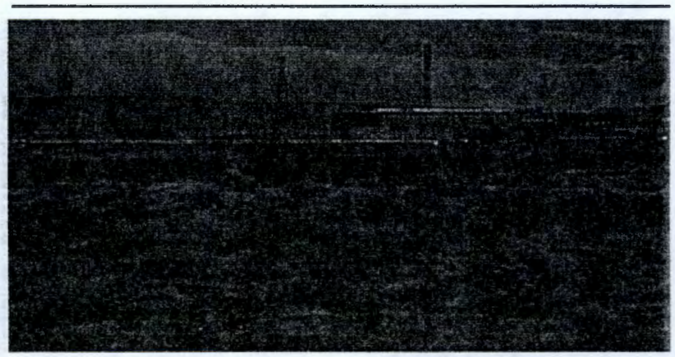
RISK/IMPACT TECHNICAL REPORT FOR THE HANFORD GROUNDWATER/VADOSE ZONE INTEGRATION PROJECT

PREPARED BY
Argonne National Laboratory
FOR THE
U.S. Department of Energy
Center for Risk Excellence
AND
Richland Operations Office

Final Draft/July 27, 1999



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July 30, 1999

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Dear Dr. Young,

Enclosed please find the final draft *Risk/Impact Technical Report for the Hanford Groundwater/Vadose Zone Integration Project.* As you know, the report reflects the contributions of a large group of scientists who began this evaluation process last October in support of the Center, following your meetings with the Department of Energy (DOE) Headquarters Office of Environmental Management and Richland Operations Office. The multi-organizational Center team that was assembled for this project under your direction includes:

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Oak Ridge National Laboratory: Mr. Wilson McGinn
Pacific Northwest National Laboratory: Mr. William Andrews and Dr. Robert Stenner
Project Performance Corporation: Dr. Curtis Travis
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Xavier University: Dr. Sally O'Connor

The Center team met with the Hanford project team in December 1998 to discuss the complicated task of identifying combined approaches for assessing impacts and risks to multiple environmental resources for this large site in its complex environmental setting. A preliminary draft report that presented initial concepts for these approaches was released for public review and comment a month later, in January 1999.

A number of helpful comments received on that document from various interested parties – including Tribal members, the Hanford Advisory Board, other community members, federal and state agencies, and DOE Headquarters advisory groups – have been incorporated into this final draft. This document has also been updated to reflect our ongoing methodology development in support of the Integration Project. We expect this report to be broadly distributed and made available on the Web sites of the Center and the Hanford Integration Project for a 60-day comment period prior to being finalized.

I would like to express my appreciation for your valuable input and guidance on the development of this report, as well as for the considerable contributions of other Center staff (notably Mr. Mark Bollinger, Ms. Gladys Klemic, and Ms. Mary Jo Acke Ramicone). I would also like to acknowledge members of the site team for their significant contributions, including Mr. Douglas Hildebrand and Mr. Richard Holten of the DOE Richland Operations Office and Dr. Pamela Doctor and Dr. Michael Graham of Bechtel-Hanford.

On behalf of the Center's team, thank you for the opportunity to develop this report for the Hanford Integration Project. The process has been unique, and we believe the final document will serve as a valuable technical resource that can be used to frame integrated risk and impact assessments at other contaminated sites across the country. We look forward to continuing to work closely with the Center for Risk Excellence in support of the Integration Project team, DOE Richland Operations Office, and the Department's Office of Environmental Management as this project is implemented.

Sincerely,

Margaret MacDonell

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1 INTRODUCTION

The purpose of this technical report is to describe methods for evaluating different kinds of risks and other impacts that could result from multiple contamination sources at the Hanford site. The overall goal is to strengthen the scientific foundation of environmental decisions to be made, to help the groundwater/vadose zone component of the environmental management program move forward 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 – ranging from regulatory agencies, Tribal Nations, local industries and community residents to 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 so we can predict what might happen from the actions we plan to take, or not 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 based on rapid technological advances in such fields as microchip sensors and genotoxicity tests. The new data gained from these discoveries will be incorporated into site decisions and field work as they become available, to ensure that the best and most effective actions are taken. This report provides an initial framework for assessment methods that reflects current understanding. This framework will continue to be enhanced as our scientific knowledge and understanding of the site increase over time.

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 U.S. Department of Energy (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. For example, in an industrial facility, the plant manager may assess accident risks based on a safety analysis of the mechanical systems. In an office, the business manager may assess programmatic risks based on resource or service availability, schedules, and costs. In the context of environmental contamination, *risk* typically refers to the likelihood that someone will be harmed by being exposed to a hazard, such as a hazardous chemical. This is the definition generally used in this report.

Impact is a more general term used to describe any effect. In the environmental arena, it has long been used to represent effects on the total human environment, considering physical-chemical, biological, and sociocultural components. This use extends back thirty years to promulgation of the National Environmental Policy Act. An impact can be beneficial, adverse, or somewhere in between (which can be a value-laden interpretation), and the term is broadly applied across all resources, including groundwater and surface water, soil, cultural, ecological, and human. In this report, *impact* is used as described here, to broadly apply to effects of all types for all resources.

For contaminated sites, impacts are typically viewed as harmful and are commonly referred to as *risks*. Use of this term to represent 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) more than ten years ago. This guidance also addresses risks to human safety, for remediation workers. In this context, risk is a direct (health) effect resulting from a hazard.

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 reduced oxygen 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 due to risk information or perceptions of a risk. As an example, impacts could be incurred by social, cultural, and economic systems if contaminants from the Hanford site were to reduce the reproductive success of a key species such as salmon. Here, the reproductive effect on the salmon is a direct effect (risk), and the associated impacts are indirect effects (impacts). Whether an impact is considered primary (health or ecological risk from exposure to a hazard) or secondary (related effects derived from our response to the hazard as a society or culture or economic sector) has no bearing on the associated level of concern. That is, both primary and secondary *effects* can be primary *issues*.

This distinction between risk and impact blurs, as the two terms have often been used interchangeably in discussing contaminated sites. Although risks are a subset of impacts , the term has often been generalized to simplify discussions. Thus, in many cases risk is used to also represent the combined general term – e.g., 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.

In any case, the term *risk* is generally taken to represent the probability of an adverse effect on a human or ecological receptor, conditional on an exposure to a given chemical or physical (or radiological) hazard – such as drinking contaminated water or being flattened by a falling brick. To be most conservative, i.e., protective, risk assessments usually assume a probability of one for the exposure event, even though this does not typically reflect reality. From this assumption, the risk is simply the probability of an indicated harm given an exposure event. In this report, *risk* is used in this conditional manner, i.e., to refer to the likelihood of harm assuming a receptor is exposed to a given hazard.

To further illustrate the distinction between impact and risk as used in this document, if contaminants were to leach from a waste disposal area through the vadose zone, they could *impact* groundwater quality. If it is assumed that someone digs a well there and drinks that groundwater, this person could incur a *risk* from the assumed exposure to those contaminants. This risk would depend on the two basic factors:

(1) Nature of the hazard – i.e., what contaminants are present in what form, at what concentrations. (For example, high concentrations of sulfate could cause relatively benign gastrointestinal effects, but low concentrations of a potent chemical such as strychnine could have a life-threatening effect on the central nervous system.)

(2) Amount of exposure – i.e., how much water the person is assumed to drink each day, for how many days per year, over how many years. (The "exposure duration" element makes it important to consider the temporal component of the hazard, e.g., to appropriately reflect how contaminant concentrations may change over time.).

1.1 OVERVIEW OF THE INTEGRATION PROJECT AND RISK CENTER INVOLVEMENT

Beginning in the early 1940s, the Hanford site in Richland, Washington, 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 that are being addressed by the environmental program. 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 this 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 (DOE-RL) Operations Office, 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. As a result, the Integration Project is well underway. 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). Also provided is 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 groundwater/vadose zone project began during 1998: system assessment, inventory, vadose zone, groundwater, and the Columbia River. The scope of activities for these elements includes: identifying the amount and location of contaminants and their physicochemical characteristics (including concentration, mobility, decay or degradation); describing the geologic, hydrologic, geochemical, and biological characteristics of the site; understanding the nature of contaminant release, transport, and dispersion mechanisms (including in interface or mixing zones), and identifying dominant factors; and determining areas that could be affected and receptors that could be exposed.

While the extensive 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 (EM-40) and Waste Management (EM-30), 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 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 and groundwater, to address key concerns of interested parties and 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 effectively addressing critical risk issues to achieve sound environmental decisions. The Center operates through a network of scientists, engineers, and risk specialists from DOE Field 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 were the manner in which uncertainties and unknowns can 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 be impacted would need to be identified to constructively focus an initial assessment. Using spatial overlays of projected future contaminant concentrations and receptors were among the options discussed for identifying possible exposures to site-related hazards in order to achieve this focus.

The Center team met on-site with the project team in December 1998 to discuss key environmental data and assessment issues. Based on these limited team discussions, the Center team released a preliminary working draft report in early January 1999 for broad public review and comment, both in hard copy and as an electronic posting on the Web sites of both the Center and the Hanford Integration Project. That preliminary working draft report identified initial concepts and issues regarding various assessment principles and methods.

Following 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 multiple interested parties, essentially at the outset of the framework development. By this strategy, it was hoped that suggestions and recommendations could be received in a time frame that would allow them to best 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 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 revised (final) draft report reflects many helpful comments received on the preliminary working draft from a number of interested parties, including the Hanford Advisory Board, 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 current draft 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 was 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. The Center's 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 Risk/Impact Technical 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 with:

- Bringing together 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 that will produce high-quality results, which can be directly used to 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 broad 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 this document 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 general categories of effects being considered are: human health, ecological, cultural and socioeconomic. The focus of this report is on technical risk and impact assessment issues. It does not address regulatory issues, site-related agreements, or cleanup goals.

Neutral 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 various contamination sources, the planned response actions, and the outcome of their collective implementation, is important to achieving that balance.

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 per available data and tools. The risk approach being developed by the Hanford team is expected to provide opportunities for the site to contribute to the national understanding of how assessments for multiple sources and environmental effects can be 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 a strategy for assessing risks and impacts in a highly complex setting and to further suggest strategies that can improve the clarity and transparency of the assessment process.

- Chapter 4 (risk/impact assessment methodologies):
  This chapter describes appropriate methods for assessing various human health, ecological, cultural, and socioeconomic effects The purpose is 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 and 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 will move the analytical process forward.

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

- Appendix A presents an analysis of tritium, iodine-129, technetium-99, and uranium 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 organize the assessment process.

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DOE, 1998a, *Screening Assessment and Requirements for a Comprehensive Assessment, Part II: Requirements for the Columbia River Comprehensive Impact Assessment*, DOE-RL-96-16, U.S. Department of Energy, Richland, Washington, March.

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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 first attempts to succinctly summarize 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 term, 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 to factors affecting risk/impact assessment for the Integration Project.

2.1 THE RISK QUESTIONS FACING THE INTEGRATION PROJECT

Given that contamination has moved into the GW/VZ in certain areas of the site, there is a need to delineate related risks and other impacts with sufficient clarity to be able to evaluate the adequacy and appropriateness of various alternative measures to protect human health and the environment. At this time, there is incomplete knowledge about exactly how much contamination is present in the GW/VZ, precisely how far it has spread, or 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 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 for the site, a considerable amount of radioactive and hazardous waste will remain on-site at the completion of the operational and cleanup mission. These 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 installations 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 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 impacted. 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 addressed by pump and treat remediation systems. It is likely, however, that certain future remedial actions may release 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 for estimating 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."

As a result 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 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, especially in terms of the potential for contaminants to migrate 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 a process for answering them that applies to each of the exposure/receptor combinations potentially affected. There are three primary bases upon which the seriousness of the problem may be judged: risk to human health, risk of ecological function impairment or resource loss, and lack of access to cultural resources for Tribal people (e.g., due to losses occasioned by health or ecological risks). These considerations drive the formation of a socioeconomic and quality-of-life impact assessment process. To define the specific risk questions to be investigated, a set of targeted questions must be applied to each of these three areas:

- 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 would involve 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 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 determined for future time periods such as 50 years, 500 years, and 1000 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 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 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 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 are important for the integrated risk/impact assessment to address:

Human Health Risks. Protecting the health of the public is a core commitment of the Department of Energy. 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, controlled and mitigated.

Site Access for Native Americans. It is important to determine whether health risks are sufficiently low to permit access to various site locations for collection of food, medicinal, ceremonial, and craft materials.

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, in the absence of major contamination. The mechanisms of this process need to be understood and means of avoiding it developed.

In regard to the issue of potential economic impacts, analytical paths can be pursued. One is the relatively straightforward development of value estimates for the resource degradation or loss that may result from effects of contamination in each impact location. The outline of an analytical process and an overview of methods for accomplishing this are presented in Section 4.4. The second major area of analysis deals with the potential for generation of social and economic impacts through stigmatization of locations, resources, or products. For the most part, such effects have not occurred in association with the Hanford site, even though many of the elements that typically precipitate such reactions have been present (e.g., newly identified hazards and new information on hazards that differ from previous information). As a basis for decision making, the risk and impact assessment should address issues along the following lines:

- What types of events related to the GW/VZ risks are most likely to trigger a stigma-based impact?
- Are there feasible actions that would decrease the possibility of such impacts occurring?
- If a stigma effect occurs in the absence of a major release of contamination, what actions are likely to speed attenuation of the impact?

2.2 RECOMMENDED STRATEGY FOR ADDRESSING RISK QUESTIONS

Effectively addressing the risk questions outlined above requires an analytical framework that is sound and appropriately structured. The following sections recommend 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 issue topics are: the long-term strategy for protective maintenance within which risks must be evaluated, a process for hazard management under uncertainty, and assessment of complex and inter-related impacts of hazard exposure. In discussing hazard management under uncertainty, the examples given are related to projecting potential contaminant releases and source terms at receptor locations. These issues are emphasized because they constitute the most important site-specific sources of uncertainty affecting the risk assessment.

2.2.1 Operational Principles for Protective Maintenance

Over the past ten 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 may 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.
- 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 a long-term stewardship perspective 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 EM 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), to be carried forward,
- 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 (to stabilize and/or contain or isolate waste) or institutional/administrative (to restrict certain uses and hence exposures, provide important stewardship information, or maintain appropriate security). In many cases, however, radioactive wastes and residual contaminants 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. 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: the long-term uncertainties associated with site barrier failure and institutional change over multi-generation time periods, and the 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

There are two approaches for handling the challenges to 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 based on these predictions. The drawback of this approach is that it is virtually impossible to perform analyses and measurements today that will reduce uncertainties over hundreds of years to acceptable levels. Since uncertainties cannot be eliminated when the system is initiated, barrier systems are often overdesigned, greatly increasing 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 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 re-evaluated and modified over time. Projects have been evaluated and implemented as needs have changed and additional technological possibilities have emerged.

While it is not possible to know the 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.

The hazard management framework is as follows:

- **Define Expected Conditions**. Based on 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, develop 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 in the barriers separating worker, public, 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 all plausible deviations from a controlled status. Evaluate the cost, design, construction, detection, or 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 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 loss of control.

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

- **Improve Site Conditions and Management Iteratively**. Increasing 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 form 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 risks should be evaluated in a cumulative manner. 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, with the level of detail varying as appropriate to the situation.

In the GW/VZ Integration Project, there are two distinct categories of impacts to be investigated. These are shown in the context of closely related technical elements in Figure 2.1. The first (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") is comprised of impacts that are not directly related to health risk (i.e., cancer or noncarcinogenic illness), such as cultural and socioeconomic impacts. This category includes that either derive from primary (health) effects or from actions taken by the public to avoid perceived risks of primary effects or 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 health 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, stakeholder agreements, or other defined values, the alternative site management conditions that would lead to that effect could be eliminated from further consideration. This 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 follow the practice of employing 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 extentthere is information to support that. 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 assuring that important linkages are not overlooked. Issues regarding implementation of dependency webs are discussed in Section 3.5.1. The effort to be comprehensive in identifying pathways for dominant chemicals to the most affected receptors should have the same 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 assessments would focus on impacts for a single generation (50 years). Impacts beyond that period would be treated in primarily qualitative or relative terms. (While impacts may be projected for 1,000 years to satisfy the DOE Order and guidance for performance assessment and composite analysis (DOE 1996, INEL 1998, DOE 1998), it should be clearly recognized that there is insufficient knowledge to place meaningful bounds on the uncertainties for such estimates.) The assessment process should then be iterated as needed to provide information for site management decisions.

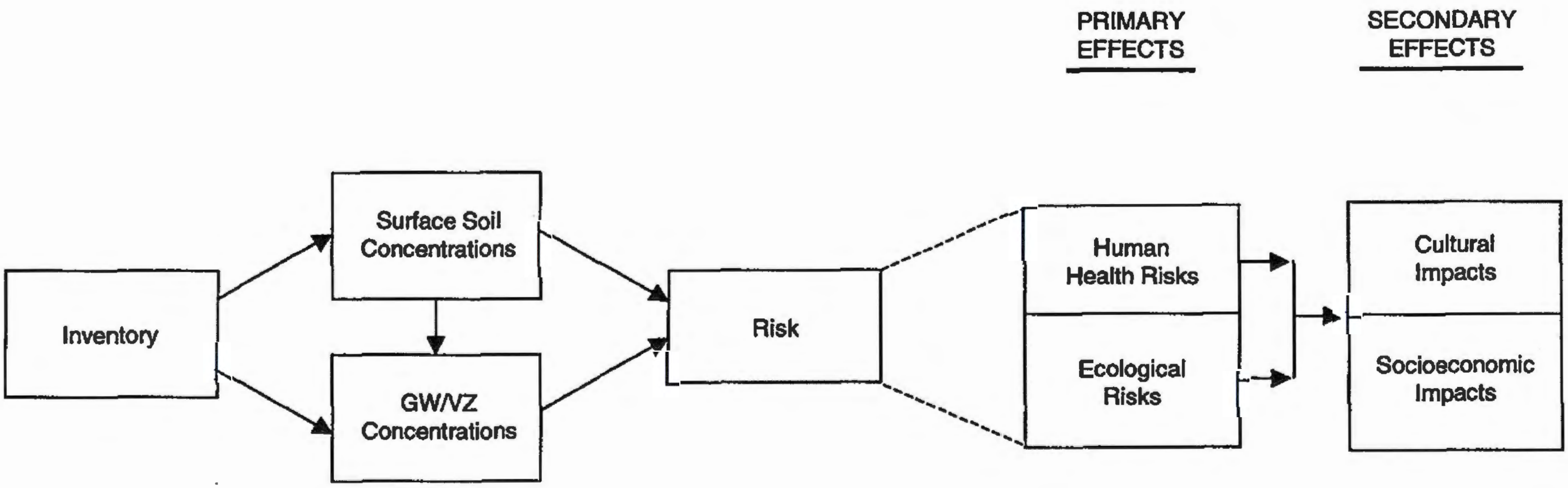

FIGURE 2.1 Overview of the GW/VZ Integrated Risk/Impact Assessment Process

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3 FRAMEWORK FOR INTEGRATED RISK/IMPACT ANALYSIS

An integrated risk/impact analysis approach is needed in order to take account of the many factors that influence and affect the risks and impacts posed by the Hanford site, and the way in which they are perceived. Lessons can be learned from the numerous assessments that have already been carried out on the site in order that valuable information can be applied to the current effort and previous inadequacies can be addressed. There are a number of approaches and methods available to assess risks and impacts, some traditional and others newly developed. By using different methodologies in the right combinations a powerful framework will be developed. Implementation of such a framework will enable assessments to be carried out to address the principle concerns of regulators, stakeholders and others 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 for application to ongoing regulatory and planning processes. The initial activity of the GW/VZ Integration Project involves identifying those that can provide an input to the understanding of the overall site risk profile. Although it is beyond the scope of this report to conduct a comprehensive review of all site assessments, summary information about several recent studies is presented in Section 3.1.1. Some lessons learned from these studies are described in Section 3.1.2.

3.1.1 Highlights of Approaches Used and Related Issues

Several recent reports prepared for the Hanford site have assessed contaminant behavior and related impacts on human health and the environment using a variety of approaches. Key information from these studies is reviewed below.

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 surrounding the Hanford site during a period of nearly 50 years (1945–1994). Both atmospheric and Columbia River 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 involved parties, nine Columbia Basin Native American Tribes and Nations were involved in the study.

The primary computational software developed for the project dealt with one radionuclide (0.74 M Ci of iodine-131) in the air and five radionuclides in Columbia River water (2.5 M Ci of arsenic-76, 6.3 M Ci of neptunium-239, 0.23 M Ci of phosphorus-32, 12.0 M Ci of sodium-24, and 0.49 M Ci of zinc–65). It was estimated that these radionuclides accounted for more than 94 percent of the potential radiation dose from the river pathway. Spatial resolution was six 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; annual changes in food distribution networks. Exposure pathways consider swimming and boating, air submersion, 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 1102 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 were used to retain time/space correlations between derived parameters. Code tests, walkthroughs, and independent verification were used for quality assurance.

Hanford Remedial Action Environmental Impact Statement. The purpose of this assessment was to establish future land-use objectives for the Hanford site (DOE 1999). The analysis considered 892 waste sites and facilities; excluded were the single- and double-shell HLW tanks. Ecological, cultural, and socioeconomic effects were analyzed using a grid of 1 km by 1 km, aggregating hazardous constituents within each cell. The Multimedia Environmental Pollutant Assessment System (MEPAS) was used to evaluate environmental transport.

Tank Waste Remediation System Environmental Impact Statement. The purpose of this assessment was to assess 177 single- and double-shell tanks and 40 Miscellaneous Underground Storage Tanks (MUSTs) in the 200 Areas of the site and the cesium and strontium capsules in storage (DOE 1996). Tank waste (containing 177 M Ci of radioactivity), MUSTs (containing less than 0.9 M Ci) and the cesium and strontium capsules (68 M Ci) together represent 97% of the radionuclides in the 200 Areas (254 M Ci). Another 1 M Ci are estimated to have been released or leached to the grounds, and 5 M Ci disposed of in the solid waste burial grounds on-site. Exposure scenarios evaluated include Native American, residential farmer, industrial worker, recreational shoreline user, and recreational land user. Vadose zone, groundwater flow, and contaminant transport were simulated using the VAM2D transport code.

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. Exposure scenarios evaluated include agricultural, residential, industrial, and recreational. Groundwater flow, and contaminant transport was simulated using three-dimensional transport codes, while a one-dimensional code simulated vadose zone flow and contaminant transport.

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-RL 1999). The radiological inventory of the AX tank farm is estimated to be 12 M Ci for the current inventory of the four tanks, 0.2 M Ci for the ancillary equipment, and 0.034 M Ci for past leaks. Vadose zone, groundwater flow, and contaminant transport were simulated using the PORFLOW transport code. An uncertainty analysis was performed using 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

A number of insights have been gained from these past assessments, of which the major ones are discussed below.

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, some stakeholders are concerned about uncertainties in these estimates. This is highlighted by the disagreements among assessments with regard to the number of waste sites and facilities. However, the major concern is over including multiple small sources that are currently not included in the inventory estimates and obtaining a reasonable bounding estimate of the inventory presently in the vadose zone and the groundwater, and potential future contributions from these other minor sources. Lessons have been learned about what still needs to be assessed and how best to conduct the assessment.

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 four of the 149 single shell waste tanks may be greater than previously estimated. This study was commissioned in the summer of 1996, after discovering that radioactive waste from the SX tank farm had reached a substantially greater depth than previously assumed. Study results estimate that an additional 1 M Ci of cesium from the four tanks studied have entered the vadose zone compared to earlier estimates (DOE-RL press release, August 27, 1998). This new finding substantiates the need for a more comprehensive assessment of the sources impacting the vadose zone and groundwater at Hanford. Although this is obviously a responsible action for DOE to pursue considering the new information, based on the results of all past studies the current vadose zone and groundwater contamination is not presenting an imminent health hazard to the public or immediate danger to the environment. This means that DOE has the necessary time to conduct a more thorough and integrated assessment to determine if there are any potential long-term impacts and to design corrective action as appropriate to mitigate any potential adverse impacts identified.

Values. Recent assessments have focused on traditional human health measures and a limited set of ecological impacts. However, the stakeholders and Tribal governments have identified a broad range of non-traditional values and concerns that lie outside the standard human health and ecological risk paradigm. Also, concern has been expressed over the need to more closely examine a variety of other toxicological and ecological endpoints, as well as multi-generational considerations (i.e., potential long-term effects on future generations). An integrated assessment approach should account for such non-traditional issues as cultural and religious values, tribal life-styles, environmental justice, socioeconomic issues, the cumulative effect of exposure to multiple contaminants, and long-term effects on future generations. It should also more closely examine the possibility of additional toxicological and ecological endpoints of concern.

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 a number of factors, including the effect endpoint of interest (health, environment, cultural, etc.) and the objective of the assessment (e.g., scoping, regulatory, building stakeholder confidence). The current restoration effort at the Hanford site is governed by what might be called the classical regulatory approach. A summary of several applicable approaches is provided below.

Classical Regulatory Approach. This is a regulatory approach that relies on a formal risk assessment process prescribed by EPA and state regulators and that is well-documented in EPA guidance (e.g., Risk Assessment Guidance for Superfund, Volume 1). It 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, 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, such as groundwater and atmospheric models, exist to support this approach, as does guidance on the physicochemical (transportation), exposure, and toxicological factors (e.g., Standard Default Exposure Factors).

The classical regulatory approach essentially represents what is perceived as the "best-science" approach. It is most useful in choosing among remedial alternatives and in setting cleanup standards. Its limitations are that: it can be demanding both in terms of time and data requirements; it typically is applied to one problem at a time (thus, composite effects are sometimes ignored); and 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. However, in some situations, it can be valuable to augment this approach with other risk/impact assessment frameworks. We discuss a few below.

Quantitative/Qualitative Hybrid Approach. The best example of a quantitative/qualitative hybrid approach currently employed at Hanford is the use of dependency webs as input to the development of the conceptual model for quantified assessment. Dependency webs are a qualitative identification of potential impact categories (biological, economic, cultural) at exposure locations. The categories identified can then be considered for inclusion in the expanded risk/impact assessment.

Dependency webs are helpful in facilitating stakeholder communication since potential impacts can be displayed pictorially. The contaminated media, or specific receptor, is placed on the web connected with risk/impact types (such as economic and cultural effects). Extending from each impact type in a dependency web are specific examples of the impacts. Any impact can be linked with another if they are interrelated. Interdependencies of potential impacts are very important and easily overlooked during standard risk/impact assessment approaches. This makes the dependency web approach useful for communicating a broader picture of the overall impacts of contaminants and to illustrate how impacts may be felt across several areas.

The limitation of the dependency web approach as currently developed is that 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.

Model-Free Approach. The model-free approach is an outcome-based conceptual approach to 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 such an 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 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 that of system components.

The model-free approach attempts to provide transparency for stakeholders by using models 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.

To further clarify the definition of the model-free approach, we provide a series of examples.

- 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 the segments of Hanford Reach. Multiplying the difference by 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, by using measured groundwater contaminant concentrations near the River at the time of the transfers, it may be possible to estimate the volumetric flow rate of Hanford groundwater into the Columbia River along the Hanford Reach. Appendix A presents development of 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. Currently available information is insufficient to conduct a similar analysis of potential future concentration increments in the River from technetium-99 plumes.

- It is also important to develop a model-free approach to predicting groundwater transport of contaminants using the historical groundwater data for tritium, iodine, strontium and other contaminants. This approach would eliminate uncertainties present in incorporating subsurface geological formations (a major concern of some state regulators) and their contaminant retardation characteristics. The historical measured concentration data already integrate all subsurface geologic factors.

- The major uncertainty in the Hanford groundwater/vadose zone project is 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 an acceptable level (i.e., a level that stakeholders will have confidence in). Current vadose zone modeling indicates a range of breakthrough times for contaminants in the vadose zone ranging from 50-65 years for contaminants with no retardation to in excess of 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 might bypass vadose zone modeling altogether by hypothesizing the shape of various breakthrough curves (magnitude and duration) and evaluating the impact on the identified effects endpoints. This approach could identify and prioritize those vadose-zone uncertainties (subsurface heterogeneity, inventory magnitude, inventory composition, etc.) that significantly impact the effects assessment. The approach could both provide information to better focus further environmental sampling efforts and to increase public confidence in final risk/impact estimates by identifying major sources of uncertainty.

Classical Uncertainty Analysis Approach. Models are a very powerful tool for predicting and estimating risks/impacts but uncertainties are introduced by the nature of assumptions which have to be made, as well as uncertainties carried in the data that is 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 projecting 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.

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, you start from the outside and define the bounding envelope of possible future trajectories. The bounding approach is particularly effective in situations when 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. Focussed environmental monitoring can then be used to reduce the width of the uncertainty envelope.

Barrier/Monitoring Approach. The Barrier/Monitoring approach addresses situations in which not all areas of a site can be returned to hazard levels compatible with unrestricted use and barriers will 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 identifies the most probable sequence of events over the next 100 years (two generations) assuming gradual barrier degradation. Next one identifies plausible deviations from the controlled trajectory and develops bounding estimates of the consequences of plausible deviations. One then develops contingency plans for detecting and responding to all plausible deviations from the controlled status. The advantage of this approach is that does not strive to eliminate all uncertainties prior to beginning the protective maintenance process; instead, it manages potential deviations from control during stewardship through aggressive monitoring and contingency planning.

This approach is not a substitute for the classical regulatory approach, but is used in conjunction with standard risk assessment and risk management approaches. Understanding gained from risk assessment approaches can inform the monitoring activities, i.e., the monitoring program can be set up to look for pollutants representing the dominant risks and to address any uncertainties in the risk assessment. Locations and timing of sampling are also informed by the risk assessment to predict the most likely future trajectories for the site and reasonable deviations.

3.3 AN EXPANDED PERSPECTIVE FOR RISK/IMPACT ASSESSMENT

The standard approach to risk assessment at hazardous waste sites is to develop a conceptual site model (i.e. select exposure pathways connecting the contaminant source with receptors) and evaluate different types of risks (primarily cancer and limited toxicological endpoints) in a discrete rather than a concurrent, integrated manner. This standard approach is insufficient and inadequate to address the broad range of issues and concerns expressed by local Tribes and stakeholders. Many concerns have focused on nontraditional assessment areas, such as, cultural and religious values, environmental justice, socioeconomic issues, and a variety of nonstandard toxicological endpoints and conditions. In response, the Integration Project team has proposed an expanded risk/impact assessment perspective that focuses more on areas of impact and associated receptors than is the case in the standard approach.

Implementing this perspective requires a broader information base than is needed for standard assessments. Information is required on the network of relationships of the affected resource or element in its exposure context (impact location) and also on the linkages of that element to larger biological, cultural, social, and economic systems. Development of two types of dependency webs is suggested as a means of framing the conceptual model for assessing risks and impacts at a detailed level.

Location-Specific Dependency Webs. After the potential impact areas are identified based on contaminant transport modeling, the effects assessment proceeds by providing a qualitative identification of potential impact categories (biological, economic, cultural) at exposure locations. The concept of dependency webs, developed by Harris and Harper (1998a) in response to the Columbia River Comprehensive Impact Assessment (CRCIA) team's requirements, is intended to ensure a holistic examination of impacted elements. The webs are intended to identify the complex interrelationships between potential receptors (including humans, fauna, flora, habitats, and environmental resources).

To provide a basis for developing a conceptual model, the dependency webs need to be expanded beyond the original concept to comprise the following elements:

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

The basic risk and impact relationships among the core elements of the dependency webs are shown in Figure 3.1. For a particular location, in this case the Hanford Reach, the potential for risks of biological effects is identified. In other situations there could be a risk of physical or other types of effects. Each type of risk may trigger a set of cultural, socioeconomic or, perhaps, other types of impacts. A set of examples of the chains of relationships between risks and impacts is provided in Appendix B. These examples of expanded and detailed dependency webs are developed for the Hanford Reach of the Columbia River.

Receptor-Specific Dependency Webs. Receptor-specific dependency webs define the network of resources and activities associated with a key receptor (or resource, such as an ecological community or system) 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 identified its food chain, economic, cultural, and other functions would be needed if impairment of salmon reproduction in the Hanford Reach were projected due to contamination in that location. Delineation of these associated resources and their linkages to each other and to the key receptor serves as the basis for evaluating the value of the receptor. These webs should 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, 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.

For each location or receptor dependency web, the analytical requirements, methods, and metrics to adequately assess each applicable element need to be delineated. Delineation of dependency web elements, specification of associated relationships, and selection of appropriate assessment methodologies are expected to be accomplished through an iterative process coordinated by the SAC group. That is, as each dependency web element is established (i.e., identified, defined, and assessment requirements determined), the SAC is expected to facilitate definition of the complex relationships and selection of assessment methods that are appropriate for that element. These activities are expected to iterate until all of the relevant impact estimates have been developed.

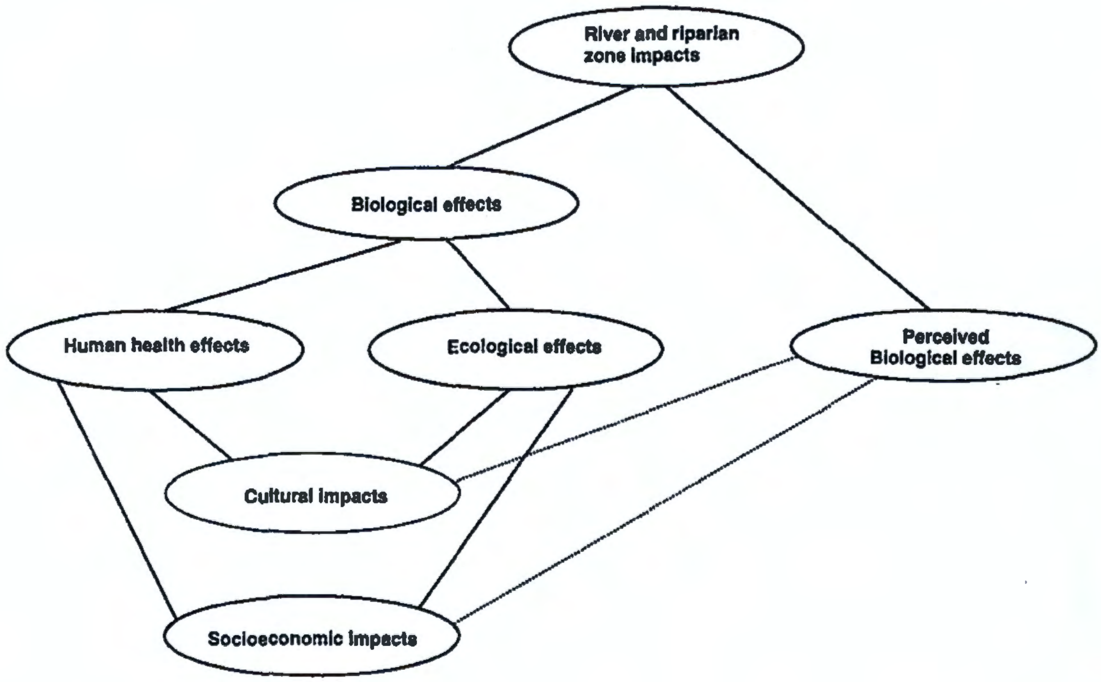

FIGURE 3.1 Use of the Dependency Web Concept to Identify Areas for Consideration in the Risk/Impact Assessment

3.4 FRAMEWORK FOR THE RISK/IMPACT ASSESSMENT

The risk/impact assessment requires a framework that will facilitate the evaluation of uncertainties and accommodate an iterative process of developing information to support risk management decisions. This section first presents 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 comprising an integrated risk/impact assessment approach and suggests appropriate phases for the analysis.

3.4.1 Principles and Objectives

The analysis framework outlined below for the risk/impact assessments builds on lessons learned from previous assessments. Also, it is consistent with the principles of utilizing sound science, considering cumulative effects, using a holistic approach that addresses interdependencies between various risks/impacts, and evaluating the uncertainties. Furthermore, it emphasizes the need for stakeholder involvement throughout the process, with input to key decisions on risk/impact assessment approach.

Application of these guiding principles implies an integrated assessment that considers:

- All hazard sources and all 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 be cognizant of the practical limitations of constraints on budget, time, and analytical capability. 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 Project Risk/Impact Assessment

Objectives	Considerations
Reconcile the disparate methodologies, assumptions, and data used in past, 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 will require less definition.
Consider the full range of possible effects, including health, environmental, socioeconomic, and cultural.	Does 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.	Does not assume common values for all groups. Different risks/impacts may require different approaches.
Account for the influence of existing environmental, cultural, and socioeconomic conditions.	Does 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 must 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.	The range of possible synergistic effects is 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 utilized 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 Hanford Environmental Dose Reconstruction (HEDR) Project in which an evaluation based on five radionuclides was estimated to account for more than 94 percent 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 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 local Tribes, stakeholders, and regulators. The purpose of this initial scoping effort is to obtain a global picture of the problem. As the assessment proceeds, the global picture and focused as appropriate, drawing from previous assessments and ongoing fate and transport modeling, environmental site characterization, and 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 is to ensure that at the project completion there will be general agreement that the limited scope studies will provide adequate information upon which decisions can be based. The decisions on study scope and design for each iteration are 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?

No.	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 ten times greater?	Simple models	If no, end analysis; if yes, do #3a
3a	When would significant risk/impact occur given simplified migration assumptions?	Intermediate models (e.g. RESRAD, MEPAS)	If in <5000 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	

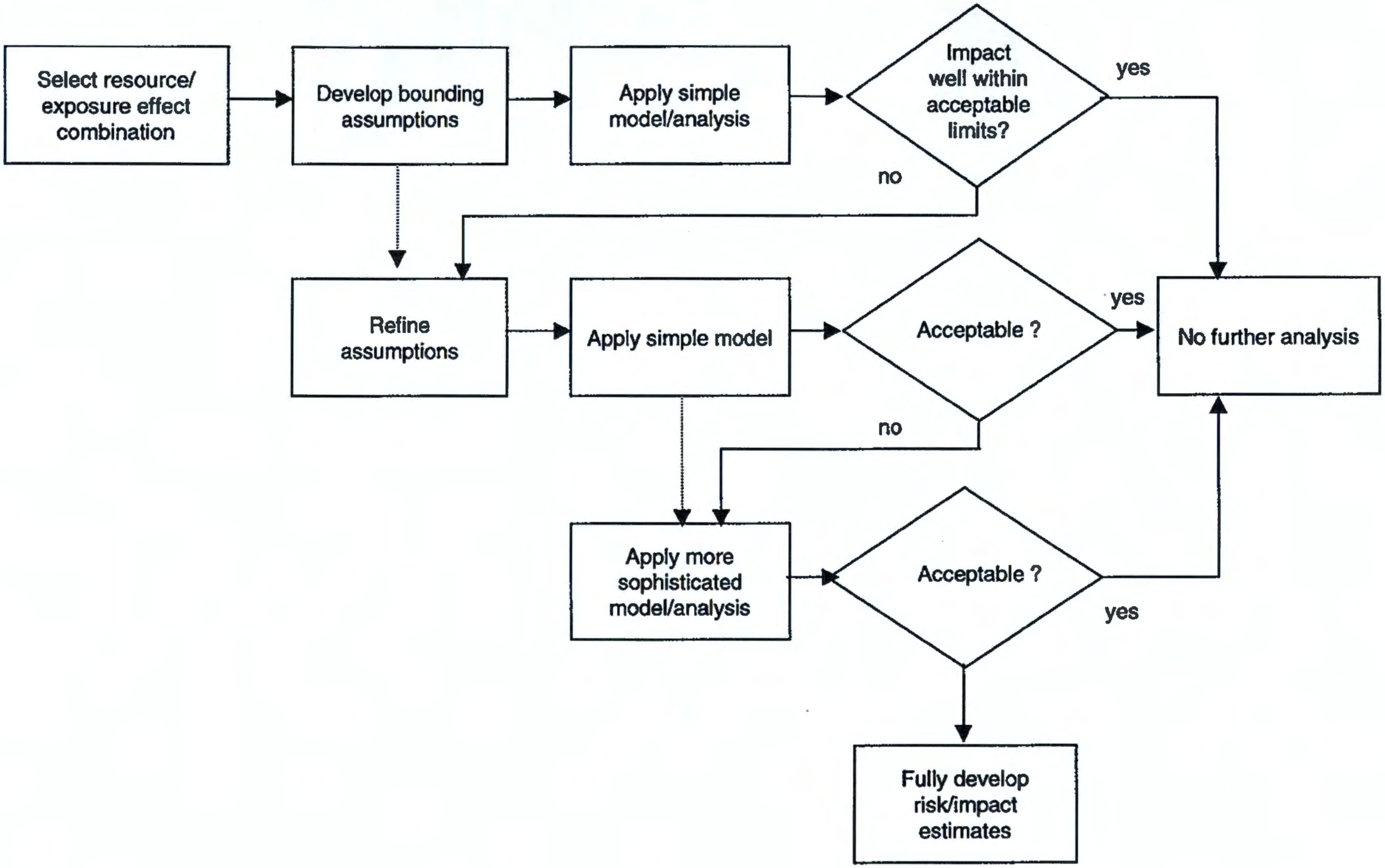

FIGURE 3.2 Iterative Process for Focusing Risk/Impact Analysis

If significant risk will occur in <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?

No.	Analysis Element	Method	Process Step
1b	Would contaminant concentrations exceed criteria levels in key 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 impacts?	Screening analysis	If no, end analysis; if yes, do #4b
4b	Any significant biological impacts?	Combination of standard and supplementary estimation methods	If no, end analysis; if yes, do #5b
5b	Magnitude of secondary impacts?	Combination of standard and supplementary estimation methods	

3.4.3 Integrated Approach

It appears that the impact assessment will be most effective if it is designed to encompass the classical regulatory approach, but with adaptations to accommodate both uncertainties regarding potential concentrations of contaminants at release points and stakeholders' concerns. The adaptations 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, the dependency web concept should be employed as a means of moving in the direction of increased comprehensiveness, but extended to specify exposure pathways and uptake for biological resources. In addition, we recommend employing a model-free approach in some contexts, to provide reality-based bounds on projections and to enhance stakeholder communication.

Figure 3.3 illustrates ways in which the complementary approaches discussed in Section 3.2 can be integrated to facilitate the assessment. It also indicates some of the major sources of information inputs at various points in the assessment process.

3.4.4 Phases of Analysis

Within this framework, the analysis should proceed in stages. The structure of the contamination and environmental relationships underlying the Integrated GW/VZ Risk Assessment can be addressed most cost-effectively by employing a phased approach. While some exploration of methods and issues related to follow-on stages of the analysis is warranted, the outcomes of initial stages will determine the need for and focus of later stages.

We recommend that the risk/impact assessment process be conducted in three major stages, as outlined in Figure 3.4. Within each of these stages, the type of iterative process described in Figure 3.1 can be

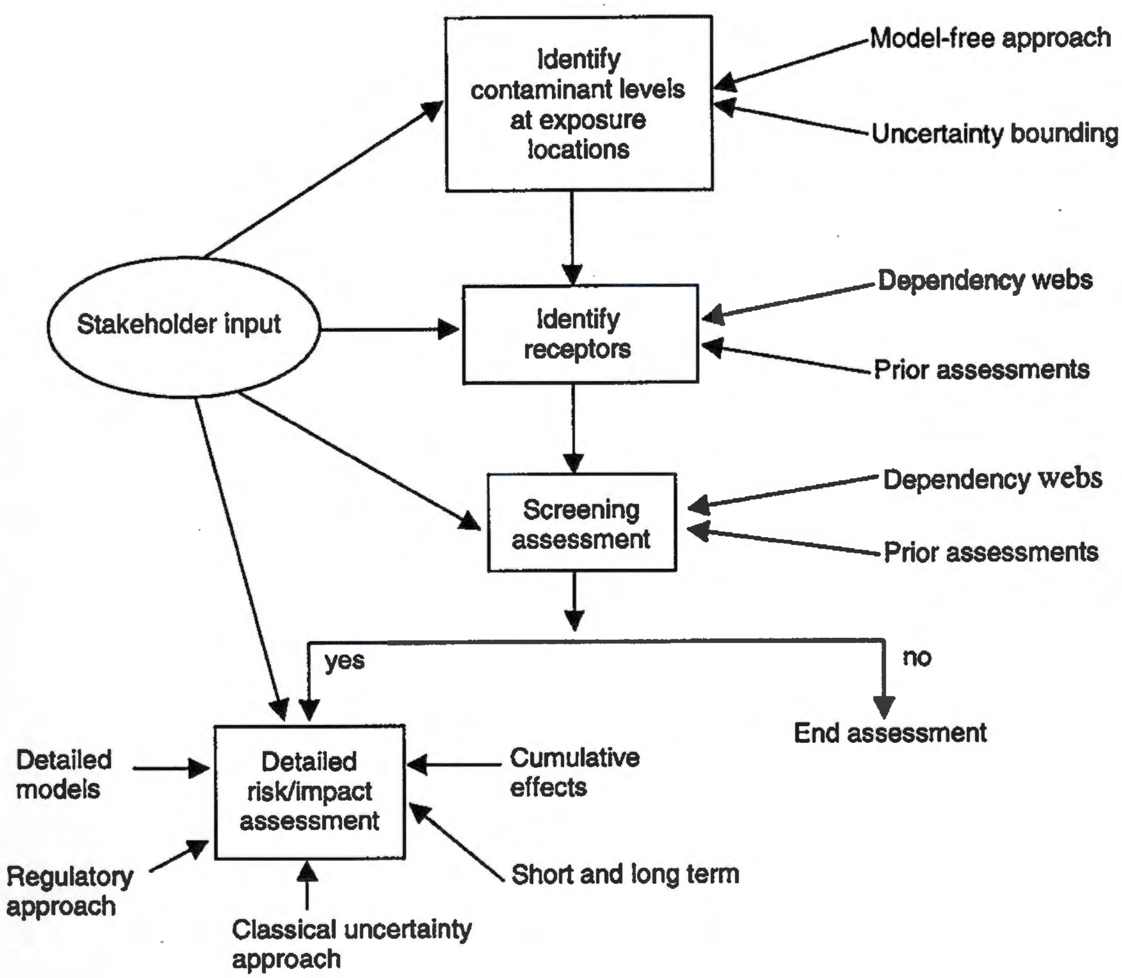

FIGURE 3.3 Overview of Information in the Integration of Approaches

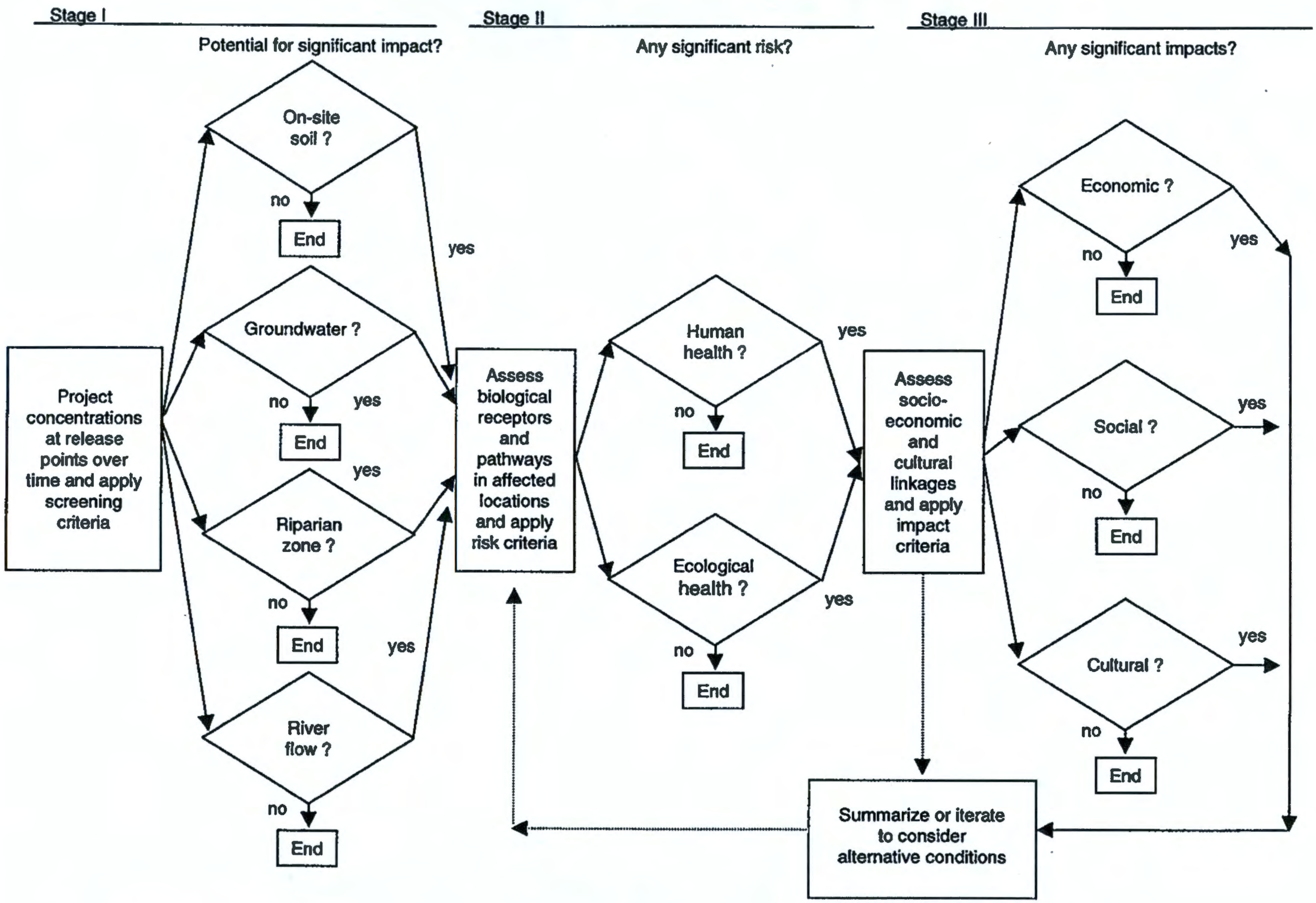

FIGURE 3.4 Phased Approach to the Integrated GW/VZ Risk Assessment

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 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 within a 50-year period (e.g., 10 years) and longer periods thereafter (e.g., 100s or 1000s of years). Development of these concentration estimates permits identification of any significant levels at any of the locations, based on screening criteria applied to contaminants individually or in the aggregate. This analysis provides a basis for identifying the appropriate set of impact area and contaminant combinations for study.

The second and third stages 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 can build on the dependency web information base, but requires development of well-specified and quantified information. On the basis of the exposure scenarios and the projected contaminant concentrations, risks to health, ecological resources, or, possibly, cultural resources would be assessed. This assessment should cover both individual contaminants and, to the extent possible, cumulative and synergistic effects. From this set of assessments, the study set of significant risks and impacts can be identified.

In the third stage, the impacts of the biological effects would be assessed. This requires identification of social and economic linkages to affected resources, which could be based on dependency webs and to a major extent on standard practice in scoping economic assessments. It also requires identification of cultural practices and resource linkages, which will depend on the inputs and effort of the cultural groups involved. From these analyses, the set of significant impacts can be identified and summary estimates prepared. The second and third stages may then be iterated to consider alternatives, if appropriate.

3.5 IMPLEMENTATION ISSUES

Three types of implementation issues are discussed in this section. These include the identification process for receptors and pathways to support a relatively comprehensive impact assessment, modeling strategies to address uncertainties, and stakeholder participation in the assessment process.

3.5.1 Receptor/Pathway Identification

The dependency webs as developed for use in the GW/VZ Integration Project are expected to serve as a tool for communicating with regulators, Tribal Nations, and stakeholders what is "at risk" due to potential contamination. The webs that have been tentatively identified to date can be considered as part of the process of ensuring a comprehensive, holistic view of potential direct and indirect impacts of contaminants. They would be complemented by standard methods of receptor identification.

While the webs offer a useful graphical depiction of the interrelation among potential impacts of contaminated media, location-specific webs may not be the best way of communicating about crucial receptors. Receptor-centered webs, as exemplified by the salmon-centered web example prepared by the Harris and Harper (1998b), could provide information related to the ripple-effect of impacts due to biological effects on a central resource on associated resources. Such receptor-centered webs would not take the place of the location-centered webs that should be especially relevant in ecological risk discussions on the ecosystem level. Examples of receptor-based webs that could further the discussion of critical receptors include: Native American (e.g., potentially one each for child, mother, and father), salmon, urban dweller, farmer, fisherman, and various commercial water users. Additional webs could be developed based upon the identification of other critical sites, species, human receptors, businesses, and so forth.

In addition, creating a set of overlapping webs at various scales of analysis could illustrate the holistic nature of the risks/impacts identified. A matrix of location-centered and receptor-centered webs, from the big picture to the very-detailed level, would provide a range of webs that are identified as key endpoints and/or receptors for the final study set. For example, for the riparian zone a set of webs could illustrate relationships for the zone as a whole, at the habitat level, at the species sub-habitat level, and for a particular receptor, such as the Southwestern Willow Flycatcher. Each web would be a reflection of complementary information detailing ecosystem functions, e.g., food resources, nesting habitat, seed dispersal, and pollination. The matrix of webs would thus be useful in communicating with segments of stakeholders, tribal nations, and the public about their concerns and the interrelationship of potential impacts.

3.5.2 Modeling Strategies

Within each stage of the assessment discussed in Section 3.4.5, the approach can 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 can be used in an assessment that takes account for 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 limits, the analysis is complete, a decision can be made, and a formal uncertainty analysis does not need to be performed. This will be the case for many contaminants. However, it is generally not possible to eliminate concerns about all contaminants with a bounding analysis. In this case, more detailed estimates of release and transport, uptake, or avoidance behaviors are needed. This type of bounding or "worst case" analysis has serious disadvantages when used to establish absolute levels, e.g., for cleanup, but is a cost-effective tool for focusing analytical resources.

This sequence of model levels will need to be reversed in situations where the primary issue is increases in uncertainties over time. In such cases it may 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, Morgan, and Dowlatabadi 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 reasons for this are twofold. First, the simpler the model, the more transparent the results will be to most stakeholders. Second, more sophisticated models generally require more data and therefore the sources of uncertainty (though not necessarily the magnitude of uncertainty) 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 will be useful in decision making. This 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 can be obtained by examining approaches used to model interactions between the contaminant and the host media (soil or rock). To simplify the chemistry involved in this process, contaminant transport calculations for impact assessments commonly use a parameter known as the distribution coefficient. This 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 interactions. Such a geochemical model would require data on all of 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 then 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, Andrews, and Mercer 1999) recommended development of a suite of conceptual models as a means of addressing uncertainty issues due to a variety of conditions, including heterogeneity in subsurface structures. It is possible that the available data will be insufficient to define a single model as the most appropriate for use. In this case, the model that results in the highest exposure can be used initially in the risk/impact assessment to provide an upper bound.

3.5.3 Public Participation

One of the unique aspects of the Integration Project is the central role that concerns of interested parties play in the overall risk planning process. Several national studies of environmental decision making have concluded that technical and stakeholder processes must be placed on an equal footing to achieve effective decisions that are defensible and lasting (NRC 1994; Presidential/ Congressional Commission on Risk Assessment and Risk Management 1997). The need for input from regulators, Tribal Nations, and stakeholders – while already clearly recognized as important to the overall Hanford GW/VZ Integration Project – warrants special attention. Public concerns about risks are closely tied to the generation of socioeconomic impacts and thus are key inputs to impact assessment efforts for the project. Ultimately, the success of the Integration Project could hinge on the effectiveness of the arrangements for stakeholder involvement in the risk assessment process. In fact, an extensive participatory process is facilitating the ongoing assessment and decision process for environmental management activities at the 200 Area and tank farms.

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

- The technical risk/impact assessment approach be determined and implemented through an explicitly defined consensual process within a working group that includes both stakeholders and technical experts,

- Deliberations of such a working group be supplemented with systematic and extensive opportunities for wider community review and input,

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

- Extensive technical reviews be conducted by external experts.

These stakeholder involvement mechanisms are to varying degrees already in place as part of the GW/VZ Integration Project. The following discussion describes approaches that could enhance or make more explicit the objectives, organizational structures, and roles of individual elements, in particular as they apply to the risk and impact assessment activities for the integration project. These approaches can be expected to strengthen the soundness and feasibility of implementing risk -driven decisions for the site.

It is important that the consensus-building activities of the Integration Project continue to encompass a broad range of public involvement activities to ensure consistent, ongoing inclusion of all interested parties in the effort. These activities should be planned, scheduled, supported and documented in ways that enable participants to contribute to decisions on site remediation and long-term site management. Such an approach should help to ensure that the sound foundations of the project developed as a result of the stakeholder participation in the Columbia River Comprehensive Impact Assessment team are continued in the GW/VZ Integration Project.

- 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 SAC Working Group primary responsibility for designing and implementing the risk element. For the process to remain transparent, methodologies, data input, assumptions, results, and broad participatory interactions should be frequently distributed in a simplified, highly visual format that can be understood by a wide sector of interested parties.

- We encourage the SAC Working Group to solicit input from a broad range of interested parties in aiming for consensus before moving ahead on methodologies, data, assumptions, membership and roles. It is also recommended 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 stakeholder groups. These functions would be developed in coordination with the GW/VZ Integration Project (SAC) team.

- We encourage inclusion of provisions for dealing with issues on which the SAC Working Group cannot reach agreement in the Working Group procedures.

- We encourage the SAC Working Group to continuously seek input from stakeholders and members of the public to supplement 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 remediation effort, different types of information need to be communicated between the public and program managers. Table 3.2 provides a preliminary example of the way in which the program phases and the public information gathering and public review can 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: Approx. 1999-00 Period of expanded research on the vadose zone and groundwater; and of impact scenario development (potential health, social, and economic impacts).	Who are the stakeholders for the various impact zones?	Interviews with HAB members, and with representatives of other entities who may have a stake in the potential impacts to a specific zone.	To ensure that stakeholders are recognized by program managers; To ensure that stakeholders' concerns are known to the program managers. To obtain guidance for designing a set of focus groups.
	What types of information do stakeholders want about the likely 200 Area remediation program options and their bases?	Focus groups (focused group interviews) with purposefully selected sets of stakeholders to discover what they "know" about the remediation program, and what their questions and concerns are.	To ensure that the VZ study will address the stakeholders' questions, and be able to explain the likely knowledge gaps in the early stages of the study. To ensure that relevant social and economic implications of the remediation options are evaluated for use with stakeholders and in program decisions.
Decision Phase: Approx. 2001-05. Period when better vadose zone information is being factored into next remediation decisions for 200 Area and remediation options are being compared and selected.	What concerns and questions do stakeholders have about the vadose zone and impact scenarios that have been developed to facilitate comparison of options?	Focus groups (focused group interviews) with purposefully selected sets of stakeholders.	To facilitate analysis of the concerns and satisfactions of the various impact zone stakeholders. To inform a citizen advisory group which 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 an Advisory Group specific to the Remediation program that meets periodically to review materials and raise issues and questions for the program managers, e.g., the HAB.	To permit program managers to address issues and concerns as they emerge during the decision phase. To gain assurance that the major stakeholders consider the remediation options and controls acceptable, given available information on effective-ness, costs, and socioeconomic impacts.
	What are domains of concern of the general public (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.	To continuously tap into public concerns, ideas, and information needs, which can be used to guide further research needs and consideration of adjustments in the program.
Implementation Approx. 2005 ff. Period when execution of remediation approach is begun, including interventions (controls) related to movement of contamination in the vadose zone.	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 Advisory Group discussions and concerns about the Remediation Program.	To ensure that the social and economic scenarios related to the remediation options and controls reflect ongoing research and are relevant to local and regional socioeconomic conditions and trends.

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4 APPROACHES FOR ASSESSING IMPACTS

Approaches, methods, and some 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 cultural and quality of life effects and in Section 4.4 for socioeconomic impacts.

As described in Chapter 1, risks are considered to apply to human and ecological health and safety, as these reflect direct or primary effects associated with site-related hazards. Impacts that reflect social, cultural, and economic responses to those hazards being present – i.e., responses made by the primary "receptor" – are considered secondary impacts. (Cultural effects can also be considered sociocultural as they strongly society-based. In recent discussions with the Hanford team, the cultural and socioeconomic components have been reassembled to reflect that primary emphasis, and the final report will likely be retailored to discuss sociocultural and economic impacts.)

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) (EPA 1989, 1996, 1997a). These approaches include default values for various exposure factors, with an emphasis on employing site-specific values where available to obtain more appropriate risk estimates. Also included is toxicity information for cancer and noncancer health endpoints from the scientific literature, as compiled by the Agency for Toxic Substances and Disease Registry (ATSDR) in individual toxicological profiles (available on the Internet). This EPA framework has been incorporated into the Hanford Site Risk Assessment Methodology (HSRAM) process.

Building on the outcome of the Columbia River Comprehensive Impact Assessment activity, a variety of exposure considerations and potential health endpoints have been identified for possible evaluation through ongoing efforts of the System Assessment Capability group. Key elements of a process for assessing the contaminants of concern, possible health implications, and appropriate exposure scenarios, are summarized below. This health risk evaluation is expected to range from qualitative to semi-quantitative, as determined by the scientific information available, with input from interested parties.

For human health effects to occur, there must be exposure 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. The assessment of potential for human health effects in the 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 data have identified a number of locations within the Columbia River Basin that may receive contaminant input at some future time, but do not currently contain measurable concentrations of contaminants. Results of ongoing and further fate and transport modeling results may also predict increases in contaminant concentrations above current levels at locations where human health risk assessments are underway. The human health assessments undertaken for the Hanford GW/VZ 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 population densities and use of resources).

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 per 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 candidate set of contaminants be screened against the range of potential health endpoints using a matrix developed to organize relevant state-of-the-art information from numerous sources. The matrix would serve as the master set of toxicological values for the health effect 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., per the National Toxicology Program), genetic testing, and microtoxicity assays. Information from the international community (e.g., International Agency for Research on Cancer) would also be evaluated.

In addition, the EPA's Environmental Criteria and Assessment Office could be consulted to develop toxicity values on a case-by-case basis, if needed. Other guidelines and regulatory standards would also be considered, with an emphasis on the relevant health databases. These include Occupational Safety and Health Administration standards (PELs and TLVs); standards and guidelines developed under the framework of the Resource Conservation and Recovery Act (including toxicity/leaching tests and exit levels) and reportable quantities developed under the framework of the Comprehensive Environmental Response, Compensation, and Liability Act, as amended. In addition, preliminary remediation goals developed by EPA Region IX and state standards would be considered.

The suggested matrix approach for summarizing existing toxicity information for all contaminants identified at impacted locations would provide a consistent method of evaluating the potential for combined effects from exposures to multiple chemicals, through identification of contaminants with similar modes of action, target organs, and/or noncancer endpoints. The concentrations of these contaminants in the impact locations would be considered as a group in evaluating their potential for causing adverse human health impacts. 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 contaminants for study from the candidate set. The initial screen would use the matrix of values on the full candidate set to identify the substances that are known to be toxic or for which toxicity is probable. Following the initial screen, a screen employing a comparison of current and projected chemical concentrations in a specific impact location (e.g., riparian zone or river flow) with concentration benchmarks for toxicity could be conducted to further focus the study set. For this screen, it would be important to retain flexibility in defining a specific risk "cutoff level" (e.g., increased lifetime cancer risk of less than one in 1 million) as the basis for the focusing 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 synergistic 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 toxic effects.

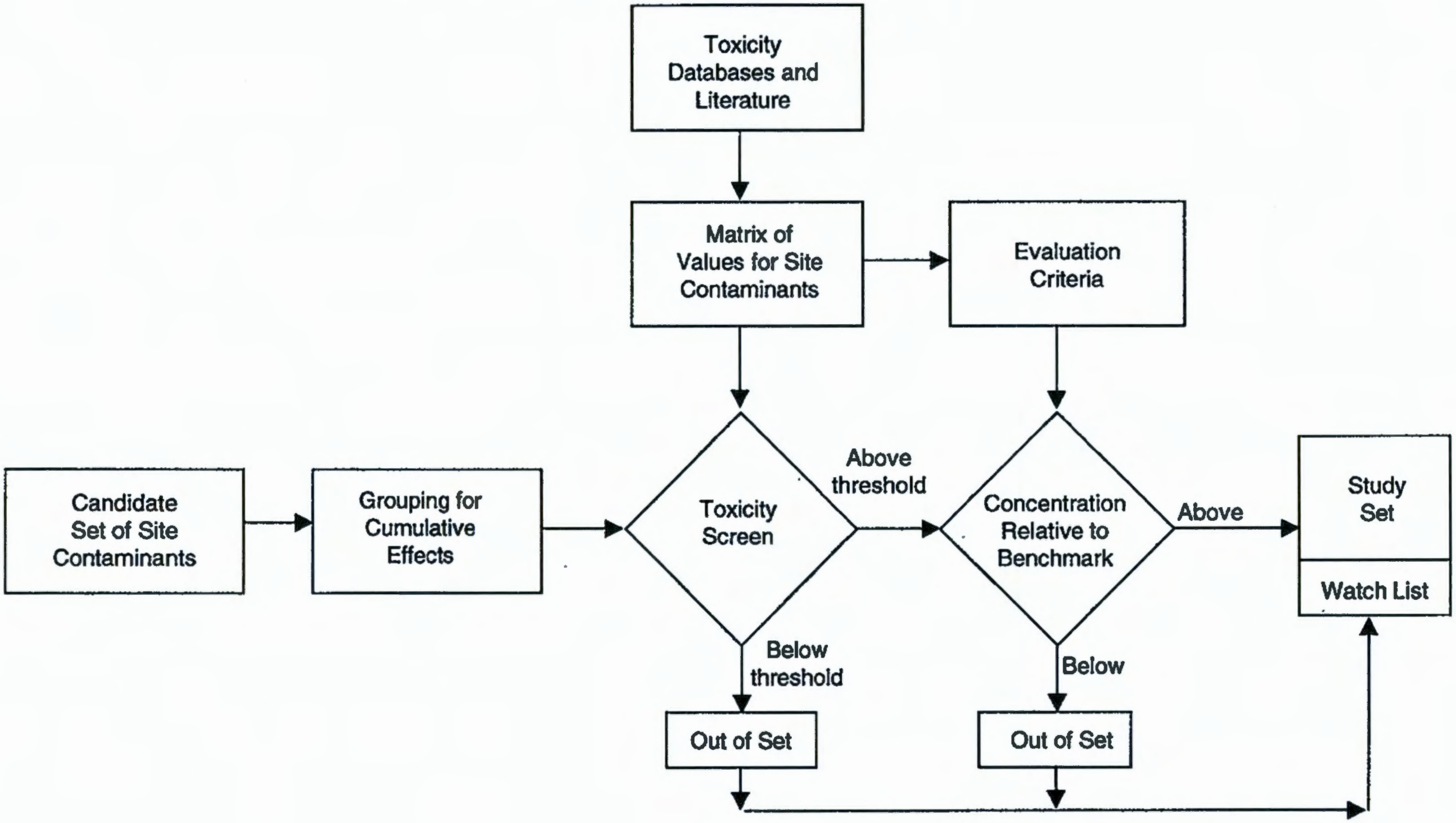

FIGURE 4.1 Toxicity Assessment Process

As an example of how criteria for determining the study set would be applied, 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 cumulative or synergistic effects, would also be considered for priority evaluation.

Those contaminants and health endpoints for which no evidence yet exists for a causal relationship could be carried forward in the matrix as a "watch list." These would be activated for further consideration as indicated by new information developed through future scientific discoveries (such as through studies being conducted through the NTP and National Institute of Environmental Health Sciences research programs). 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 an 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 SAC, based on the CRCIA efforts (DOE 1998). These can affect populations and individuals, based on key combinations of impacted locations and related exposure scenarios – and considering 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, ethnicity-specific, and gender-specific factors would be considered on a case-by-case basis, as indicated for each exposure scenario (discussed below) – and has been done as part of the initial CRCIA effort and many other Hanford project assessments. For individuals, both the representative average individual 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, but not for the noncarcinogenic effects (as these are ratio-based estimates, not statistical likelihood estimates).

The set of exposure scenarios and primary impacted locations to be evaluated will continue to be developed in concert with all interested parties. This process includes 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 contaminant and medium. Basic components of this process include:

- Identifying a list of realistic exposure scenarios for impacted locations, with input from regulators, Tribal members, and stakeholders (including the general public). These scenarios would include consideration of individuals, sensitive subpopulations, and unique exposure activities as indicated, e.g., 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 dependency webs together with existing data and methods, and developing specific conceptual models to guide the risk assessment. For those who may be interested in additional scenarios, a unit-based scenario assessment matrix tool can be provided to allow "personalized construction" of a broad range of possibilities. (That is, by reflecting unit concentrations and unit exposure times for each route of exposure, together with appropriate toxicity values for the indicated exposure routes, the amount of both the contaminant and the exposure can be scaled to fit the indicated location and scenario of interest. Activity-specific elements of a given scenario can be combined to produce individualized estimates.)

The study set criteria being developed through the SAC process will be used to guide the selection of scenarios to be assessed for impacted locations in the first phase of the study process, emphasizing the evaluation of a limited, representative range than a full suite of possible scenario options. (As this suite can be separately evaluated by those individuals who may interested).

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. Exposure scenarios for relevant pathways and 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 phased from further analysis at this stage.

The remaining set of exposure pathways could be prioritized for analysis by magnitude, severity, and likelihood of exposure, as necessary. Thus, the steps of a health effect assessment can be:

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

- Conduct a contaminant screen based on current and predicted future concentrations compared with existing concentration-based standards and guidelines (per EPA and state protocols, as well as other approaches, e.g., international). Consider anthropogenic and natural background levels.

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

- Quantify potential exposures and risks for these receptors based on existing and innovative methods, as practicable. (For example, EPA's revisions to the Cancer Assessment Guidelines [EPA 1996, 1999] would be incorporated in the evaluation of carcinogenic risk). Uncertainties in the estimated risks would be clearly stated and discussed. Use of quantitative uncertainty analysis would be considered.

It would be helpful to integrate results of this assessment with the overall impact assessment process currently under way for various areas and activities at the Hanford site, in order to aim toward harmonization so future assessments could be more readily linked.

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

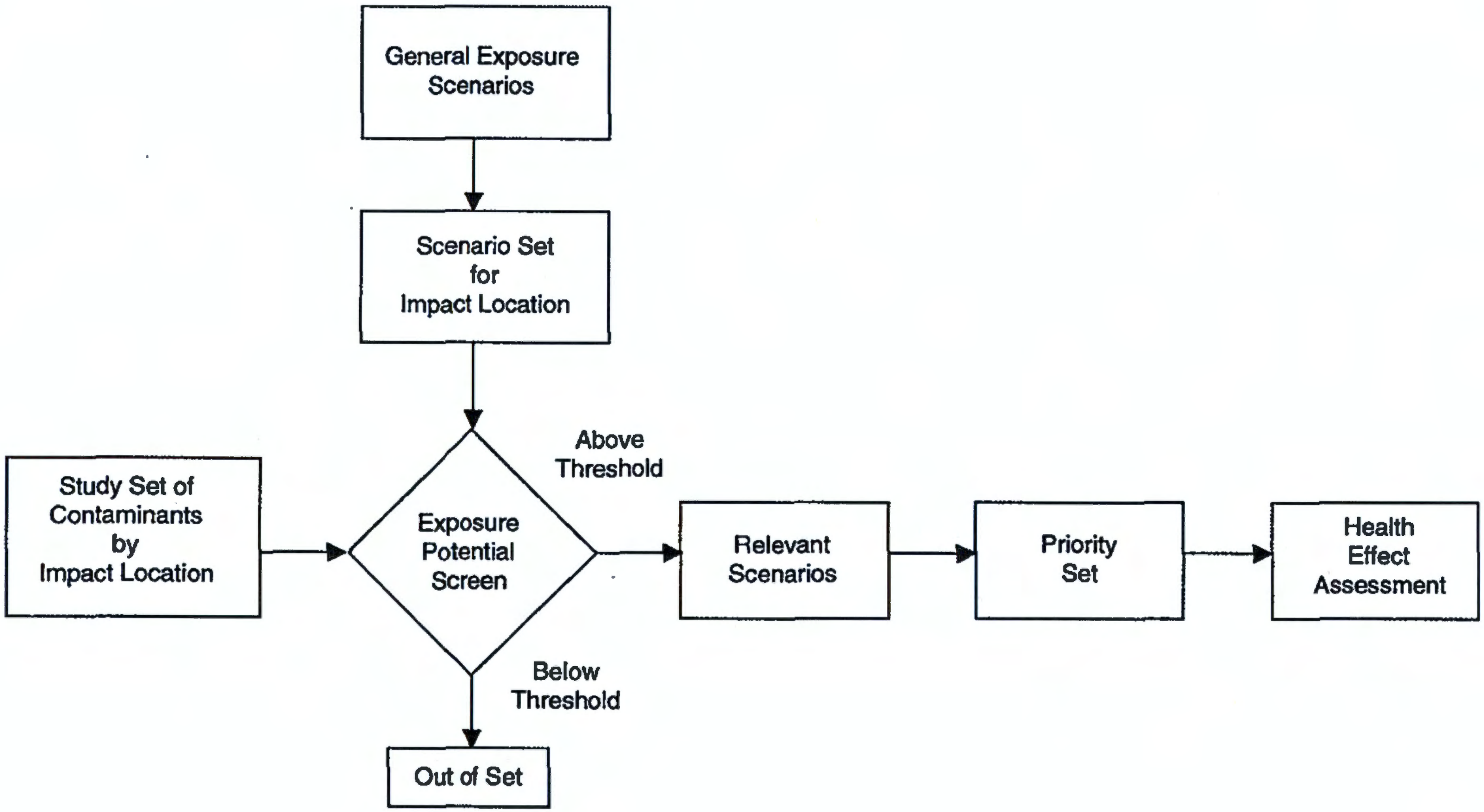

FIGURE 4.2 Exposure Assessment Screening Process

in an environmental medium at a site with risk-based standards or guidelines, with the elimination from further consideration of those substances present at concentrations lower than the screening levels. Alternatively, the total carcinogenic or noncarcinogenic risk from all the substances may be tallied, with substances contributing less than some defined proportion of the total deleted from further consideration. (This latter is the method suggested in the most standard reference, EPA's Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual).

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 single contaminant's concentration with a benchmark level, prior to any assessment of whether that chemical may interact with other chemicals present to exert toxic effects. An example would be for several types of organic solvents that cause nervous system toxicity. The critical effect for a substance's reference dose is the adverse effect observed at the lowest dose, such as decreased body weight. Under the standard methods of contaminant screening, and without consideration of the potential for neurological effects common to many solvents, these substances could potentially be eliminated from further consideration when their combined effects could be significant.

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 would be accomplished by identifying not only the critical effect associated with a substance, but all of the types of toxic effects associated with the given substance. In addition, mechanisms of toxic action within biological systems would be included in the matrix where available. The following example of the matrix format could be used to develop and assess the study set for health effects based on chemical toxicity information together with impact location and specific exposure considerations:

Impact Location	Key Contaminants and Active Metabolites	Toxicological Endpoints of Primary Concern	Mechanisms of Action	Applicable Exposure Routes (e.g., inhalation, ingestion, dermal, immersion)	Primary Exposure Scenarios

Contaminants with similar toxicological endpoints of concern and/or mechanisms of action would be grouped. The current and projected future concentrations would be considered as a group (e.g., using a "hazard index" type approach). Professional judgment would be required in the decision on whether to exclude any of the 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 indicate contaminants for which available data indicate the potential for synergistic effects. A screening "mixtures" risk assessment would be conducted for these chemicals in accordance with the approach currently being developed by EPA.

4.1.4 Innovative Approaches

Innovative approaches are being developed that can augment the basic risk assessment elements laid out in the HSRAM process. The HSRAM process is consistent with regulatory frameworks and reflects standard practice being applied nationwide. This approach can be augmented by innovative assessment methods that will continue to be advanced by an explosion of technological and scientific developments. By staying current with these advances and reflecting them in their risk analyses, the Hanford site can provide national leadership in state-of-the-art risk assessments for complex sites. The hazard identification, exposure assessment, toxicity and effects models, and risk characterization models can all be improved by new data and tools being developed in multiple areas. Many are still in the exploratory stage, while others are already is use to better inform our health risk assessment process; they include:

- Genetic-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 radiation or chemical exposure.

This incorporation of new information as it is developed is consistent with the theme of EPA's recent cancer guidelines, which recognizes the importance of reflecting new toxicity data in risk assessments. One way that risk assessment has been streamlined for complicated sites with multiple chemicals is to develop a matrix that presents unit contaminant concentrations and exposure factors, such that these can be scaled to reflect different levels and scenarios at various impacted locations. This allows ready comparison among chemicals and radionuclides contributing to estimated cancer risks and non-cancer effects, to identify those of most concern and thus deserving of priority attention for decision makers and further study. The chemical mixtures assessment would serve as an overlay to this standard compilation.

4.2 ECOLOGICAL EFFECTS

The evaluation of ecological risks is an evolving science that is open to new ideas and methodologies. This section of the report discusses some of the ways the Hanford GW/VZ project may be able to build upon the full body of scientific information that has been collected at the site by PNNL scientists and others. The PNNL work, along with the work done by the Fish and Wildlife Service, has built 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. The assessment will consider ecological resources at appropriate spatial (locations both on-site and off the Hanford reservation) and temporal scales and address the general ecological resources identified as the candidate set in the CRCIA requirements. It is important that the ecological risk assessment be conducted in a scientifically defensible manner that identifies risks to ecological resources of concern at both local and regional scales, in the present and the future. It also must permit linkage of the ecological risk results to other impact sectors (including human health, cultural, and socioeconomic).

The scope and complexity of any ecological risk assessment at the Hanford site will be dependent on the scale of the particular evaluation under consideration. Because of the vast size of the site, any regional assessments will initially be qualitative in nature, identifying ecological and contaminant conditions and focusing on exposure across a large spatial scale. More quantitative assessments evaluating effects will be conducted at the impact site-specific level. However, as the body of data for a particular ecological receptor increases, these site-specific assessments may be incorporated into reevaluations of the regional assessment. The integration of the ecological risk assessments with other impact sectors, and the development and application of regional and site-specific ecological risk assessments at 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 depicts the relationship between contaminants in particular locations and the assessment of receptors in those locations. In the selection of the receptor study set, both the ecological role of the receptor and cultural and economic 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, cultural, and socioeconomic). The use of dependency webs (as discussed in Section 3 of this report) represents an approach for integrating the ecological interactions of the non-ecological sectors into the ecological risk assessment. For example, the assessment endpoints to be evaluated by the ecological risk assessment would be based on ecologically important considerations, and also include endpoints deemed important from a cultural, socioeconomic, or human health perspective. Similarly, dependency webs could be used to incorporate non-ecological management goals into the interpretation of ecological risk acceptability.

4.2.2 Identifying Receptors and Habitats for Evaluation

In the ecological risk assessment, an assessment endpoint is defined as a particular aspect of the ecosystem that is considered desirable to protect, and thus serves as the 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 exposure routes associated with a site or region, as well as considerations of cultural, socioeconomic, and human health concerns.

While conceptually simple, identifying appropriate assessment endpoints is a challenging task that will require extensive interactions and consultations among appropriate parties. Clearly defined assessment 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 will 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, etc. In addition, input via the dependency webs will identify additional ecological receptors for inclusion in the assessment. Criteria for selecting candidate receptors will include, to the extent appropriate, the requirements identified in the CRCIA II document (DOE-RL 1998). After the selection of an appropriate candidate set, specific study set receptors will be selected for detailed evaluation in the assessment. Factors considered 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,

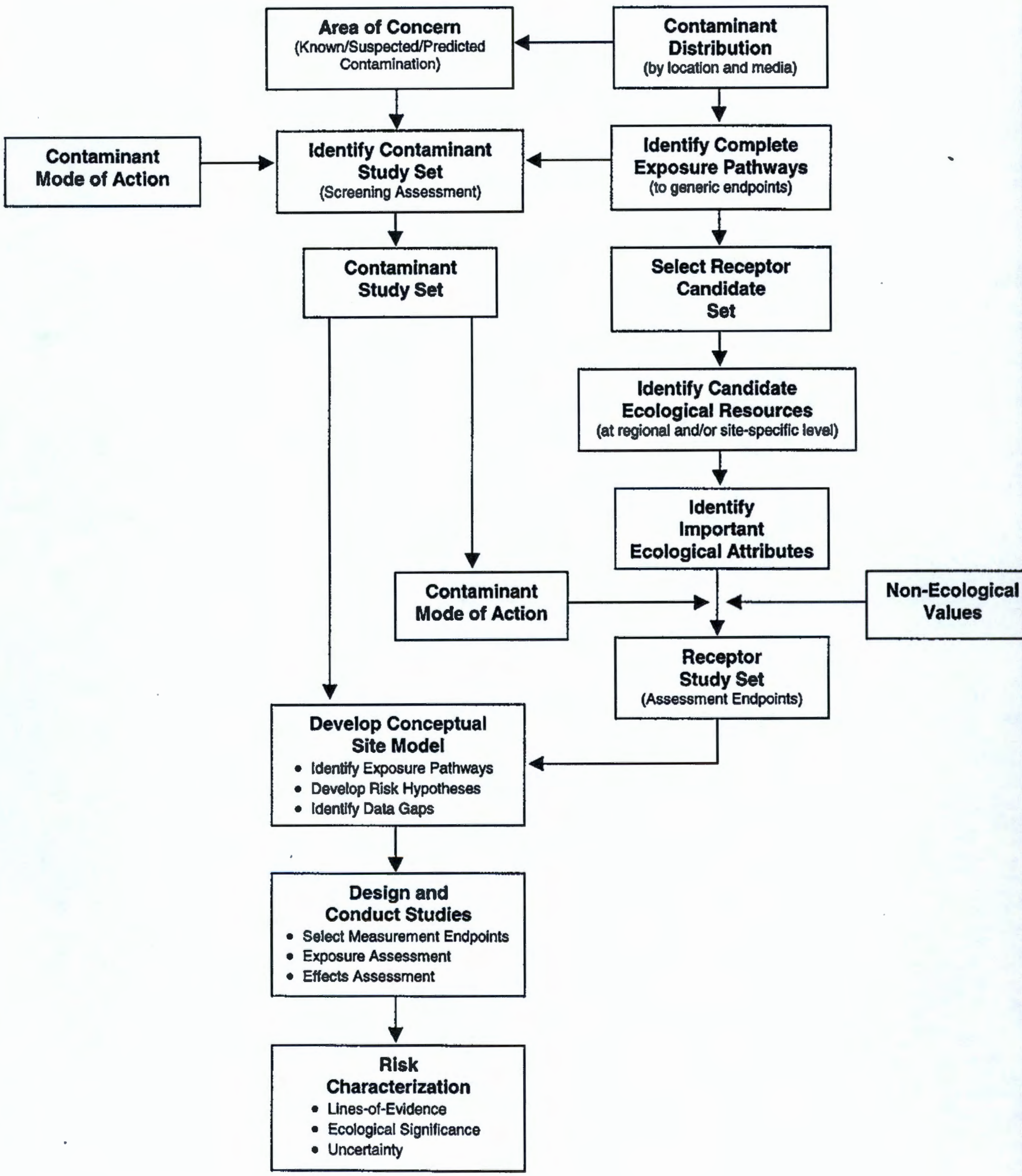

FIGURE 4.3 The Ecological Risk Assessment Process

- 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, and dependency webs can be used to obtain some of this input.

4.2.3 Assessing Ecological Risks at a Regional Scale

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

- characterization of the distribution of the candidate receptor set across the region of interest;
- characterization of the nature and extent of contamination across the region of interest; and
- a qualitative characterization of risk based on 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 will involve development of a regional scale conceptual model and will be based on both site-specific (as available) and literature-derived effects data. As site-specific effects data are generated by local scale investigations, these data can be used to reduce uncertainty and strengthen the regional assessment. Data on the distribution of receptors and the nature and extent of contamination at the Hanford site and surrounding region are extensive. The site-wide Hanford Geographical Information System houses voluminous 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, i.e., by evaluating the degree of overlap among ecological receptors and the distribution and extent of the non-site stressors. Cumulative impacts may be evaluated by examining the degree of exposure overlap of the site and non-site stressors among the receptors. The results of the regional assessment can 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 at a Local Scale

At the local or site-specific level, the ecological risk assessment will follow a three phase process including:

- 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.

Though risk characterization occurs as part of the screening assessment, it is relatively rudimentary and addresses whether to proceed to the baseline assessment or not. Its focus is on identifying the specific contaminants and broad receptor groups that would be evaluated in detail in the baseline risk assessment. As site-specific risk assessment results are obtained across the Hanford site, these results can 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. Due to the very conservative nature of a screening assessment, the screening level will overestimate potential risks, thereby resulting in a very protective list of constituents to be further evaluated in the baseline assessment.

As part of the site-specific assessment, a conceptual model would be developed. This conceptual site model will 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 will 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 is developed and agreed upon by all appropriate parties, an appropriate set of specific methods (defined as the measurement endpoints [EPA 1997b]) for evaluating effects to the assessment endpoints can be developed. The specific nature and extent of the methods will 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, or young surviving to fledge, can be employed.

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 to provide support to risk management decisions. In contrast to human health risk characterization, there are no standard risk numbers (such as 10^{-4} - 10^{-6}) for ecological risk characterization that are applicable to all types of studies that would be conducted in the baseline assessment. Rather, ecological risk estimation will be based on a lines-of-evidence approach (EPA 1997b; Menzie et al. 1996). This approach makes a qualitative estimation of risk based on 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. Although the assessment may identify risks, those risks may not warrant remedial action. The ecological significance of impacts is arguably the most important aspect of the risk characterization, and interpretation of ecological significance should include considerations of:

- 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 will rely heavily on the professional judgement of the risk assessors, together with consultations and discussions with all appropriate parties.

4.2.5 Evaluating Risks under Future Environmental Conditions

The assessment of ecological risks in future time periods could utilize the same approaches identified for the regional and local scale assessments. However, it will be more problematic because of the difficulty in adequately predicting contaminant fate and transport, future distribution and status of ecological receptors, and future human activities and development. Fate and transport modeling will likely identify a number of locations within the Columbia River Basin that may receive contaminant input at some future time. Because of the absence of site-related contaminants at these locations currently, it is unlikely that any ecological risk assessments will have been conducted at these locations. The ecological risk assessment of these types of sites under future conditions will 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 are developed for other locations in the Hanford impact area, these may be used in preference to literature values.

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

4.2.6 Methods for Evaluating Risks

The assessment of risks to ecological resources consists 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 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 based upon 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. There are, however a variety of contaminant-, media-, and receptor-specific standard methods that 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 down to those that are feasible for the given site.

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. Samples collected from upstream or up-gradient locations are necessary to identify incremental risks associated with the site under evaluation and to differentiate them from effects or risks due to environmental stressors from other sources (e.g., upstream discharges). Because the goal of a reference site is 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 exposure assessments. First, contaminant concentrations in environmental media can be directly measured, and doses to receptors can be estimated using 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 will be needed to adequately evaluate exposure for all assessment endpoints. However, direct measurement of contaminant concentrations in tissues of biota is preferable to contaminant uptake modeling or use of biomarkers wherever feasible 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 will be necessary to ensure the appropriateness and value of the data used in the exposure assessment.

Direct measurement of contaminants in tissues may also allow site-specific bioconcentration and bioaccumulation factors to be developed 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 permits a better understanding of the degree of risk and will 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 it can reasonably be concluded that the contaminant poses no risk to that receptor.

4.2.6.2 Effects Assessment

In the effects assessment, concentrations of the contaminants of concern are quantitatively linked to adverse effects on 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 upon information currently available in the literature, or 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 at the individual, population, community, and ecosystem levels.

Available literature pertaining to toxic 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-RL 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 closely coordinated with chemical sampling of media and biota in order to associate the degree of effects to the degree of contaminant exposure. Further, toxicity testing with media from areas of concern and reference locations can be used 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) so that cleanup criteria can be developed, as well as to assist with evaluation of residual risks for Natural Resource Damage Assessment issues.

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[c]
Individual	Current	+[b]	+	+	-	+	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 level 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 (trustees, Tribal Nations, regulators, stakeholders).

[b] 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.

[c] 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.

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 1000 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 due to 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 its implications in making risk management decision 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 in predicting current and future contaminant fate and transport, and
- Limited capabilities in predicting future socioeconomic and cultural conditions.

It is important to note that the level of uncertainty associated with risk assessment for future conditions is 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 in the assessment. For example, an assessment evaluating a single species, such as a threatened or endangered species, will have much greater certainty than will assessments evaluating risks as the community or ecosystem level. This 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) will 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 will be much greater than that anticipated for current condition assessments.

4.3 CULTURAL/QUALITY OF LIFE EFFECTS

> *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.* (EPA 1993)

Although they may vary in specifics and intensity, all cultures share the same general quality of life indicators: community and individual wellbeing, spirituality, concern for future generations, peace of mind, resource access and use, and sustainability of the worldview. The presence of residual contamination could have a negative impact on the quality of life of proximate cultural communities. Cultural communities are defined as the subsets of larger communities that are linked by heritage, occupation, interest, or background. The term can encompass hunters, farmers, tribes, former Hanford site landowners, etc. The requirements to determine any negative impact on the quality of life derive from NEPA and, in the case of Native Americans, treaties and the trust obligation as well as NEPA.

Cultures can be conceived of as having two components: the general worldview (e.g., the value of nature) and the 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 illustrates this

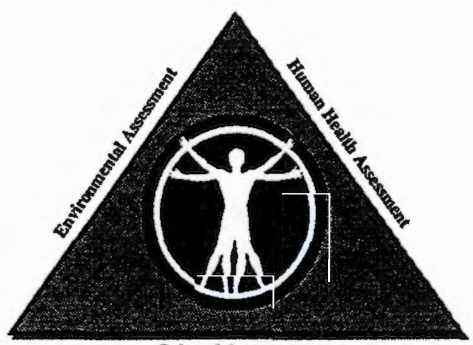

FIGURE 4.4 Relationship of Assessment Elements for the Evaluation of Quality of Life Impacts

relationship. The health and ecological risk findings are not the endpoint in the quality of life evaluation but 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 the quality of life.

However, even if, by scientific or regulatory definitions, there is no human health or ecological risk, the patterns of life could be disrupted to the point that the culture is harmed. This could happen if access to or use of resources is restricted or banned constructively by a governmental authority (i.e., there is no risk as long as salmon intake is limited to a certain number of pounds per year). It could also happen due to a perception (i.e., there is contamination in the river and therefore the salmon are also contaminated and no longer pure or safe.)

4.3.1 Quality of Life Assessment

Assessing risk to the quality of life of the cultures affected by the Hanford site depends on prior 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, the cultural impact assessment seeks 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 the 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. Cultural communities are subsets of the larger community that have a common heritage, occupation, geography, or interests. The cultural communities that are identified within the potential impact area should then screened to determine which are most likely to be affected by the decision at hand. The equity interests being assessed here are 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 most likely to carry the greatest impact are those which should be studied in greater detail.

The "rules of engagement" of the cultural impact assessment process must then be developed and communicated broadly. These rules should be designed to establish how the study will be conducted and how the results of the study will be used. Decision makers and community members need to be aware that the results of the cultural risk assessment are valuable information that will be factored into a decision along with other information such as environmental impact, economic effects, budgets, and political realities. Decision makers and community members must not be led to believe that cultural impacts will necessarily trump all other considerations.

Social science tools such as questionnaires, interviews (open-ended or structured), expert elicitation, focus groups, and ranking of topics of concern will be the means of assessing cultural impacts. These tools need to be developed in conjunction with the cultural communities being studied. Community members should be involved in developing the cultural health indicators, developing data gathering techniques, gathering the data (after training in conducting interviews), evaluating the data (discussing findings that may be in conflict), and determining how proprietary 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 cultural communities and the general public. It is also important that the draft and final decision documents describe how the cultural impacts study factored into the decision.

In summary, a quality of life risk assessment would involve the following elements:

- Culturally sensitive exposure scenarios for human and ecological risk assessments,
- Knowledge of the resource access or use patterns valuable to the cultures under study,
- 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 4.2 Quality of Life Indicators and Assessment Measures

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

Table 4.2 lists indicators and assessment measures that could be used in a quality of life assessment. Some of these indicators may defy quantitative assessments and require more qualitative 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 a measure that could give a useful perspective on quality of life impacts. Caution must be taken in scoping the quality of life assessment to ensure that the risks to the culture being assessed are a function of the loss of use of resources or locations or the presence of residual contamination as opposed to larger societal impacts or other issues.

Quality-of-life assessment methods used to gather data on the quality of life indicators can include expert elicitation (oral interview by people trained in both the subject matter and interviewing techniques), surveys, questionnaires, and discussion/focus groups. The actual methods to be used and their format must 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 inter-relatedness of ecological and human health risks with cultural impacts.

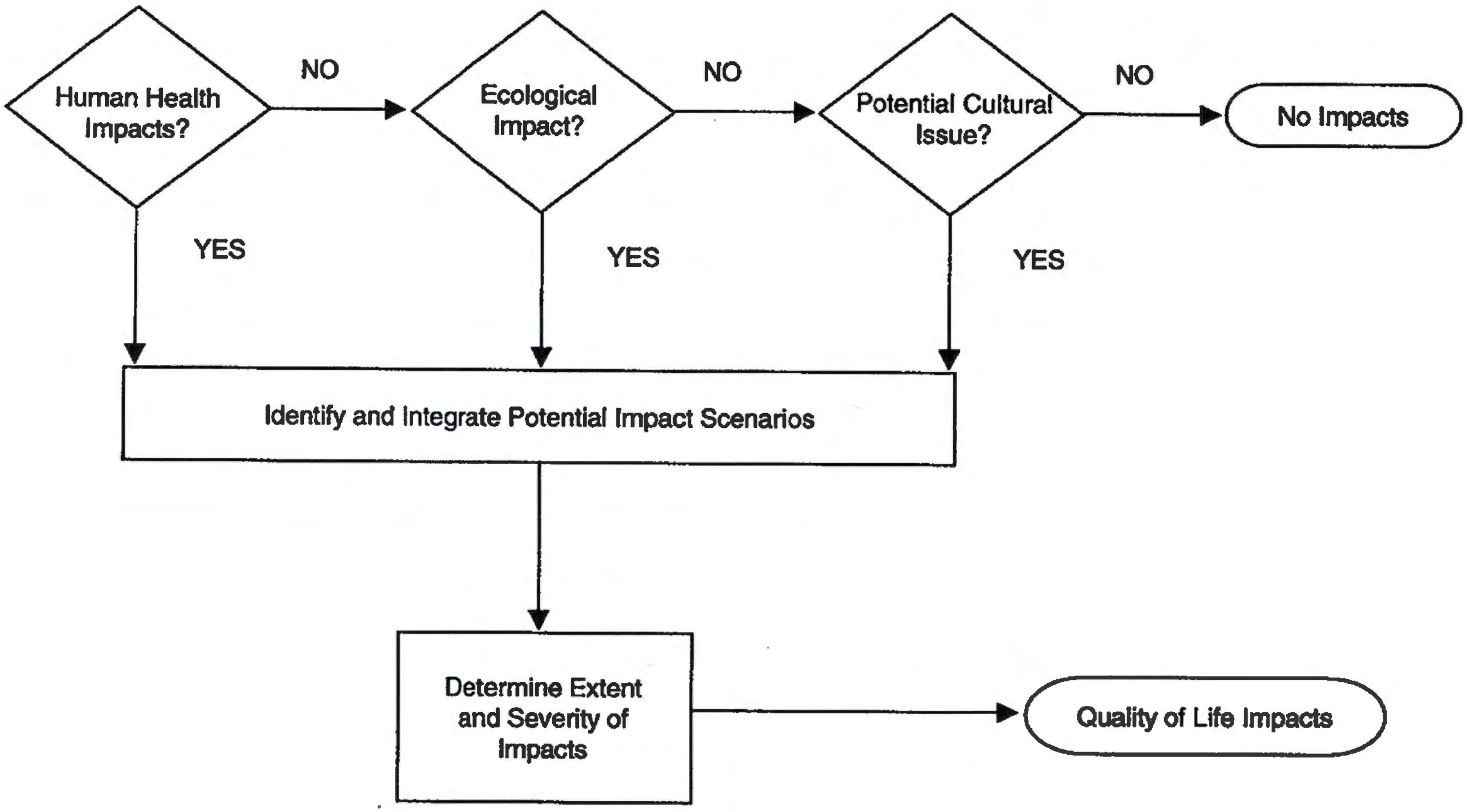

FIGURE 4.5 Quality of Life Evaluation Process

4.3.2 Native American Cultural Impacts

The link between the worldview and its manifestations often takes on a strong significance in Native American cultures, in which the symbolic content of nature takes on a greater significance than its visible material content (Hanes 1995: 4 citing Murdock 1980:144). The Native American perspective is that nature is intrinsically spiritual as sacredness is imbedded in all phenomena (Hanes 1995:4). This perspective results in the development of sacred emotional attachment to native plants and animals and to natural landform features (Hanes 1995:4). Loss of access to a place may have a worldview impact even though the place is not contaminated.

Tribal Culture. The methods for assessing effects on tribal culture should be primarily qualitative and based on key indicator variables such as the health of ecosystems and ethno-habitats, integrity of culturally important places, and prospects for cultural survival. The following, in addition to those listed in Table 4.2, can be such indicators:

- Landscape ecology conditions that are stable and resilient over time,
- Stable habitat trends and species 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 is to develop a general listing of species (plant, animal, and aquatic) or landforms of tribal interest. Tribal proprietary interest in certain resources and places limits availability of this information (Hanes 1995:6). However, sufficient documentation of Tribal concerns and practices may exist to allow a broad-scale, qualitative analysis of impacts. This general listing should be narrowed to core species of concern and matched with a list of species with viability concerns. Methods for gathering this information include the use of expert elicitation (interviews) and unstructured surveys (Harris and Harper 1997: 789-790). Identification of ecosystem viability and habitat trends can be accomplished through a viability panel assessment.

General indices for ecosystem viability include:

- Trends toward resilient and healthy area-wide ecosystems,
- Reliable and predictable habitats for culturally important wildlife, aquatic species, and plants, and
- Trends toward a generally desired future condition.

Composite ecological integrity can be rated high, moderate, or low compared to historical integrity.

Access Issues. Access to ethno-habitats is of critical importance to tribal peoples for a range of issues including harvesting culturally-important species, use of sacred areas, and cultural survival through passing knowledge between generations. The Harris/Harper service-per-acre-year metric may be appropriate here. More important than accessing the negative impact to tribal culture from the loss of access to ethno-habitats is a methodology for minimizing future impact of such loss It is highly unlikely that tribes will regain total access to the Hanford site in the foreseeable future. However, the tribal nations 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. For example, certain sacred areas may be cleaned up to levels that allow either complete or limited access. Again, tribal proprietary interests may limit specific identification of these areas, but may allow general areas of the Hanford site to be identified.

4.4 SOCIOECONOMIC IMPACTS

Scenarios for social and economic impacts will need to be developed consistently with the scenarios that emerge from studies about the migration of the contaminants. However, there are special considerations that affect the social and economic impact scenarios. Socioeconomic 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.

4.4.1 Social Impact Assessment Process

The level and scope of social 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 4.3 provides a rough example of how the impact zones and stakeholders might be characterized.

TABLE 4.3 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, WA state government, city and county governments
Columbia River, Benton/Franklin County (Tri-Cities, etc.) and region upstream from the McNary Dam	local business and industry, agriculturists, tribal governments, WA 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; WA and OR state government, city and county governments

For a social assessment related to the GW/VZ integration program, the basic steps would be the following:

- Conduct a social assessment that identifies relevant populations, communities, and social structures within the potential impact zones.
- Identify ways in which the social environment would change in response to the range of stimuli 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.

- Re-evaluate elements of the analysis as new information becomes available.

Methods and tools for conducting the social assessment are based in long-established social science methods for describing communities, social and economic structure, perceptions, opinions, and values. There is Council on Environmental Quality' guidance on social assessment in NEPA implementation available at http://ceq.eh.doe.gov/nepa/nepanet.htm and a summary of guidelines and principles for the social impact assessment process published by the Department of Commerce (1994). Likewise there is a substantial social science literature 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 major approaches for gathering primary data are interviews and focus groups (structured group interviews). The quality of the information obtained from these approaches is dependent on the rigor of the processes by which the respondents are selected and the questions designed. An iterative process of using 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.

Broad scale mail or phone interviews with random samples of the public can be used, but are expensive to design and conduct and fraught with credibility pitfalls. In the case of the remediation program alternatives, a broad scale public survey would not be advisable until after 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, is usually used to obtain a profile of the social and economic structure of specific locales. This type of profiling has been done 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 following: 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 so forth. 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.

Characterization of the region along the Columbia River below the Hanford site, extending to the Pacific Ocean, will 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 others, in connection with the current debate over restoration of Columbia River salmon runs. This can be supplemented through primary data collection.

4.4.2 Economic Impact Assessment Process

The following discussion provides illustrative examples of approaches rather than attempting to identify a complete study set of impacts and suggest an approach for each. The focus, instead, 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 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 there is a final section dealing 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 considered. From changes in resource quality, it is the derived set of changes in public information regarding human health risks and ecological system functioning that 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.

4.4.2.1 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," 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.

There are two chains of events that 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 or not. Protective actions could involve government proscription of resource use, avoidance of products or locations by the public, or both types of actions. 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 induced in this manner 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.

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.

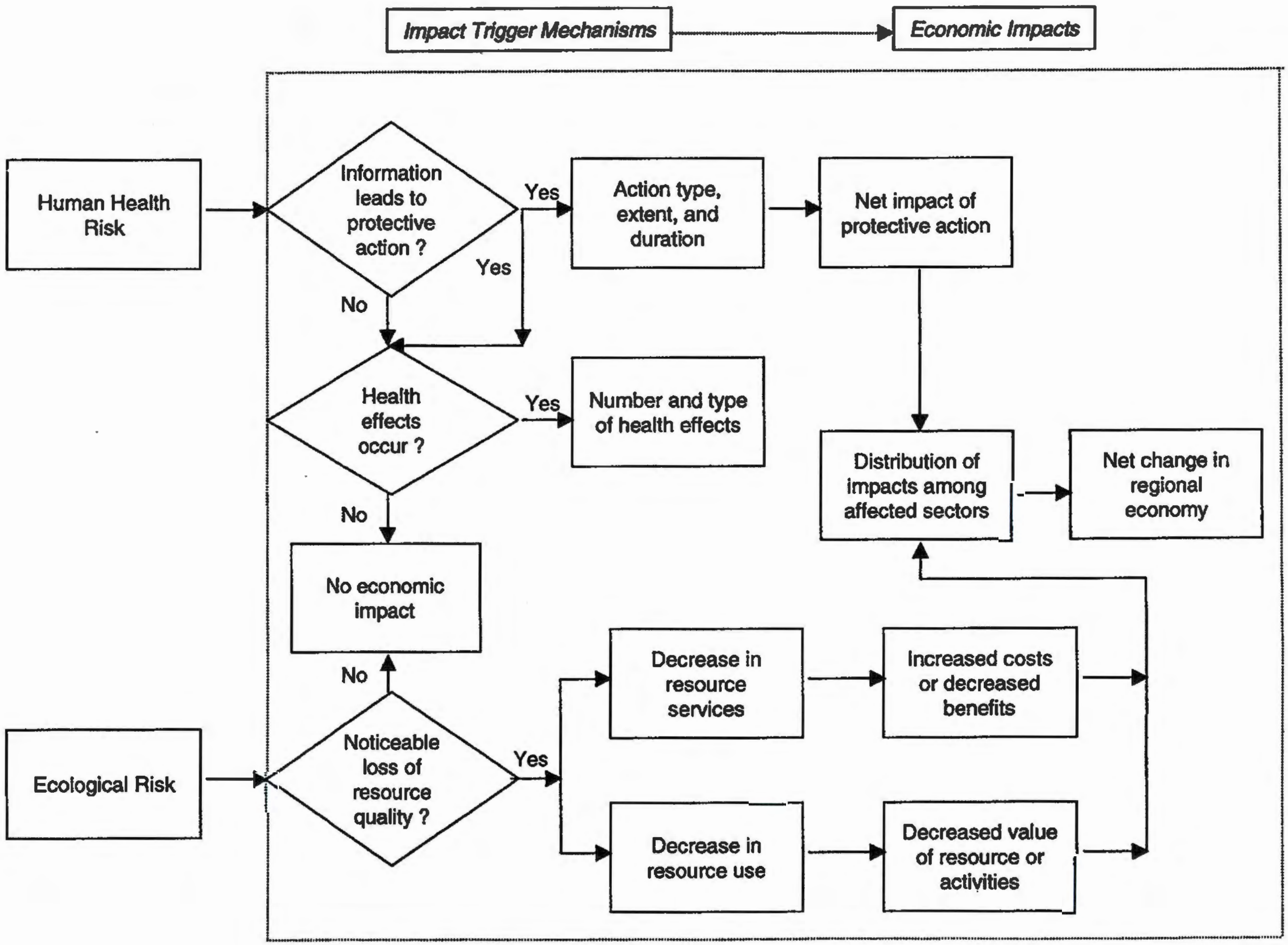

Figure 4.6 The Economic Impact Process as It Relates to Human Health and Ecological Risks

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 so 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 so 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, due to an unacceptable risk level or through public avoidance of use, due to 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, 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 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, there would be increased costs of providing alternative water supplies to persons presently dependent on river water for drinking. Revenues also might possibly 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. Though 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. This occurs 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 result in shrinking the regional economy, where funds recirculate among economic sectors.

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

- The extent and probability of particular effects on environmental resource quality,
- The ways in which these resources are linked to local economies, and
- The ways in which the local economies are tied to the larger regional and the national economy.

Developing such an understanding will require participation of a wide range of experts and stakeholders, but will 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 then would provide a basis for identifying the sectors and regions that must be included in the 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.

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 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.

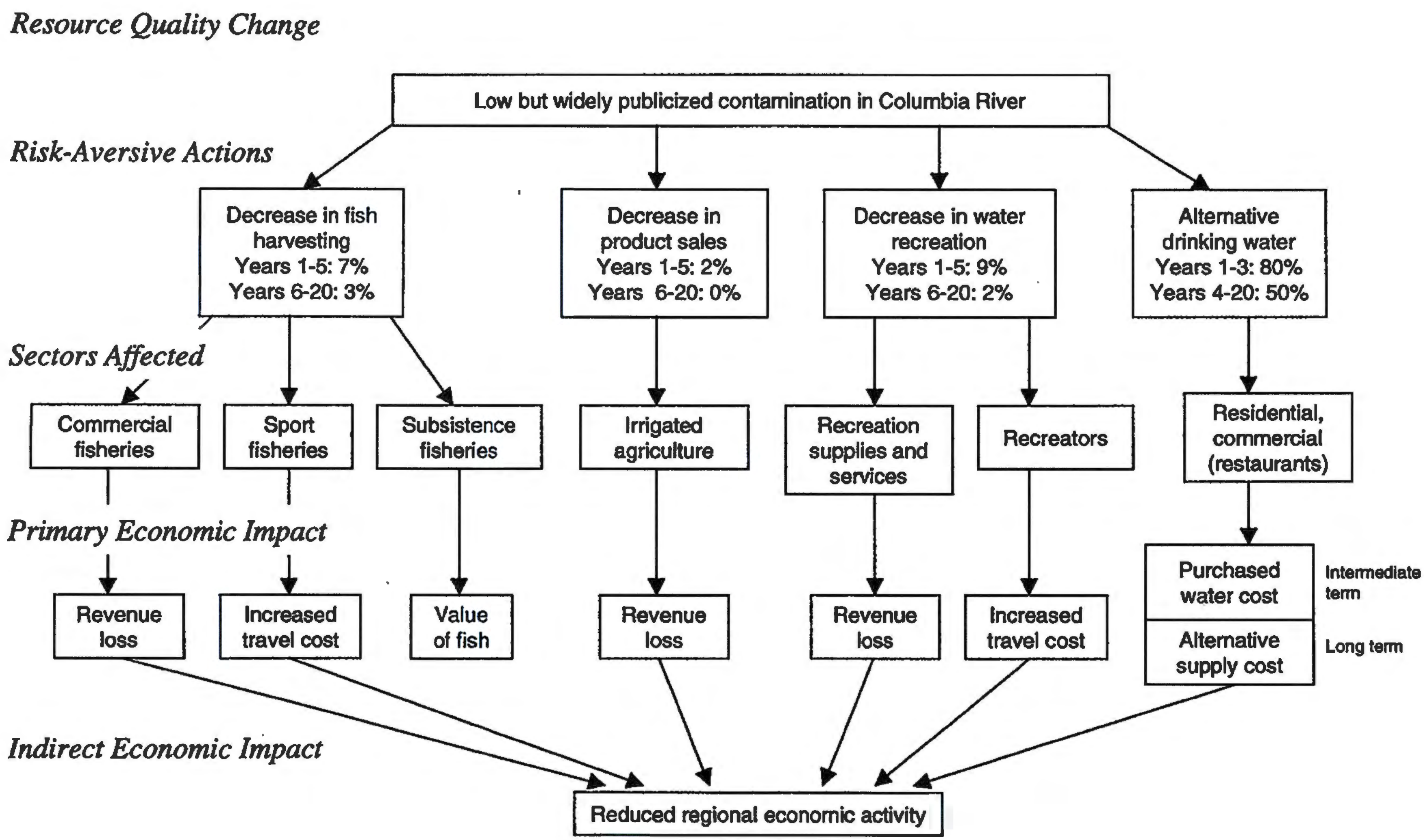

FIGURE 4.7 Example of an Economic Impact Scenario Framework

Table 4.4 Example of Elements in 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	Residential and agricultural sectors; fisheries; recreation
		Lower Columbia River region	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	Residential and agricultural sectors; fisheries; recreation
		Lower Columbia River region	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

4.4.2.2 Define the Economic Assessment Scope

One of the most basic steps in defining the assessment scope is to establish the baseline conditions against which GW/VZ integration project-related 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. The degree to which DOE activity at the Hanford site drives the economy of the Tri-Cities area will make it 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 which could be impacted by contamination of the river but which are not economically dependent on the Tri-Cities area. Based on the 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 impacted 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 "in scope," 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 handling 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 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.

4.4.2.3 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, i.e., mad-cow disease) can be estimated using 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 they 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. 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 Environmental Protection Agency 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. An evaluation of recent approaches for feasibility and applicability will be needed. If methods and data are inadequate for quantification, these impacts may have to be analyzed qualitatively.

Measuring losses from contamination events sustained by Tribal economies, in some of which many activities and exchanges are not monetized, will 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 the person essentially is 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 U.S. AID 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. Highly uncertain results beyond 10- to 20-year projections.
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 production would be affected.

Some potential impacts, like loss of recreational activity, may require a combination of techniques to quantify impact values. This 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.

TABLE 4.6 Example of Methods Available to Estimate Potential 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

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 is done 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 impacts of major contamination of the Columbia River lasting for thousands of years were estimated without discounting, the estimate could indicate that it was 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. There is sufficient basis and justification for constructing such estimates, but the controversy surrounding them 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.

4.4.2.4 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 social/cultural 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, due to the magnitude of the related economic effects. For example, the cost of providing alternate 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 longer than 10 to 20 years generally fail the reality test of time (Casman, Morgan, and Dowlatabadi 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 projection 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 cultural effects and health and ecological risk is presented in Figure 4.8.

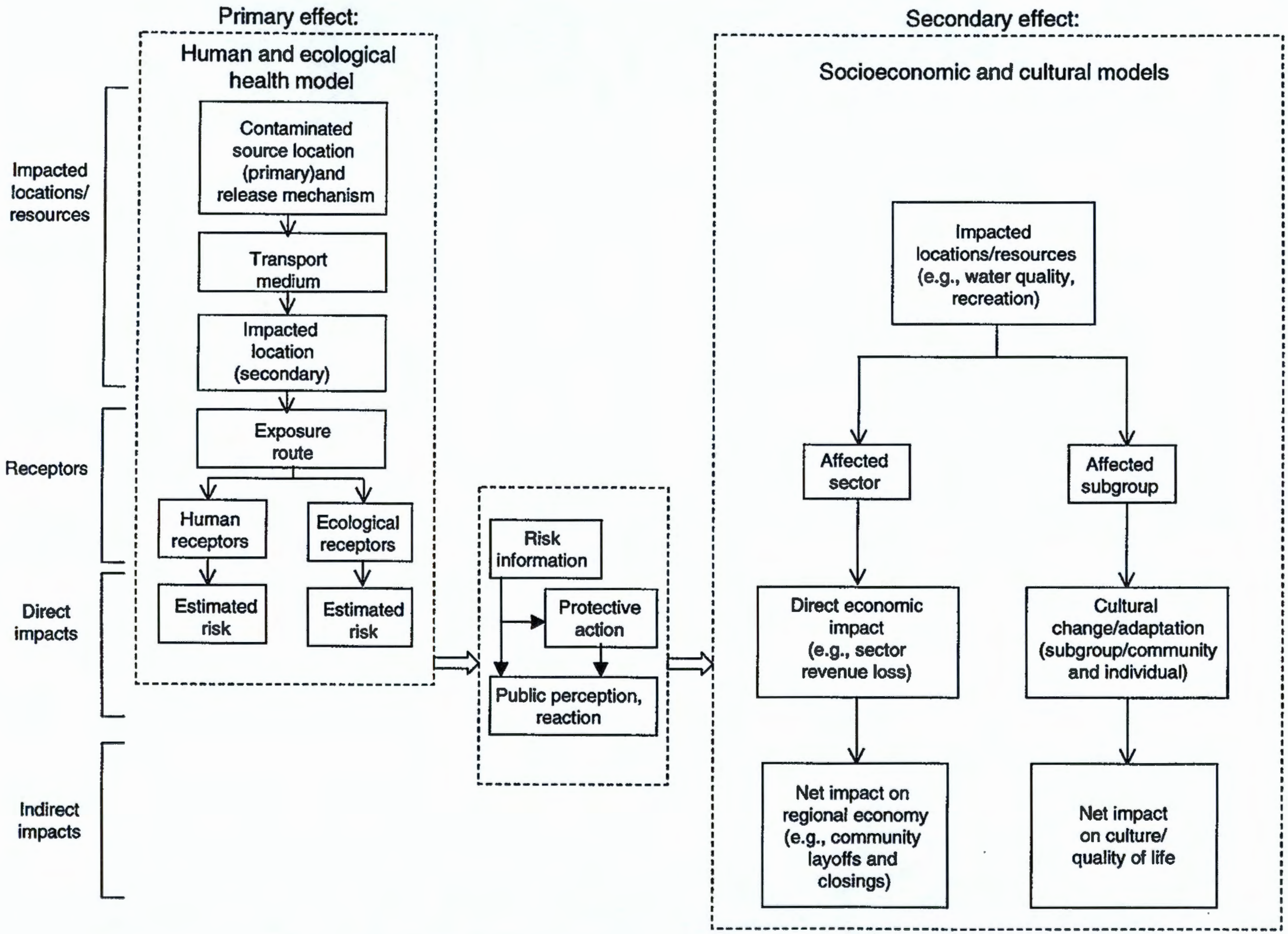

FIGURE 4.8 Illustration of Integrated Conceptual Models

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

Following the identification of methodological options, the next steps in the risk assessment design involve identifying impact locations and selecting topics for study from the candidate sets (the large group of 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 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. Exploration of the use of dependency webs in specifying exposure pathways and in developing information about key relationships would also be needed. Additional ideas for research needs can be found in the Wilkey et al. (1999) discussion of science and technology development needs.

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

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

- **Resolve Inventory Issues.** Develop an integrated view of inventory by starting with current estimates of inventory and historical knowledge. Working with stakeholders, 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 intermediate-level environmental transport models to develop "best estimates" of the hazard trajectory for the site and any other affected locations. Identify time limitations of the safety envelope (time until significant contamination reaches release points).

- **Develop Reality Checks.** Increase public and scientific acceptance of estimates by using the model-free (or model-lite, e.g., considering conceptual, story-based versus quantitative) approach to validate intermediate-level model estimates of breakthrough times for significant contamination.

5.2 CRITERIA FOR SELECTING STUDY SETS FROM CANDIDATE SETS OF IMPACTS

In each of the main impact categories it will be necessary to prioritize issues for study from a candidate set. Criteria for developing the candidate set and for selecting the study set for each impact type are presented in the following discussion

5.2.1 Human Health Risks

Potential Criteria for the Human Health Assessment Candidate Set. In selecting the candidate set for the human health assessment, the objective 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 endpoints. Typical receptor scenarios include current and future residents, workers, and recreational visitors both on a site and in the surrounding area. The scope of these categories should be expanded from the more traditional scope in identifying the broad candidate set for initial consideration.

Human Health Endpoints

In assessing increased cancer risks associated with GW/VZ project contaminants, carcinogenicity data from multiple sources should be evaluated. For example, data and potency estimates from the International Agency for Research on Cancer should be reviewed as well as data from the U.S. EPA. Additionally, mutagenicity data should be evaluated on a contaminant-by-contaminant basis. These data should be screened for conclusiveness, and used qualitatively in conjunction with quantitative potency estimates.

For noncancer endpoints, the concentration present in a given environmental medium is generally translated into an exposure concentration for a given receptor. It 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 the contaminant. In selecting the candidate set for human health assessment, a comprehensive review of the current toxicity database would be conducted, with consideration of toxicity observed in various studies including teratogenicity/embryotoxicity, developmental, reproductive, neurological, and immunological studies. Available information on the mode of action, and mechanism where available, should also be summarized. This updated toxicity review will allow contaminants with the same or similar mechanisms of action or target organs to be identified, so that the potential for additivity, synergism, and antagonism can be assessed.

This expanded consideration of health endpoints will be facilitated by the matrix approach described in Section 4.1.3. Such a matrix will allow for grouping of chemicals by various parameters (such as mode and mechanism of action, target organ, and type of toxicity exhibited). This would be complemented by a comparison of the site contaminant concentrations and estimated intakes with critical effect levels.

Receptors and Exposure Parameters

Site-specific data and stakeholder input are important to an evaluation of the exposure scenarios to be used in assessing the potential for adverse human health effects. Non-classical types of exposures, such as those relevant to the Native American community and other unique populations in the vicinity of the Hanford site would be evaluated as part of this process. Input from interested community members will be used to guide the evaluation of chronic exposures (such as via fish and water consumption) as well as exposures that occur only seasonally or intermittently . Based on exposure potential, the need to evaluate population subgroup receptors such as children and the elderly would be further considered. Assumptions regarding population projections and distribution will also be guided by stakeholder input.

Other Influencing Factors

In addition the targeted consideration of potential health effects and exposure parameters, the candidate set would include evaluation of co-factors 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.

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 for the contaminants of concern, impact locations, and actual receptors at those locations. The following criteria are suggested to help focus the investigation for the initial integrated assessment. It is important to note that those not retained for quantitative assessment will nevertheless be retained for qualitative consideration, and new toxicity data would be evaluated for these contaminants as those data become available.

- For carcinogenicity, individual contaminants that contribute >1% to the total incremental cancer risk should be retained. Another consideration is to retain all contaminants that contribute to risks based on a given point of demarcation that may be defined at another level by the 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 should be examined to determine if these contaminants should be retained in the risk assessment or put on a watch list pending future information.

- For noncancer endpoints, individual contaminant concentrations and/or exposure levels should be compared with existing benchmark criteria, with those exceeding benchmarks retained. Additionally, segregated hazard indexes for all contaminants by specific health endpoint, target organ, and mechanism of action should be constructed to screen for potential additive or synergistic effects (as well as antagonistic effects). It is envisioned that the outcome will be inclusion of some contaminants for further evaluation that may have been excluded had the only criteria been comparison with benchmarks. However, where data do not indicate that exposures are likely to cause toxicity, contaminants should be screened 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 impact locations and via the same exposure routes). As appropriate, the receptor in a group with the potential for the greatest exposure and/or health impacts from a given pathway should be selected as representative for that group, with consideration of the reasonableness or likelihood of that exposure (as other receptors would be impacted to the same or a lessor degree). Limiting the number of scenarios/receptors evaluated in risk assessment by such an approach would help focus the 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 impacts associated with the GW/VZ project contaminants.

5.2.2 Ecological Risks

The development of study sets for ecological risk evaluation includes 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 by the risk assessment. Identification of these study sets will require the development of candidate sets of ecological resources and potential contaminants from which the specific study sets will be drawn.

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 to ecological resources.

Potential Criteria for the Ecological Risk Assessment Contaminant Study Set. Although the evaluation of process history, modeling results, and characterization data may identify a large number and variety of contaminants that may potentially pose an ecological risk, it is more likely that only a subset of the candidate set will 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 from the candidate 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 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 distributions of ecological receptors. The identification of contaminant exposure should encompass all media and will likely result in different contaminant subsets for each environmental media. For example, organic compounds may dominant the contaminant list for sediment, while metals will dominate the surface water contaminant list.

Candidate set 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 concentrations. 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 are surface water concentrations of selected contaminants that are considered to be protective of freshwater and marine biota.

In addition to evaluating media concentrations, the candidate subset contaminants should also be evaluated with regards 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. On the basis of the evaluations of media concentrations and dose, those candidate set contaminants for which one or more complete exposure pathways are indicated and which also occur at levels exceeding safe concentrations should be retained as the contaminant study set, to be evaluated in detail in the risk assessment.

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 types (e.g., terrestrial, aquatic, forest, shrub-steppe, and palustrine). The nature of the candidate set for a specific site or region will be a function of the environmental setting at the location of concern.

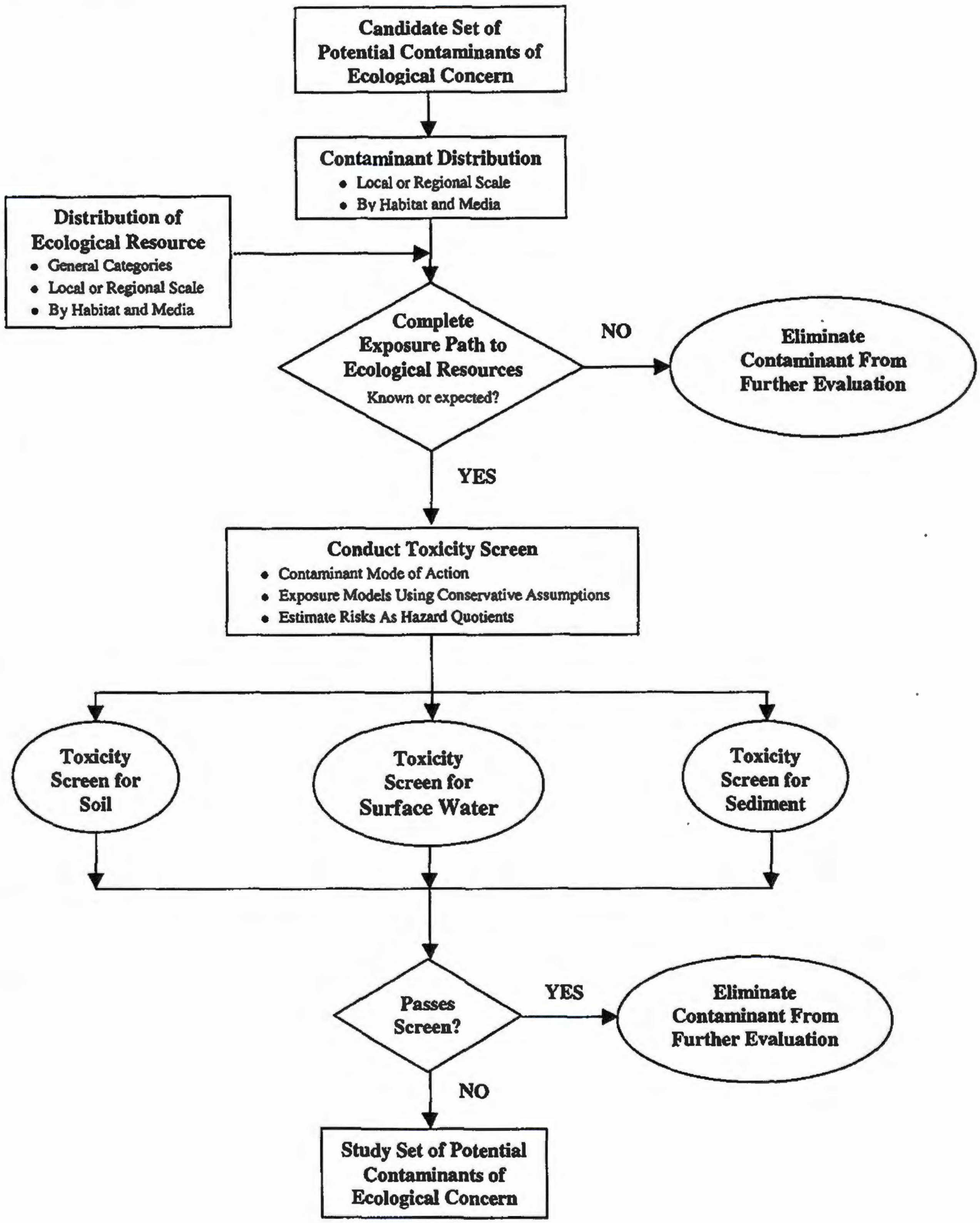

FIGURE 5.1 Framework for Identifying Study Set Potential Contaminants of Ecological Concern

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

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

The first step in this framework 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 nutrient cycling, providing nesting, nursery, and foraging habitat for fish and wildlife, and water purification. 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 (such as 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 the presence of commercially or recreationally important resources. These 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.

At the conclusion of these evaluations, the receptors in the initial candidate set will have been characterized on the basis of their ecological, regulatory, socioeconomic, and cultural roles and importance.

Next, the distributions of each candidate set receptor and each study set contaminant of concern should be evaluated to identify which of the candidate set ecological receptors are being exposed (or could be exposed on the basis of fate and transport modeling predictions) and to which study-set contaminants. For example, at a particular site PCB's may occur only within sediments, and not in the water column or in soils. Thus, only those candidate set receptors that inhabit (e.g., infaunal macroinvertebrates), or come

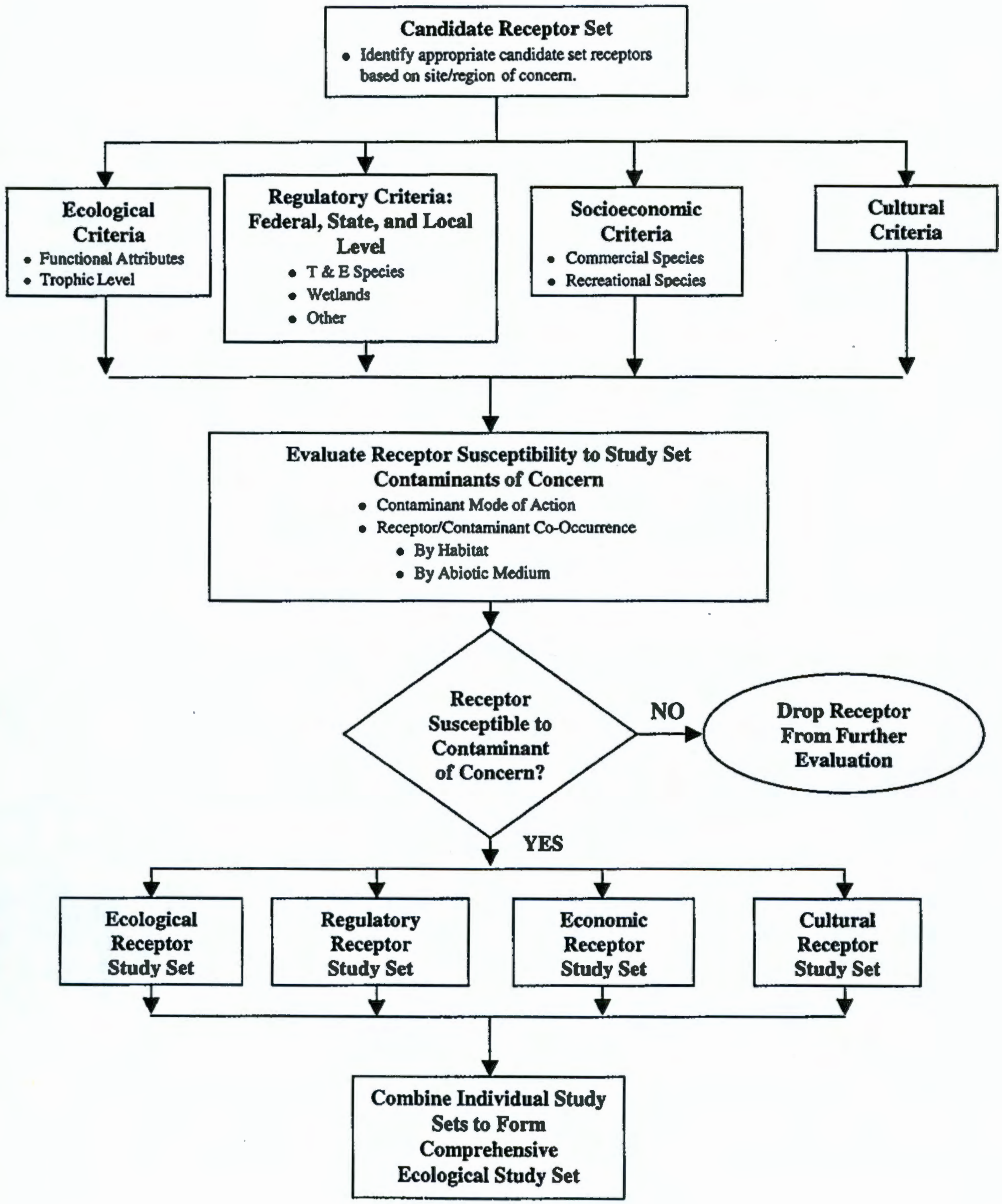

FIGURE 5.2 Framework for Developing a Comprehensive Study Set of Ecological Receptors

in contact with, sediments (e.g., foraging shorebirds such as the avocet) should be evaluated further for adverse effects from PCB exposure.

Each candidate receptor/contaminant study-set pair should next be evaluated to determine whether the candidate receptor is susceptible to the known or suspected mode of action of the study set contaminant. Candidate set receptors unlikely to be affected by the study-set 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 from the candidate receptor set 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 which co-occur with one or more of the study set contaminants and which 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 may 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 based on 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 based on 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 Cultural Impacts

Potential Criteria for the Cultural Impact Candidate Set. The objective in selecting candidate sets is to be sufficiently comprehensive to include all cultural communities whose quality of life will likely be impaired. Impairment could occur through loss of access to or limited use of the Hanford site or resources affected by it (e.g., salmon, plants, or animals).

Potential Criteria for the Cultural Impact Study Set. The cultural communities that should be included in the study set are those likely to endure the greatest cultural harm – in the short term as well as in the long term. A cultural community should also be included in the study set if the government owes a particular responsibility to the community' welfare. Moving from candidate sets to study sets will require development of methods that are capable of determining if the cultural 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 the distribution of impacts. The magnitude of total effects is important, but not to the exclusion of consideration of who bears the burden of impacts.

5.2.4 Socioeconomic Impacts

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 percent 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., population subgroups, populations, 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 incorporated 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 constitute less than one percent of economic activity in the impact region should probably be excluded, unless they are crucial to the economic well-being of a population subgroup considered to be potentially impacted.

The candidate set should be structured to allow assessment of both the magnitude and the distribution of impacts. The magnitude of total effects is important, but not to the exclusion of consideration of who bears the burden 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 health risk assessment.)

In summary, the candidate set should:

- Include all major potentially affected economic units (e.g., those contributing > 1 percent to the regional economy or which are critical to a population subgroup),
- Cover specific markets and the regional economy sufficiently comprehensively to account for 95 percent of economic activity,
- Permit assessment of both magnitude and distribution of impacts among sectors and population subgroups, and
- Include both market and non-market effects.

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 sector or a population subgroup should be evaluated. A threshold of ten percent 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 wellbeing 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 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 data and information should receive consideration, 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 methods of linking with the illustration-based dependency webs to focus on the appropriate pathways, food chains, and uptake factors for the quantitative assessment. This is a cross-cutting issue affecting each of the impact areas.

5.3.1 Human Health Risks

Conduct a toxicity-concentration screen to capture primary contributors to estimated risk.

Evaluate bases for grouping contaminants to help prioritize and streamline the assessment.

Evaluate biochemical structure/molecular models and other information to aid in assessing contaminants for which toxicity data are lacking.

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., increases mortality, reduces reproductive success, impairs 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, 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, maintains nutrient cycling) associated with each candidate set receptor and associated assessment endpoint.

Toxicological evaluations are needed of Hanford GW/VZ contaminants for species anticipated to be included in an ecological risk assessment.

Benchmarks may need to be developed, as well as appropriate biomagnification factors based on the specific contaminants, receptors, and habitat availability and use.

Reference site data collection efforts involving species, population, community, and ecosystem parameters at a comparable unaffected site are essential to an adequate assessment of ecological risks to Hanford area receptors.

Studies addressing biodiversity parameters are also important. Diversity indices incorporating 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 Cultural Impacts

Review existing methods and data related to indicators of social/cultural health to cull relevant examples. Identify techniques that need to be developed or enhanced, including 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.

Since some information on tribal cultural patterns will be of a proprietary nature, it is imperative to build assessment capacity within the affected tribes. This will be needed to gather the information required to develop appropriate exposure scenarios for human health and ecological risk assessments and also to ascertain the cultural patterns that could be at risk. Develop an approach (incorporating capacity building, as indicated) whereby affected parties can gather information needed to identify social and cultural resources that could be at risk.

Harm to quality of life – particularly Native American quality of life – can also come from the act of environmental remediation or restoration if disturbing the soil destroys or damages cultural artifacts, burial grounds, or plants of great significance. Methods will be needed to determine when the harm of remediation/restoration outweighs the risks of allowing contaminants to remain in place.

5.3.4 Socioeconomic 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, Portland area) economic models.

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

Develop a basis for projecting relationships between various types of events related to the 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.

REFERENCES:

Wilkey, P.L., J.L. Regens, D.G. Hodges, E. Zimmerman, G. Fleming, and LC. Mohr, 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, IL, February.

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 difference between these measurements 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 five-year reporting period, 1993-1997, the average concentration differences for tritium, iodine-129, and uranium were:

- Tritium: 46 pCi/liter
- Iodine-129: 0.00008 pCi/liter
- Uranium: 0.07 pCi/liter

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 contours of 900 pCi/liter 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 ten 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 that it 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, as the source ores for this type of fertilizer commonly contain elevated levels of uranium (Dirkes 1990).

Tritium currently is the major radioactive contaminant of Hanford groundwater and the Columbia River in terms of concentration. It is the most mobile of radioactive contaminants, moving at essentially the same speed as water (H_2O). 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/liter) for at least 10 to 15 years. However, during that period the difference between upstream and downstream measurements has never exceeded 67 pCi/liter.

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/liter	RPH, pCi/liter	Hanford Increment, pCi/liter	Ci/Yr	Grams/Yr	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

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 five-year moving average for the curie 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/liter would be reduced to 68 pCi/liter by radioactive decay; however, the 1997 value was 28 pCi/liter. If this anomaly is attributable to improvements in analytical technology, a back-calculated value of 69 pCi/liter 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.

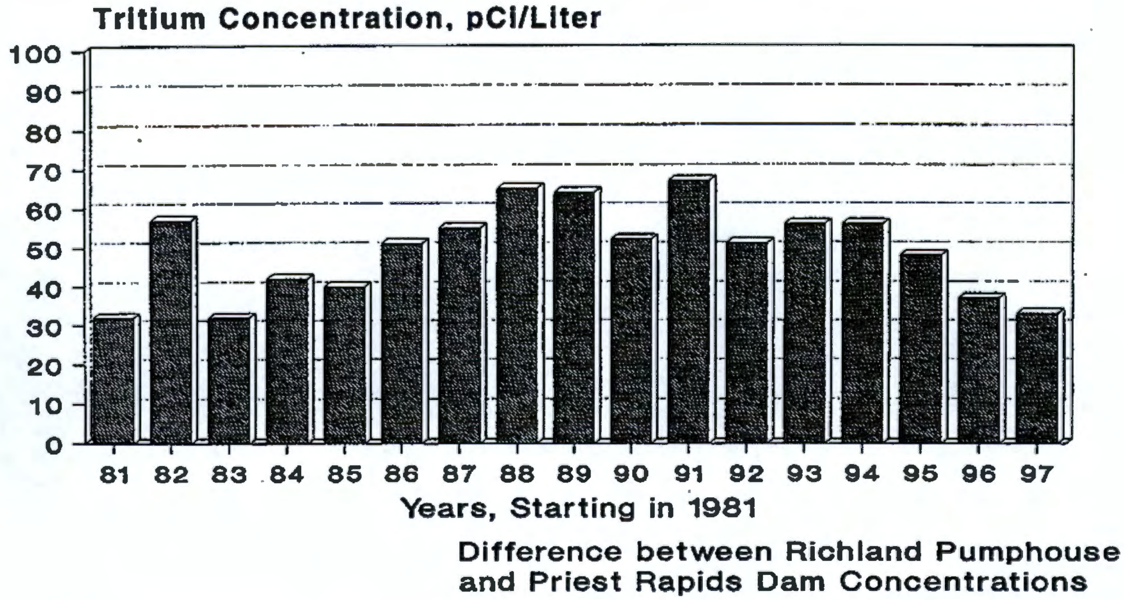

FIGURE A.1 Incremental Tritium Concentration Change in the Columbia River, pCi/L

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.

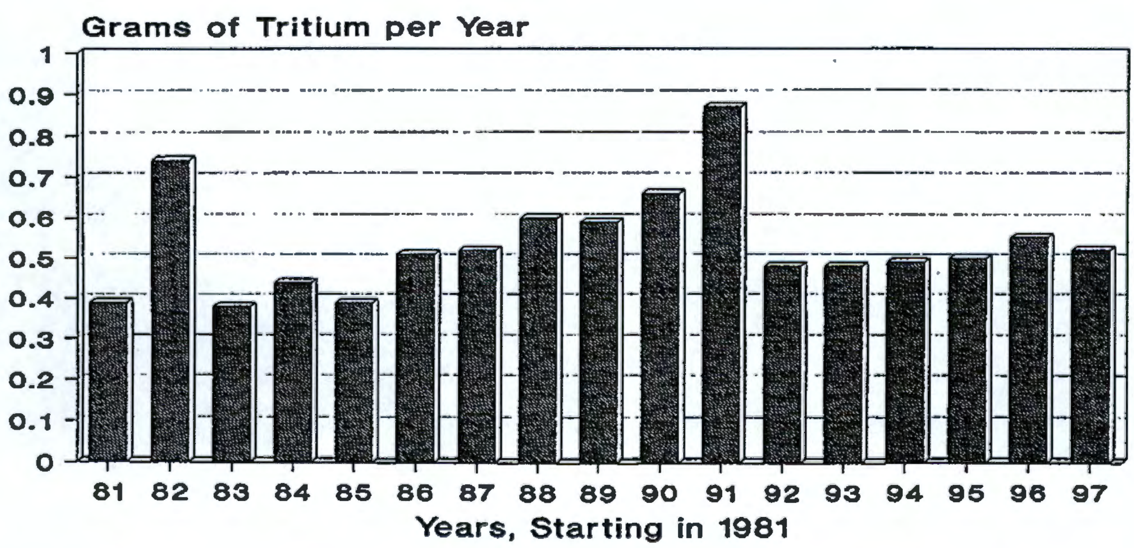

FIGURE A.2 Mass Flow of Tritium from Hanford Site Groundwater to the Columbia River

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/year).

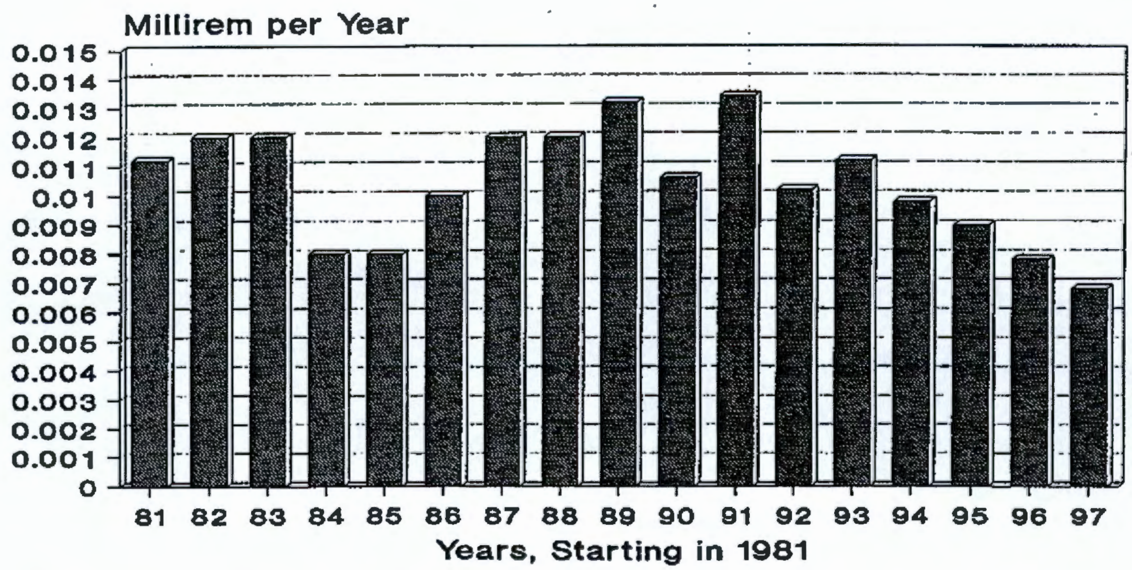

FIGURE A.3 Annual Whole Body Dose for an Individual Drinking 730 Liters/Year of River Water

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/liter 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 0.007-0.013 mrem. The average annual dose to the hypothetical maximum exposed individual 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 obtained from drinking a single glass of 2% milk. Milk contains about 2,000 pCi/liter of natural potassium-40, compared to about 50 pCi/liter 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).

The estimated 0.01 mrem per year MEI dose from the hypothetical 2 liter/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 200-East PUREX facility took place in the 1956-1972 and the 1983-1988 periods. Although the leading edge of the tritium 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 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/liter contour around the 200-East facility diminished, reflecting the 11-year gap in operations.

But while the effect of the hiatus in operations was observed near the 200-East facility, the extent of the 20,000 pCi/liter 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/liter are shown for 1990 and 1993 at the river interface near the Old Hanford Townsite (OHT), and concentrations as high as 140,000 pCi/liter 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.

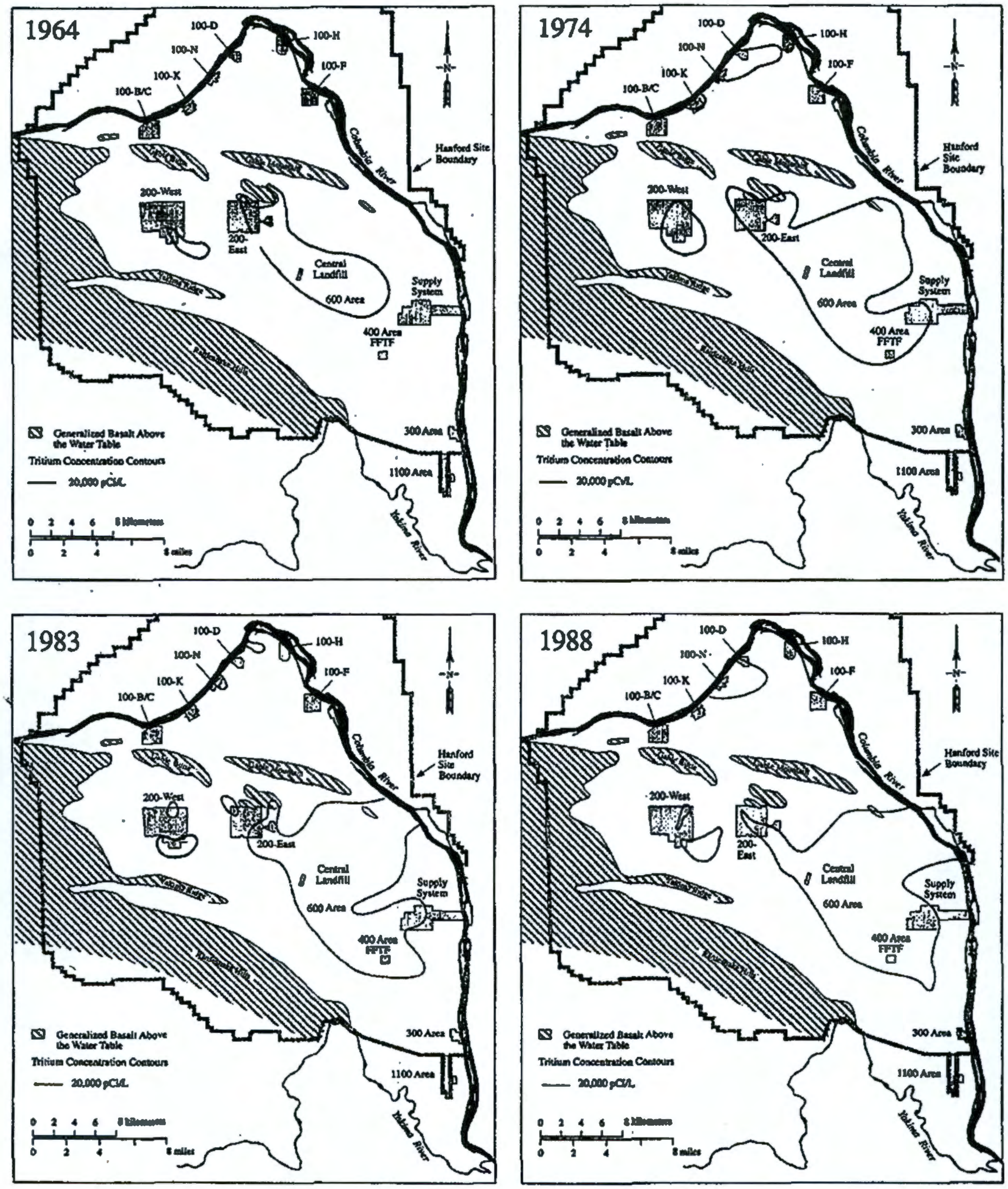

FIGURE A.4 Historical Tritium Concentration Contours (Source: Dirkes and Hanf 1998)

Figure A.5 shows two 200,000 pCi/liter 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).

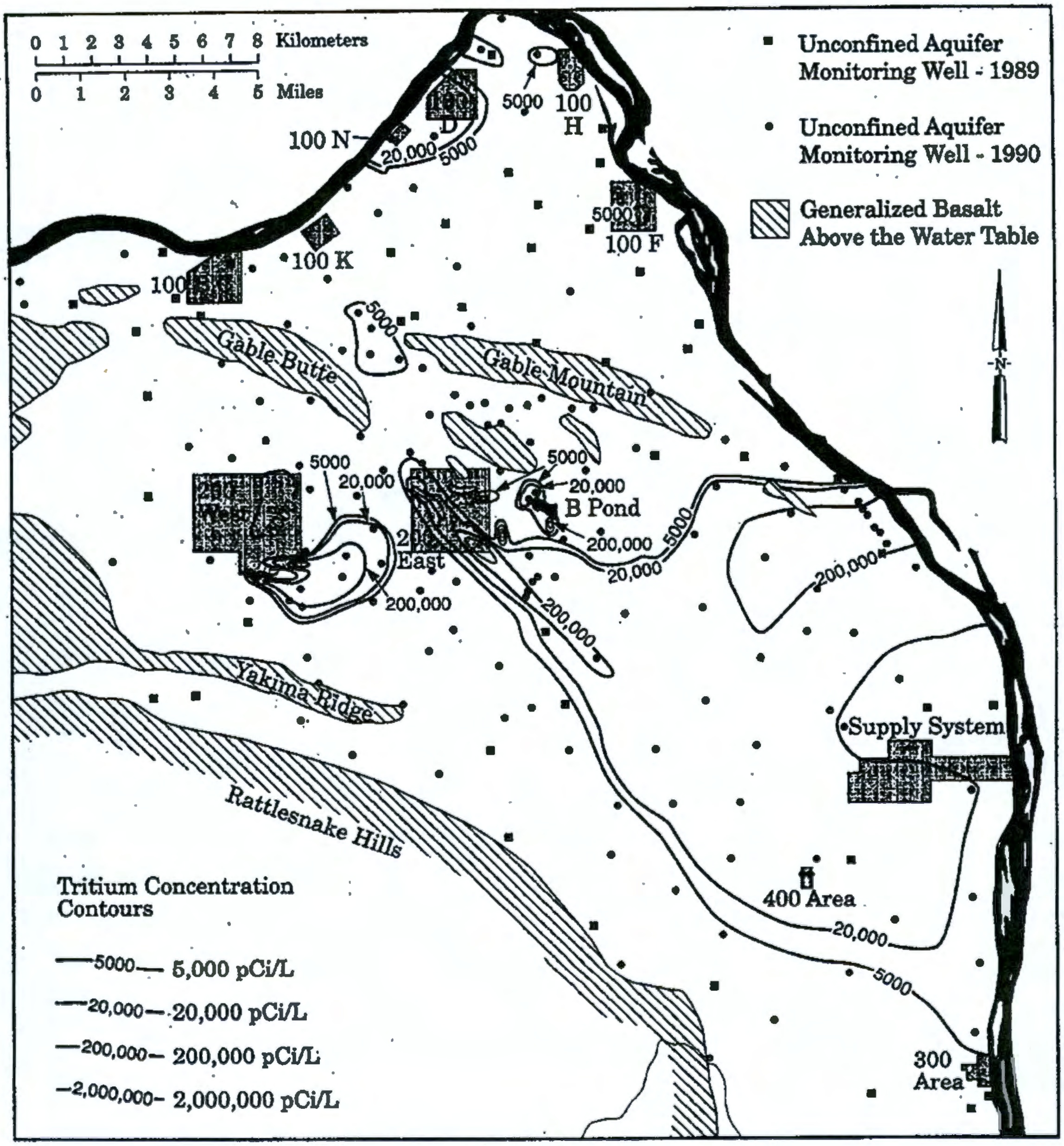

FIGURE A.5 Tritium Concentration Contours for 1990 (Source: Dirkes and Hanf 1998)

From this scale of illustration, the 20,000 pCi/liter and the 200,000 pCi/liter contours contiguous to the southeast corner of the 200-West facility appear to show little change in the 1990 and subsequent maps. Scientists at Pacific Northwest National Laboratory 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.

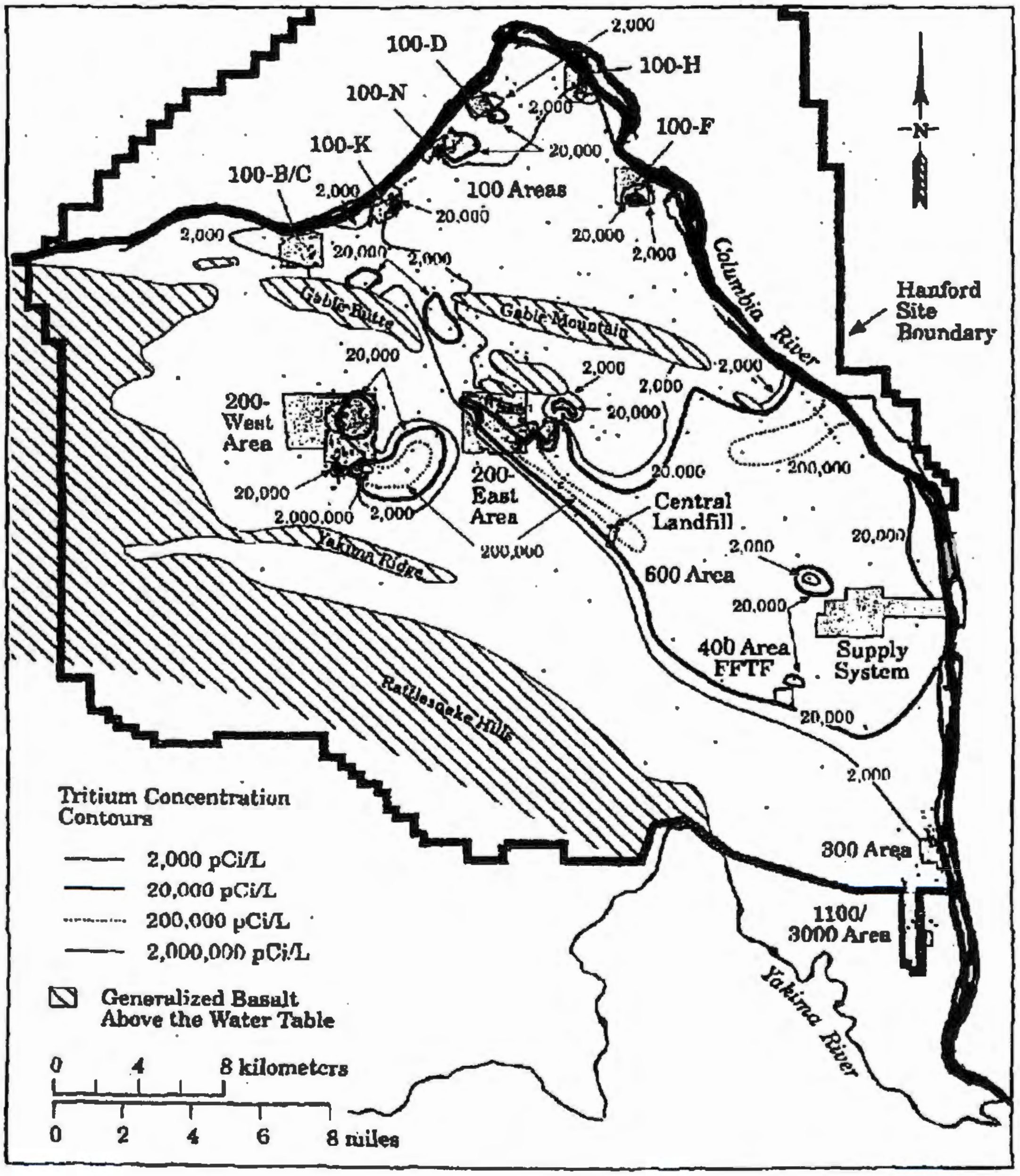

FIGURE A.6 Tritium Concentration Contours for 1993 (Source: Dirkes and Hanf 1998)

Figure A.7 provides the 1997 tritium contour data for the Hanford site (Dirkes and Hanf 1998). The 200,000 pCi/liter 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/liter 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/liter in the 1989-1992 period. By 1997, the concentration peak had passed, and the average concentration had dropped below 100,000 pCi/liter.

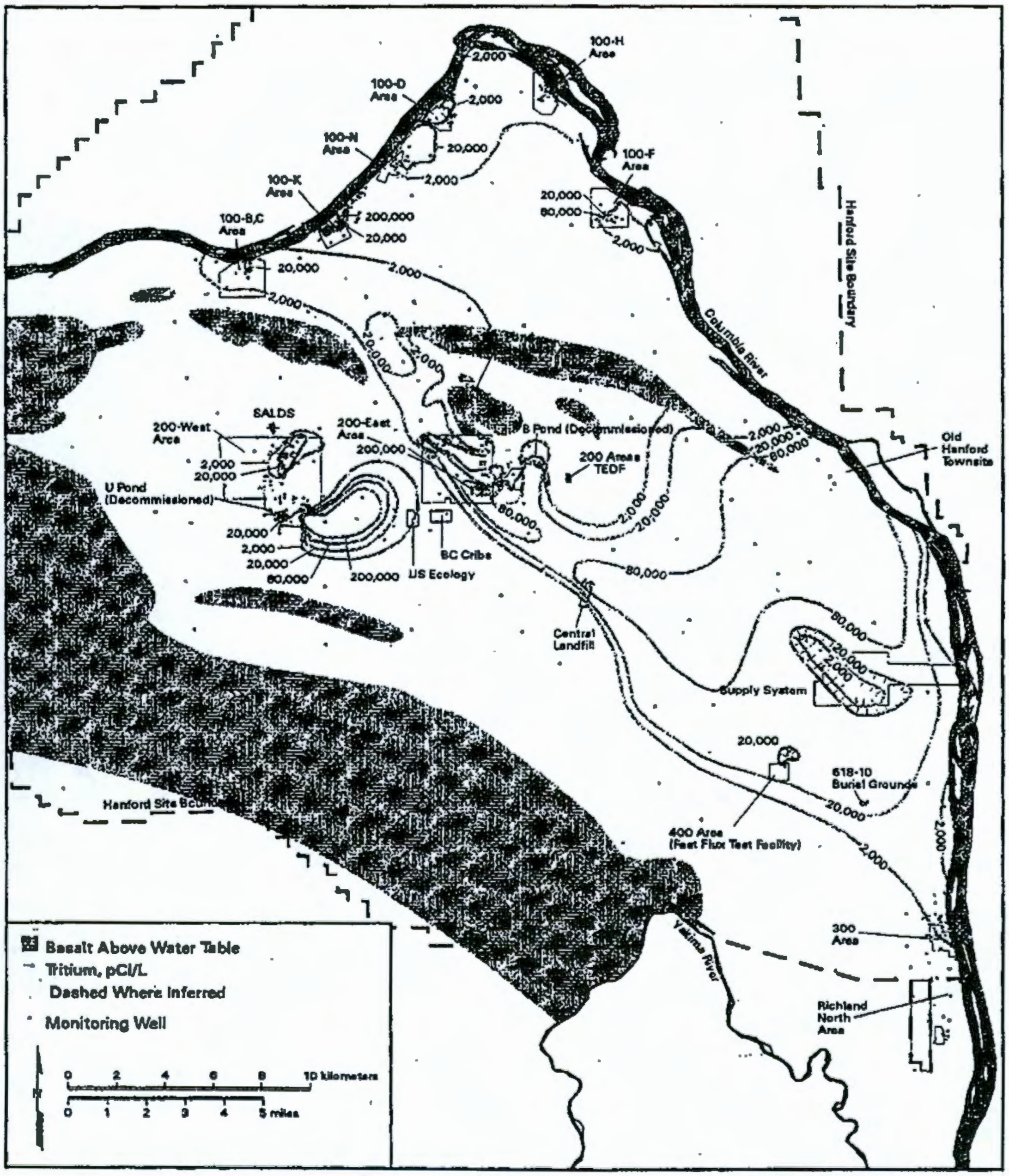

FIGURE A.7 Tritium Concentration Contours for 1997 (Source: Dirkes and Hanf 1998)

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, i.e., 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 is the natural global tritium production rate, 4 million (4E6) curies per year
B is 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 (3.1E9) curies
t is 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 megacuries over this period. The tritium concentration at the Priest Rapids Dam can also be expected to decline in these relative proportions.

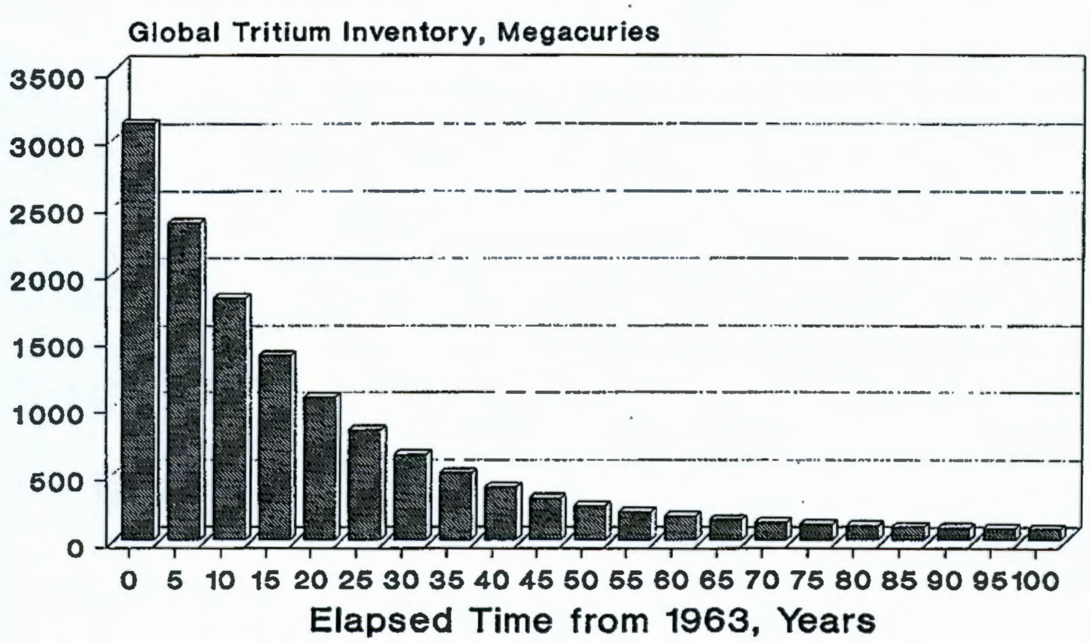

FIGURE A.8 Approach of Global Tritium Inventory to Steady-State Value of 71 Megacuries

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 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.

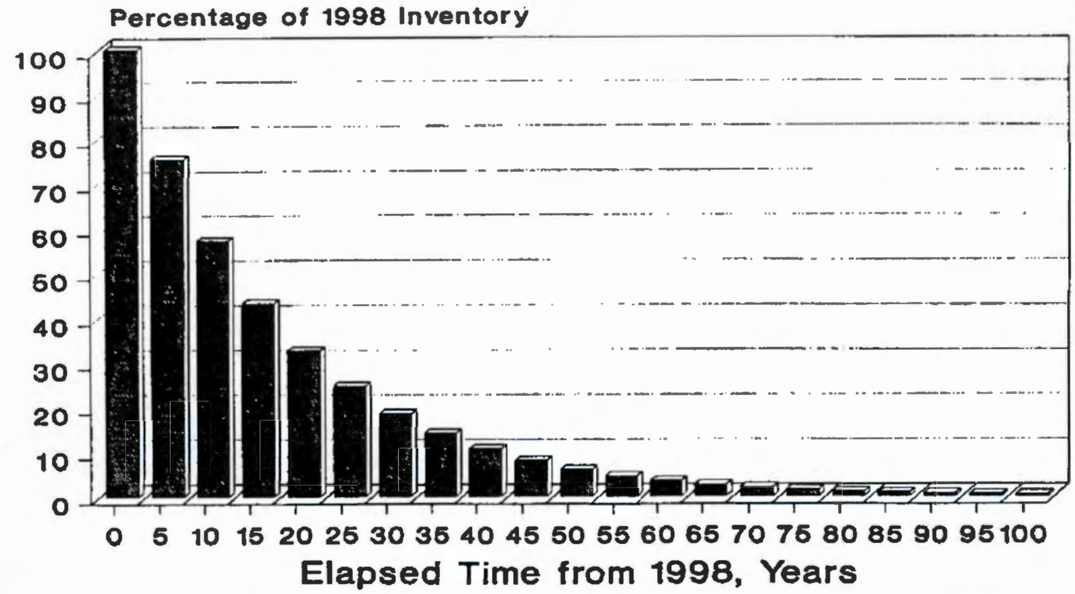

FIGURE A.9 Remaining Hanford Groundwater Tritium Inventory as a Percentage of 1998 Value

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 due to 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/liter increment between upstream and downstream concentrations should be less than 1 pCi/liter 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 ten meters below current levels because of the elimination of process water recharge to the groundwater. In general, the further 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.

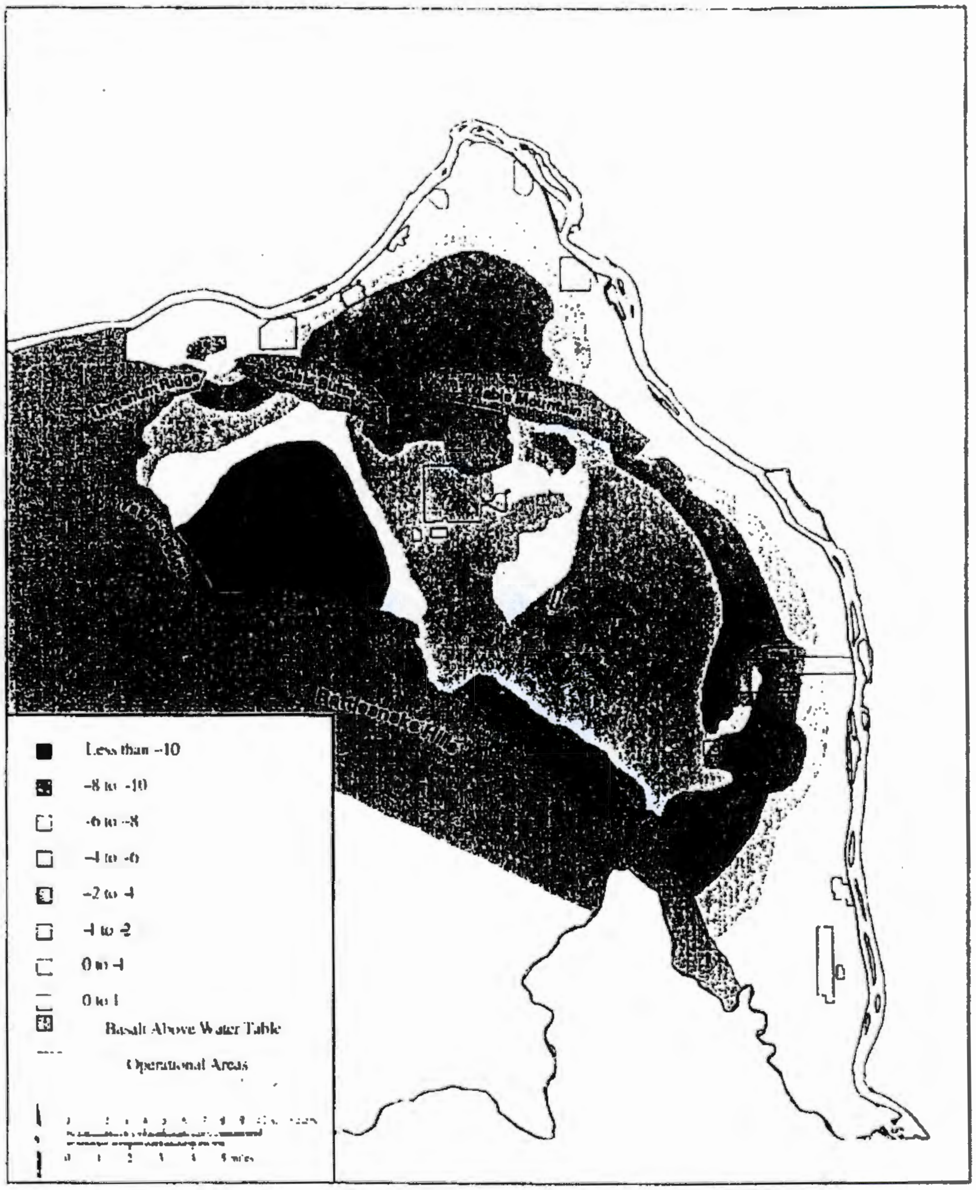

FIGURE A.10 Estimated Changes in Water Table Levels (Source: Cole et al. 1997)

A major contributor to the long-term lowering of the groundwater level was the sharp reduction in effluent discharges from the 200-W and 200-E 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 shows that reduction, and uses the lower rate for future Hanford site projections (Cole et al. 1997).

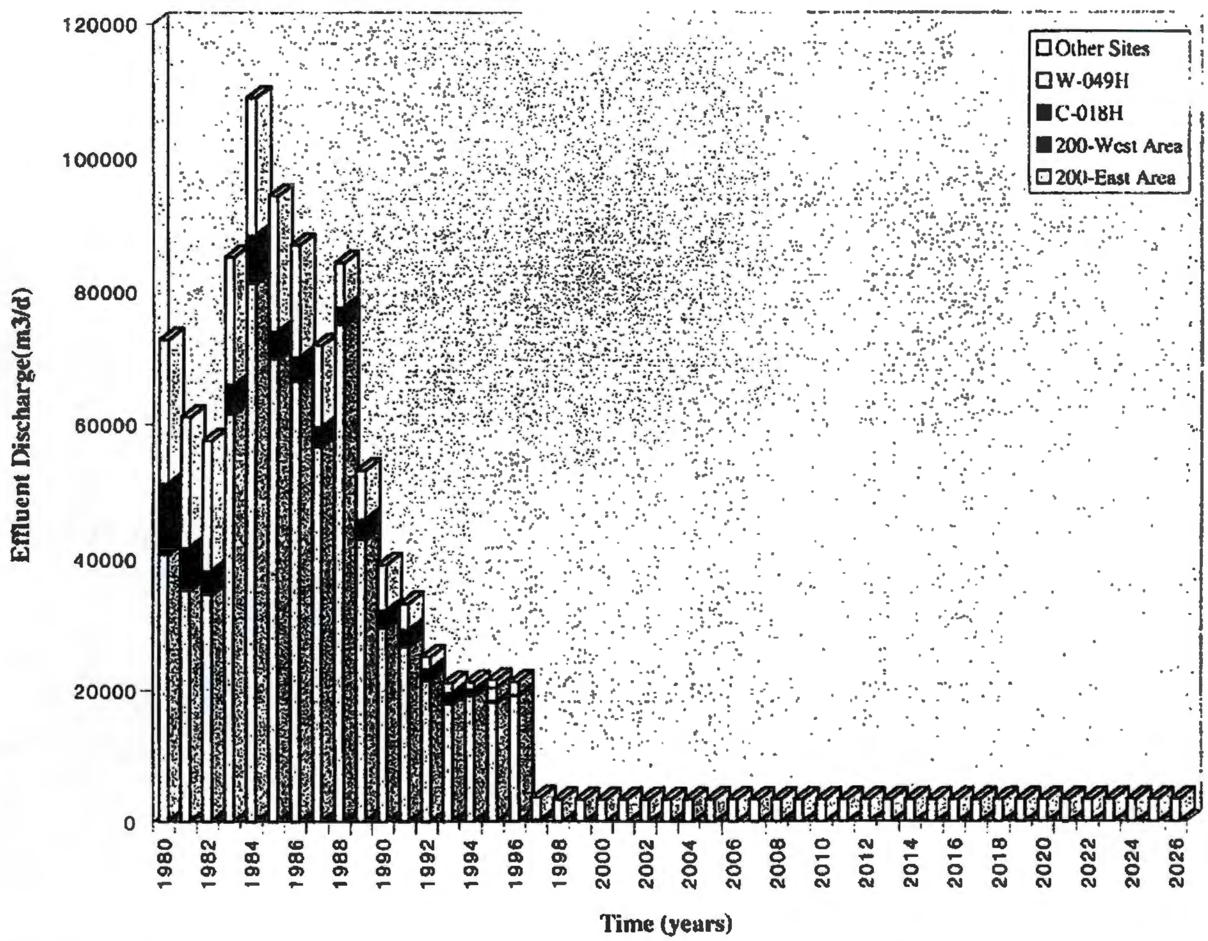

FIGURE A.11 Estimated Annual Effluent Discharge Rates Used as a Basis for Three-Dimensional Modeling (Source: Cole et al. 1997)

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.

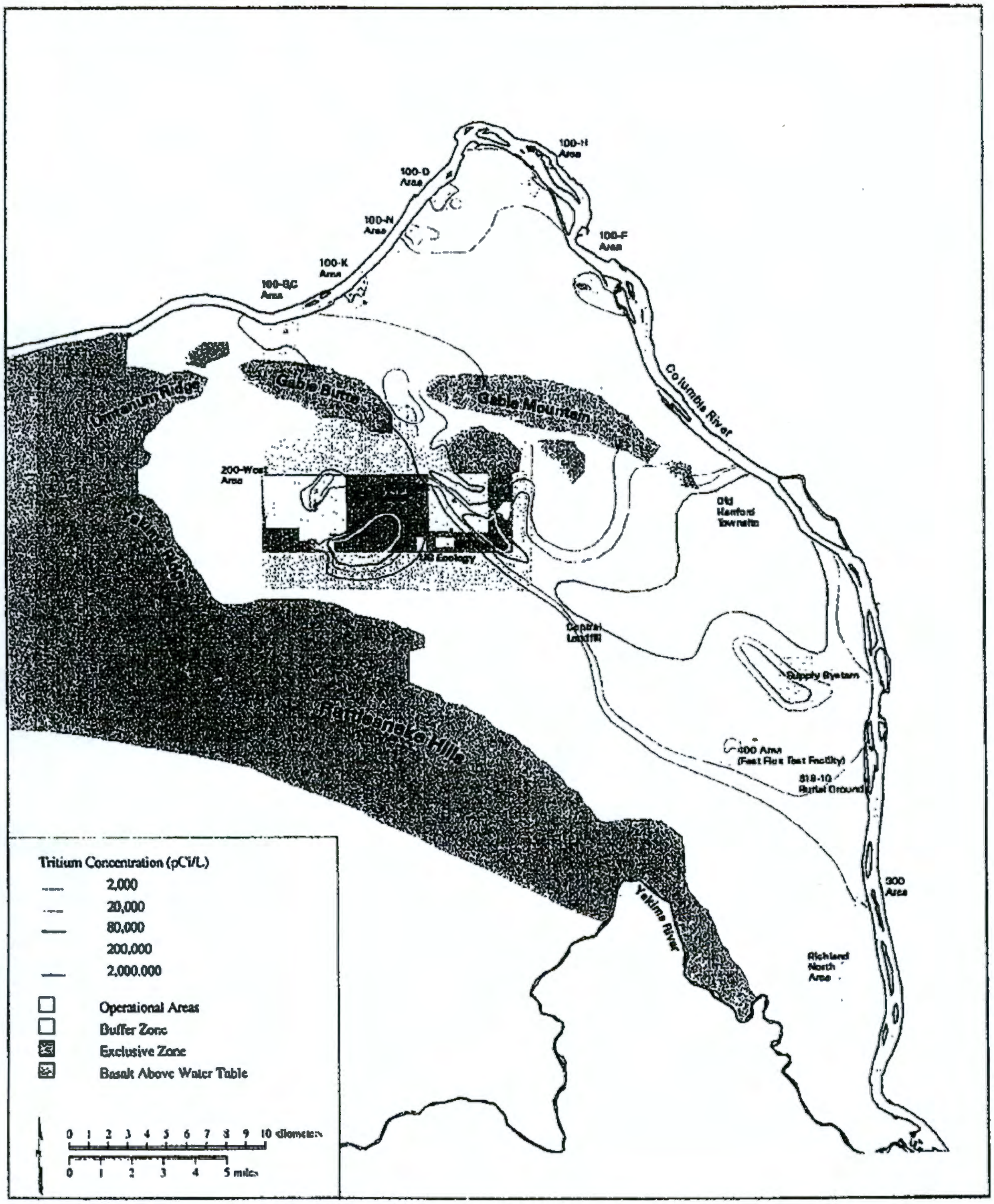

FIGURE A.12 Tritium Contours Predicted by the Three-Dimensional Analysis for 1996
(Source: Cole et al. 1997)

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

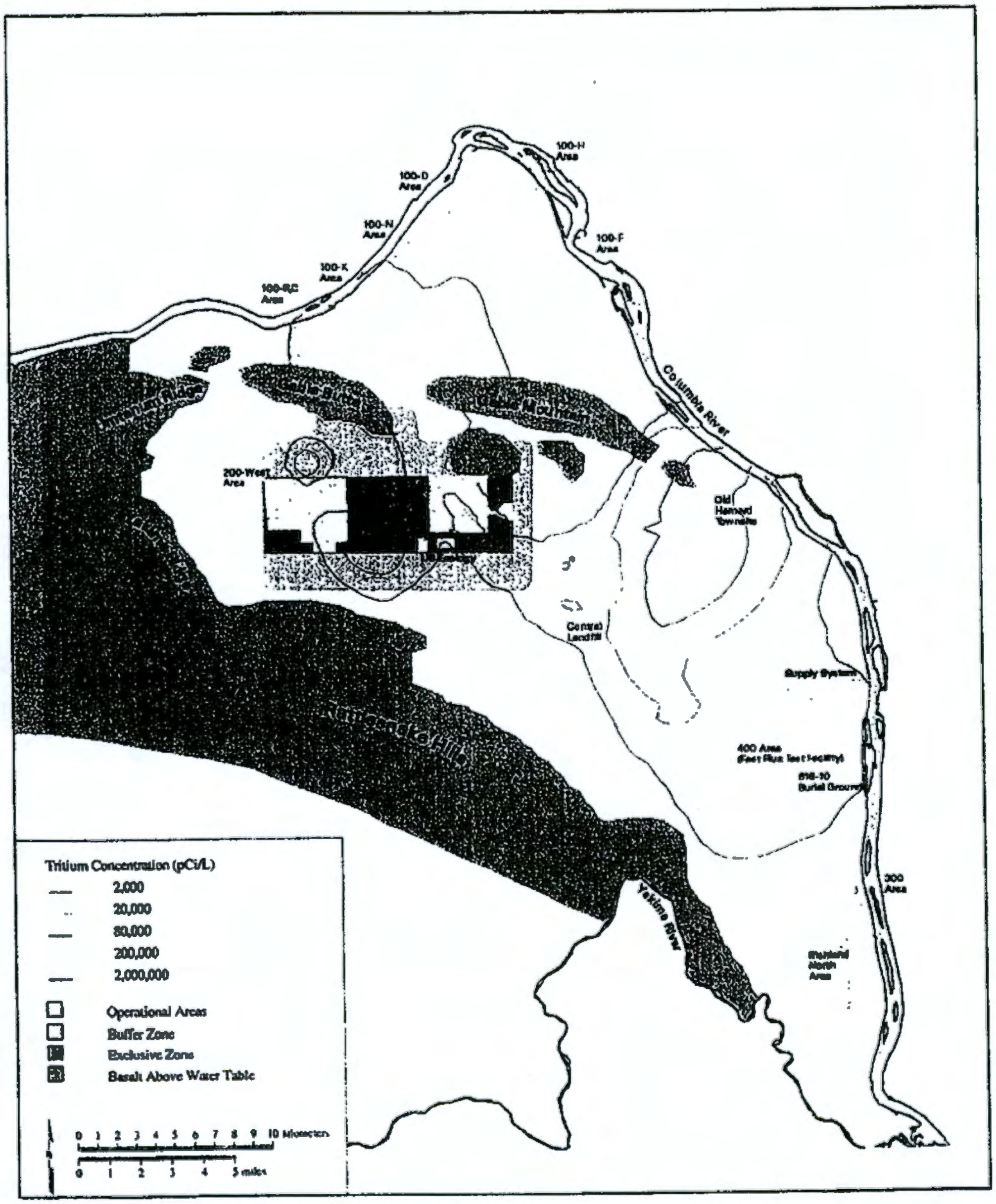

FIGURE A.13 Tritium Contours Predicted by the Three-Dimensional Analysis for 2020
(Source: Cole et al. 1997)

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

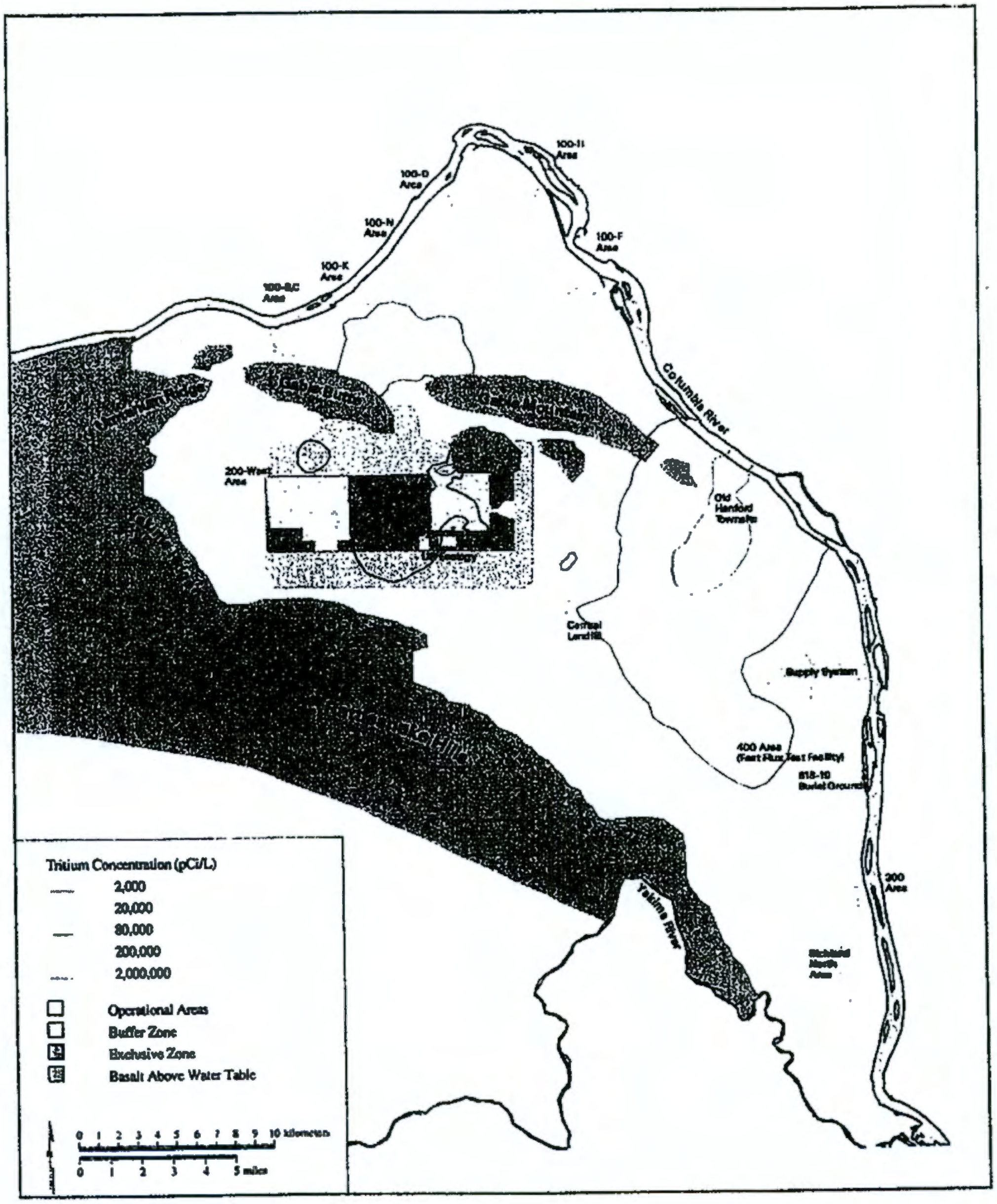

FIGURE A.14 Tritium Contours Predicted by the Three-Dimensional Analysis for 2050 (Source: Cole et al. 1997)

Figure A.15 shows the disappearance of all tritium plumes of 2000 pCi/liter 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.

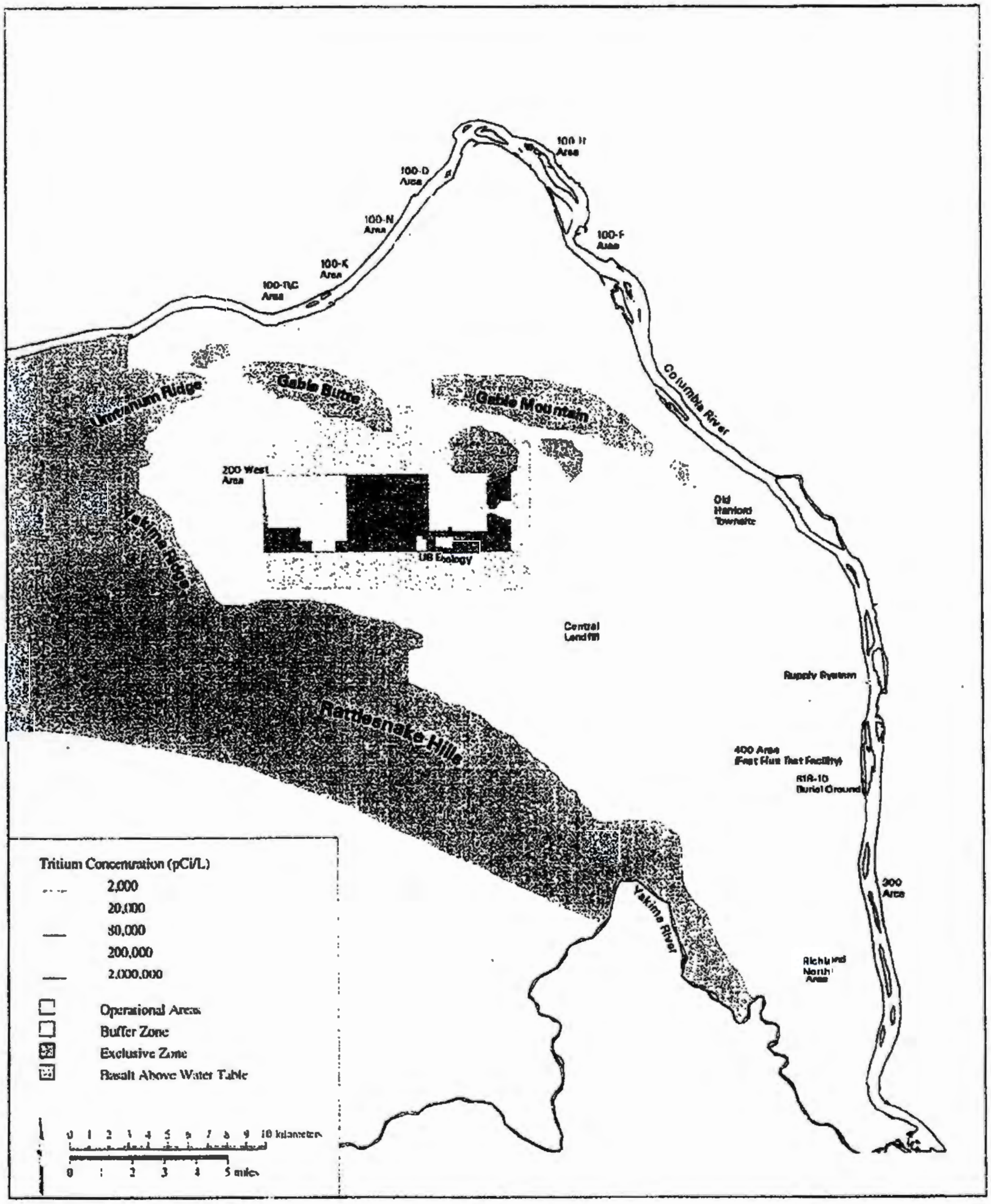

FIGURE A.15 Tritium Contours Predicted by the Three-Dimensional Analysis for 2100
(Source: Cole et al. 1997)

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 dams 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. These can be extended to develop the conceptual models that will be used to conduct the risk and impact assessments. 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. 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 socioeconomic impacts and impacts to quality of life for affected cultural groups. Figure B.1 shows the major types of possible biological effects from contamination 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. Though humans are the broad receptor category, there are groups within the population, such as hunters, swimmers, and subsistence fishermen, whose exposures need to be specifically assessed. These groups will have somewhat different exposure pathways that need to be considered. The assessment leads to estimation of risks and noncarcinogenic health effects from individual contaminants.

Figure B.4 presents the relationship between biological effects and both cultural and socioeconomic 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 socioeconomic 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 uses 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 it suggests appropriate metrics for impact assessment.

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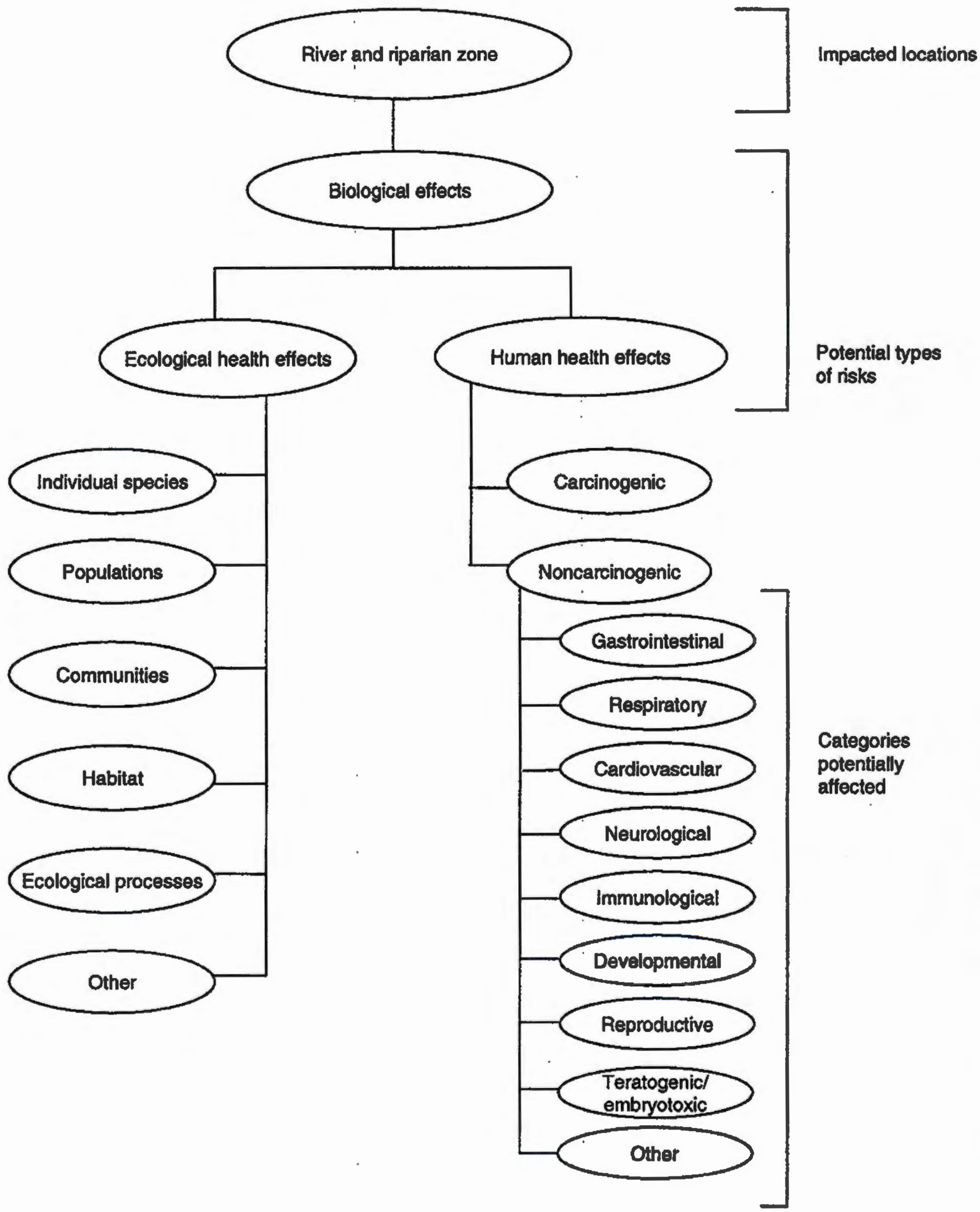

FIGURE B.1 Example of a First-Level Risk Model for the Hanford Reach

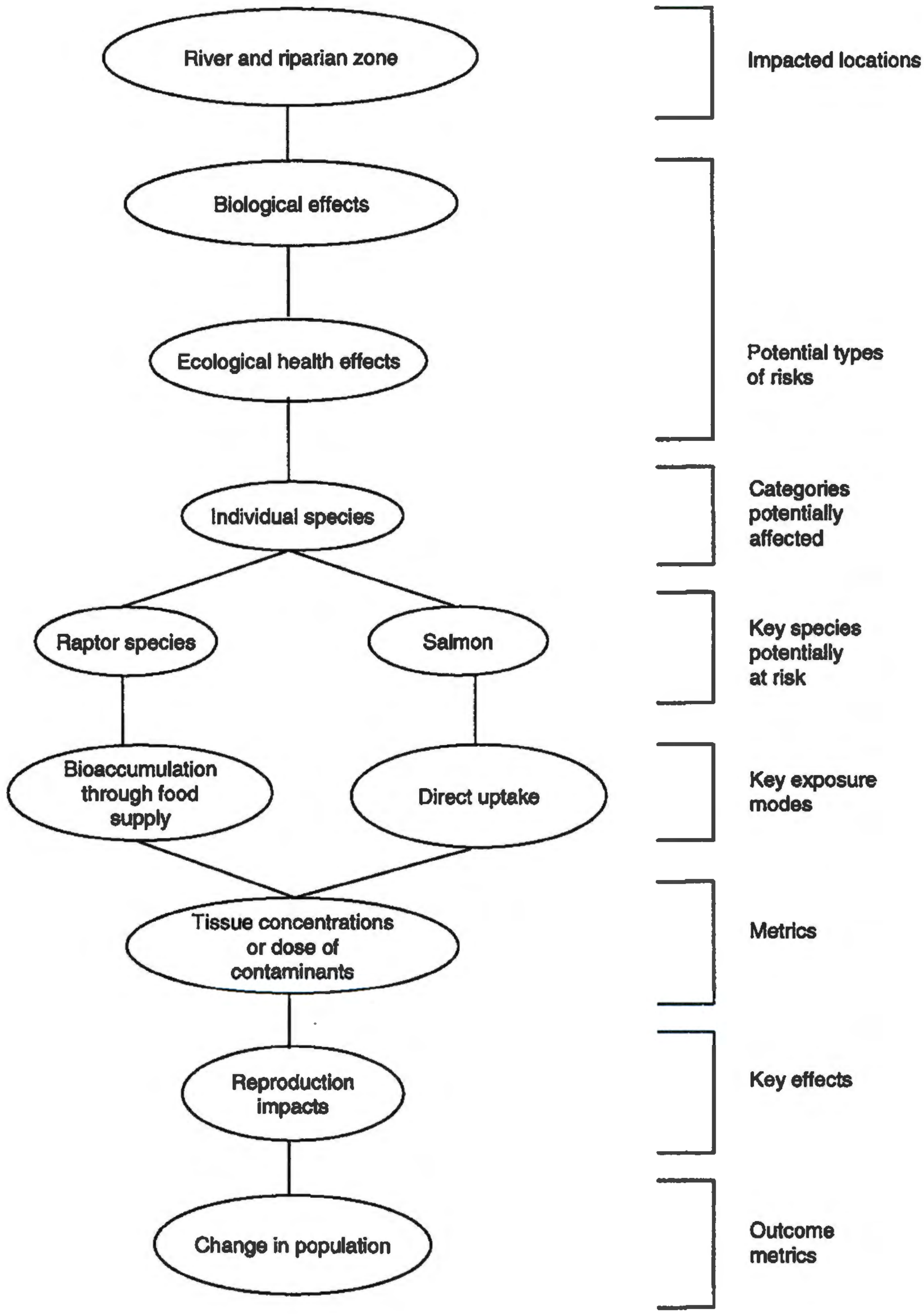

FIGURE B.2 Example of a Second-Level Ecological Risk Model for the Hanford Reach

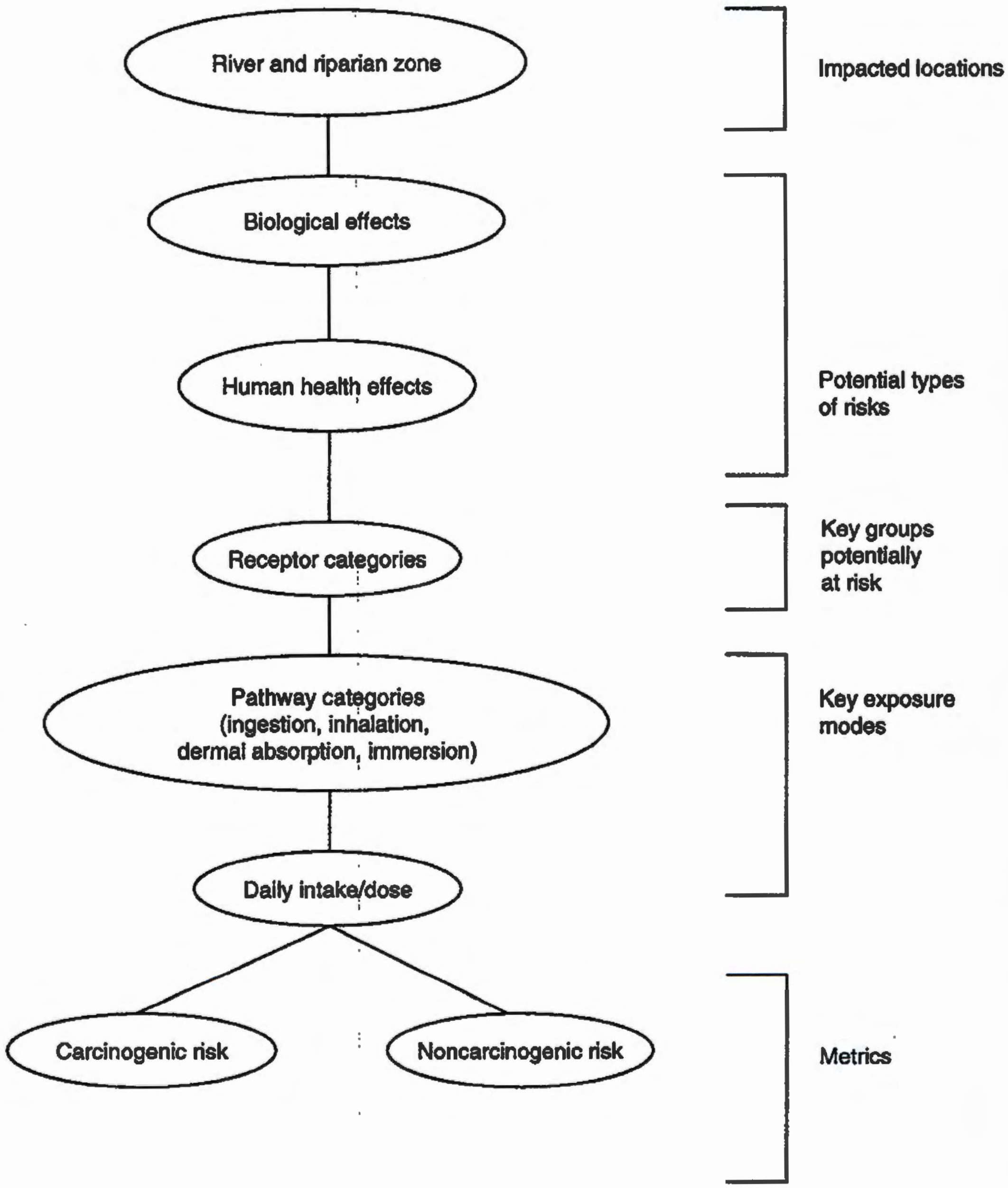

FIGURE B.3 Example of a Second-Level Model for Human Health Risks for the Hanford Reach

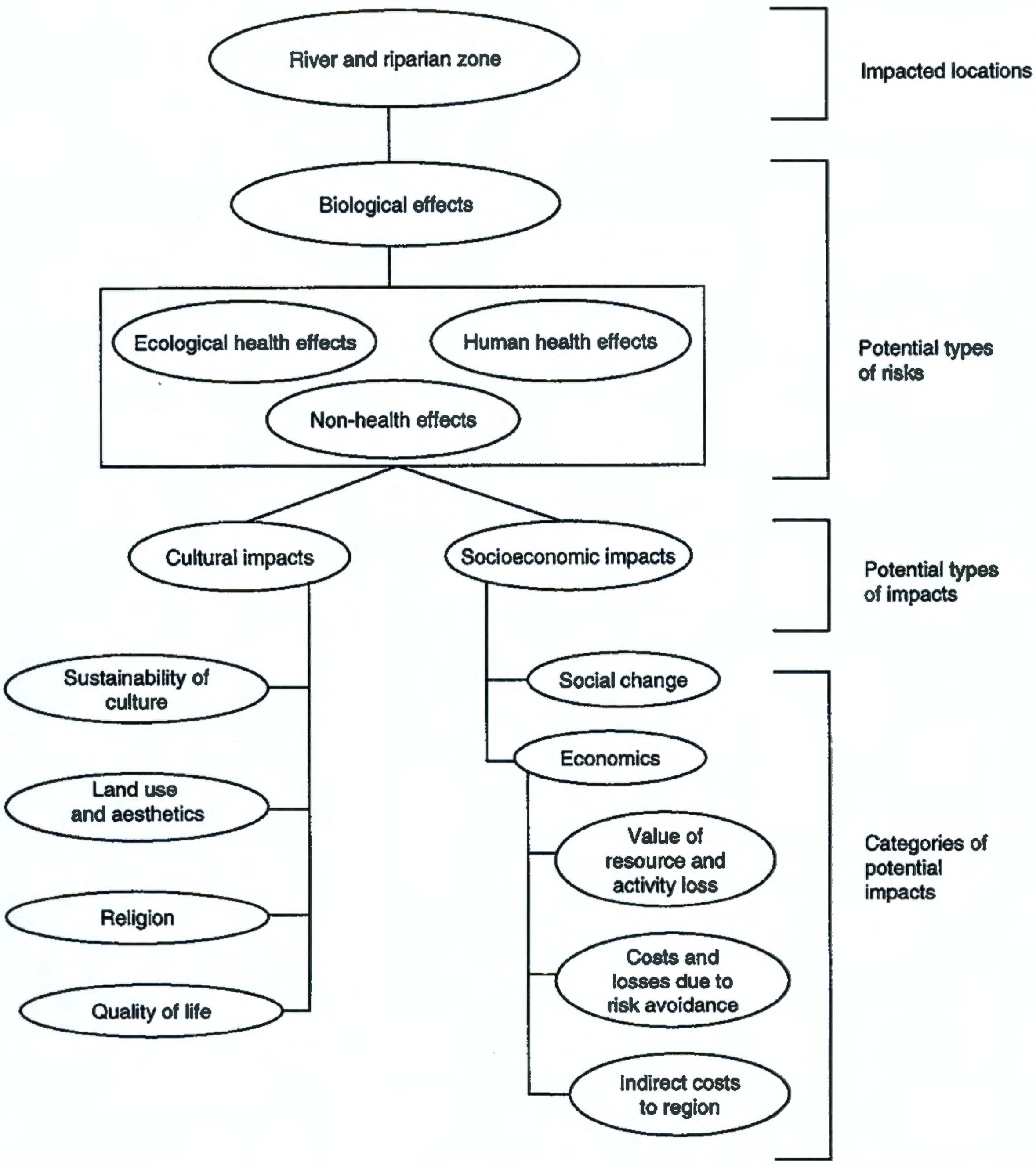

FIGURE B.4 Example of a First-Level Integrated Impact Model for the Hanford Reach

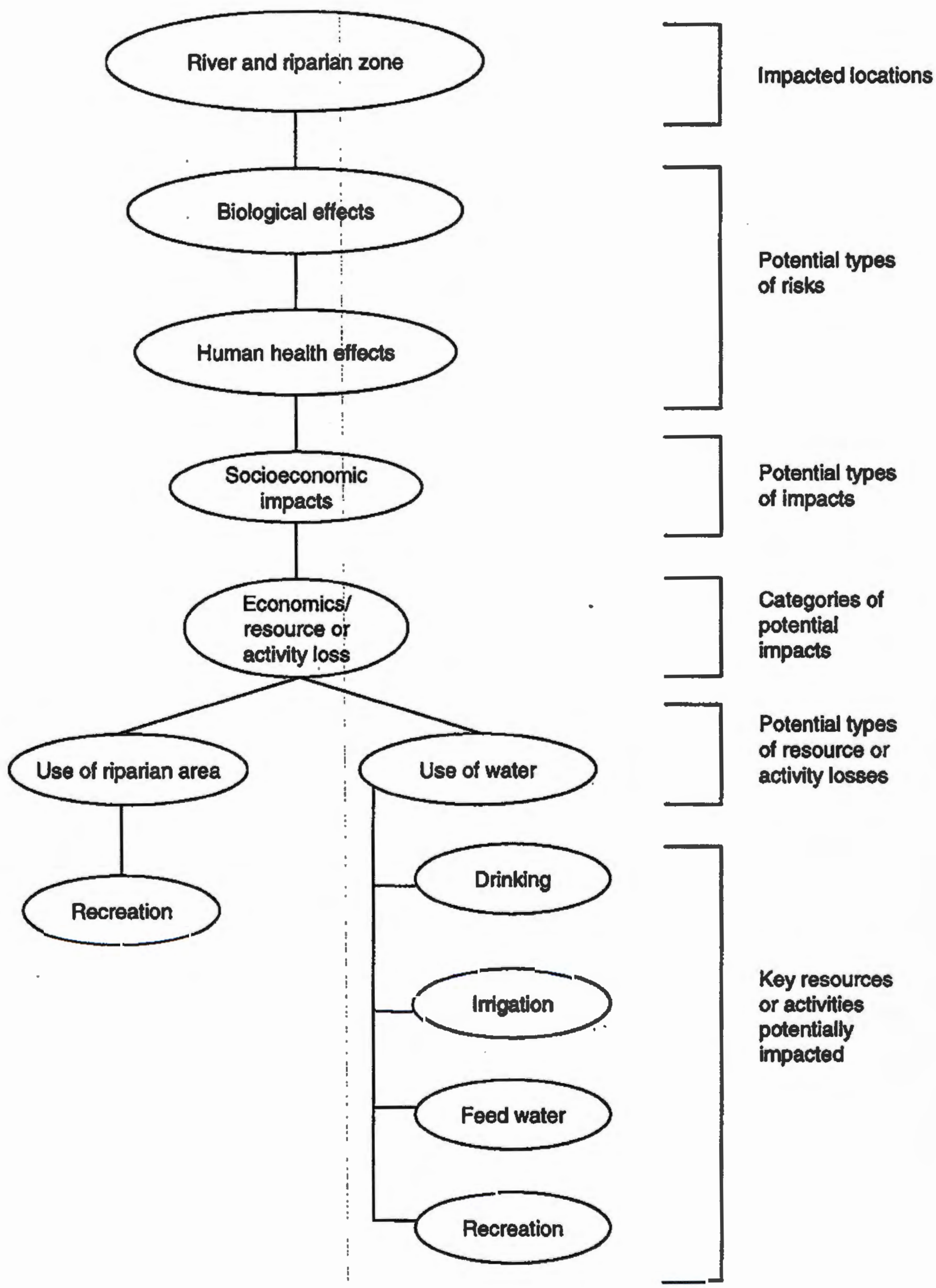

FIGURE B.5 Example of a Second-Level Economic Impact Model for the Hanford Reach

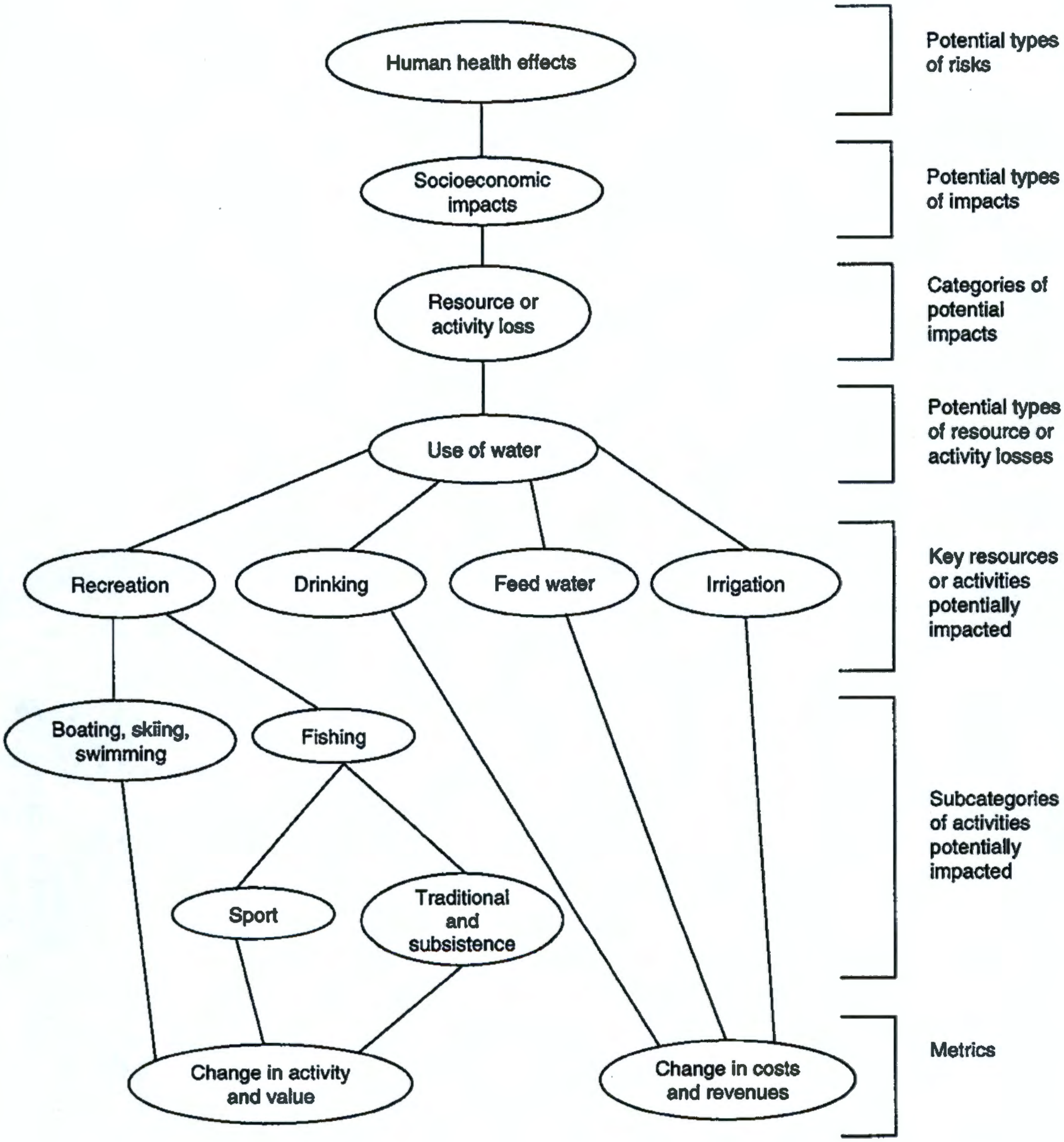

FIGURE B.6 Example of a Third-Level Economic Impact Model Associated with Water Use for the Hanford Reach