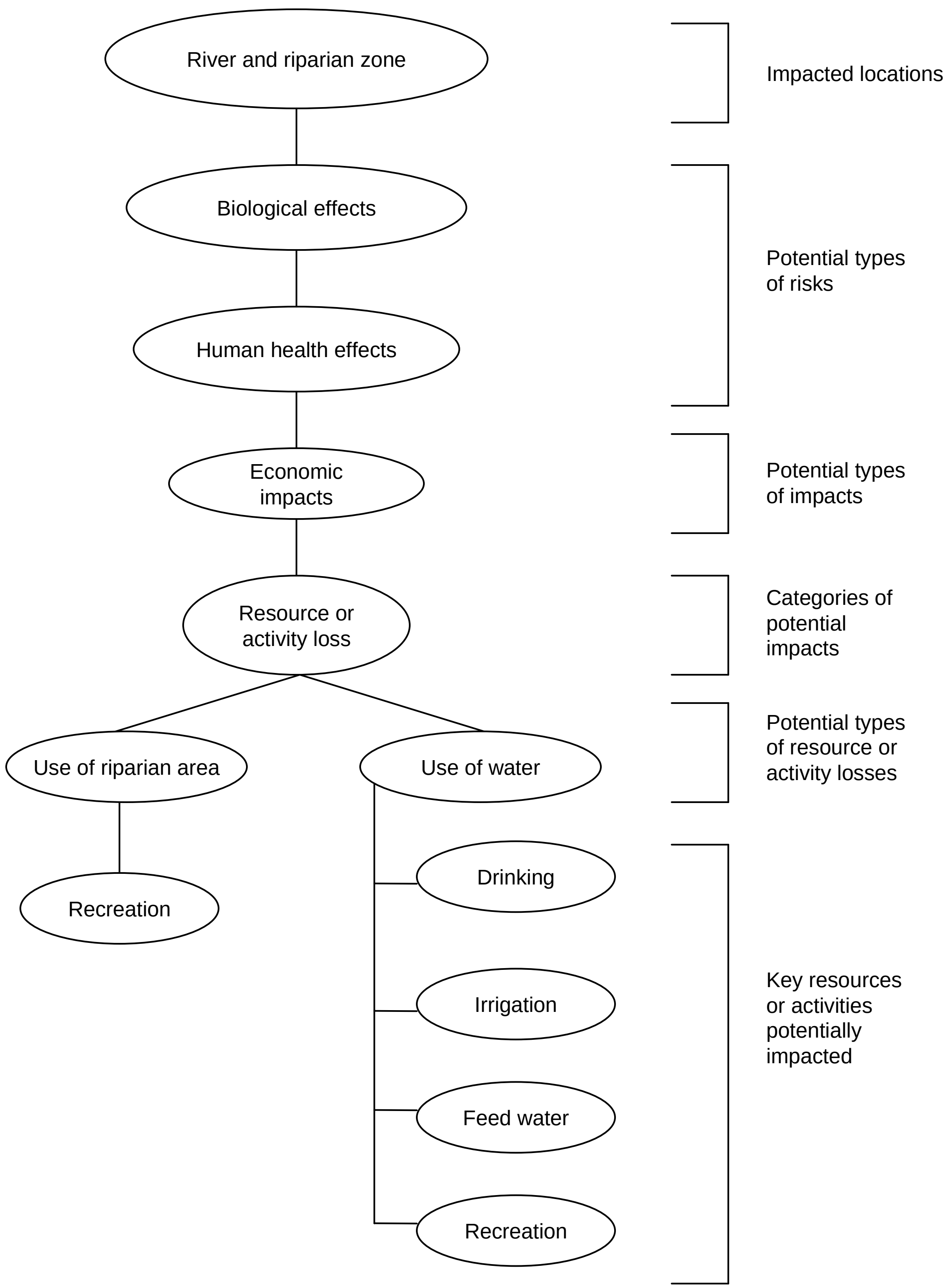

FIGURE B.5 Example of a Second-Level Economic Impact Model for the Hanford Reach

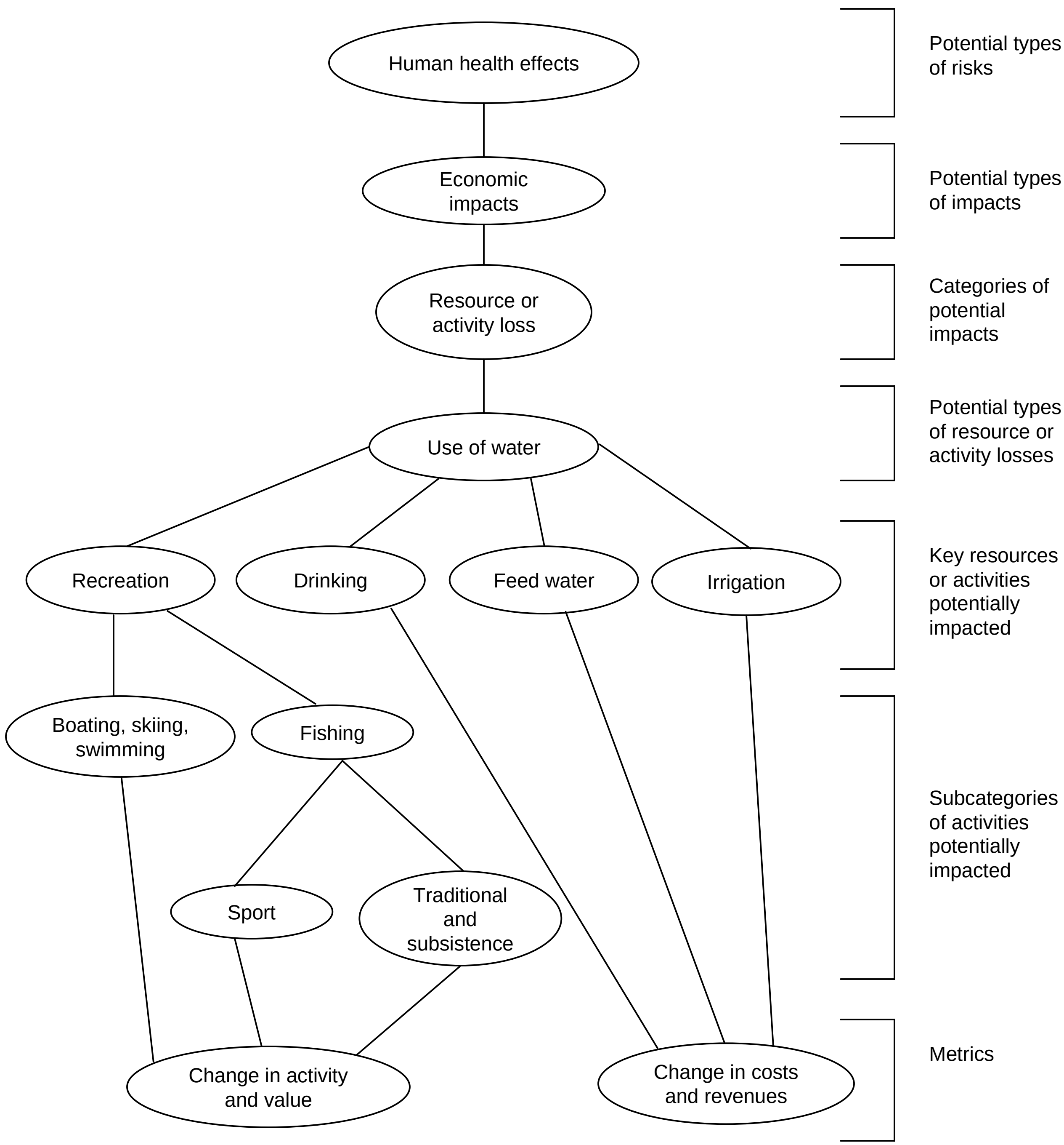

FIGURE B.6 Example of a Third-Level Economic Impact Model Associated with Water Use for the Hanford Reach